BACHELOR'S THESIS IN ARTIFICIAL INTELLIGENCE

RADBOUD UNIVERSITY NIJMEGEN

Designing pleasant stimuli for a visual noisetag BCI

OPTIMIZING USER EXPERIENCE WHILE MAINTAINING CLASSIFIER ACCURACY

Author:
Lynn van Oss
s1009855
Artificial Intelligence
Radboud University

Supervisors:
prof. dr. P.W.M. Desain
Radboud University

dr. C.S. Verbaarschot
Radboud University

dr. S. Ahmadi
Radboud University

July 2020

Abstract

Visual noisetag brain computer interfaces (BCIs) are brain controlled devices that allow users to communicate or control other devices (e.g. a TV). These BCIs particularly give patients with certain forms of paralysis the opportunity to communicate and be independent. Unfortunately it can be annoying and exhausting to look at the flashing stimulus, currently used in these BCIs. This thesis aims to optimize the user experience of these BCIs by using moving textures as stimuli. Hoping to obtain a stimulus that increases pleasantness and decreases fatigue. To achieve this participants rated a collection of moving textures, and some interesting ones were tested on performance by integrating them in a visual noisetag BCI. Results show that although the moving stimuli are subjectively preferred over the flashing stimulus, they cannot maintain the high performance of the BCI with the flashing stimulus. Despite these findings adding motion can still be promising to optimize the user experience of a visual noisetag BCI, but more research is needed on the generation and processing of the responses.

Contents

1 Introduction

Due to constant advancements in technology, brain computer interfaces (BCIs) are emerging and starting to play a bigger role in daily life. BCIs are computer-based systems that read brain signals, process them and use the output to send a control command to a device. They can be used for patients to replace, improve or restore lost control or by healthy people to enhance normal control or supplement new control [3]. An example of a replacement for lost control is a BCI speller. By now there are many kinds of spellers, one of them is the speller created by MindAffect [1] which makes use of a visual noisetag BCI created by Thielen et al. [10]. The speller consists of a M x N grid representing the alphabet where each cell contains one letter or symbol (see Figure 1). These cells then flicker according to a pseudo random noise-code which can be used by an evoked BCI as a stimulation sequence. If a participant then looks at a specific cell, Broad-Band Visually Evoked Potentials (BBVEPs) are elicited in the brain, which are measured by the EEG. These signals can then be translated back into which cell the participant was attending to and can be used to select the right letter to spell words or even whole sentences [10].

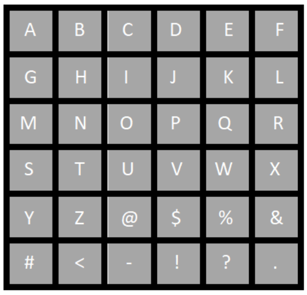


Figure 1: Example of a 6 x 6 grid speller

These spellers can give patients with for example Locked-in syndrome (LIS), Amyotrophic lateral sclerosis (ALS) or comparable diseases the opportunity to communicate. These people are aware but are not able to communicate or move due to paralysis of nearly all muscles. Often they still can make small movements with their eyes such as blinking and moving vertically [8]. They are thus locked in their own bodies and cannot communicate with their loved ones anymore although they do have thoughts they want to share. This can be really frustrating for these patients. Research has shown that these patients particularly want to be able to communicate and be independent again [5, 13].

One disadvantage of a visual noisetag BCI speller is that the flashing stimuli that are used can be exhausting and annoying to look at, especially if the number of buttons is high [11]. If you want to have a conversation via this device you need to focus on flashing buttons for a long period of time. This is not very pleasant and can be challenging for patients with LIS, ALS or comparable diseases. However these flashing stimuli are what make these devices work so well. The BCI of MindAffect [1] has an accuracy of 95% and a detection speed of approximately 2 seconds. So is it possible to change these flashing stimuli while maintaining the high performance of the system?

Liu et al. [6] recently researched improving a N200 speller via dual-directional motion encoding. N200 spellers avoid flashing stimuli, but their information transfer rates

(ITRs) are lower than other visual BCI spellers. With their novel dual-directional N200 speller, they succeeded in improving the speed of the N200 speller and created a very promising non-flashing, with low visual fatigue, BCI speller. So adding motion to the stimuli is very promising.

To use motion as stimuli in a visual noisetag BCI it is important to keep in mind that we need a stimulus that can represent a binary sequence and which aspects of the current stimulus ensure the high performance. With the current stimulus of the BCI the buttons flash (i.e. the button turns white) if there is a one and they do not flash (i.e. the button turns black) if there is a zero in the binary sequence. It is thus important to find stimuli that can also represent a binary sequence like the flashing stimulus.

A form of motion is apparent motion, this is an illusion of motion created by the brain. When the brain sees a rapid series of still images it fills in the gaps between these images and creates a perception of continuous motion [7]. This may be useful, as with the right speed two alternating images can be perceived as a movement. Which meets one of the requirements of adding motion to the stimuli of a visual noisetag BCI.

For the BCI to pick up a signal to convert into an action there needs to be some change in the response at the visual cortex. For the current stimulus this is changing from black to white, which gives a clear distinguishable response. When thinking of making it more pleasant one can think of reducing the percentage of whiteness of the stimulus, as this will make it less intense. This can be in the form of textures, say for example small white lines on a black screen. But these small stimuli still need to be able to elicit a distinct response, as mentioned above. Xu et al. [12] investigated using such tiny targets in visual BCIs. They found that despite the weak elicited EEG features this innovative technique can strengthen communication via BCIs. Thus also small stimuli are promising to optimize the user experience of visual BCIs.

The above mentioned addition of motion can be in the form of rotation, translation or size transformation. By changing shapes, size, direction, etc. of the tiny targets, a lot of different moving textures can be formed. Whether these new, and hopefully more pleasant, stimuli can still evoke a clearly distinguishable brain response remains unknown. Although there is much research on the brain response on motion [2, 4, 9], there is no research on this response in relation to BCIs.

Using the broad variety of stimuli, we aim to answer the following research question: *Is there a more pleasant stimulus for visual noisetag BCI, while maintaining a high performance?* This question can be subdivided into two sub questions considering the investment in moving textures: *Can moving textures provide a more pleasant stimulus for visual noisetag BCI than solid colors? Do moving textures give the same BCI performance as solid colors?*

For this research it is hypothesized that there are one or more moving textures that are more pleasant than solid colors as stimulus. Considering the promising results of the studies by Liu et al. [6], Xu et al. [12] and the knowledge on apparent motion, moving textures (in the form of tiny targets) are able to optimize user experience and maintain a high performance despite the weaker EEG responses. However, this will differ per texture since they vary a lot, for example in kind of movement. Thus, one texture may affect the performance more than other textures. It can be that one texture only slightly affects the performance, but it does not optimize the user experience. Or that one texture is way more pleasant than solid colors but it affects the system performance enormously. It is thus important to find a balance between improving the stimulus and maintaining a high system performance.

2 Methods

2.1 Participants

Due to COVID-19 only two university students (both female, aged 20 and 22 years) participated in the BCI experiment. Both confirmed they do not have any history with epilepsy or comparable diseases and signed a written informed consent. The participants also had normal or corrected-to-normal vision and reported no central nervous system abnormalities. The survey was filled in by 19 people including the two participants of the BCI experiment. They also had to confirm that they do not have any history with epilepsy or comparable diseases. Gender and age of these participants are unknown since the survey was filled in anonymously.

2.2 Experimental stimuli

To add moving textures to the buttons of a BCI, first a set of different textures needed to be designed. A lot of different textures were considered, varying in shape, size, placement, etc. Because the original noisetag BCI stimuli were black and white, all new variations were also designed in black and white. While designing the textures it was kept in mind that they needed to be pleasant to look at if they would move in a certain way. So, the percentage of whiteness of the textures was kept low. For the types of movement some literature on the perception of movement was reviewed, but unfortunately there was not much to find regarding responses that could be useful for the visual noisetag BCI. Aside from the information found on apparent motion [7].

After looking at different kinds of movements and features for the textures, four movements and features were selected.

Movements:

- Shifting horizontally
- Shifting vertically
- Rotation
- Enlargement

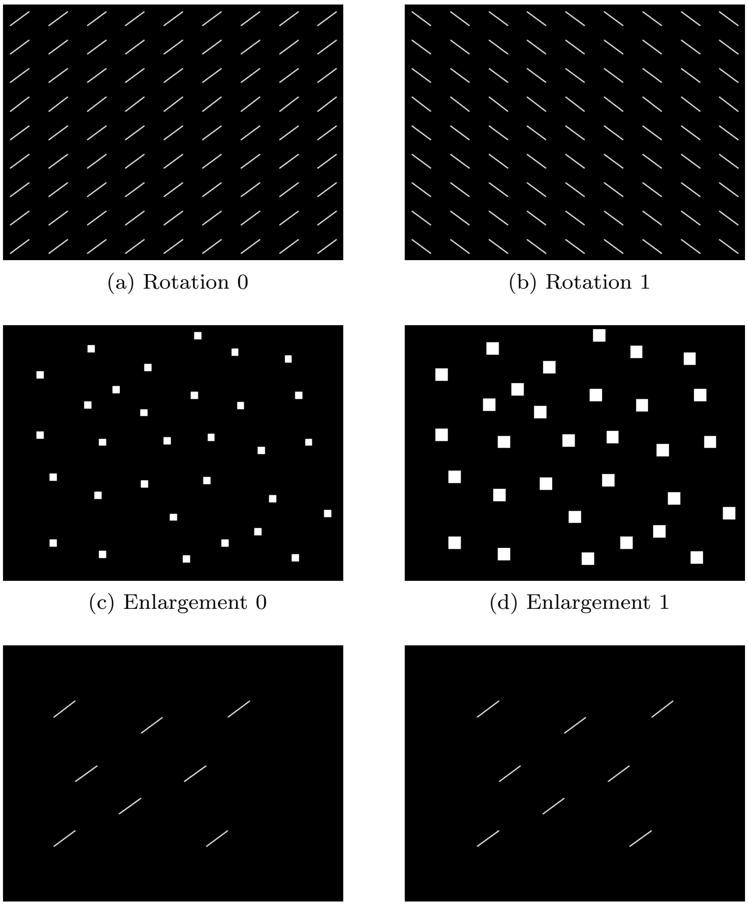
For shifting horizontally and vertically the shapes moved either 2 or 4 pixels in horizontal or vertical direction. The angle for rotation differed for local and global change. For local it rotated either 15 or 30 degrees and for global 5 or 10 degrees. And the enlargement also differed for local and global. For local it multiplied the size of the individual shapes with either 0.4 or 0.8 and for global it zoomed the picture to 0.8 or 0.95.

Varying features:

- Type of change
- Shape
- Size of individual shapes
- Density

Where the type of change means that all shapes move individually (local) or the image moves as a whole (global). And the possible shapes were squares, lines and curves. These shapes were either small (2, 5, 6 pixels) or large (4, 10, 12 pixels) in the aforementioned order. And they were randomly placed 100 or 300 times in the images (Density).

To get an idea of what the texture look like, some example images were created (see Figure 2). Note that these images give an illustration of the textures and are not the textures used in the experiment. The movements in the textures of the experiment are more subtle and are thus harder to perceive in static images.



(a) Rotation 0

(b) Rotation 1

(c) Enlargement 0

(d) Enlargement 1

(e) Shift horizontally 0

(f) Shift horizontally 1

Figure 2: Example of moving textures

The combination of the chosen movements and varying textures gave a set of stimuli consisting of sets of two images, one that correspond to the ones and one that corresponds to the zeros in the binary sequence that is used in the visual noisetag BCI. The images had a fixed size of 3,57 x 3,57 cm which was based on the size of the buttons of the matrix speller used in the experiment of Thielen et al. [10].

set of stimuli:

$$S = \{(img0_1, img1_1), ..., (img0_n, img1_n)\} \qquad with\ n = number\ of\ stimuli$$

This set became very large so it was decided to filter the set before using it in the experiment. The stimuli were filtered on if they could be perceived as a movement based on own intuition. This narrowed the set down to 55 stimuli (n = 55).

2.3 Experimental setup

The experiment was divided into two parts. The first part was conducting an online survey to test the overall pleasantness of the selected stimuli. And the second part consisted of a full BCI setup with 8 interesting stimuli, collected from part one of the experiment, integrated in the BCI to test the system performance.

The survey took approximately 15-20 minutes and the BCI experiment lasted a maximum of 35 minutes, depending on the intermediate breaks. In case of the survey, the participants were able to take a break at any time as long as they wanted. They could save their intermediate results and continue another time. And for the BCI experiment the participants could take a break between each calibration round of a maximum of 2 minutes. If they wanted to continue with the next calibration round they could press any key.

The survey was created using the survey web application LimeSurvey. This software was provided by the Radboud University.

For the BCI experiment the participants were connected to the visual noisetag BCI created by MindAffect [1] (see 2.3.1). They were seated 75 cm away from a 24 inch screen with a refreshing rate of 60 Hz, which presented the flashing buttons. For each of the 9 conditions a calibration round of 10 trials was performed. Each trial consisted of cueing the target for 1 second, a stimulation of 4,2 seconds and afterwards a small break of again 1 second. The code that came with the MindAffect [1] kit was used for the experiment, with only some small adjustments to replace the solid color stimulus with the textures.

2.3.1 The MindAffect kit

The visual noisetag BCI that is used for this research is created by MindAffect [1]. The developed kit is easy to use and adjustable for different kinds of research. The setup is easy, the participant wears a headset with six TMSi water based electrodes (4 channels, one reference and one ground electrode) at the back of the head. These electrodes measure EEG at the visual cortex. If the participant looks at a button with a certain flickering pattern the brain also emits a pattern resembling the pattern of the button. So, by measuring these brain signals the system can detect at which button the participant is looking. And this can be used to control certain devices such as a speller.

2.4 Experimental task

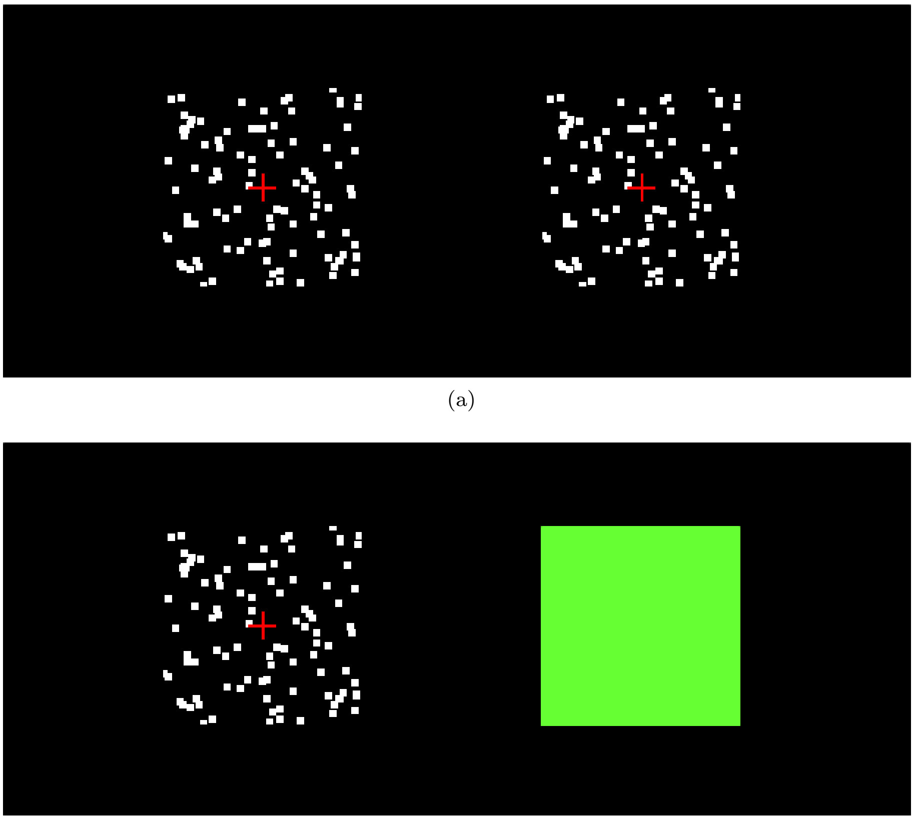
2.4.1 Survey

For this part a survey was sent to the participants by email. In the survey the original BCI stimulus and the stimuli of the above-mentioned set were presented randomly one-by-one as a moving image with a red cross in the middle as a focus point. The original BCI stimulus was presented three times to check the consistency of the participants reports. So, for each stimulus the two corresponding images were shown in a video alternating according to a random binary sequence. The stimuli flickered for 7 seconds and then a black screen was shown for 2 seconds. Hereby it was possible to instruct the participants to focus on the red cross for the same period of time. For each stimulus two questions were asked: Did you see a movement in this image or did you see two alternating images? This is an important question because the focus is on moving textures and not on flashing textures like the original stimulus. And the participants were asked to rate pleasantness, ease to focus and fatigue [1] on a scale of 1 to 7 after focussing on the video for one period. The answers were collected anonymously.

2.4.2 BCI experiment

For the second part of the experiment 8 interesting stimuli, obtained at the first part of the experiment, and the original visual noisetag BCI stimulus were tested to measure the performance of the system. To get these performances the participants were connected to the visual noisetag BCI. They were seated in front of a screen which was used to display two buttons (see Figure 3(a)). Both with the same stimulus but representing different codes. Then for each of the 9 conditions a calibration round was executed. For each trial one button was cued by making it flicker green for a short period of time (see Figure 3(b)). The responses measured at the visual cortex of the participant were then used to calculate the performance of the visual noisetag BCI for each condition. If necessary the participants were able to take a break in between the calibration rounds, if not they could just press a key to continue to the next round.

[1] fatigue was rated on a scale of 1 to 7 where 7 meant not tiring at all which is counterintuitive, so from now on the term energy is used instead of fatigue.



(a)

(b)

Figure 3: Example of experiment screen setup

2.5 Data analysis

2.5.1 Survey

First the gathered data of the survey is restructured such that for each stimuli we can get the performed manipulations and the answers of all the participants. Here manipulations means the type of movement and the varying features of the texture (e.g. high or low density). With this data a collection of figures is made describing the overall pleasantness of the stimuli. This overall pleasantness is defined as a combination of pleasantness, ease to focus and energy, rated in the survey. The following formula describes this overall pleasantness, called rate score.

$$rate\ score = \mu(pleasantness) + \mu(ease\ to\ focus) + \mu(energy)$$

This rate score is then plotted for all textures and for each of the manipulations to see if there are any patterns in the data. And to examine if the results are significant a pairwise t-test is performed.

2.5.2 BCI experiment

The data gathered with the BCI experiment is used to calculate the performance of the visual noisetag BCI for each of the stimuli. From the utopia software of the Mindaffect kit [1] some rough performances are gathered. However, this is just a prediction performance using the entire trials training data and thus is not a good unbiased estimation of the general performance. So to get a good performance an offline analysis is performed. First the gathered data is preprocessed using a stop band filter, with a bandpass between 1 and 25 Hz, so it stops below 1 and above 25 Hz. Then the data is sliced on the 9 conditions, this gives an X of shape (9,840,5) and the corresponding trial labels (Y) using a sample rate of 200 Hz and a trial length of 4,2 seconds. After the slicing is done each of the 9 datasets is analysed by fitting a canonical correlation analysis (CCA) model and performing a 10-fold cross-validation on the data. This gives the performances of the system, as the average accuracy across folds, for each of the 9 conditions.

3 Results

3.1 Survey

A lot of data was collected after 19 participants filled in the survey. The goal of the survey was to see if there were any patterns or preferences among the textures and to find some interesting textures to test in the second part of the experiment.

The following bar chart represent the rate scores for all the textures, where the last three (56, 57 and 58) are the control conditions.

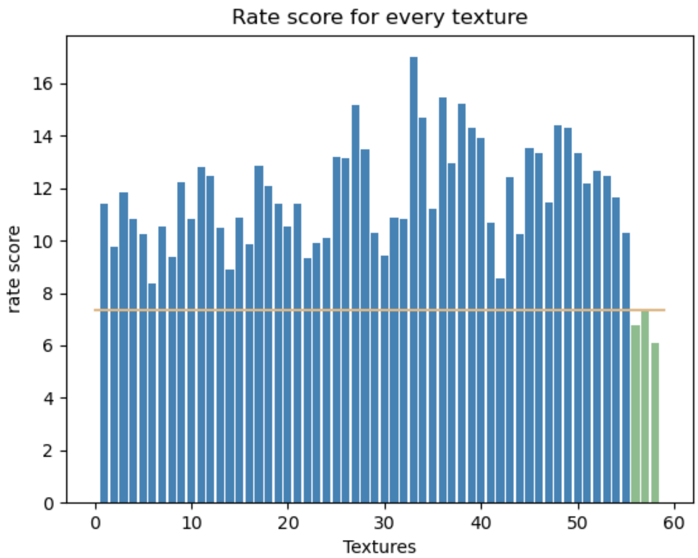
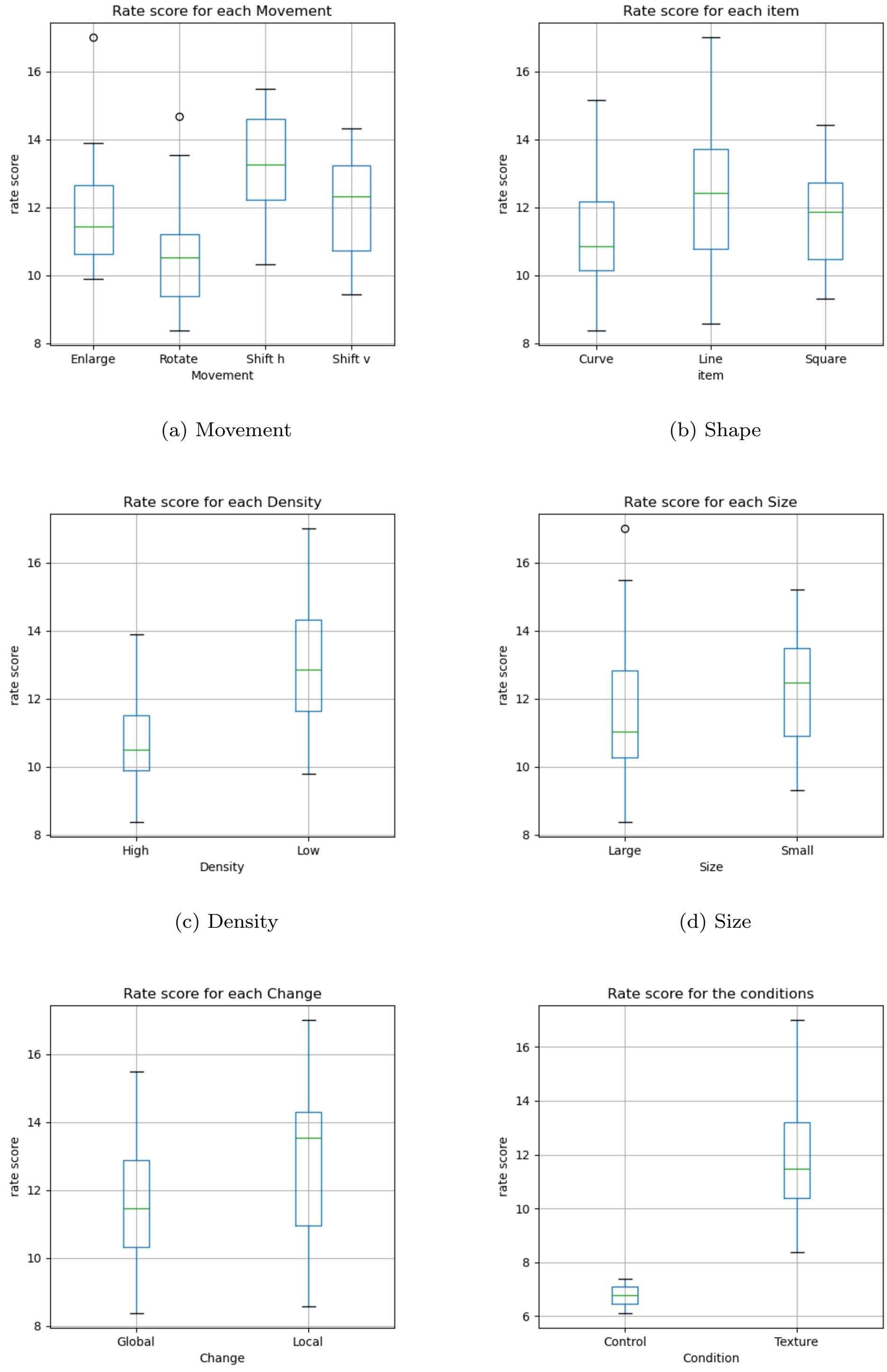


Figure 4: Rate scores

Here we can see that all textures score higher than the control condition. However from this plot we cannot say much about what features of the textures score higher than others (e.g. shape: line, square or curve). Therefore some boxplots were created (see Figure 5). They represent the rate score of the textures separated on one of the manipulations. So for example the rate scores for lines, squares and curves (the manipulation here is shape). This way any patterns, if present, could be seen in the gathered data.



(a) Movement

(b) Shape

(c) Density

(d) Size

(e) Change

(f) Condition

Figure 5: Rate scores per manipulation

By observing these plots some patterns can be seen. The following type of manipulations were significantly different ($p < 0.05$), thus they were preferred based on the data.

- shift horizontally over rotation for movements ($p = 0.001985$)
- Low over high density ($p = 0.000008$)
- Textures over control conditions ($p = 0.00003$)

These preference of shifting horizontally over rotation, low over high density and textures over control conditions may be useful for further research.

From the data there were no clear preferences for all the manipulations. So it was decided to test the best rated textures for each of the movements and shapes and the worst and mediocre rated textures, according to the overall pleasantness (i.e. rate score). Due to some overlap between these textures, 8 textures were tested in the second part of the experiment. These decisions were made based on interest. We investigate in moving textures, so we were interested in the influence on the performance of the system of the different kinds of movements. Also it was believed that the type of shape would have influence on the motion of the stimuli, so we were also interested in the best rated for each of the shapes. And it was also interesting to test the worst and mediocre rated textures for comparison. The chosen textures were identified as follows (see Appendix for the corresponding images):

- # 06 global_curve_300_12_rotate_5 (worst)
- # 21 global_square_300_2_enlarge_0.95 (median)
- # 27 global_curve_100_6_shift_2h (curve)
- # 33 local_line_100_10_enlarge_0.8 (Line, enlarge)
- # 34 local_line_100_10_rotate_15 (rotate)
- # 36 global_line_100_10_shift_2h (shift h)
- # 48 global_square_100_2_shift_2h (square)
- # 49 global_square_100_2_shift_2v (shift v)

3.2 BCI experiment

The Utopia software of the BCI kit of MindAffect [1] gave a predicted performance of the system (see Table 1). However this is just a prediction and not a good estimation of the general performance. Therefore an offline analysis was performed, already discussed in the methods section (see 2). This 10-fold cross-validation analysis gave the unbiased performance measures of the data (see Table 2).

Table 1: Predicted performances

	06	21	27	33	34	36	48	49	OG
EXP 01	60%	40%	40%	80%	40%	50%	30%	60%	100%
EXP 02	50%	40%	70%	70%	40%	40%	30%	70%	100%

Table 2: General performances

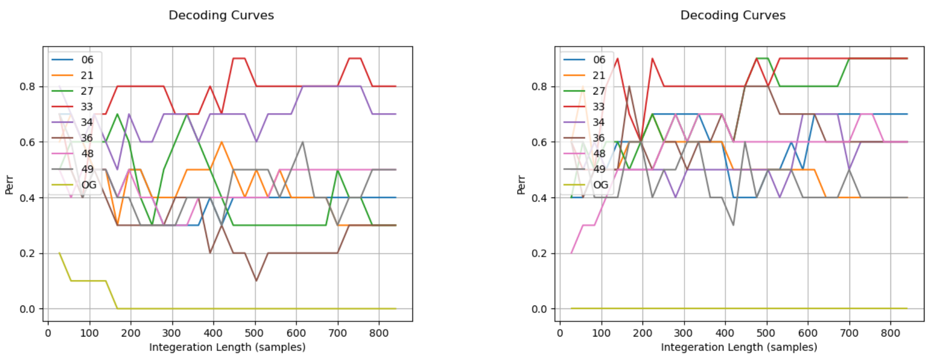
	06	21	27	33	34	36	48	49	OG
EXP 01	37,4%	31,4%	35,2%	9,9%	17,8%	45,1%	38,2%	28,6%	96,5%
EXP 02	24,4%	44,9%	17,0%	14,5%	24,9%	30,2%	34,1%	0,4%	99,5%

The performance of the textures are surprisingly low for a 2-class problem. One would expect at least a performance of 50% (change level) for this problem. Because of these low performance the distribution of true targets was reviewed (see Table 3).

Table 3: Distribution of true targets

	06	21	27	33	34	36	48	49	OG
EXP 01	6/4	4/6	5/5	4/6	4/6	5/5	6/4	1/9	3/7
EXP 02	4/6	4/6	3/7	4/6	3/7	5/5	6/4	6/4	5/5

The corresponding decoding curves (see Figure 6) also show that for the control condition the classification goes well but for the other conditions it seems more random, here the curves are not descending. A decoding curve plots the error for each of the samples. So you expect it to descend as you want the error to decrease. The control condition has a high performance and thus a low decoding curve.



(a) Experiment 01

(b) Experiment 02

Figure 6: Decoding curves

To inspect the differences in performance between the conditions a Wilcoxon Signed Rank test was performed between the combinations of the conditions. All computed p-values where larger than 0.05 so there is no significant difference between each of the conditions, and they are so to say drawn from the same distribution.

4 Discussion

The gathered survey data supports the hypothesis that moving textures are more pleasant than solid colors as stimuli. The bar chart of the rate scores (see Figure 4) shows that the created textures score higher than the three control conditions. And the boxplot for the control condition (see Figure 5(f)) also shows that this preference is significant. So the people who participated in the survey rated the moving textures higher than the control condition. The low performances of the moving textures (between 0,4% and 45,1%) compared to the high performance of the original stimulus (96,5% and 99,5%) from the BCI experiment , however suggest that these textures do not maintain the high performance of the system (see Table 2).

From the prediction performances (see Table 1) it can be seen that there were some textures that scored around 70% which is not bad. However after computing the unbiased general performances (see Table 2) it was observed that these performances were much lower than predicted. The only condition that does score high is the control condition, which is what was expected. The other conditions however score below change level which at first seems unlikely, because you would expect the classifier to at least select the right class 50% of the time (change level). But after inspecting the data a reason for these low performances could be that the distribution of the true target was not evenly spread (see Table 3). So for some conditions one class was only three out of ten times the true target. And if the classifier then only gets the data from the other seven trials it is not able to say anything about the true target and will mostly make a wrong prediction.

The outcomes of the BCI experiment were only gathered from two experiments. Testing it on a larger group would have given more reliable results. Unfortunately this was not possible due to COVID-19.

Apart from suggesting a preference for the moving textures over solid colors the survey did not suggest much about the different manipulations on the textures. Not much patterns were found, which would have been interesting for further research. To be able to find more patterns in the collected data from the survey, it would have been more convenient to better structure the tested textures. By really tuning only one parameter at a time it would have been easier to derive conclusions. In this study it still varied within the categories. So for example small sizes differed between the shapes. They all had the same categories (e.g. small and large) but they should not have differed within these categories.

Getting back to the research questions, the gathered data from the survey supports that moving textures provide more pleasant stimuli than solid colors. People preferred the moving textures over the original stimulus. The second question however is not supported by the data. The gathered performances for the moving textures are not as high as the performance of the control condition (solid colors). Which may be due to the uneven target distribution or by not being able to test on large groups.

5 Conclusion

To conclude, adding motion to the stimulus of a visual noisetag BCI needs more investigation. Liu et al. [6] showed that motion elicits a response that is high enough to control a N200 speller. And also the use of tiny targets researched by Xu et al. [12] showed promising results. Investigating more in the responses of these studies and the way the visual noisetag BCI processes its responses can be useful. There is also a much wider spectrum to look for more pleasant stimuli. In this study only moving textures were considered, but there are much more types of stimuli that may optimize user experience.

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Appendix

Layout survey

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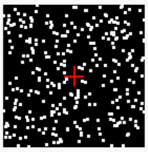
Resume later Exit and clear survey

Please fixate on the cross for one period (between black screens) and answer the following questions.



Did you see a movement in this image or did you see two alternating images?

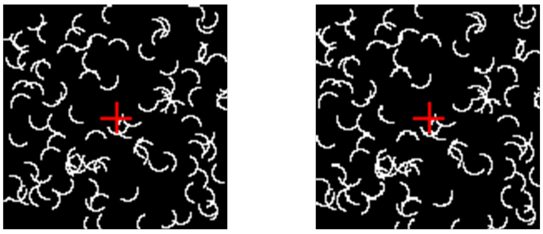
Choose one of the following answers

- ○ I saw a movement
- ○ I saw two alternating images
- ● No answer

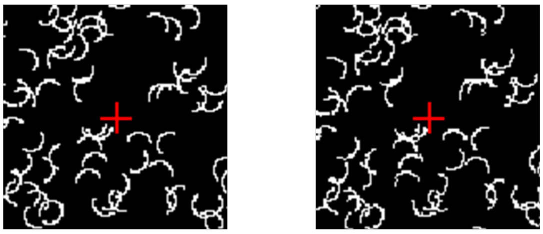
Rate the following:

	1	2	3	4	5	6	7	No answer
Pleasantness (with 1 being very unpleasant and 7 very pleasant)	○	○	○	○	○	○	○	●
Ease to focus (with 1 being very difficult and 7 very easy)	○	○	○	○	○	○	○	●
Fatigue (with 1 being very tiring and 7 not tiring at all)	○	○	○	○	○	○	○	●

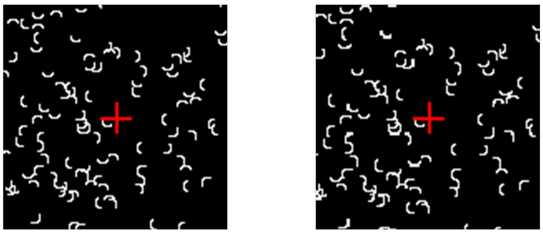
Textures (set S)



01



02



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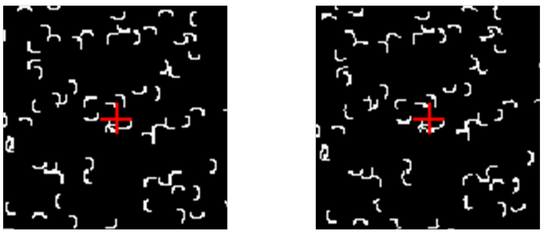

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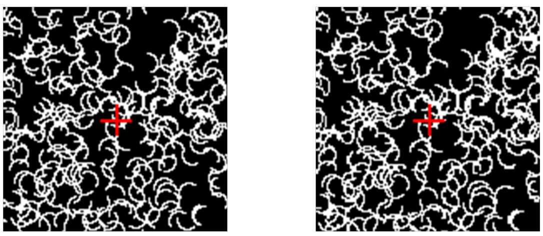

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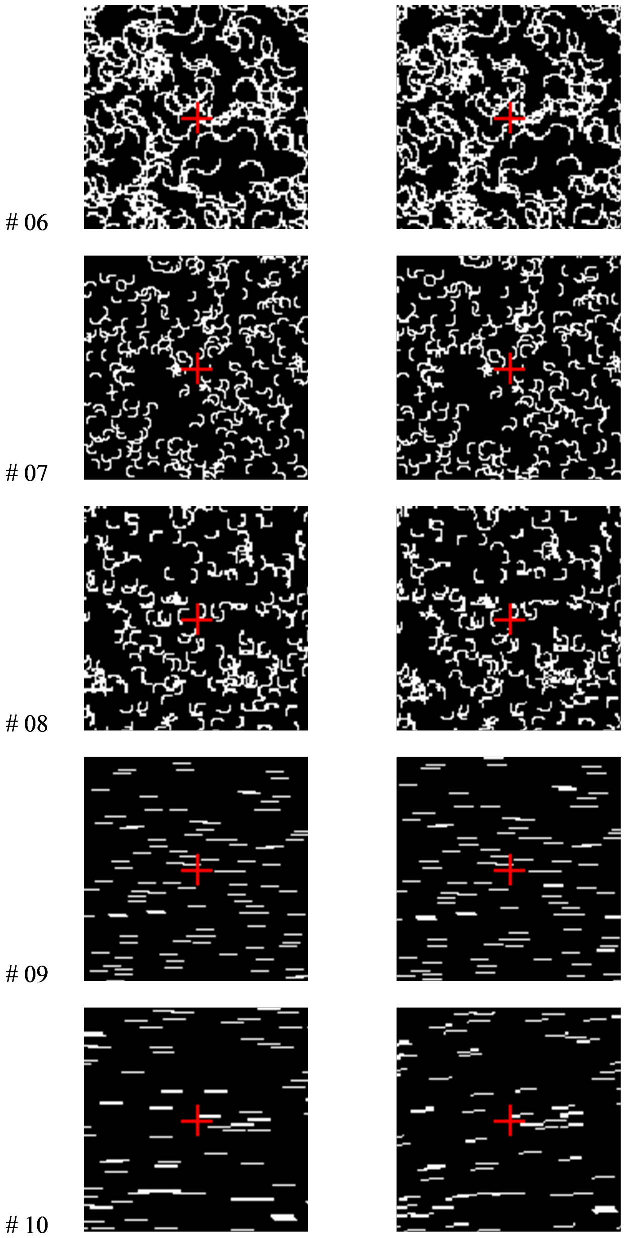
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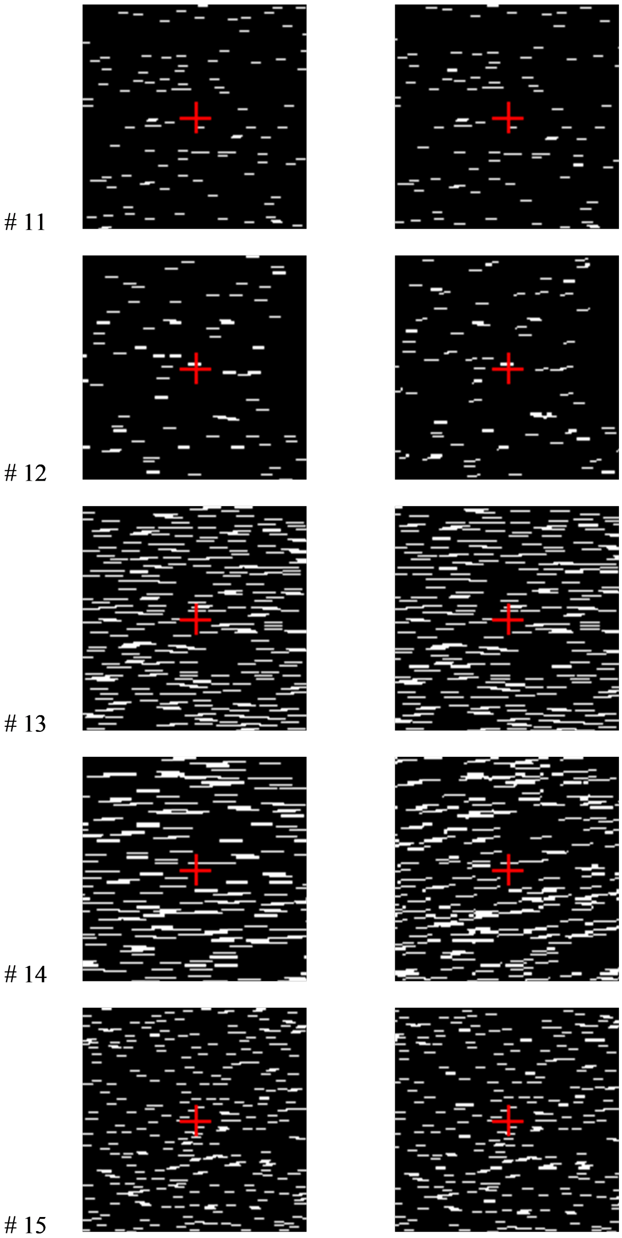
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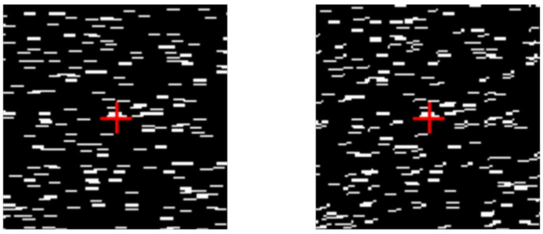

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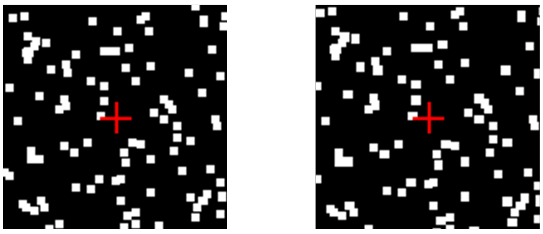

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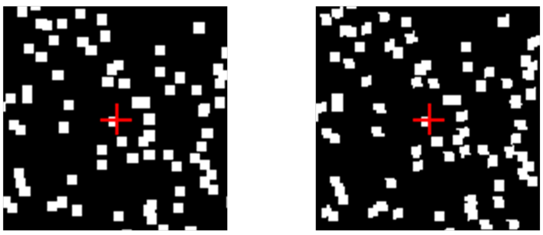

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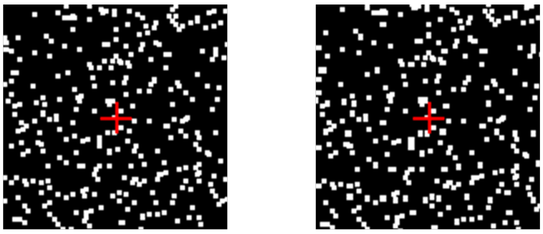

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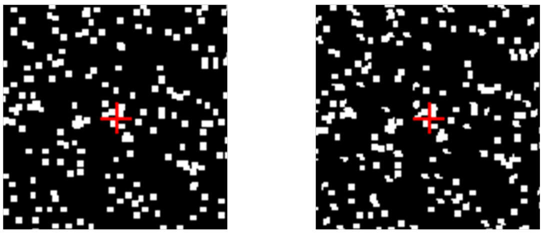

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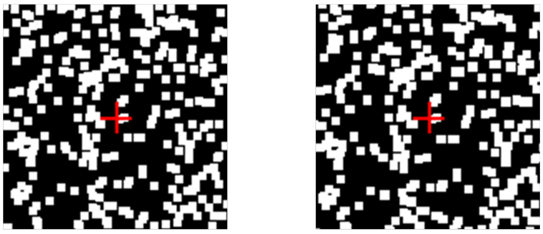

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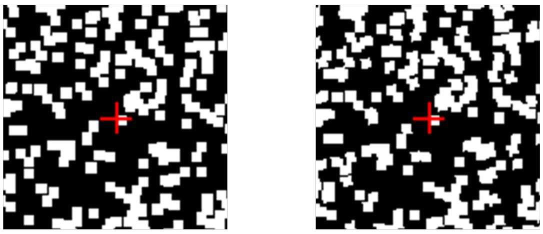

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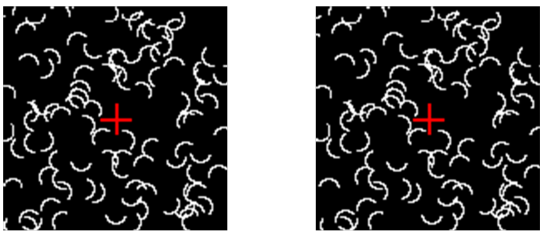

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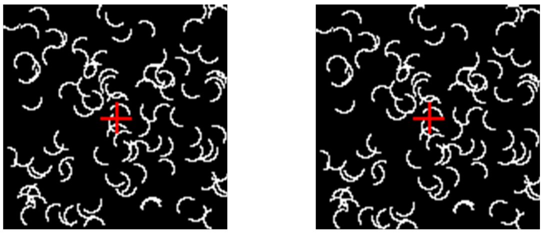

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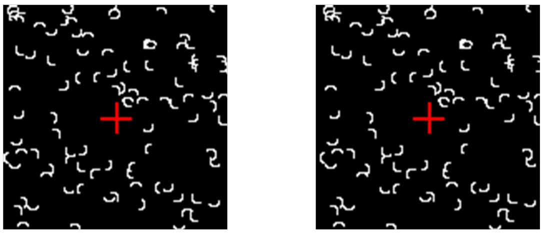

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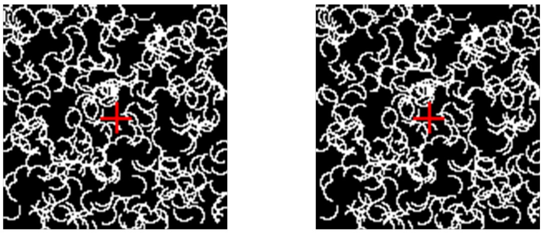

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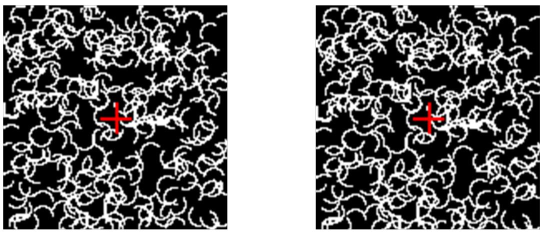

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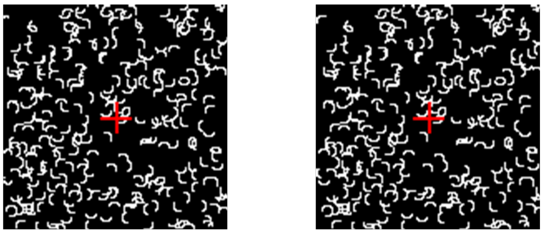

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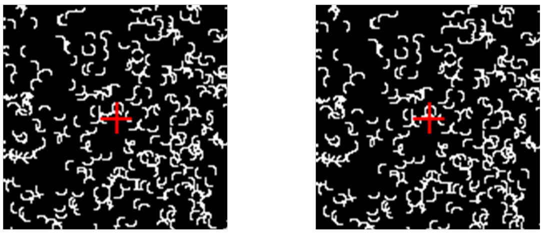

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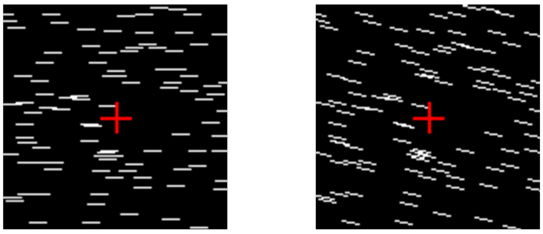

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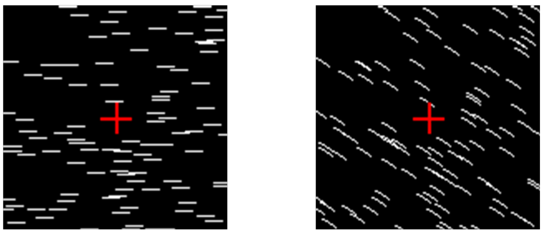

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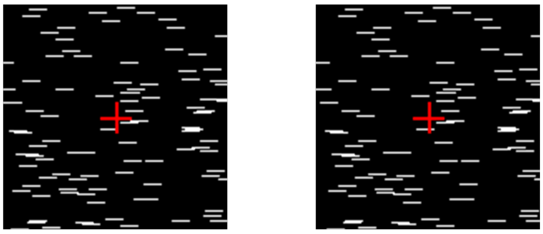
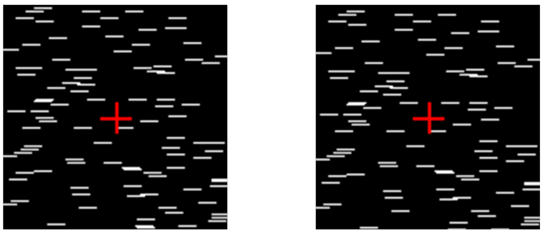
36 

37 

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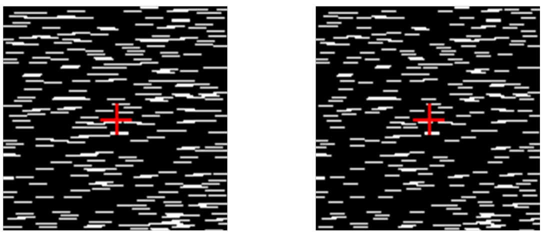
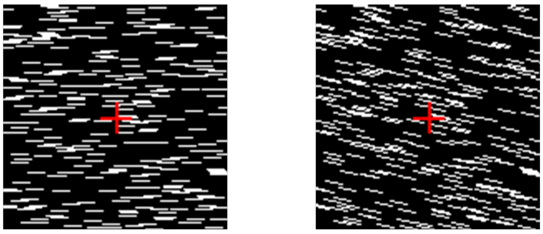
40 



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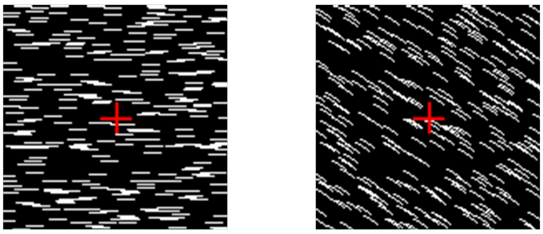

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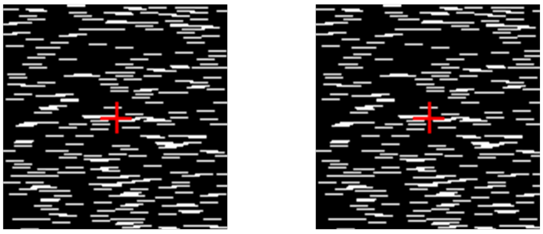

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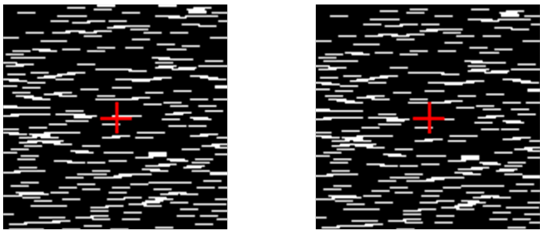

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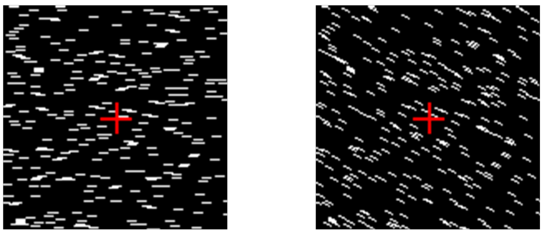

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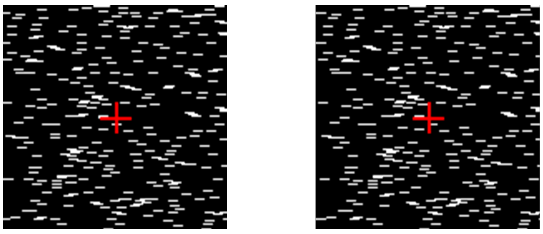

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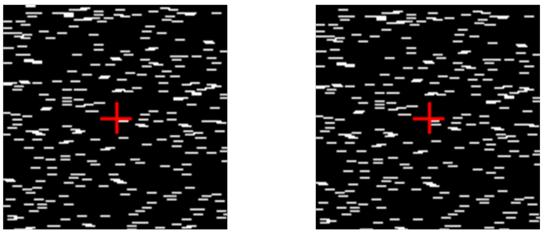

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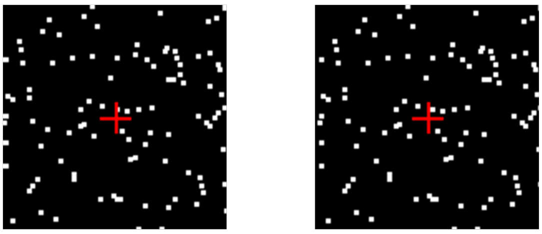

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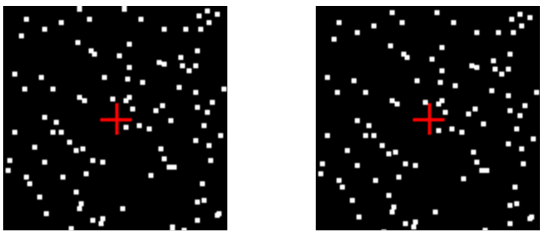

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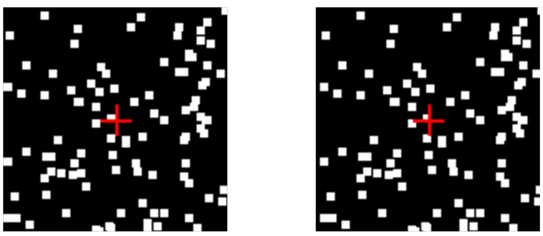

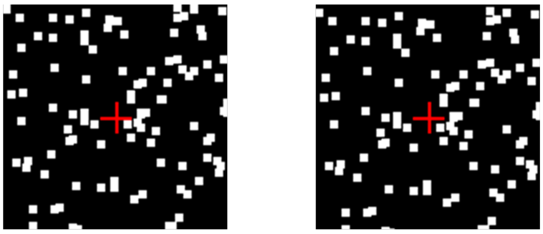

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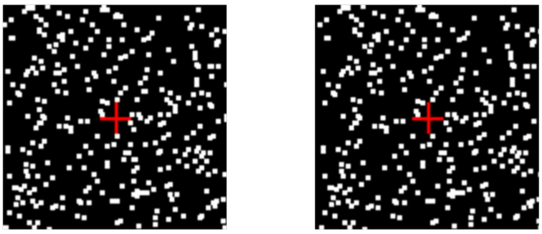

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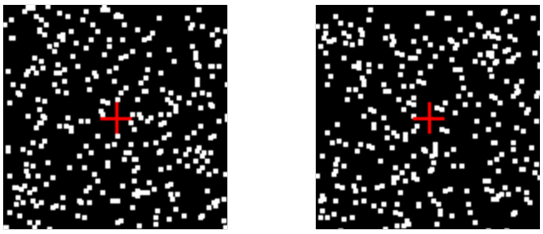

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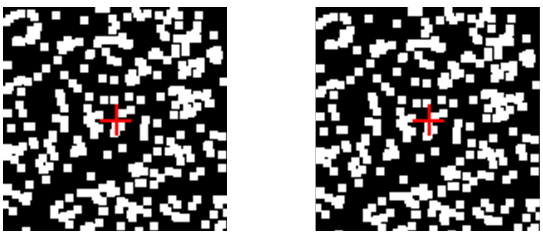

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