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Cognitive Neuroscience

The influence of spatial frequency and retention on the trade-off between working memory and eye movements in the paradigm of comparative visual search

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List of Abbreviations

4AFC 4 alternative forced choice

cpd cycles per degree

CVS comparative visual search

WM working memory

1 Introduction

Working memory can be defined as "a brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning" (Baddeley, 1992). Its characteristics are thus that it is temporary, provides a storage with limited capacity (about 3 to 7 junks of information) (Brady et al., 2016; Diamond, 2013). It further is distractible, meaning that external disturbance can greatly reduce the performance of the working memory (Collins, 2001). Lastly, very important characteristics of the working memory are that it can explicitly "load" items from the long term memory, store them, and, importantly, manipulate the stored information to apply it to a task or a situation. Working memory and eye movements are closely linked in behaviour, as they complement each other during orientation. Gaze can only be directed to one area at a time and is usually shifted with fast eye-movements called saccades. One theoretical proposal states that the primary function of visual working memory is to maintain information across saccades so that it can be integrated with new information afterwards (Hollingworth et al., 2008). At the same time, working memory is "fragile", as its, as stated before, limited, temporary and distractible, so that fixations may be used to acquire relevant information immediately before needed, reducing working memory load by reverting to an external "in-world" storage (O'Regan, 1992).

In comparative visual search paradigm tasks, these two resources, working memory and eye-movements, are in trade-off with one another. The comparative visual search (CVS) paradigm is a task well-established in cognitive neuroscience to investigate decision processes regarding cost-benefit balances in a controlled set-up (Hardiess and Mallot, 2015). In CVS, subjects have to find differences in visually separated arrays of items (Hardiess, Gillner, et al., 2008). In order to compare the arrays, memorization of several items is necessary, a cognitive load that can be reduced by frequent acquisition (exploration) behaviour (Hardiess and Mallot, 2015). However, the optic flow evoked by the ultra-fast saccadic eye-movements drastically reduces visual perception ("saccadic suppression") and can be regarded as a visual blank of varying length, depending on saccadic amplitude (Bahill et al., 1975). The longer the saccade (i.a. blank) the higher its time and energy cost (Solman et al., 2014). Studies have shown the immediate relevance of this to behaviour: In tasks that require orientation with an involvement of both working memory and gaze shifts, longer gaze shifts necessary to solve the task led to a decrease in fixations (Ballard et al., 1995), in a task with higher working memory load this was compensated for by an increase in gaze shifts (Droll et al., 2007). This shows that, depending on the individual assessment of the costs of the task, a certain strategy regarding the trade-off between memorization and acquisition is established. The former is mediated by a stronger involvement of working memory, the latter by more gaze shifts.

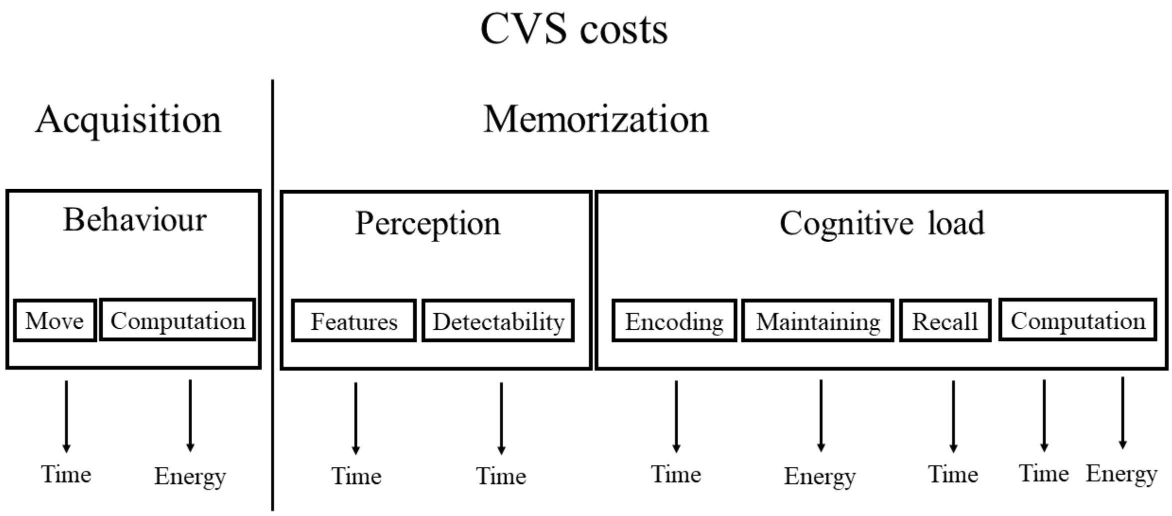

Figure 1: Schematic of the possible costs in the comparative visual search task for both acquisition and memorization. The two behaviours consist of several subprocesses that entail costs of either time or metabolic energy. Own illustration after Alvarez and Cavanagh (2004).

As depicted in Fig. 1 the costs for the acquisition of information in both time and metabolic energy should be roughly positively correlated to the distance and thus time and computational effort of each gaze shift, while the costs for memorization in the CVS are somewhat more complex: Both the expenses for the perception (e.g. number of feature dimensions, detectability of information) and the encoding, maintenance, recall and computation of the information (= cognitive load) influence the overall memorization costs and determine visual working memory capacity limit (Alvarez et al., 2004). To investigate on this matter, we reverted to the CVS paradigm used by Hardiess and Mallot (2015), where subjects had to count the differences between two columns of stimuli. We tried to incorporate an even more controlled setup by using Gabor patches of four different orientations as comparators. This allowed us to better quantify the perceptional costs of memorization by testing for two different spatial frequencies. As Hardiess and Mallot, we also controllably varied the acquisitional costs by showing only one column at a time and inducing a delay in the change from one column to the other. To ensure that our chosen Gabor patches were within typical human perceptional range, we tested our contrast sensitivity for different spatial frequencies and whether it lies on the Campbell-Robson contrast sensitivity curve. To validate the difference in perceptional cost of the two spatial frequencies tested, we conducted an experiment with a 4 Alternative Forced Choice (4AFC) task with each subject, displaying the Gabor patches for different short time frames. Findings on the influence of spatial frequency on manual reaction time (Breitmeyer, 1975) and on saccadic reaction time (Ludwig et al., 2004), revealed different latencies in the response of low-spatial transient and high-spatial sustained channels (Breitmeyer, 1975). Murray and Plainis (2003) found that the contrast gain diminishes with increasing spatial frequency and argued for the distinct gain properties of the Magnocellular (M) and Parvocellular (P) pathways as a possible neural substrate: The M channel has a high contrast gain that saturates at low contrast levels, while the P channel is much less sensitive, though within a much wider range (Kaplan et al., 1990). Consequently, the faster M channel would be responsible for target detection in typical situations, with the slower P channel only contributing at spatial frequencies over 7 cycles per degree (Murray et al., 2003). Additional findings from (Chen et al., 2018) support this theoretical framework on a level more immediate to behaviour: In the macaque brain, the superior colliculus (SC), the "saccade command center", over-represents low spatial frequencies at a population level. Accordingly, we expected that the increase in processing time for higher spatial frequencies would lead to a decrease in performance in the 4AFC task. If this held true, the high spatial-frequency Gabor patch would represent higher perceptional costs and thus lead to a change in strategy during the CVS, namingly a higher involvement of acquisition behaviour.

Finally, we performed an experiment on the relation of spatial frequency and contrast sensitivity in target detection.

2 Materials and Methods

2.1 General

9 volunteers aged between 24 and 28 participated in the experiment. All subjects were naïve to the purpose of the experiment. The subjects had normal or corrected to normal vision. A personal computer running MATLAB (version R2018a, MathWorks Ltd.) was used for stimulus presentation, experiment control, and recording the subjects' responses in the 4 alternative forced choice and in the comparative visual search tasks. The software controlling the experiment incorporated the Psychophysics Toolbox extensions (Brainard, 1997). Stimuli were shown on a Fujitsu B22T-7 LED proGreen (21.5" 1920 x 1080 pixel, 60 Hz) monitor driven by the computer's built-in Intel HD Graphics 4600 graphics board. The viewing distance between subject and monitor was 60 cm. This distance was maintained by using a chin rest. Stimuli were viewed in a normally lit room. Before the experiment started, subjects had to read a written task instruction.
The stimuli consisted of Gabor patches of two different spatial frequencies. For the low spatial frequency condition Gabor patches with 2 cycles per degree (cpd) and for the high spatial frequency condition Gabor patches with 8 cpd were used (Fig. 2).

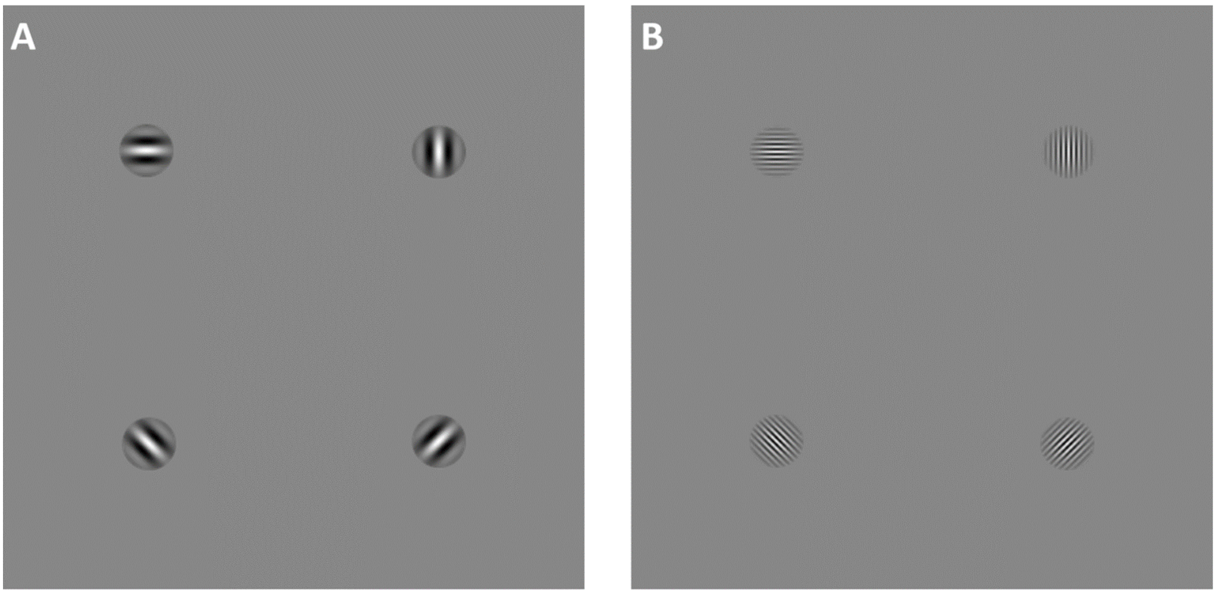

Figure 2: Stimuli overview. One stimulus has two varying conditions, the spatial frequency, which can either be low **A)**, at 2 cpd, or high **B)**, at 8 cpd. For each spatial frequency the Gabor patches can also vary between four orientations.

2.2 4 Alternative forced choice task

In the 4 alternative forced choice task (4AFC) we presented the subjects with a stimulus of a random orientation and random spatial frequency. A proportion of 0.25 correct trials was the chance level and 0.625 was the perception threshold used in this analysis. In total there were 8 different stimulus conditions (Fig. 2). A rectangle was displayed in the center of the screen and the subject hat to fixate the center of that rectangle. In this rectangle the stimulus was presented. The stimuli appeared in a pseudo-randomized order, so that spatial frequency and orientation varied from trial to trial. Stimulus duration ranged from 16.6 ms to 100 ms (16.6, 33.3, 50, 66.6, 83.3 or 100 ms).
After the presentation of the stimulus an answer screen appeared (Fig. 3). The answer buttons to choose the orientation alternated between two configurations. The mask in the center of the answer buttons was used to destroy the formation of an after image of the stimulus. The checkerboard corresponded to the spatial frequency of the previously presented stimulus.

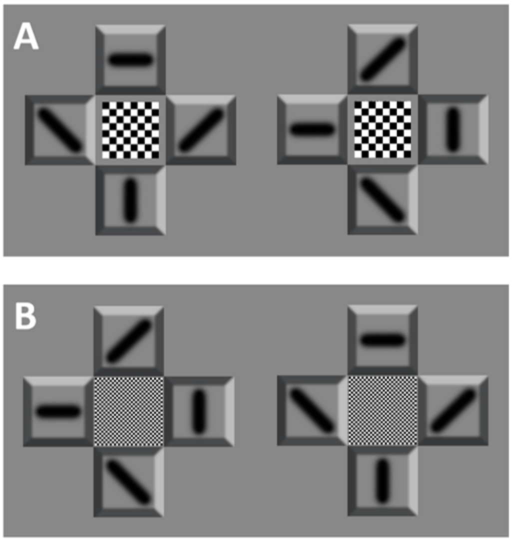

Figure 3: Answer mask. After each stimulus presentation a mask surrounded by 4 answer buttons appeared on the screen. The pattern of the checkerboard in the center corresponds to the low spatial frequency stimuli (**A**) or the high spatial frequency stimuli (**B**). For each spatial frequency there were two possible configurations of the answer buttons

The subject then had to choose the orientation it has seen out of the four possible orientations, if the orientation wasn't perceived confidently the subject had to choose randomly. The trial ended, when the subject clicked on of the answer buttons. A new trial started when the space bar was pressed. In total a subject had to complete 192 trials in a random order (2 stimulus conditions x 4 orientations x 6 presentation durations x 4 repetitions = 192 trials).

Before the main experiment was started, the subject could familiarise themselves with the stimuli in a training protocol. In this protocol, each spatial frequency, stimulus condition, stimulus orientation and presentation duration was shown at least once. The subject could repeat this training until they felt comfortable with the protocol.

2.3 Comparative visual search task

In the comparative visual search task (CVS) the subject had to compare two lists of stimuli and count the differences between them. One of the lists was always hidden behind a mask which moved with a varying delay.
Each trial of the CVS task consisted of two columns (with a separation of 24 degrees of visual angle) with 12 stimuli each. The stimuli were the same as in the 4AFC task (Fig. 2). One list contained only Gabor patches one spatial frequency (spatial frequencies weren't mixed in a trial) but the order of the orientations of the Gabor patches was randomized. The stimulus configuration differed between the two lists at one, two or three random positions. A maximum of three differences was introduced to avoid premature trial completion, so that the subject had to go through the whole list. During all trials an opaque gray mask was visible which always covered one side of the screen so that only one list was visible at all times. The corresponding positions were connected by a black line, that was visible at all times, even in the covered part of the screen. The subject could shift the mask from one side to the other via left and right mouse click to compare the two stimulus lists as often as desired. One of two mask delays (0 or 2 seconds) were used and the order of used delays was randomized. The delay was initiated with the mouse click. During this mask delay, both columns remained hidden (Fig. 4). In total a subject had to complete 60 trials (2 spatial frequencies x 2 delays x 3 numbers of differences x 5 repetitions = 60).

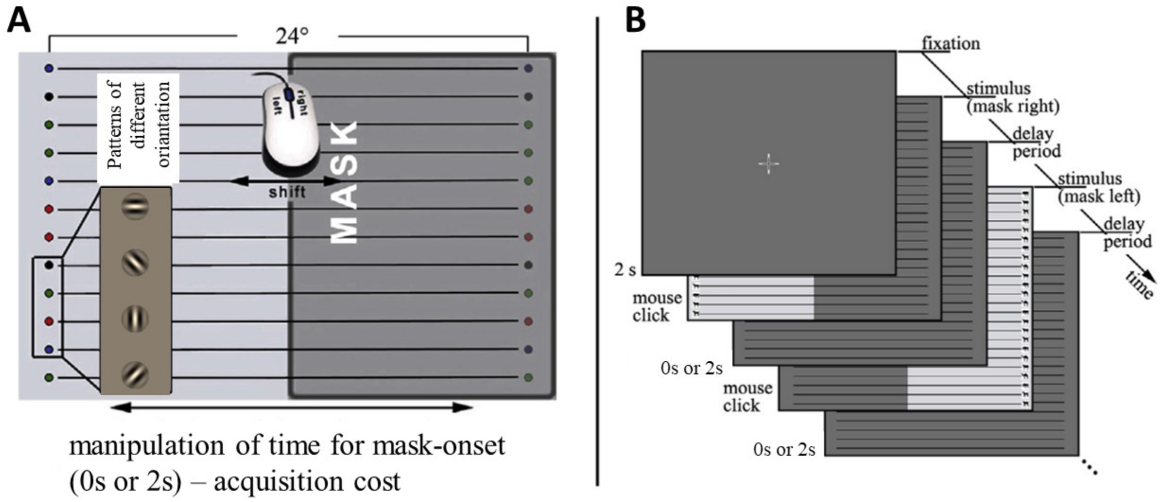

Figure 4: Experimental paradigm. (**A**) Task setup. A stimulus image consists of two columns (column distance: 24°) with 12 items each. Items were Gabor patches of different orientation with either a low spatial frequency or a high spatial frequency (see Fig. 2). A gray opaque mask (shown here as transparent for sake of illustration) was always covering one column and could be shifted (to the other column) by clicking one of the two mouse buttons. The time for mask-onset after each click was manipulated by using one of the two mask delays. (**B**) Trial procedure. After presenting the fixation cross, the stimulus image appeared automatically with the right column covered. After clicking the left mouse button, the delay period started. Both columns of items were hidden during the time of delay and only the black lines were presented. The stimulus image reappeared after 0.0 or 2.0 s with the left column covered. After clicking the right mouse button, the delay period started again. A trial was terminated by pressing the spacebar.

The subjects' task in each experimental trial was to compare the two lists of stimuli to find the number of differences (one, two or three) as quickly and reliably as possible. After completion of the comparative search, space-bar had to be pressed to finish a trial. Afterwards, the identified number of differences had to be reported by clicking the corresponding number on the computer screen. During the fixation phase a fixation cross was displayed in the center of the screen for 1.5 s. Next to the fixation cross the delay and the stimulus condition of the upcoming trial was displayed. To get used to the stimulus presentation and the mouse controls, this task also included practice trials. In total there were four practice trials, one for each delay and stimulus condition combination. After this practise phase, the experiment started by presenting the first trial. Subjects could take a break whenever they wanted but before they started a new trial. To avoid verbal rehearsal aiding in memorization during the delay phase, and thus adding an uncontrolled factor, these processes were articulatorily suppressed in all trials. To achieve this suppression, subjects had to repeatedly say out loud three irrelevant syllables (e.g., 'bla-bli-blu').

2.4 Exclusion criteria

Some data had to be excluded from our analysis, since some subjects showed performances that were either much worse than expected or much better. We can't ultimately exclude that software errors are responsible for these performances but assuming that it was the actual performance of the subjects we had to formulate criteria to either exclude or included these outlying performances.
For the 4AFC task a subject had to perform at least at chance level (25% correct) in at least 50% of the presentation durations. Otherwise we assumed that stimuli either weren't perceived at all or the subject wasn't motivated to complete the task. We also excluded data of subjects when their detection threshold was outside of the presented range of presentation duration, since we can assume that in those cases the selected presentation durations didn't accurately reflect were the detection threshold of the subject might be.
For the CVS task we also implemented exclusion criteria to ensure that all subjects were motivated to complete the task. If in at least five of the 60 trials there were no switches in between the stimulus lists or the total duration was shorter than five seconds, we excluded the data from our analysis.

2.5 Analysis

Data transformation as well as plotting where performed in Python 3.10 using the libraries Numpy, Scipy and Matplotlib. Statistical tests where conducted in Microsoft Excel.
For the analysis of the 4AFC data we calculated the percentage of correct answers for each stimulus duration. We fitted a logistic function to the data of a single subject.

$$P_{chance} + (1 - P_{chance}) * \frac{1}{1 + e^{-k(x-x_0)}}$$

Where the chance level $P_{chance} = 0.25$. The sigmoids midpoint x_0 as well as the logistic growth rate k where optimized using the Trust Region Reflective algorithm to get the least squares. Using the fitted logistic function we computed the perception thresholds for every subject. All fits where visually inspected. Only perception thresholds within the presented stimulus ranges where used for subsequent analyses. The output of the stimulation software included trial number, number of differences, delay, cpd, reported differences, response time, number of switches and processing time. Processing time was calculated as the mean of all periods between two switches minus the delay duration.
We conducted the analyses on the error rate of the answers, the response time (duration of one trial), the number of switches between the two columns and the processing time between two switches. Further, we constructed a strategy index

$$S = \log_{10}\left(\frac{t_p}{n_s}\right)$$

where t_p is the processing time and n_s the number of gaze shifts, both normalized between 0 and 1. The aim of the strategy index was to reduce the two dimensional strategy to a single dimension.

2.6 Contrast sensitivity

We used the software "Kontrast.exe" to determine the contrast sensitivity curves for the three experimenters. This software presented a fixation point in the center of the screen and displayed gratings with a fixed spatial frequency but of varying contrast either on the left side or the right side of the fixation point for 100 ms. The subject had to press the corresponding mouse button when they saw the grating (Left mouse button when the grating was perceived on the left side of the fixation point, right mouse button when the grating was perceived on the right side.) When no grating was perceived, the subject had to guess. The next stimulus was displayed immediately after the mouse click. To vary the spatial frequency in this experiment the subject had to complete on set of trials with a distance of 1 m to the monitor resulting in a spatial frequency of 10 cpd of the grating, and in a second run of trials the distance was 2 m resulting in a spatial frequency of 20 cpd. One run consisted of 180 trials (9 contrasts x 20 repetitions) so in total a subject had to complete 360 trials.
Analysis was done using MATLAB (version R2022a, MathWorks Ltd.) including the Psychophysics Toolbox extensions (Brainard, 1997). First the Michelson Contrast was calculated using this formula:

$$c = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$$

With this formula we could calculate the contrast of each of the 9 stimulus condition. The presented Michelson contrasts ranged from 0 to 0.064. For the two-point-contrast calculations we also needed the averaged light intensities of the monitor calibration. This data was already measured for this exact monitor in a previous year. Now with the help of the Psychophysics Toolbox a logistic function was fitted the proportion of correct answers per stimulus condition. from this fit we could extract the perception threshold at 75% for each subject.

3 Results

3.1 4 Alternative forced choice task

The fitted logistic functions returned four perception thresholds that where not covered by our stimulus range. Consequently, we excluded these subjects from subsequent analyses. The excluded fits are indicated as gray lines in figure 5. The perception thresholds inferred from the fitted sigmoids ranged from 30 ms to 90 ms. The thresholds compared for the two conditions of differing spatial frequencies were not significant but showed a light trend (Wilcoxon, Z = 1.5, p = 0.06) see also figure 5, Right. Except for a one individual, all subjects showed the trend that higher spatial frequencies resulted in a higher detection threshold.

Because our data indicates that smaller spatial frequencies are harder to perceive, we used the same two stimulus levels in the comparative visual search task to manipulate the detectability of the stimuli.

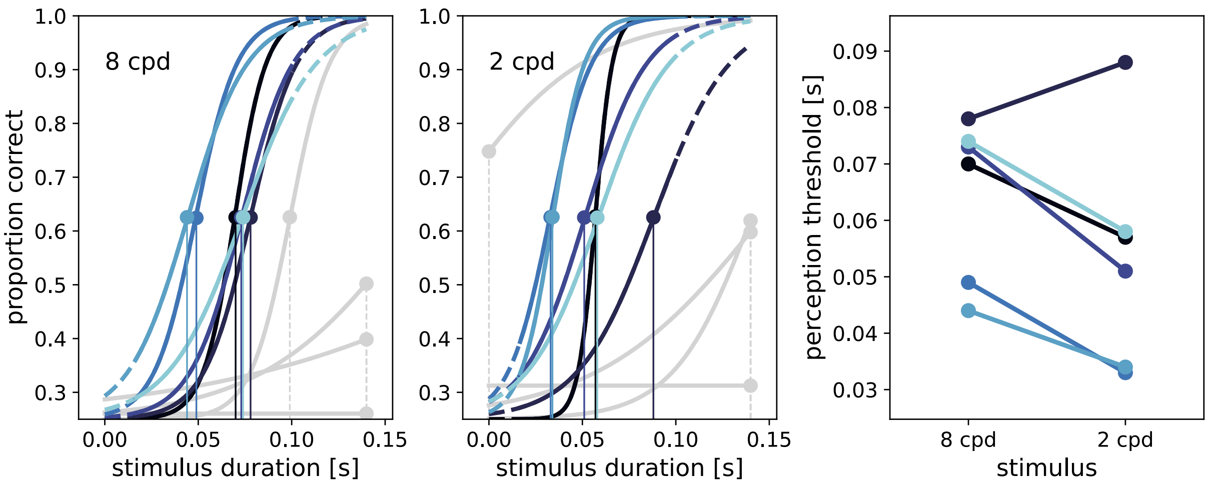

Figure 5: Fitted data from the 4AFC task (**Left** and **Middle**). Stimulus duration on the x-axis and probability of correct answer on the y-axis. The detection threshold is marked with a point and a line on the x-axis. Curves are colorcoded so that each color corresponds to one subject in each plot. Gray curves are excluded from our analysis therefore don't appear in the **right** plot. **Right**: Detection threshold for the two spatial frequencies for each subjects. Each color corresponds with one subject.

3.2 Comparative visual search task

One subject had to be excluded due to too many trials without switches (> 5). The subjects were mostly able to maintain performance regarding trial duration and error rate throughout the experiment and also did not change their number of switches per trial with experiment progress (see 6).

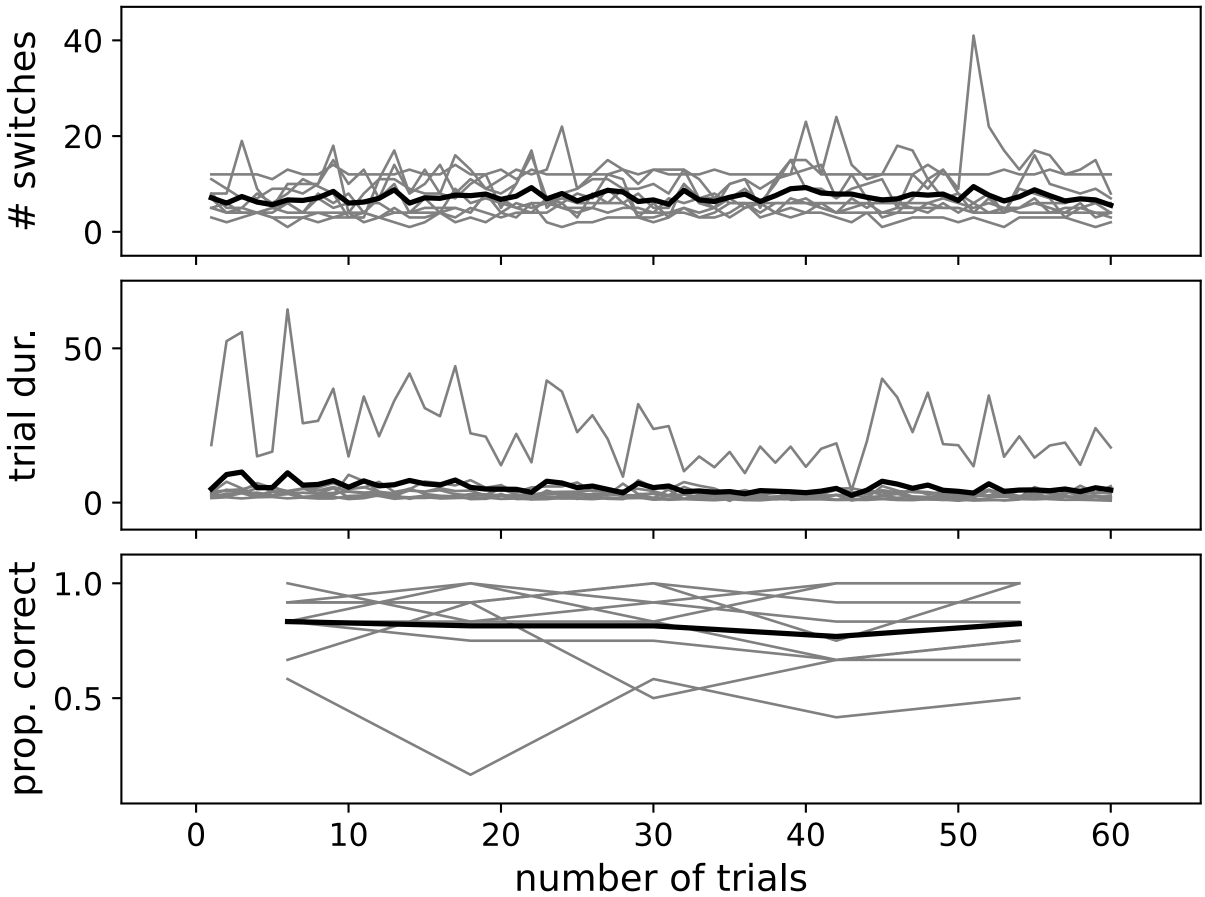

Figure 6: Mean performance over trials for number of switches, trial duration and correct answers. Black line represents the mean of all subjects, which are shown as gray lines. One subject took a lot more time in some trials, another subject partly performed substantially below average in percent correct answers. Overall, trial number did not influence performance or strategy.

3.2.1 Population level effects

When comparing the results between different stimulus conditions, also the median error rate stayed constant throughout conditions (see 7), as well as the number of switches (8). However, the response time and, as the number of switches did not change significantly ($\mathrm{W} = 0$, $p < 0.05$), the processing time increased significantly in the high spatial frequency trials as compared to the trials with low spatial frequency Gabor patches ($\mathrm{W} = 0$, $p < 0.05$). Note that the outlier (VP6) in response time and thus processing time stretches the scale quite substantially, so no uniform distribution can be assumed anymore.

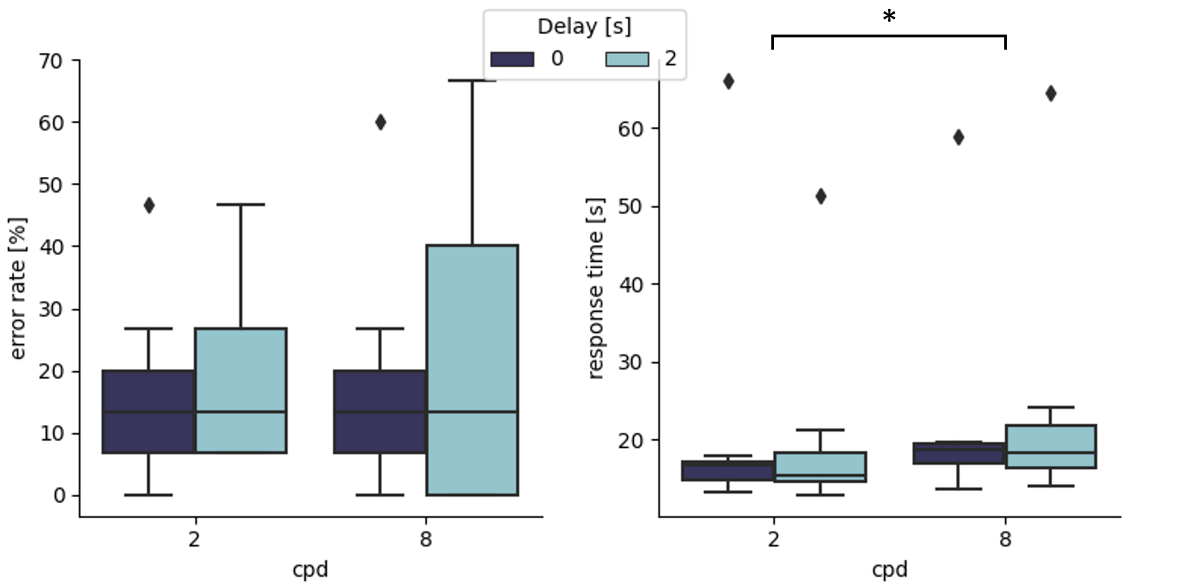

Figure 7: Error rate and response time for different stimulus conditions. Boxplots are shown for 2 and 8 cycles per degrees and colour-coded for 0 and 2 seconds delay respectively. A significant difference can only be found between 2 and 8 cycles per degree (W = 0, $p < 0.05$) for response times.

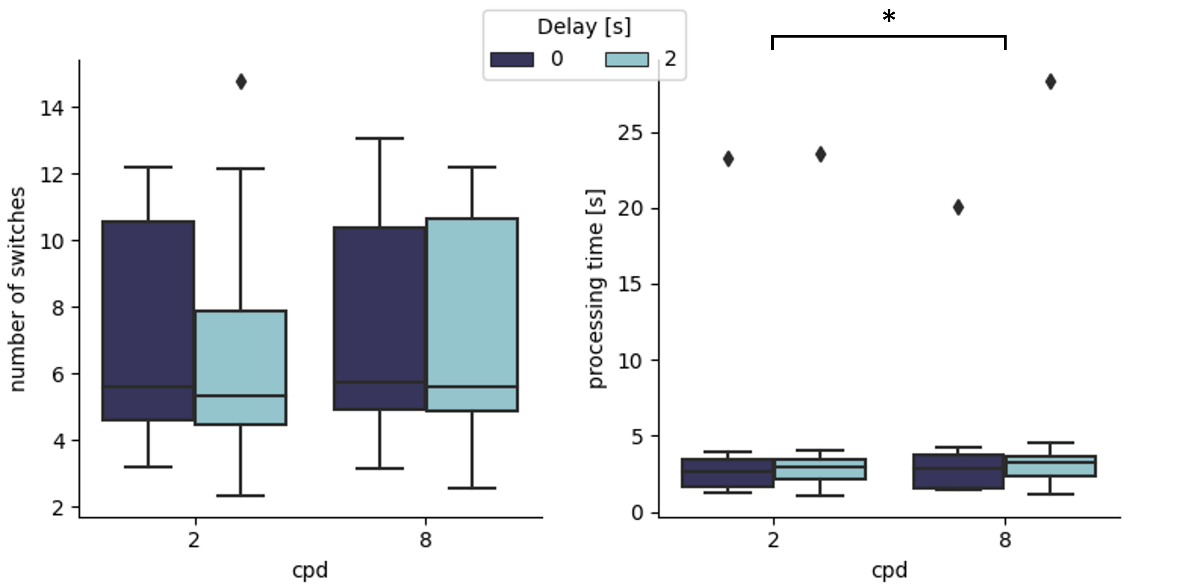

Figure 8: Number of switches and processing time for different stimulus conditions. Boxplots are shown for 2 and 8 cycles per degrees and colour-coded for 0 and 2 seconds delay respectively. A significant difference can only be found between 2 and 8 cycles per degree (W = 0, $p < 0.05$) for processing times.

3.2.2 Individual level effects

To get an insight into the distribution of individual strategies, we plotted the strategy spaces spanned by the processing time and the number of gaze shifts (9). Each individual is represented by its mean and SEM across all categories for both variables. The majority of our subjects clustered in the bottom right, indicating acquisition strategists, whereas a single individual leaned strongly towards memorization.

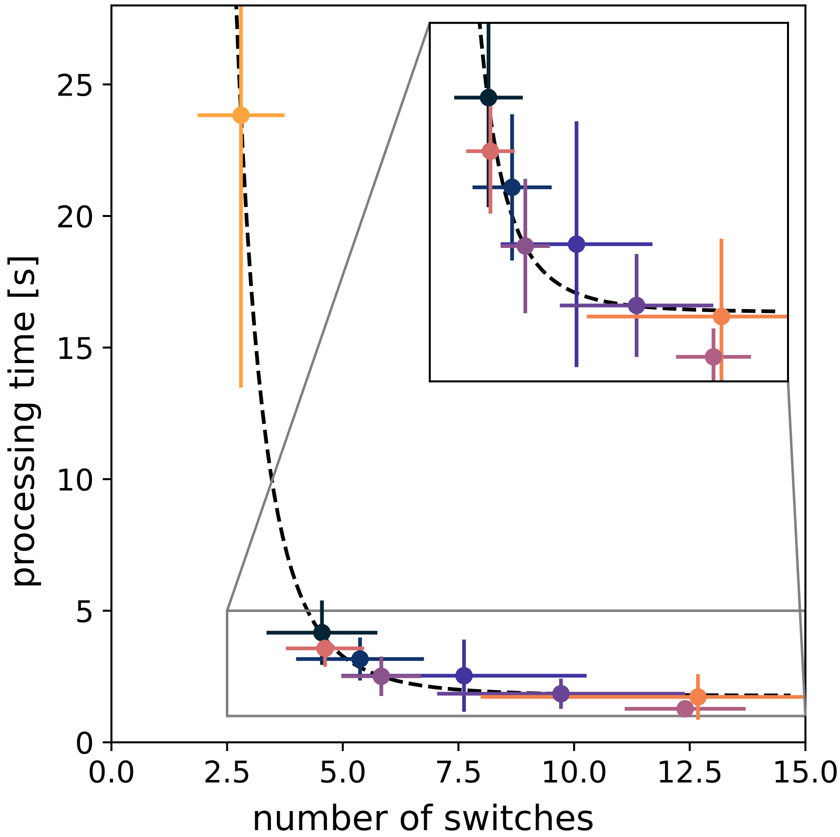

Figure 9: Strategy space for all included individuals across all stimulus categories. Colors represent individuals. The points indicate the mean of the respective individual on the respective dimension. The error bars show the standard error. The dashed line shows a powerlaw function fitted to the means. The inset shows the fit in detail for the cluster in the lower right to better asses the powerlaw fit in that region. The outlier (yellow) is included since it did not strongly affected the fit.

Increasing the difficulty of perception, i.e. increasing the cycles per degree in the 8 cpd condition lead to a consistent change: Individuals increased the amount in which they used their previously observed strategy. That is, individuals that worked with memorization increased their memorization time, while individuals that worked with acquisition increased their number of gaze shifts (10).

The strategy index reflected the same pattern that was observable on the strategy space: Most subjects clustered on the acquisition end of the spectrum and a single outlier strongly leans towards memorization.

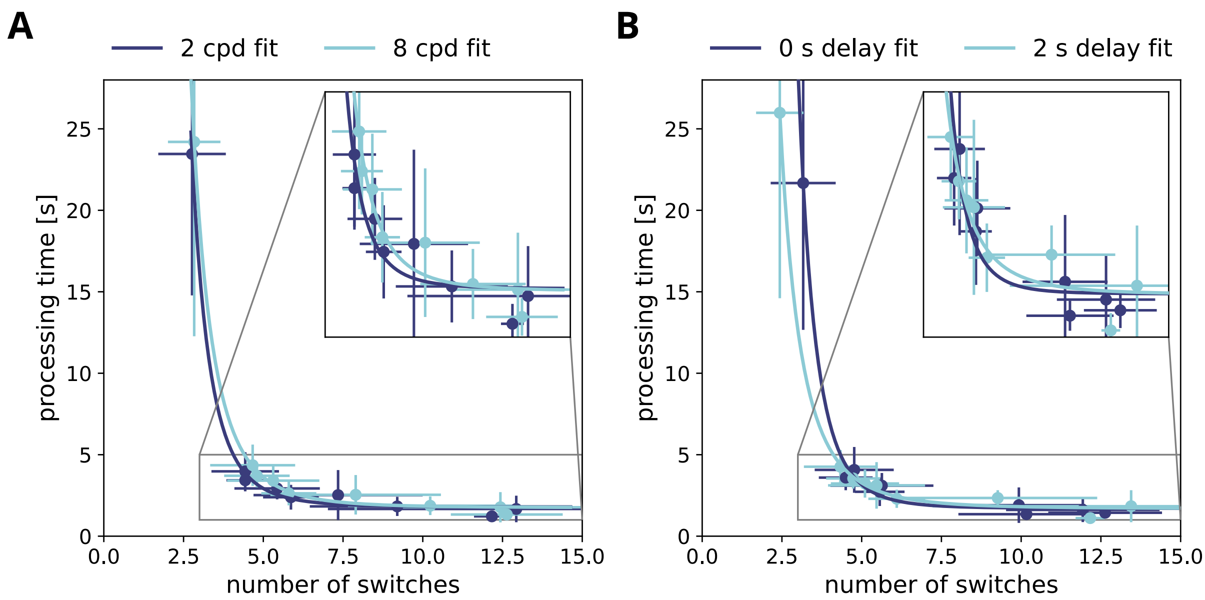

Figure 10: Strategy space separated (a) by cycles per degree conditions (two shades of blue) and (b) by delay. The increase in cycles per degree move the individual mean up the axis it utilizes the most: Points in the bottom right move more towards the bottom right. Points in the center move along the diagonal. Increasing the delay shifted the strategy of all individuals towards memorization.

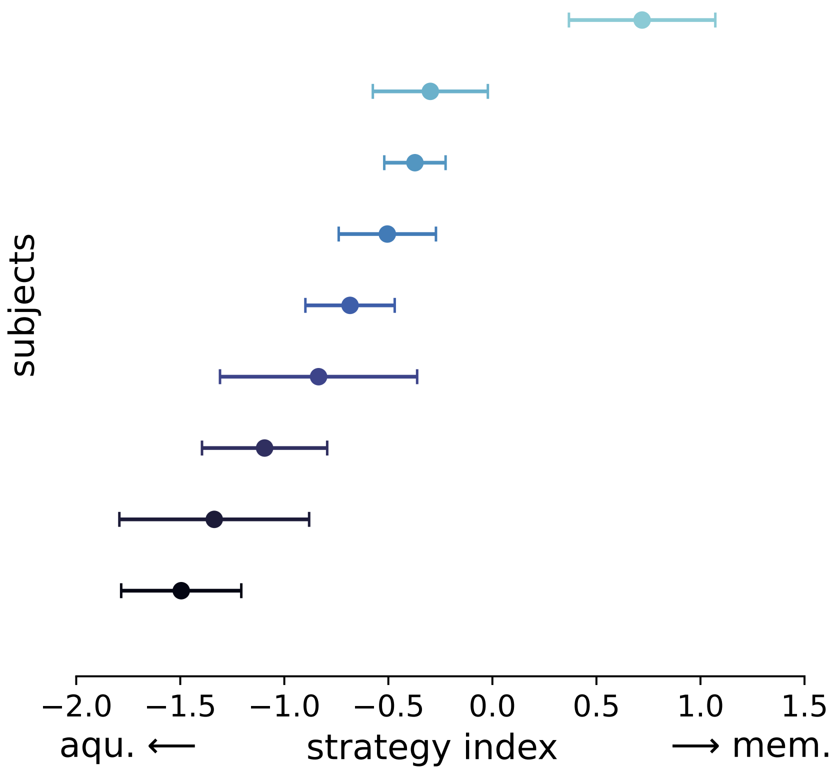

Figure 11: Strategy index colored by subject ID grouped across all stimulus regimes. The distribution of subjects along the strategy index resembles the distribution observable in the two dimensional strategy space in figure 9.

The strategy indices separated by delay and cycles per degree condition respectively (12 show the same pattern already visible in the strategy space.

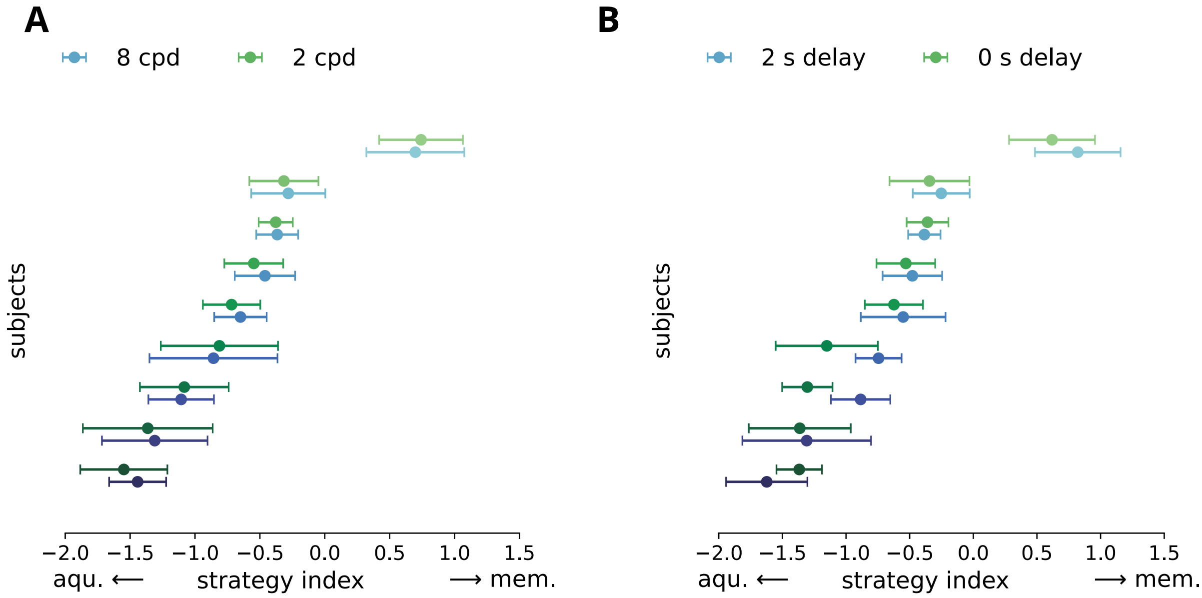

Figure 12: Strategy indices separated by the two spatial frequencies (a) and the two delay conditions (b). In both cases, the same pattern observed in the strategy space can be observed here as well: Changes in the difficulty of perception (a) seem to shift acquisition strategists more towards acquisition, whereas memorization strategists are shifted more towards memorization. Raising the acquisition costs seem to shift all individuals towards increased memorization.

If a subject had difficulties perceiving the stimulus, i.e. had a higher detection threshold in the 4AFC task, we expected them to lean more towards a memorization rather than aquisition strategy. To relate the individuals strategy to the detection threshold, we computed a linear regression of the detection threshold and the strategy index but did not find a relationship between the two in our dataset.

3.3 Contrast sensitivity

The fitted logistic functions returned perception thresholds ranging from 0.017 to 0.019 Michelson contrast for the lower spatial frequency. The perception threshold for Michelson contrast for the higher spatial frequency of 20 cpd is outside the range of presented contrasts for all three subjects. All three subjects reported that they didn't perceive the stimulus for any contrast in the 20 cpd condition. The mean perception threshold of 0.0173 in the condition with the lower spatial frequency is lower than the mean perception threshold of > 0.64 in the high spatial frequency condition.

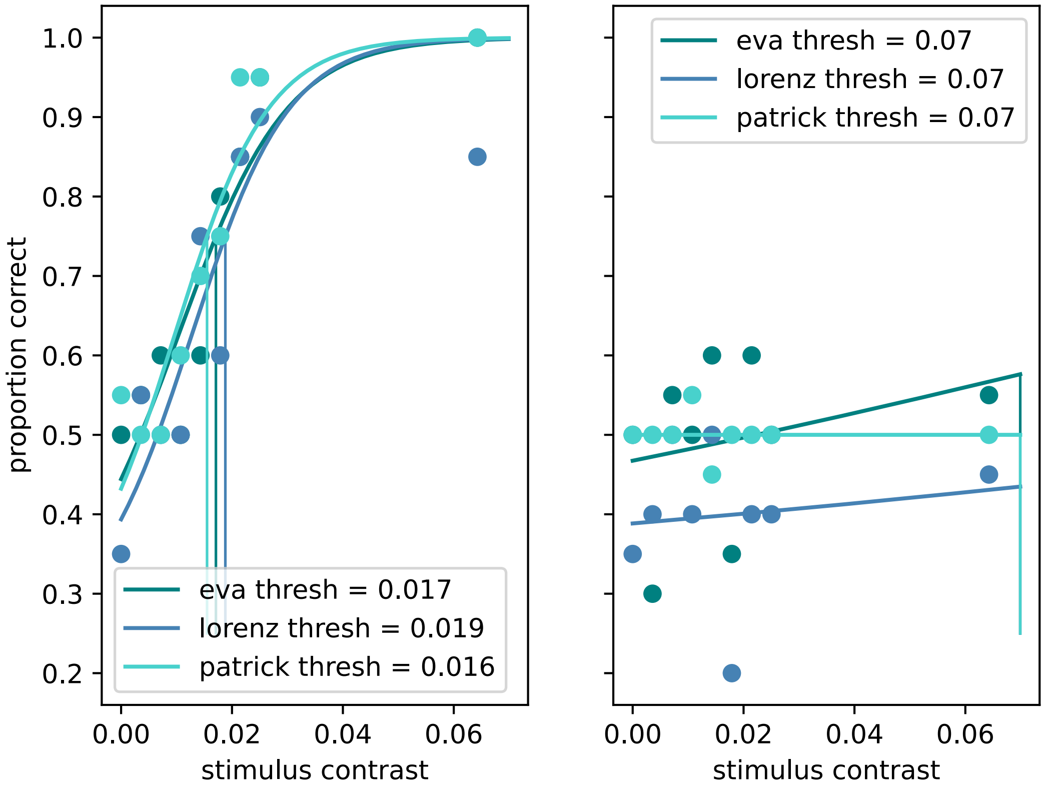

Figure 13: Psychometric function for contrast sensitivity for all three subjects. On the Y-axis is the proportion of correct answers, on the X-axis is the range of presented Michelson contrasts. Colors are matched to the subjects in both plots. **Left:** Curves for a low spatial frequency (10 cpd) **Right:** Curves for a high spatial frequency (20 cpd)

4 Discussion

The data showed a detection threshold of about 0.06 s in the 4AFC task, with results varying between individuals and a dependency on spatial frequency: The Gabor patches with the lower spatial frequency (2 cpd) had a lower detection threshold than the patches with higher spatial frequency (8 cpd) and were thus perceived more easily. In the comparative visual search task, on the population level, only response and processing time were significantly influenced by the different spatial frequencies, the varying delay had no significant effect on the subjects behaviour. On the individual level, the strategy space spanned by processing time and number of switches fitted a power function. The strategy index revealed a slight shift towards memorization in many individuals for both the higher spatial frequency as well as the 2 s delay condition. No correlation of mean detection threshold in the 4AFC with the strategy index could be found. The data sampled in the contrast sensitivity experiment found a detection threshold at a contrast level of about 0.017 in the 10 cpd condition, in the 20 cpd condition the detection threshold was not within the range used in this experiment.
Overall, the 4AFC experiment conducted as part of this project was able to replicate the effect expected. Higher spatial frequencies take longer to be processed, presumably because of the different gain of the M and P channel (Murray and Plainis 2003), leading to higher detection thresholds regarding the time the stimulus is presented necessary for reliable detection. This effect would also account for the difference in detection threshold for the contrast levels tested in the third experiment, on contrast sensitivity.
As to why some participants were unable to reliably detect the stimuli presented within the given range of periods of display, while one subject even exceeded the range towards 0 s, we could not find any suggestions in the literature but think it would be worth going over the stimulus presentation style again and try to find strategies improving or impeding performance.

The subjects' performance in the comparative visual search task was overall stable and could show trends in some of the effects expected. The constant error rate and trial duration for most of the participants over the number of trials shows that the ongoing task did not alter the performance or strategy. The population level analysis could only show a significant influence of spatial frequency on the processing and response time, suggesting that the subjects mostly just accepted the higher costs for perception and thus memorization and took more time in these trials, keeping consistent with the number switches and the error rate. The Wilcoxon signed-rank tests were non-significant for the two delay conditions, maybe because the delay was too short to substantially increase the acquisition costs, or because the subjects' strategy was laid out on minimal acquisition from the beginning on. The former reason would not be in line with the findings of an effect by Hardiess and Mallot (2015), who used 1.5 s as delay. We therefore rather hypothesize that the delay used was actually too long: First of all, it seems a little bit unrealistic, as no saccade would take so long, which might have influenced the participants' behaviour. But more importantly, a delay of that length does not only put costs on acquisition, but on memorization too, as information needs to be maintained over this period. This eventually equal rise in costs eue to the cross-interaction might be the reason explaining the unchanged, or even reversed strategy of some participants.

Analysis of the individual strategies revealed an alignment of individuals along a power-fit function in the strategy space of processing time over number of switches. Congruent with the expectation, subjects with higher numbers of switches had a shorter processing time. This directly demonstrates an example of the trade-off between memorization and acquisition in this task. In this individual analysis, other than in the population, it can also be seen, that the longer delay shifts the strategies towards memorization. This is not only visible in the shift of the power-fit function, but very prominently for three individuals in the shift of the strategy index. The influence of the higher spatial frequency on memorization costs and thus strategy seen in the overall population is however, although very consistent, not large. We generally think, that more pronounced differences in acquisition and memorization costs might solve this problem and lead to significant changes in strategy. In order to overcome the effect of parallel rise in acquisition and memorization costs with longer delays it might help to increase the energy costs of the acquisition instead.
The fact that no correlation between mean detection threshold and strategy index was found is not surprising, as many other factors such as concentration level or personality may have influenced either experiment.

Finally, our analysis of the experiment on the relation of contrast sensitivity and spatial frequency in sinusoidally grated targets such as our Gabor patches showed an influence of contrast level on perceivability of a stimulus as well as an influence of the spatial frequency of the stimulus on the contrast sensitivity as described by Campbell and Maffei (1974). However, the 20 cpd stimuli were apparently so difficult to perceive that within the contrast range given no subject could perform significantly above chance. The thresholds for 10 cpd and interpolated from the results of the subjects for 20 cpd however lie on the spatial frequency contrast sensitivity function (also referred to as Modulation Transfer Function; Arden (1978)) found by Campbell and Maffei (1974) and later Campbell (1983) at the respective spatial frequencies.

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