Sensory Information about Reading Progress on the E-reader

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Abstract

In this study, we test whether sensory information about reading progress on the e-reader can serve as a memory index to readers to improve readers' memory of the text. Two prototypes that provide readers with information about their reading progress while they are reading on the e-reader have been developed for this study. One prototype makes use of visual elements on the screen, and another of a haptic interface on the back of the e-reader to convey this information. Test results of memory tests and and qualitative data suggest the visual elements do not have a strong effect on the reading experience. The haptic interface faces some usability challenges, but shows promise in providing readers with a haptic memory index during reading.

1 Introduction

1.1 Background

In recent years, research has been conducted on how reading from digital devices influences our reading experience. Studies have looked at several different metrics by which the reading experience and cognitive processing of a text can be measured. For example, several studies show that reading speed is lower when reading from a screen than from paper, but lately there have been arguments to step away from reading speed as a measure of the quality of information

obtained from a text when reading on different platforms (1). Instead, it can be measured directly by how well one has memorized and understood the text, but using these measures has yielded unclear results so far. On the one hand, it has found that when reading short text from a printed sheet, from a computer screen or a Kindle screen, reading comprehension is on average somewhat lower on the e-reader, although this difference is not significant (2). A study focusing on memorising texts has found that subjects do significantly worse at placing events from a story in the correct order when having read from an e-reader than when having read from physical paper (3).

How could such a result be explained? Mangen has emphasized how the sensory-motor experience of reading a physical book has a strong link with cognitive processing and memorising the text (4). She refers to an experiment conducted by Morineau et al, which tested whether the presence of a physical book vs. an e-book improved a test subjects' skill on memory tasks. This study found that a paper book provides support in recall tasks whereas a digital document hinders it (5). Based on this result and the theoretical analyses of Mangen, it seems that reading texts from physical books supports memory better than reading the same text from the e-reader.

1.2 Physicality and memory

How could the physicality of a paper book vs. the immateriality of e-reader constitute for a different reading experience and possibly different cognitive processing of the text? Some theoretical research has explored factors in digital and physical reading which may constitute for a difference in cognitive processing of the text. A possible explanation is a difference in immersion. Mangen has discussed how phenomelogical immersion, which we experience when immersed in a book where the immersion is largely part of the product of our own imagination, may arise with more difficulty on digital platforms. In her view, this has to do with "the sensory–motor affordances of distinctly different materialities of technology than with plot" (4). She explains that because a book is tangible, we experience its phenomenology differently than intangible texts on the e-reader. This might lead to one being less immersed in a text on the e-reader, which is likely to have an effect on how well one memorises and comprehends the text.

Another possible explanation focuses on how physical books can serve as a memory index. When considering how (in)tangibility of a reading medium may be related specifically to mem-

ory of the text, Morineau discusses how materiality and context can serve as an external memory index. When holding a book we have read, it will give rise to memories of the book, whereas on the e-reader, he says, "this physical association between content and support is split up" (5).

Possibly Morineau's suggestion that a physical object may serve as an index for memory can be extended from the book as a whole to the individual pages: when we associate a certain page (or section) of the physical book to certain events in the story, this may make it easier to recall the relative positioning of these events, improving our ability to correctly place events in their right order while and after reading. Therefore the presence of physical pages, being linked to specific parts of the text through their physicality, could lead to a better memory of a read text.

1.3 Hypothesis

If it is true that physical pages serve as an index for memory and thereby improve our ability to retain episodic information from the text while and after reading, ideally such an index would be provided on the e-reader as well. Several characteristics of pages help us identify the location of a page within a book. The position of a page within a book can be sensed through:

1. Visual information of how it looks to be positioned among the other pages, and;
2. Haptic information encoded in thickness of the other pages still remaining in either hand.

This study aims to test whether visual and haptic information about the position of a fragment within a text on the e-reader may also serve as an index for memory and thereby improve readers' memory of the text.[1]

1.4 Method

To study visual and haptic information about reading progress on the e-reader as an index for memory, two prototypes were designed which provide readers with such information. One makes use of visual elements on the screen to convey sensory information and the other uses a haptic interface placed on the back of the e-reader. The design of the prototypes proceeded as

[1]Most e-reader currently do provide readers with information about the position in the text by a 'page read' indicator at the bottom, but this differs from sensory information in its ability to serve as an index. Firstly, looking at the 'pages read' information linterferes with reading, whereas the sensory information of a physical book doesn't.

follows: first an initial design was made in the form a mock-up or prototype. This design is tested by conducting a small experiment with users, gathering qualitative data about the usability of the design. This data is used to create a second version of the prototype, which is used in an experiment where participants read a story using it. The content of the experiment will be discussed in the section for the corresponding prototype.

2 Visual prototype

2.1 Description of prototype

The visual prototype that was created for this study consists of see-through bars that show on the screen of the e-reader, similarly to watermaks on a page. The heights of the bars are a mapping from the pages one has either read or still has to read at any point in a story or book. When holding a paper book, in our left hand we will hold the pages we have read already, and the visible thickness of this represents our progress throughout the book. This can be compared to the thickness of pages we hold in our right hand, which we still have to read. The height of the bar on the right represents the number of pages one still has to read, and the one on the left the pages that have been read. At each turn of a page, the left bar grows, and the right bar shrinks.

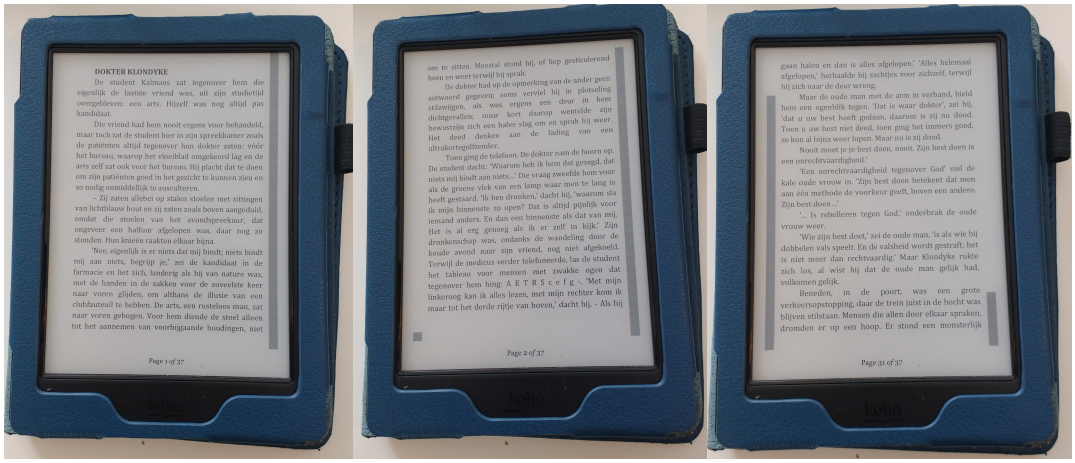

Figure 1: Photographs of the visual interface as displayed on the e-reader.

2.2 Methodology

Two experiments were conducted with the visual prototype described above. In both experiments, Dutch fictional texts were used. Participation criteria required participants to have Dutch as a native language and to have no dyslexia. Participants were aged between 18 and 29 years old and were all students at Leiden University. This age restriction was chosen as age has been found to have a strong effect on episodic memory among adults (6). Convenience sampling was used to gather participants. Participants were not required to have an e-reader to take part in either of the two experiments, but were asked whether or not they owned an e-reader. Participants who were unsure how to use an e-reader were given a small demonstration before the start of the experiment. The Kobo Glo HD e-reader was used in the experiments.

Trial (n = 4)

A trial was held with a within-subject set-up with repeated measures to test the design of the prototype and the experiment set-up. In this trial each test subject read a first story, filled out the memory test for this story, then read the second story and filled out the test for the second story. The test consisted of placing ten sentences taken from the text in the correct order. They would read one of the stories with the visual representation of the reading progress and one without. The order of this condition and the order of the stories was randomized. The stories 'Over de lengte van een gang' ('About the length of a hallway') and 'Over de leegte van een stadion' ('About the emptiness of a stadium') were used in this experiment. The stories are both by the same Dutch author, Herman Koch, and both around 2500 words long.

Participants were asked about their liking of the visual elements on the screen representing their reading progress. Participants either found thickness of the bars about right (two out of four) or slightly too large (two out of four). It was also suggested to make the bars somewhat darker. Based on this the look of the visual elements was altered slightly to the version that was used in the larger experiment.

Due to the repeated measures, a natural learning effect was anticipated. To reduce this learning effect, participants were told what type of test they would have to make before reading the first story, so they would have the similar knowledge of the test during both reading sessions. However, participants reported they found it difficult to read naturally due to this knowledge.

Therefore, a cross-subject setup without repeated measures was found preferable for the larger experiment. In this setup there is no need to tell participants about the type of test they will have to make before they start reading, which will allow more natural reading.

Experiment (n = 35)

In the experiment, participants were asked to read the story 'Dokter Klondyke' by W.F. Hermans of 7800 words. They were randomly placed in either the group with the visual representation of reading progress (group A), or the group that read the text on the e-reader with the normal interface (group B). It was tracked how long they needed to read the whole story.

After finishing with the story, they were asked to make two tests to estimate their ability to recall the order and place of events in the story. Test 1 is based on the test used by Mangen (3), who asked participants to place events from a story in the correct order. In the version of the test used in this experiment, sentences are taken from the text directly and participants are asked to place these in the correct order, to prevent that a presentation of the event as chosen by the researcher might have an effect on how well participants can recall the event. The sentences are chosen to all be part of a new 'scene' in the text and to refer to either a character, place and/or situation in that scene. Test 2 was devised for this experiment and requires participants to indicate on what page number six given paragraphs are found. This is so that they have indicate in absolute terms whereabouts a piece of the text is, rather than in relative terms as is done in Test 1.

Additionaly, participants were asked to indicate their enjoyment and focus during reading as a drawn line. These lines were scanned and these scans were run through a script to extract hundred points on the x-axis that are evenly spread out on the y-axis (see Figure 2). This data was used to visualize and quantify the information in the lines. The scripts for this procedure were written in Processing and can be found in Appendix I.

Furthermore, the participants in group A were asked to indicate to what degree they found the visual elements to be clearly represting their reading progress, and to what degree they found them distracting.

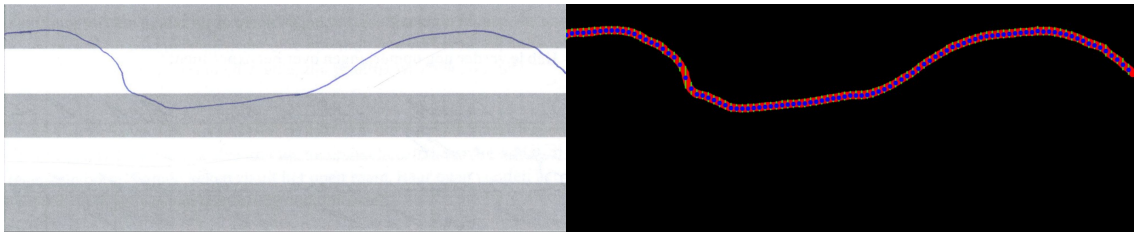

Figure 2: The line as drawn by a participant describing his focus (left), and the points describing the line after processing (right).

2.3 Results

The graphs and visualizations of the results of this experiment were created using ggplot2 (7) in RStudio (8), unless mentioned otherwise.

Memory Tests

It was found that neither group did significantly better on either memory tesy. The Mann-Whitney-Wilcoxon Test was used to determine the p-value of the results of the two groups being different, as it can not be determined that the test results follow a normal distribution (A shapiro test shows $p = 0.045$ for the results of Test 1, and $p = 0.36$ for Test 2.)

Mann-Whitney-Wilcoxon Test results in ($p = 0.58$) for Test 1 when comparing the two conditions, and ($p = 0.23$) for Test 2. Figure 3 shows the test results as boxplots. Y-axes show the scores (0-100 for Test 1, 0-36 for Test 2). The bottom and top of the box show the first and third quartiles, the whiskers the data within 1.5 times the box length. The dots are outliers that fall outside of this range, only present in Test 2.

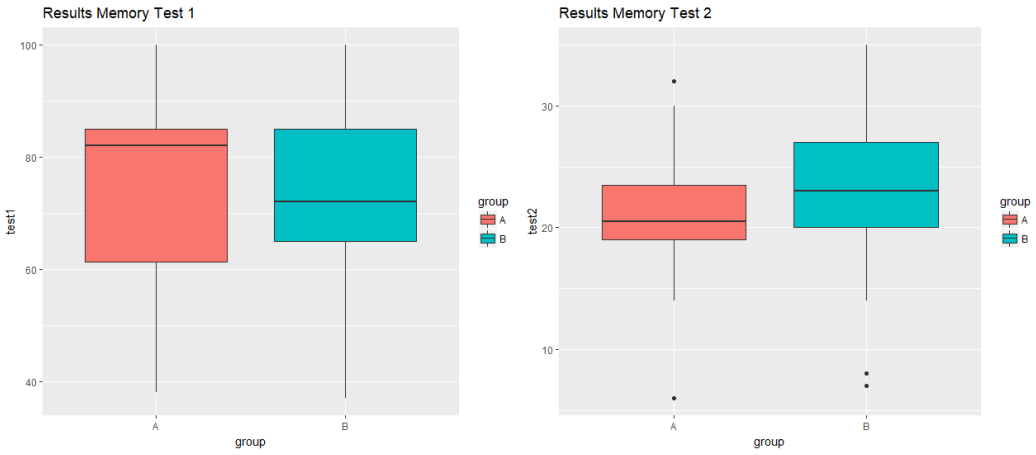

Figure 3: The test results for Test 1 and 2 as boxplots.

Test 1 is based on the test that was used by Mangen, who found by using this type of test that participants who read from a physical book do significantly better at this test than participants who read from the e-reader. It is supposed in this experiment that group A, in which participants are provided with visual clues, would be more similar to Mangen's group reading from a book than group B, who are provided no visual elements. Strangely, test 2 that was devised for this experiment shows a stronger trend that the visual elements support memory than Test 1. Possibly, a test like Test 1 is not suitable for every type of fictional story; in the experiment conducted by Mangen, a mystery story was used.

Variance between participants was quite high; Test 1 shows a standard deviation of 18.6 with scores ranging from 37 to 100, Test 2 a standard deviation of 6.6 with scores ranging from 6 to 35. The distribution of scores can be seen in the histogram in Figure 4.

Figure 4: Distribution of scores on Test 1 and Test 2.

Reading time and Memory Tests

The results suggest that on average, participants who read longer performed somewhat better on Test 1 ($p = 0.10$), but this effect is absent when using Test 2 ($p = 0.72$). This can be seen in Figure 5, which plots the reading time in seconds (y-axis) against the score on the tests (x-axis). The mean reading time was 32 minutes, with a rather high standard deviation of 9 minutes and 15 seconds.

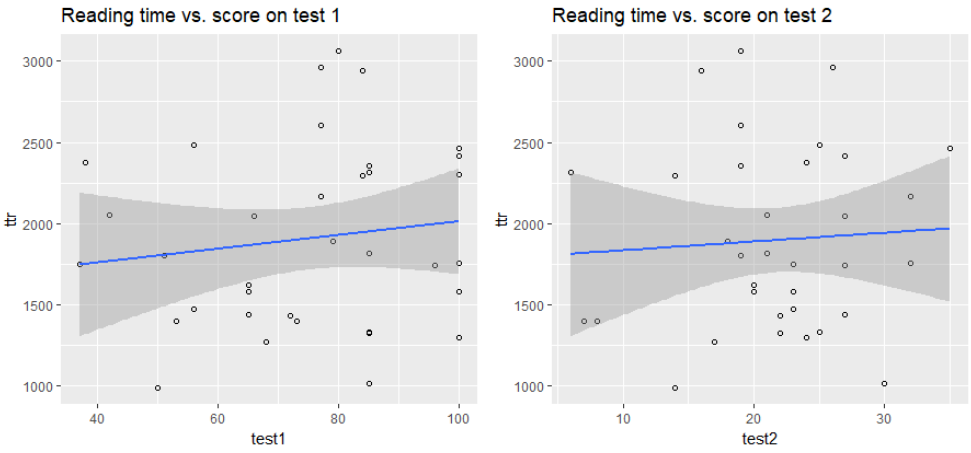

Figure 5: Reading time vs. performance on test.

Self-reported reading enjoyment and focus

Participants were asked to describe their enjoyment of the story and their focus on reading as a draw line in a graph, indicating in what parts of the story they roughly felt more or less focused or enjoyed. The digitized data of these lines have been used to create averages in each point for both groups, which can be seen in Figure 6 (focus) and Figure 7 (enjoyment). Participants in group A show less enjoyment in the beginning of the story, but more in a large middle section.

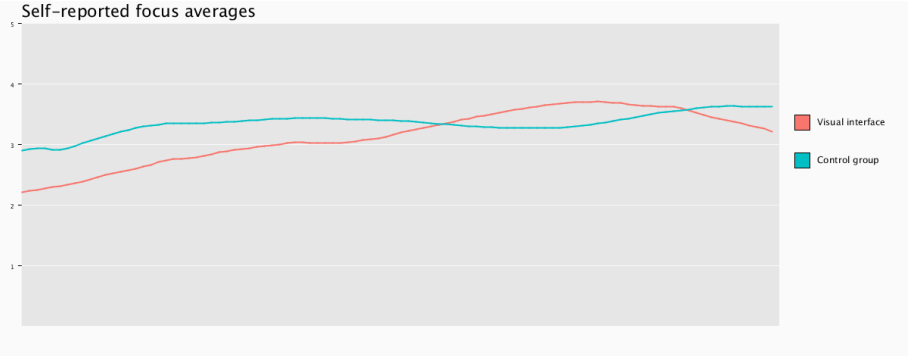

Figure 6: The avarage self-reported focus for both groups.

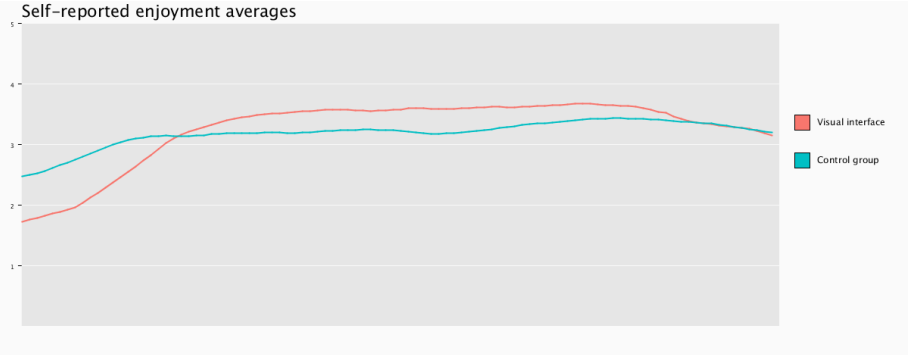

Figure 7: The avarage self-reported enjoyment for both groups.

When taking the average of the hundred points for each participant, we get a number describing the average height of their enjoyment throughout the story. The same can be done for the focus. These averages have been plotted against test scores. The plots for enjoyment can be seen

in Figure 8, where the y-axis described the enjoyment and the x-axis the test-score. There is no significant correlation, though enjoyment and Test 1 ($p = 0.27$) almost seem to have a negative trend, while Test 2 ($p = 0.87$) shows no correlation with the enjoyment to be spoken of.

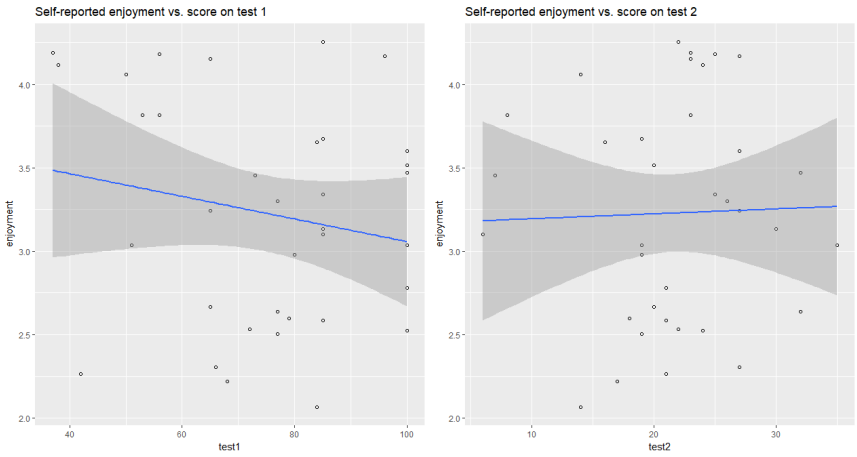

Figure 8: Self-reported enjoyment vs. test scores.

Figure 9 shows the same type of plot, but for the focus. The average of the self-reported focus line do show a weak trend to correlate with the test-scores, although it is not significant: Test 1($P = 0.61$), Test 2 ($P = 0.57$).

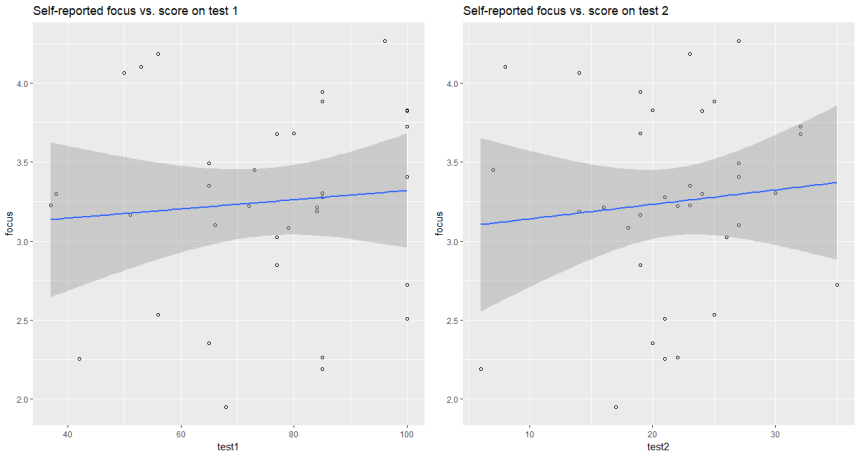

Figure 9: Self-reported focus vs. test scores.

Effect of gender

On average, male participants had higher test scores than female participants in both tests. (See Figure 10) On Test 1, the average score among female participants was 73 vs. 82 of male participants. On Test 2, women scored 20 on average and men 24. The difference is not significant (P = 0.3541), but there does seem to be trend for Test 2 (P = 0.3541 for Test 1, P = 0.07108 for test 2).

Figure 10: Test scores per gender.

When looking at the distribution of the scores of Test 1 (see Figure 11), we see that there is a majority of participants with a relatively high score above eighty, which is much higher than some of the low scores around thirty or fifty. Because this difference is rather big, one low scorer influences the average by quite a bit. There are few participants who scored close the the actual average. This gives the impression that among women, there were more 'low scorers' in this experiment, bringing the average down by quite a lot. When only taking into account the best half of the participants of both genders, the difference is much smaller: the eight best women scored an average of 87, and the eight best men average of 91.

The scores of Test 2, however, are more evenly distributed (see Figure 11): the better half of both genders also did comparable to the overall picture with a mean of 24 for women and 28 for men.

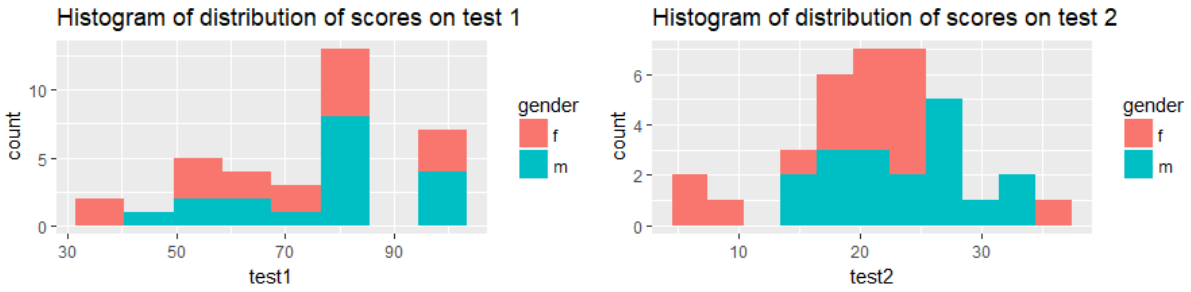

Figure 11: Histograms showing the distributions of scores for Test 1 and Test 2.

Qualitative results & impression

Participants in group A were asked to report whether they found the visual elements distracting. When having to answer this question, some participants asked: 'what visual elements?' - it turned out some hadn't noticed anything unusual when reading. Only five out of eighteen of the participants in group A owned an e-reader themselves. Possibly the participants who do not own an e-reader didn't notice anything unusual, simply because they didn't know what the screen 'normally' looks like.

Some participants remarked that they found the text difficult to read. The text was written in 1948, which is not so old as to constitute for language use being entirely different, but participants remarked they found the construction of sentences unusual at times. This may also have to do with the literary style of the text.

It is possible that an agree of awareness of page numbering may have affected the scores of especially Test 2. Some participants said to only have noticed the page numbers at the bottom after a while, and said they knew the page numbers better when they had incidentaly looked at them at the right fragment.

2.4 Intepretation & Discussion

The presence of visual elements that represent one's reading progress did not significantly improve participants' scores on either of the memory tests. Other measured variables do not vary much between the conditions either. This suggests that the visual elements did not affect the reading experience. This is in line with some reactions of the participants, who said they hadn't

really noticed the bars much during reading. This suggests that when participants reading the text, the information encoded in the bars is not registered well. To be sure of this, participants could be tested with eye-tracking - although such invasive measurements might affect how naturally participants read.

Besides this, it is possible that individual differences in ability simply have a stronger effect on the test results than the interface of the e-reader. Individual differences between the scores are quite big, so that even if the visual elements did affect reading in a subtle way, it is possibly not picked up by this experiment set-up. Since the convenience sampling led to a rather homegenous group of similar age and level of education, it is likely that a randomized sample would show more variance. Therefore, experiments focused more on usability may be more suitable to more directly assess how readers experience the added sensory information. Using such experiments, one can't directly whether a positive effect on the reading experience also means that a person's memory of the text has improved. But it is likely that when readers report to feel that sensory information supports their reading, that this positively influences their processing en memorizing of the text. Individual differences in taste and ability will affect any post-hoc ability test, but not a more direct test of usability.

It seems peculiar the enjoyment of the story does not seem to correlate at all with performance on the tests, and self-reported focus only to a slight degree. It seems likely that participants who enjoy the story more are more impressed by its events and therefore would remember them better. Perhaps enjoyment is too broad as a measurement, as many different dimensions of a story may lead to a higher enjoyment. Attention to just few of these dimensions perhaps has little to do with recollecting the order of events. Also it could be expected that one who enoys the story more is also more attentive to its progression, but for this reason self-reported focus may indeed be a better indicator than self-reported enjoyment.

The gender difference in test scores was not anticipated in the study. We know of no other study that shows men are better at episodic memory in such a task; some studies show that women perform somewhat better at episodic memory tasks (9)(10). Considering the size of the sample, the effect may be incidental.

3 Haptic prototype

3.1 Description of prototype

The haptic interface for the e-reader that was developed for this study, is a disc on the back of the e-reader that can be rotated. When the disc is rotated slightly, one page of the e-reader will turn either forwards or backwards, depending on the direction of the rotation. It is possible to rotate the disc by many degrees at once, which will turn several pages in succesion. A click is given as audiofeedback for each pageturn.

Mock-up (n = 6)

A small trial was held with a mockup of this design to find out what a natural starting point would be for the beginning of a text, what is considered the most natural direction of rotation and how much the disc should be turned in order the finish the book. In this mockup, a non-functional disc with the same look and feel was placed on the back of the e-reader and participants were explained what the goal of the disc was. They were allowed to hold the ereader and rotate the disc to experience how the interface haptically feels. They were then asked what starting point seemed natural to them and how much the disc should be rotated. Out of six participants, all indicated the top of the circle would be a natural starting point. Two said half a rotation would be required for the whole book and four a whole rotation. All of the participants indicated they found clockwise the most natural direction of rotation.

Functional prototype

The functional prototype that is built in succesion of the mock-up works with a half rotation, although most participants in the mockup experiment indicated they found a whole rotation more natural. This choice is based on technical limitations of common potentionmeters. The starting point of a text is at the top of the disc. Rotating the indicator on the disc downward by a small amount will turn one page forward on the e-reader.

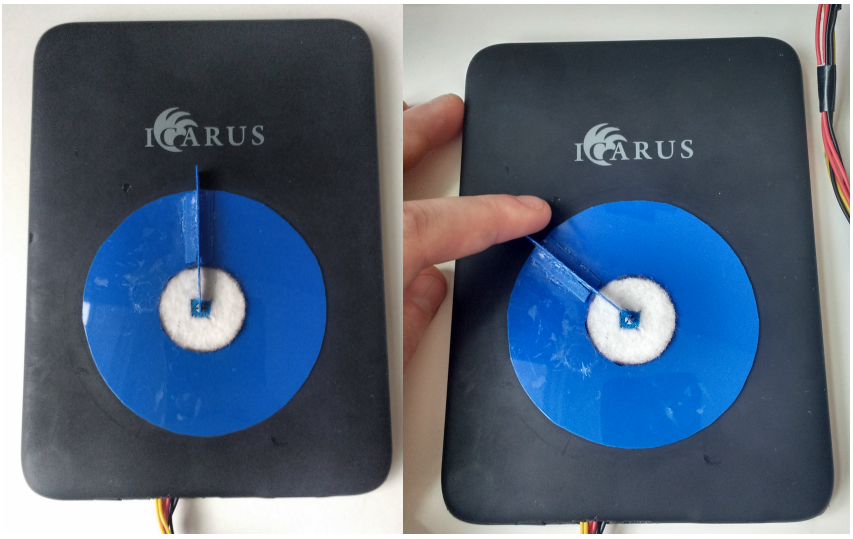

Figure 12: Pictures taken of the haptic prototype. The rotation is clockwise when facing the screen (reversed from these pictures, which are facing the back).

3.2 Methodology

Experiment (n = 8)

An experiment with the haptic e-reader prototype was conducted with eight participants. Participation criteria were to own an e-reader and to be aged between 18 and 29 years old. There were no criteria for native language, as the story read in the experiment was in English. Each of the participants owned an e-reader him or herself. Participants were given the task to read a short story, The Last Question by Isaac Asimov, on the haptic e-reader. Beforehand, they were explained (but not shown) how the pages of the e-reader can be turned using the haptic interface and told not to use other methods of turning the pages. Participants were observed and filmed during reading and some of their behaviour was tracked to assess the usability. Upon finishing the reading, participants performed some searching tasks to asses the haptic interface as an index for memory. Lastly, participants were asked to elaborate on their experience with the prototype in a semi-structured interview. There was no control group in this experiment.

In the experiment we tested whether the prototype offers enough ease of use so that using it doesn't distract from reading. As Mangen (3) described, phenomenological immersion in a text

can only occur when the medium does not disrupt the presentation of the text. Immersion in the text is required for a good cognitive processing of the text. The usability was tested in accordance with usability metrics, which describes certain types of tracked behaviour in using the prototype and how many errors or flaws in this behaviour are permitted. Besides these usability metrics, participants were asked to elaborate on how they liked to use the prototype in a semi-structured interview and whether it allowed them to focus on the text. Impressions from the video footage were also taken into consideration for testing the usability.

To test whether the prototype can serve as an index for memory, we asked participants to navigate to specific parts of the text with some search tasks using the disc. With these tasks, we want to measure how well participants have a haptic understanding of where a certain location or fragment in the text is. Participants were also asked to elaborate on how they found these tasks in the interview.

Usability metrics

The usability metrics below described the different behaviours that are tracked while the participants is reading, the course of the navigation tasks and their quantitive answers in the interview. During reading, it was tracked how many errors each participants had in turning a page. Because the disc needs to be turned be a specific amount of degrees to turn one page and not more, and there is no haptic feedback, an important suspected usability flaw is that it may too difficult to turn just one page. The task of turning a page is considered 'failed' if the participant unintentionally moves two or more pages at once. It was also tracked when participants make the page-turn error, to see how this develops throughout the reading task. The text hast 38 pages in total on the e-reader.

In the navigation tasks, participants will be asked to navigate using the disc in one motion. This is to see how well they can estimate how much movement is required for moving to a certain section of the text. In the navigation tasks to fragments, participants will be presented a fragment and asked to find it using the disc. They are allowed to make more than one motion with the disc, so they can more or less 'browse' for the right part.

The 'current' column in the table below shows the average score among the eight participants in the experiment.

Time	Task	Measured	Current	Worst	Planned	Best
During reading	Turn one page to read linearly*	Number of errors	9.75	38	5	0
First navigation	Go to halfway of story **	Number of pages off	2.88	18	4	0
Second Navigation	Go to 1/3 of the story	Number of pages off	2.125	13	4	0
Third Navigation	Go to end of story	Number of pages off	2	38	2	0
First Navigation to Fragment	Go to fragment 1	Time taken (in seconds)	28.67	60	12	5
Second Navigation to Fragment	Go to fragment 2	Time taken (in seconds)	39.57	60	12	5
Third Navigation to Fragment	Go to fragment 3	Time taken (in seconds)	35.75	60	12	5
Questionnaire	Describe focus during reading	Answer on scale 1-5	3.5	1	3	5
Questionnaire	Describe easy of use using the disc	Answer on scale 1-5	3.5	1	3.5	5

3.3 Results

Usability and focus

One of the most apparent problems with reading on the prototype was turning the disc the right amount to turn exactly one page. On average, participants performed worse than the planned amount; almost ten mistakes on average, against the planned five. Five participants reported in the interview that they rather turned the disc too little initially, and when trying to readjust the degree, overdid this and turned two pages. All participants said to find the sound feedback helpful (although one said she wouldn't want it on her own e-reader). However, one complained of the short delay inbetween the sound and the actual turning. Possibly, improving this timing would also improve users' ability to turn by the exact right amount.

Participants did grow accostumed to using the disc throughout reading rather quickly and made considerably less mistakes in the second half of reading than in the first half (see Figure 13). This is in line with their answers on the semi-structured interview, where all participants indicated that they felt they grew accustomed to using the disc. There were some differences in the time they indicated themselves to need to grow accustomed, varying from about five pages to halfway through the story. On average, participants reported a score of 3.5 on average when asked on a scale from 1 to 5 how well they were able to focus on the story.

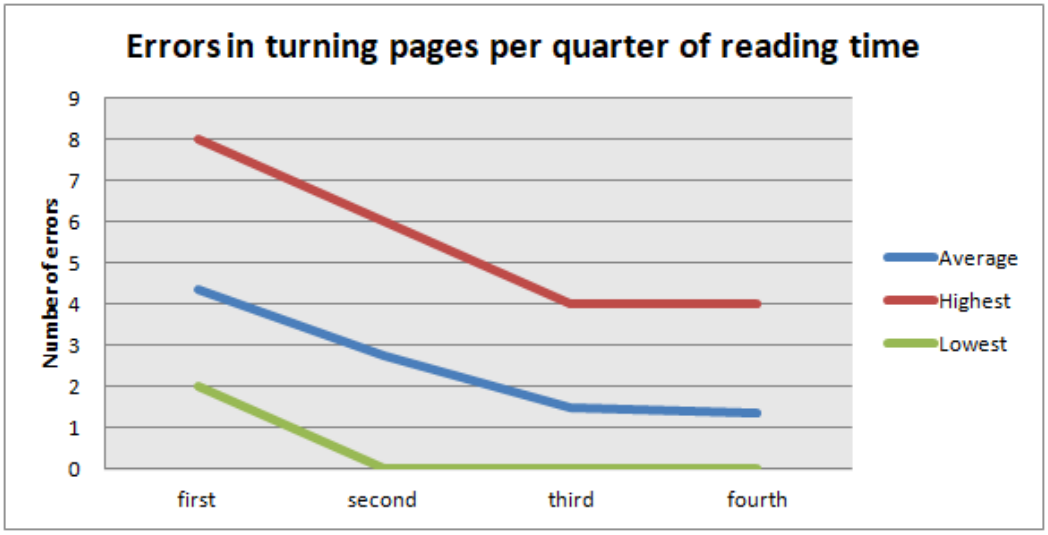

Figure 13: Errors in pageturning per quarter of reading time.

Still, the considerable total number of errors in exact turning is an important point of consideration for a possible improved prototype. All participants indicated in the interview that difficulties with turning the pages distracted from their focus on the story. A commonly mentioned problem is that they lose their train of thought when skipping a page. Two also indicated the motion of turning the right amount distracted from their focus: when they were nearing the end of a page, they grew aware they would have to perform this task and this hindered them in focusing on reading. However, most participants also said their focus became less distracted due to these problems further on in the story, and that they found it easier to regain their focus when incidentally skipping a page.

Concluding, participants do grow accostumed to the page-turning rather quickly, but an experiment with a longer duration is required to ensure that they grow accustomed to a satisfactory degree. Making the sound feedback more accurate may improve the usability of turning pages.

Other usability factors and impressions

Some participants held the e-reader somewhat awkwardly, seemingly not wanting to touch the disc with their other hand while not having the intention to turn a page (see Figure 14). Two also reported in the interview that they were afraid to unintentionally move the disc while just

holding the e-reader. To leave more room for one's hands, the half of the disc that is not used could be left free for some more hand room.

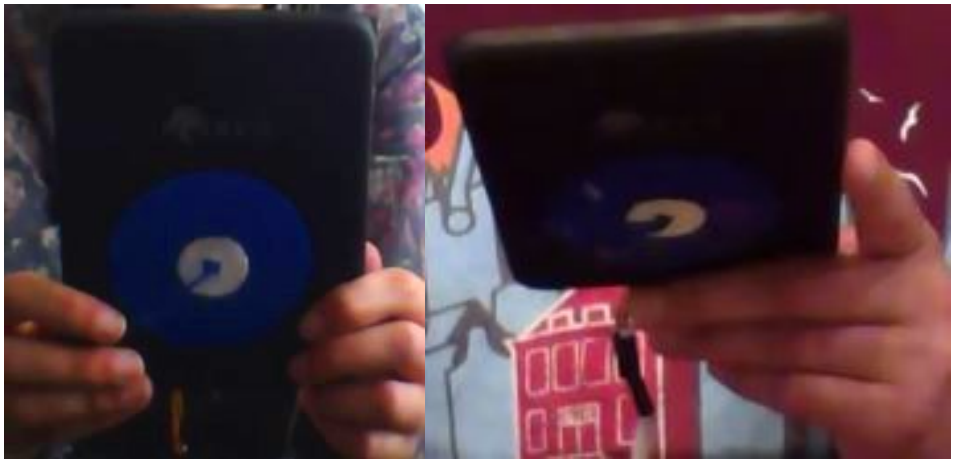

Figure 14: Frames from video-footage of participants reading, which show a somewhat awkward hand position that avoids touching the disc.

All but one participant were of the opinion that the turning side of the disc should remain on the right side. One participants (who was right-handed) said he would like to be able to use the disc with just his left hand. Leaving one half of the disc 'closed' would also be a solution to this, because this would allow more freedom in how to operate the e-reader so that either hand could be used.

Navigation Tasks and Haptic Memory

Navigating to an exact location in one motion was very succesful among the participants. From this, it seems that haptically participants have a good idea where 'halfway through the book' is. This means that by feeling this location, they might also be able to use it as a point of reference or index for memory.

Navigating to find a specific fragment took participants longer than estimated. The estimation was too optimistic, as participants who took quite a bit longer than the estimated twenty seconds were not dissatisfied with the task. Four participants expressed a positive attitude towards searching for fragments with the disc and said they preferred it to searching on the e-reader

normally. Two of them compared it to a progress bar featured on many e-readers, that indicates where you and that you can use to navigate. They said they found this bar imprecise and prefered the disc over it. Three were moderate in their answer and did not express a strong liking or disliking, and one disliked using the disc for searching. She mentioned she found it a lot of fussing to get to the correct page, and that she sometimes felt as though the distance between pages differed.

3.4 Interpretation & Discussion

Generally, the participants showed a positive attitude towards the haptic interface and were well able to navigate to a certain area or fragment in the text. The main usability flaw lies in turning the disc by the right amount of degrees. Participants report this as the only source of distraction of their focus when using the prototype. Although the effect on focus is not detrimental - participants still report a focus of 3.5 on average, and also say they get used to the page-turning after a while - this is clearly the the aspect of the prototype that needs to be improved for a full immersion in the text.

Haptic feedback may be a feasible improvement for a prototype to address this problem, so that participants can feel some feedback when having turned one page. Although implementing this would be perfectly fine for an experimental setting, this solution gives rise to a conflict in the research and practical use of an e-reader. A system of haptic feedback would be impossible to implement in such a way that it can adjust to texts of different lengths, and is therefore unlikely to be brought to commercial e-readers. In the context of an experiment solely testing the effect of e-reader reading with haptic affordances, this would not be a problem as a text with a specific length could be chosen. But outside of this context, a solution that could be implemented for readers in the real world when found profitable to the reading experience seems preferable. In this light, improving audio feedback as was used in this experiment may be a preferable option.

Regardless of this usability flaw, the reported focus and the reactions of the participants suggest that the reading experience with the prototype is quite good. The fact that participants were very good at tasks where they had to move to halfway of the story by feeling, also indicates they have a good haptic understanding of where 'halfway' is. One participant explicitely said she "kind of knows where things are haptically". This suggests that the haptic information provided

by the interface might serve as an index for memory; in other words, always feeling where one is while reading might help to remember where other events of the story were and what the relative position of events is. Therefore it would be interesting to conduct more experiments with such a haptic interface.

Improvements for prototype

Several possible improvements in a haptic prototype can be concluded from the experiment.

As mentioned above, the feedback on turning the disc for one page should be improved. This can be done with more accurate audio-feedback.

Since only half the rotation of the circle was used, it would be an improvement to leave the other half of the e-reader 'closed', so there is more space for the readers' hands. This would also allow for the disc to be turned with either hand. Seven of eight participants were of the opinion the side of the disc that is 'turnable' should remain. Sinking the moving part into the normal back of the e-reader than than placing it on top would also leave the possibility to place the e-reader down.

These improvements could be implemented as is illustrated in Figure 15. As is indicated by the dotted line, such a design would also enable the disc to be rotated multiple times, which might offer a solution to texts with many pages.

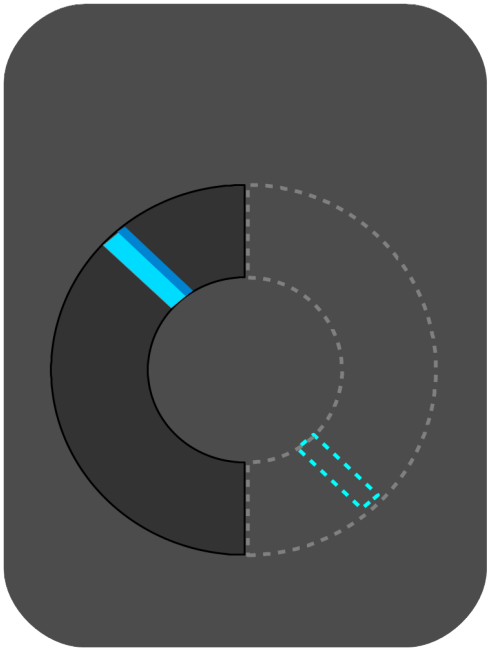

Figure 15: A schametic drawing of the improvements suggested for the haptic e-reader. The turnable half-disc could be sank into the e-reader, so it can still be placed on its back. Two indicators could be used, so that when one indicator reaches the bottom, the other appears at the top and one can continue reading with a new rotation.

4 Conclusion

This study has has tested two interface prototypes for the e-reader that provide sensory information about reading progress on the e-reader. The prototypes were tested to see whether the information they provide while reading may serve as an index for memory and thereby improve readers' memory of the text.

The visual prototype, consisting of bars on the screen that represent the pages read and the pages to go, was tested by having participants read a short story either with or without the interface, and comparing their test scores on two different memory tests that were devised for this study. Participants who read with the visual interface did not do significantly better on either test. Possibly, participants simply didn't notice the visual elements very much while read-

ing: their eyes are busied with reading, rather than registering information about the changing shapes. In fact, several of the participants said they hadn't really noticed the presence of the visual elements while they were reading. The fact that they did not consciously notice them does not necessarily mean the visuals have no effect on the reading whatsoever, but this in combination with the test results suggests that the effect of reading with these visuals is rather small. To gain more conclusive data about the effect of visualized progress on the screen of an e-reader, eye-tracking could provide some insights in how readers react to these elements.

Another consideration is that this study has only taken short fictional texts into account, as this was convenient to do due to the experimental set-up. However, the benefits of providing readers with more information about their reading progress may be bigger in a longer text. Most novels are not read in one sitting, but rather left for a day or more and then picked up again, at which point additional information about the reading progress may help to pick up the story again. Therefore, reading texts in several phases would add a new dimension to these prototypes which were not tested in this research. The fact that the texts in this experiment were all read in one setting made it impossible to take this in consideration. Additionaly, it's possible these prototypes would affect reading different types of texts in different ways. For example, the visual representation might help remember where a piece of information was in a shorter text, which could be helpful in types of texts that you often go back and forth in, like a scientific paper.

The haptic interface, that consisted of a turnable disc on the back the e-reader, was tested with a stronger focus on usability, as it poses more usability challenges than the visual prototype. It can only be purposeful as an index for memory if its usability is up to standard, and when it has been ascertained the interface doesn't distract from reading. Participants of the experiment quickly adjusted to reading with a haptic interface and indicated they generally felt focused on reading regardless of this new interface. The main distractions were caused by the uncertainty about how much the disc should be turned in order to turn one page. The most important suggestion to improve the prototype is make the sound-feedback more accurate in timing. Additionaly, the comfort of use could be improved by reducing the disc to half the size so there is more room for one's hands.

Tests as well as qualitative data suggests that participants had a good haptic understanding of certain locations in the text through the disc. It would be worthwhile to investigate this further and study the haptic interface with the inclusion of memory tests as were used in this study,

when usability flaws have been improved. It is likely that the intuitive understanding of where a place in the text is located on the disc means that this location can serve as a memory index to readers, improving their episodic memory of the text.

References

1. Noyes, J. M., & Garland, K. J. (2003). VDT versus paper-based text: Reply to Mayes, Sims and Koonce. *International Journal of Industrial Ergonomics*, 31(6), 411-423.

2. Margolin, S. J., Driscoll, C., Toland, M. J., & Kegler, J. L. (2013). Ereaders, Computer Screens, or Paper: Does Reading Comprehension Change Across Media Platforms?. *Applied Cognitive Psychology*, 27(4), 512-519.

3. Mangen, A., Robinet, P., Olivier, G., & Velay, J. L. (2014, July). Mystery story reading in pocket print book and on Kindle: possible impact on chronological events memory. *In IGEL Conference–The International Society for the Empirical Study of Literature and Media.*

4. Mangen, A. (2008). Hypertext fiction reading: haptics and immersion. *Journal of research in reading*, 31(4), 404-419.

5. Morineau, T., Blanche, C., Tobin, L., & Guéguen, N. (2005). The emergence of the contextual role of the e-book in cognitive processes through an ecological and functional analysis. *International Journal of Human-Computer Studies*, 62(3), 329-348.

6. Hultsch, D. F., Masson, M. E., & Small, B. J. (1991). Adult age differences in direct and indirect tests of memory. *Journal of Gerontology*, 46(1), P22-P30.

7. RStudio Team (2016). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA URL http://www.rstudio.com/.

8. Wickham, H. (2009) ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.

9. Herlitz, A., Nilsson, L. G., & Bäckman, L. (1997). Gender differences in episodic memory. *Memory & cognition*, 25(6), 801-811.

10. Lewin, C., Wolgers, G., & Herlitz, A. (2001). Sex differences favoring women in verbal but not in visuospatial episodic memory. *Neuropsychology*, 15(2), 165.

Appendix

I. Processing Scripts

Draw graphs using scanned lines

```
Table fun;
Table focus;
boolean safe = false;

IntList averages1;
IntList averages2;

void setup() {
  size(1200, 470);
  focus = loadTable("focus.csv", "header");
  fun = loadTable("fun.csv", "header");

  averages1 = new IntList();
  averages2= new IntList();

  int columnTotal1;
  int columnTotal2;

  for (int i =2; i <102; i++) {
    IntList column1 = new IntList();
    IntList column2 = new IntList();
    columnTotal1 = 0;
    columnTotal2 = 0;

    for (TableRow row : fun.rows()) {
      int group = row.getInt("group");
```

```
      if (group == 1) {
        column1.append(row.getInt(i));
        columnTotal1 += row.getInt(i);
        println("i:" + i);
        println(row.getInt(i));
      }

      if (group ==2) {
        column2.append(row.getInt(i));
        columnTotal2 += row.getInt(i);
      }
    }
    averages1.append(columnTotal1 /18);
    averages2.append(columnTotal2 /17);
  }
  Table table = new Table();

  printArray(averages1);
  printArray(averages2);
  TableRow row1 = table.addRow();
  TableRow row2 = table.addRow();

  for (int i = 0; i <100; i++) {
    table.addColumn(str(i));
    row1.setInt(str(i), averages1.get(i));
    row2.setInt(str(i), averages2.get(i));
  }
  saveTable(table, "data/funaverages.csv");
}

void draw() {
```

```
  background(250);
  stroke(1);
  fill(0);
  textSize(22);
  text("Self-reported enjoyment averages", 30, 0, 1000, 30);


  for (int i = 0; i <5; i++) {
    fill(230);
    noStroke();
    rect(30, 30 + i* 80, 1000, 79);
    strokeWeight(1);
    stroke(1);
    line(25, 29 + i * 80, 29, 29+ i*80);
    fill(0);
    textSize(8);
    text(str(abs(5-i)), 15, 26 + i * 80, 20, 20);
  }

  strokeWeight(2);

  //middle line
  for (int i = 1; i < 100; i++) {
    stroke(#F8766D);
    line(30+(i-1)*10, 30+ averages1.get(i-1),
30+i*10, 30+ averages1.get(i));
    stroke(#00BFC4);
    line(30+(i-1)*10, 30+ averages2.get(i-1),
30+i*10, 30+ averages2.get(i));
  }
```

```
  strokeWeight(1);
  stroke(0);
  fill(#F8766D);
  rect(1050, 150, 20, 20);

  fill(#00BFC4);
  rect(1050, 200, 20, 20);

  fill(0);

  //text("Self-reported focus during reading", 10,10,600,30);
  textSize(12);
  text("Visual interface", 1080, 152, 100, 20);
  text("Control group", 1080, 202, 100, 20);
  if (!safe) {
    saveFrame("funLines.png");
    safe = true;
  }
}
```

Extract data points from scanned lines

```
PImage blank;
PImage testperson;
PImage drawnLine;
int[][] line;
String currentPerson;
Table table;
String domain = "fun";

void setup() {
  table = new Table();
```

```
table.addColumn("id");
table.addColumn("group");
for (int k =0; k < 100; k++) {
  table.addColumn(str(k));
}


size(1000, 400);
String path = sketchPath();
String[] filenames = listFileNames(path+ "/" + domain);

for (String file : filenames) {
  String fileNameTemp = file;
  IntList line = new IntList();

  background(0);
  testperson = loadImage(domain + "/" + fileNameTemp);
  testperson.resize(1000, 400);

  fill(255, 0, 0);
  stroke(255, 0, 0);

  // Draw crude line where there is much more blue
  for (int i = 0; i<testperson.width*testperson.height; i++) {

    float s_entered = saturation(testperson.pixels[i]);
    int xpos = i % 1000;
    int ypos = i / 1000;

    if (s_entered > 25) {
      point(xpos, ypos);
```

```
  }
}

filter(DILATE);
loadPixels();

//Find points of Line
for (int x = 0; x < width; x += 10) {
  IntList spots = new IntList();
  int previousY = -1;
  int newY;

  for (int y = 0; y < height; y++) {

    int loc = y * 1000 + x;

    if (red(pixels[loc])> 50) {
      stroke(0, 255, 0);
      strokeWeight(2);
      point(x, y);
      newY = y;
      if ( previousY >0) {
        if (newY - previousY < 3) {
          spots.append(y);
        }
      }
      previousY=newY;
    }
  }
  if (spots.size() >0) {
    int midpoint = int(spots.size()/2);
```

```
        int ydot = spots.get(midpoint);
        stroke(0, 0, 255);
        strokeWeight(8);
        point(x, ydot);
        line.append(ydot);
      } else {
        line.append(-1);
      }
    }
    saveFrame(domain + "Lines/" + fileNameTemp);
    println(file);
    println(line);

    TableRow newRow = table.addRow();
    newRow.setString("id", file);
    newRow.setInt("group", file.charAt(0));

    for (int k =0; k < 100; k++) {
     newRow.setInt(str(k), line.get(k));
      newRow.setInt(str(k), line.get(k));

    }
    saveTable(table, domain + ".csv");
  }
  println("done");
}


void draw() {
  //int a = mouseX + mouseY * 400;
  //println(a);
```

```
}

String[] listFileNames(String dir) {
  File file = new File(dir);
  if (file.isDirectory()) {
    String names[] = file.list();
    return names;
  } else {
    // If it's not a directory
    return null;
  }
}
```