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# Leftward Biases in Attention: Eye Fixations as Indicators of Attention and Memory Encoding

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*Abstract*

The current study examined the presence of a leftward bias in attention defined by the number of fixations. The aim was to explore a leftward bias in attention and whether this is related to visual long-term memory (VLTM) encoding. This was achieved by using a quantitative research approach consisting of a survey method and memory simulation. An eye-tracker was used to determine the number of fixations. A memory questionnaire was used to assess VLTM based on the simulation. Participants were sampled using purposive sampling (N=35). The eye-tracking data were analyzed using a one-way repeated measures ANOVA and the results showed a statistically significant difference between the left and right fixations, F(14, 28)=2.74, p=.01, η2=.58, indicating a large effect size. Participants demonstrated a higher number of left fixations even when stimuli on the right were present. The results support the notion of a lateral bias in attention. The findings from the paired sample t-test demonstrated that more items on the left were correctly recalled when compared to the right. On average, participants recalled more items on the left (M=66.49, SE=1.8) than the right (M=62.02, SE=2.2), t(34)=2.541, p=.008 (one-tailed). The eta squared (.429) indicated a small to medium effect size. Based on the findings, there were no significant associations between the number of fixations and the number of items recalled. The study concludes that a leftward bias in attention is present but there was no significant correlation with VLTM encoding.

*Keywords*: attention, eye-movements, fixations, lateral bias, pseudoneglect, visual long-term memory.

## 1. Introduction

People sample the visual world through eye movements (Dolgünsoz, 2015), defined by the number of fixations (Rajashekar et al., 2008; Schneider, 2018). Eye movements demonstrate the allocation of attention (Duchowski, 2007; Eimer, 2014; Hartman, 2015; Itti & Koch, 2001; Szelest, 2014; Theeuwes et al., 2009; Wedel & Pieters, 2000; van Gog et al., 2009), and visual attention is often equated with eye movements based on their overlapping neural systems (van Renswoude et al., 2018).

We are exposed to a multitude of stimuli, but not all encountered information can be processed. Relevant information must be extracted from a scene based on our limited fixations (Schneider, 2018). The selection of significant information ultimately guides subsequent higher-order cognitive functions including learning, thinking, and memory (van Renswoude et al., 2018).


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A fundamental part of sensory processing involves searching the visual world and attention permits the management of this sensory input (Duecker & Sack, 2015; Eckstein, 2011; Forte, 2016). Where we focus our eyes relates to what we pay attention to and how attentional resources are regulated. The way we direct our attentional resources will ultimately determine the perception of the visual world and what is encoded to memory. Attention thus enables us to prioritize certain sensory stimuli, allowing for the optimal distribution of attentional resources (Thomas et al., 2017).

Attentional capacity is, however, limited and the mechanisms underlying our capacity to focus attention is asymmetrically represented in the brain (Nicholls et al., 2008; Sosa et al., 2010), meaning that people do not attend equally to their right and left sides (Dickinson & Intraub, 2009; Gigliotta et al., 2017; Nuthmann & Matthias, 2014). Visual information competes for attentional resources and ultimate memory representation (Olivers et al., 2011). Some information becomes the exclusive focus of attention while other input is ignored.

When viewing the visual world, first saccades are generally directed toward the left (Dickinson & Intraub, 2009) and this leftward bias may determine subsequent information processing and memory encoding (Lee et al., 2004). This leftward bias is known as pseudoneglect (Bowers, & Heilman, 1980), and may selectively increase the representation of left-sided stimuli in memory (Schneider, 2018), as stimuli located in the right hemifield are ignored (Benwell et al, 2013; Brodie, 2010; Brooks, 2014; Foulsham et al, 2013; Schmitz et al., 2011; Szelest, 2014; Toba et., 2011).

With the expansion of the digital world and technologies, Madore et al. (2020) argue that attention is an asset that should be used efficiently. It is described as an "attention economy" (Madore et al., 2020: 87). Relying more on digital media and technology increases debates about the potential bearing this may have on other cognitive processes, like memory. The debate concerns questions about why people occasionally recall content but other times forget. Similarly, why are some people able to remember better compared to others?

Internationally, online teaching is not a novel means of instruction. Locally, however, the availability of resources for online teaching has been restricted. The unplanned move to online teaching methods, amidst the Covid-19 lockdown regulations, required the development of online course material to ensure the continuation of the academic year. The implications of a leftward bias in attention may have repercussions for the planning and designing of virtual academic material for future learning.

Effective "perceptual-visual learning" depends partly on how and where educational content is presented (Istrate, 2009: 1). The design of educational content is essential to the educational message portrayed as poorly designed courses can negatively impact the learning experience. Exposure to large amounts of sensory information requires the ability to direct attentional resources efficiently to the most important features (Yotsumoto & Watanabe, 2008). The design of online course material can thus play a determining role in student success, especially where a lot of content is presented (Rottmann & Rabidoux, 2017). If not properly designed and structured, online learning can easily become a "disinviting learning environment". The location and position of content is therefore significant in planning and creating e-learning courses, which Istrate (2009) notes as the left upper part of a page.

As attention is an asset that should be managed optimally, online resources must be thoroughly planned and executed. A well-structured online platform should ensure that our limited attentional resources are optimally distributed. Significant and useful content should thus be located where attention is more likely to be directed. If attention is directed more towards the left visual field, this may instruct the layout of virtual content. In addition to attention, memory is a core feature of academic learning (ElMir, 2019) and attentional resources should enable efficient memory encoding. A leftward bias in attention, i.e., pseudoneglect, may thus influence additional information- and memory processing.

Research suggests that a neuro-typical population seems to recall more items from the left visual field (Della Sala et al., 2010; McGeorge et al., 2007), while making significantly more errors in recalling items from the right. If attention is biased to the left, the inclination is that these items are better remembered: "...[suggesting] a spatial asymmetry in forming or retrieving...visual short-term memory" (Della Sala et al., 2010: 848). Lateral biases may, therefore, depend on perceptual and attentional functioning (Olivers et al., 2011; Szelest, 2014).

This study attempted to perform a systematic replication of previous research, showing that more items on the left were recalled compared to the right (Della Sala et al., 2010), with the addition of using an eye-tracker measuring attention by means of eye fixations. The number of fixations was used as an indication of attention to determine how this relates to memory encoding. The findings contribute to a better understanding of our cognitive processing system, pertaining to both attention and memory. Practically, the findings can be valuable in designing efficient teaching and learning platforms, offering guidance to create virtual platforms that warrant sufficient navigation. Apart from the academic value, the findings may hold implications for sports activities and driving based on the nature of attention distribution. The results can ultimately enhance our understanding of the asymmetrical nature of attention distribution.

The study firstly examined a leftward bias in attention, by measuring eye fixations, and secondly, attempted to determine whether the preferential focus to the left prejudiced memory encoding. The aim was thus to determine if pseudoneglect is present and how this influenced visual long-term memory (VLTM). The following hypothesis was formulated: A leftward bias influences attention and what is encoded to visual long-term memory.

## 2. Method

It was hypothesized that a higher number of leftward fixations demonstrates perceptual pseudoneglect and this will favorably bias the memorization of items presented in the left visual field. The objective was to measure attention by means of an eye-tracker to determine the number of left and right fixations. VLTM was assessed by means of a self-constructed memory simulation and questionnaire.

The research was quantitative using a quasi-experimental research design and intended to determine if more fixations were made to left-side stimuli. Participants were required to watch a simulation containing several types of stimuli, presented on the right or left side of a focal point, or both, while their eye movements were recorded using the Tobii Pro X3-120 Eye Tracker version 1.0.7. The eye-tracker weighs only a 118g and is 324mm in length. The experiment took place in an eye-tracking laboratory. After the simulation, participants completed a memory questionnaire to determine whether more items were recalled from the left hemifield compared to the right.

## 3. Participants

Local university students and staff members were invited to participate in the study. Both male and female participants were included aged 18-60 years old. Purposive sampling was used with the following inclusion criteria: computer literate, proficient in English, no history of brain injuries and, normal/corrected vision.

The sample consisted of N=35 participants: 12 males (34.29%) and 24 females (66.71%). The majority was white comprising 60% of the sample. Most participants were between the ages of 18-29 encompassing 62.8% of the sample. The 50-60 age group comprised 17% of the sample.

## 4. Instruments

A survey method was used to collect data along with the eye-tracker. Participants completed a demographic questionnaire and watched a memory simulation containing several types of images presented in either the left – or right hemifield, or both. The instruction was to memorize as much of the content as possible.

### 4.1 *Memory simulation*

The simulation included 37 slides created using Microsoft PowerPoint, saved as JPEG images and uploaded to the Eye tracker program, Tobii-pro-x3. Some slides contained instructions while the main presentation slides contained various stimuli including letters, images, and words. The stimuli were presented in either the left/right side of a focal point marked by an 'x' in the center of the screen. Some slides contained a stimulus on the left side only; other slides contained the stimulus on the right side only. Several slides included dual presentation where multiple stimuli were presented. Before each slide, an image containing only an "x," was displayed. Depending on where the content was presented, different hemispheres would be activated (Nicholls et al., 1999).

Single items were displayed for three seconds, while multiple or dual presentations were presented for 12 seconds. The differing times used were based on previous studies (Brady et al., 2008; Della Sala et al., 2010; Foulsham et al., 2013; Schurgin, 2018). When single items were presented the duration of the display was shorter compared to when more stimuli were displayed. All the slides were presented in a fixed order with all participants viewing the content in the same order.

Once the memory simulation concluded, participants completed the memory questionnaire. The data collection session lasted about 15-20 minutes.

### 4.2 *Memory questionnaire*

VLTM was assessed by means of a forced-choice test (Schurgin, 2018). The forced-choice test included showing the exact images presented during the simulation and participants had to indicate recalling seeing an item by clicking the respective box next to the image. The questionnaire was designed to assess memory recall related to the memory simulation to determine if more items, presented in the left hemifield were recalled. The questionnaire included seven questions with different options provided.

### 4.3 *The eye tracker*

The Tobii Pro X3-120 Eye Tracker and applicable software developed in 2017 was used. The eye-tracker weighs 118g and is 324mm in length, mounted at the bottom of the computer screen (Tobii, 2017). It records eye movements and produces numerical information in terms of gaze duration and number of fixations. The eye-tracking data was used as a measure of attention. The number of left – and right fixations was calculated to determine the number of fixations for each slide presented during the memory simulation. The aim was to explore whether pseudoneglect influences the distribution of attention by determining if more fixations to the left were made compared to the right. Based on the number of fixations, it was hypothesized that this may be associated with the number of items correctly recalled from the memory simulation.

## 5. Procedure

Participants were invited via an internal university communication system. A general announcement containing the purpose of the study was posted and employees were invited via email, containing details of the study. A booking system was created where participants could schedule a time for data collection.

All data were collected at a computer laboratory on campus. On arrival, the researcher discussed the study and procedure and participants signed an informed consent document before the study commenced. Two computer stations were available in the same room. A laptop was set-up in one location where the demographic questionnaire was completed via Google Forms. A second laptop, described as the eye-tracking station, was set-up at a second location. The eye-tracking station included two computer screens, a touch screen for the participant containing the eye-tracker and a second computer screen for the researcher. A keyboard and a mouse were available for the researcher to control the simulation. Participants completed the demographic questionnaire first. After this, they were asked to move to the eye-tracking station where the memory simulation was presented. Participants were seated comfortably in front of the screen and each session started with a calibration to ensure that eye movements were recorded. The calibration session required participants to follow a red dot using only their eyes.

Once the memory simulation concluded, participants were asked to move back to the first computer to complete the memory questionnaire.

The researcher assessed each participant individually and only the researcher and the participant were present in the laboratory during assessment.

## 6. Ethical considerations

Ethical approval was granted by the Faculty of Humanities Research Ethics Committee (Reference number: GW20160825HS.). Informed consent was obtained from all participants before the study commenced. Confidentiality was maintained and participants had the option of withdrawing from the study at any stage. Participant numbers were used an no personal information was connected to the data.

## 7. Data analysis

The data was analyzed using SPSS version 27. Eye -movements were measured to determine the number of left – and right fixations. The number of fixations details the number of times a participant focused on stimuli on the left/right side of the presented slide. The total number of fixations per slide was captured for each participant. Longer fixations represented stronger attentional pathways.

To determine whether a leftward bias in attention was present, the differences between left – and right fixation patterns were explored by means of a two-way repeated measures ANOVA: 2 x 15, Side (Left/Right) x Slides for the number of fixations. To explore whether more items on the left were recalled, a paired samples *t*-test was performed to compare the left and right memory scores. Lastly, to determine whether a leftward bias in attention is associated with what is encoded to memory, correlational analysis was conducted between the number of left/right fixations and the memory scores.

Table 1. provides a description of the stimulus presented on each slide.

Table 1. Stimulus description per slide number

| SLIDE | Recode nr. | STIMULUS DESCRIPTION | | | Duration presented (ms) |
|---|---|---|---|---|---|
| | | Left side | Centre | Right side | |
| 3 | 1 | E | | | 3 |
| 5 | 2 | B | | | 3 |
| 7 | 3 | AC | | F | 5 |
| 9 | 4 | P | | ZD | 5 |
| 11 | 5 | TU | | RG | 5 |
| 13 | 6 | King of hearts | | | 3 |
| 15 | 7 | | | King of spades | 3 |
| 17 | 8 | Queen of diamonds | | Jack of diamonds | 5 |
| 19 | 9 | Queen of spades | | Queen of hearts Jack of clubs | 5 |
| 21 | 10 | Queen of clubs King of clubs | | Jack of spades King of diamonds | 5 |
| 23 | 11 | 60km Road sign | | | 3 |
| 26 | 12 | | Fruit and vegetables | | 12 |
| 29 | 13 | Word columns | | Word columns | 12 |
| 31 | 14 | | | 30km Road sign | 3 |
| 33 | 15 | Cat | | Dog | 5 |
| 36 | | | Watches | | 12 |

8. Results

8.1 *Measure of attention: Number of fixations*

The n values indicate the total number of fixations. Table 2 provides the data for the average number of fixations captured per slide. The first part of the table provides the average number of left fixations. The second part of the table provides the average number of right fixations for each slide.

Referring to the data, slide 29, for example, contained a list of words. Two columns of random words were presented on both the left – and right side of the focal point. The data below shows that the average number of fixations was higher on the left (M=41; SD=18.7) compared to the right (M=22.5; SD=11.2). Similarly, for slide 26 containing fruit and vegetables, presented as a single table containing two columns in the center of the slide, more fixations were observed for the left side (M=34; SD=9.5) in relation to the right (M=30; SD=11). Additional analysis will reveal whether these differences were significant, but it seems that participants fixated more on items on the left when items on the right were also present.

Table 2. Average number of left and right fixations per slide

| | Slide | n | M | SD |
|---|---|---|---|---|
| **Left** | 3 | 34 | 5.85 | 4.67 |
| | 5 | 20 | 1.55 | .83 |
| | 7 | 34 | 8.88 | 3.16 |
| | 9 | 34 | 7.59 | 5.08 |

| | Slide | n | M | SD |
|---|---|---|---|---|
| | 11 | 34 | 10.38 | 5.55 |
| | 13 | 34 | 9.00 | 4.00 |
| | 15 | 15 | 1.20 | .41 |
| | 17 | 34 | 9.71 | 5.02 |
| | 19 | 34 | 9.00 | 5.45 |
| | 21 | 34 | 11.91 | 5.74 |
| | 23 | 34 | 5.88 | 3.23 |
| | 26 | 34 | 34.21 | 9.54 |
| | 29 | 34 | 41.26 | 18.70 |
| | 31 | 29 | 2.97 | 1.66 |
| | 33 | 34 | 7.94 | 3.17 |
| **Right** | 3 | 23 | 1.43 | 1.00 |
| | 5 | 34 | 7.21 | 6.06 |
| | 7 | 34 | 5.82 | 2.76 |
| | 9 | 33 | 8.42 | 4.22 |
| | 11 | 34 | 9.85 | 4.1 |
| | 13 | 23 | 1.13 | .34 |
| | 15 | 34 | 10.03 | 5.18 |
| | 17 | 34 | 7.47 | 4.22 |
| | 19 | 34 | 15.88 | 8.59 |
| | 21 | 34 | 12.35 | 5.50 |
| | 23 | 33 | 4.48 | 2.80 |
| | 26 | 34 | 30.26 | 11.10 |
| | 29 | 32 | 22.50 | 11.20 |
| | 31 | 34 | 7.09 | 4.06 |
| | 33 | 34 | 8.32 | 3.90 |

8.2 *ANOVA*

The results show that a significant interaction effect was found when the slides and left vs. right fixations were compared $F(14, 28)=2.74$ $p=.01$, $\eta^2=.58$, indicating a large effect size. A significant main effect for the slides was found: $F(14, 28)=50.6$, $p=.00$, $\eta^2=.926$, but no significant main effect was found for the left and right fixations: $F(1, 2)=.48$, $p=.56$, $\eta^2=.19$. Accordingly, it is argued that the findings show that participants demonstrated significantly different fixation patterns given the slides and number of left and right fixations. The images in the Appendix provide interesting findings regarding the fixation patterns of some participants.

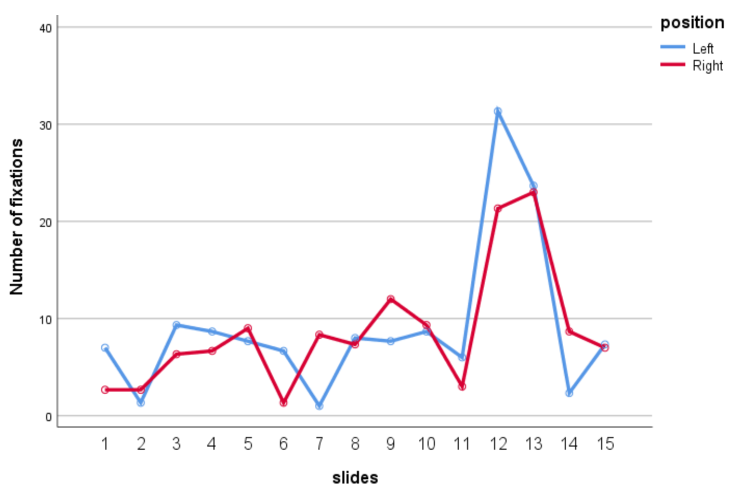


Figure 1. Average number of right and left fixations per slide

Figure 1 provides a graphical representation of the total number of left and right fixations per slide. Slide 12 containing the fruits and vegetables shows a higher number of left fixations compared to the right. This is an interesting finding since participants were able to move their gaze in both directions and fixate on either left or right stimuli as both hemifields contained stimuli. The average number of left fixations was, however, higher despite the presence of information on the right side. Slide 14 contained an image more towards the right, explaining the prominent right fixation.

### 8.3 *Paired sample t-test*

The number of items correctly recalled, based on the memory simulation, was assessed with the memory questionnaire. A correct score was allocated if a participant selected a particular item that was part of the simulation. The total number of correct responses for the left condition was 22 and 25 for the right condition. Each condition's score was calculated as a percentage: Left condition = Score/22 x 100; Right condition = Score/25 x 100. The findings showed that participants scored higher in the left condition (M=66.49, SD=10.64) compared to the right condition (M=62, SD = 12.16).

To determine if the differences between the memory conditions were significantly different a paired sample *t*-test was conducted. There was a significant difference between the two memory conditions, on average, participants recalled more items on the left (M=66.49, SE=1.8) than on the right (M=61.60, SE=2.1), $t(34)=2.86$, $p=.004$ (one-tailed). The eta squared (.483) indicated a small to medium effect size. Participants thus recalled more items presented from the left. The mean increase from the right memory scores to left memory scores was 4.89 with a 95% confidence interval ranging from 1.4 to 8.37.

### 8.4 *Correlational analysis*

To determine whether the higher number of leftward fixations was linked to a higher memory recall for items presented on the left, a one-tailed bivariate correlational analysis was performed. The data show no significant correlations between the number of fixations and the memory scores ($p>0.5$). Based on the findings, the total number of fixations is not related to memory recall.

## 9. Discussion

The purpose of this study was to investigate a leftward bias in attention and to determine whether this was related to what was encoded to VLTM. Schurgin (2018) describes VLTM, as a long-term storage system for visual content. The findings from this study showed significant differences between the number of left and right fixations with participants demonstrating a higher number of left fixations. The findings thus suggest that more attention was allocated to the left hemifield (Eimer, 2014; Foulsham & Kingstone, 2012). The findings support the notion of a leftward bias in attention and a preference for the left hemifield, i.e., pseudoneglect, in agreement with previous research (Brooks et al., 2011; Çiçek et al., 2009; Cocchini et al., 2007; Hatin et al., 2012; Lee et al., 2004; Loftus & Nicholls, 2012; Loftus et al., 2009; Nicholls & Loftus, 2007; Toba et al., 2011; Porac et al., 2006). This may result in a tendency to ignore stimuli on the right side, as seen in the images included in Appendix A. The images show that some participants focused exclusively on stimuli on the left, ignoring the right side or demonstrating minimal fixations towards the right.

A higher number of fixations suggests that more attention was allocated to stimuli (Chen & Chen, 2017). Longer durations of fixation are associated with higher cognitive load and higher cognitive effort (Borys, & Plechawska-Wójcik, 2017; Dolgünsoz, 2015). Borys and Plechawska-Wójcik (2017), for example, aimed to identify if significant differences exist in the visual analysis of experts and novices using medical images. The researchers observed that the experts produced longer fixations on the lesioned area, and students, who correctly diagnosed the problem, also showed longer fixations, i.e., more attention to the tumour areas (Borys, & Plechawska-Wójcik, 2017).

The visual world is experienced by means of eye fixations (Borys & Plechawska-Wójcik, 2017; Dolgünsoz, 2015; Heyman et al., 2017; Schneider, 2018). Fixations are essentially when our eyes stop scanning a scene, enabling us to extract detailed information from visual surroundings (Tobii Pro, 2020). Most information is captured through fixations (Schneider, 2013) and determines what we pay attention to (Borji & Itti, 2013; Theeuwes et al., 2009; Van Gog et al., 2009; Wedel & Pieters, 2000). Visual information is integrated to create a memory representation of the visual scene (Rajashekar et al., 2008). Research supports the argument that fixations influence what is encoded to memory (Bochynska & Laeng, 2015; Chen & Chen, 2017; Foulsham & Kingstone, 2012; Godfroid et al., 2013; Laeng et al., 2014). Lateral biases in attention can theoretically skew our attentional resources (Jarodzka et al., 2017; Schmitz et al., 2013; Theeuwes et al., 2009). More fixations, i.e., attention, to the left hemifield may thus predict a higher memory score for items presented on the left. Della Sala et al. (2010), and Szelest (2014) found that participants recalled more items on the left. Della Sala et al. (2010) reported that participants remembered more bindings between colors, and location and identified more objects located on the left compared to the right. Similarly, Dickinson and Intraub (2009) found that more visual items were remembered from the left when using naturalistic visual scenes. Based on the current findings, significant differences, with regard to the amount of information recalled between the left and right side, were observed.

Participants demonstrated more fixations to stimuli presented in the left hemifield and right and left fixations were significantly different. The leftward bias did seem to impact the allocation of attention and the consequent encoding of information. The data from the VLTM memory assessment show that there were significant differences in the number of items correctly recalled with participants, on average, recalling more items from the left side. A leftward bias in attention was thus present and seemed to be linked to VLTM. Despite the higher number of left fixations and a higher recall of left memory items there were no significant correlations between the number of fixations and the number of items correctly recalled.

Extant literature suggests that the leftward bias is related to memory, however, the current study findings found no correlation between the lateral bias in attention and memory. The small sample may have limited the extent to which significant relations could be identified. Similarly, the nature of the memory simulation and questionnaire could have limited the analysis of the findings. The differences in memory recall and prominent leftward fixations suggest a valuable opportunity for future research to explore this in more detail.

## 10. Conclusion

The findings show that attention seems to be asymmetrical in nature. The participants appeared to favor the left side, similar to other findings (Benwell et al., 2013; Cocchini et al., 2007; Nuthmann & Matthias, 2014; Schmitz et al., 2011; Zago et al., 2017). Based on the results, it is argued that attention is not allocated equally across the visual field as participants demonstrated more fixations to the left hemifield. A lateral bias in attention is therefore plausible. Although more items from the left memory condition were correctly recalled, similar to the findings from Della

Sala et al. (2010), and Szelest (2014), the findings from this study showed no significant association between the leftward bias in attention and what was encoded to visual memory.

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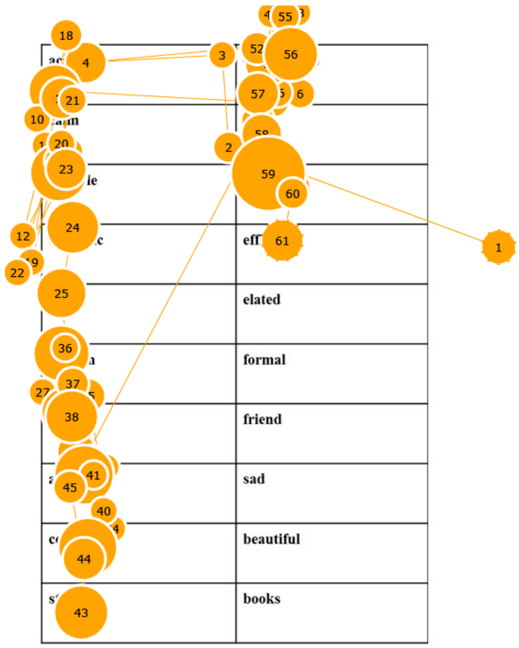
## APPENDIX: The number of Fixations

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|---|---|
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| adventure | happy |
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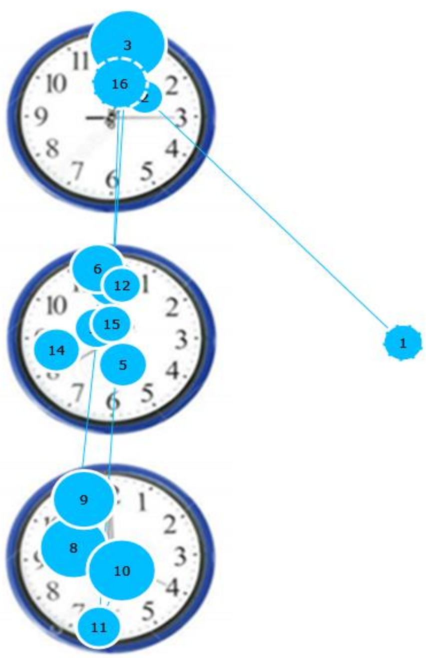
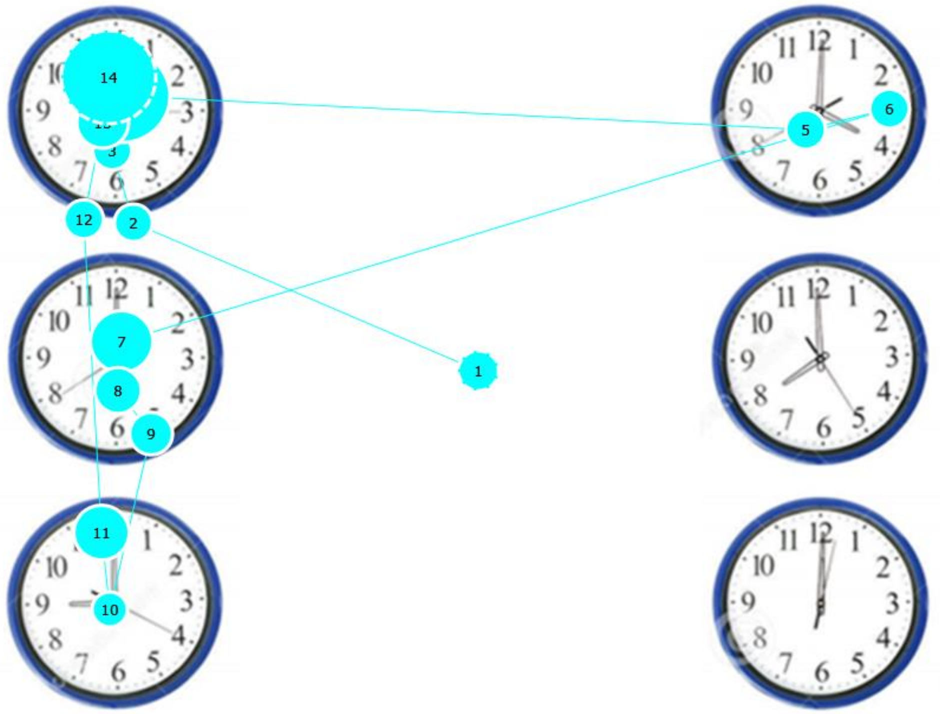
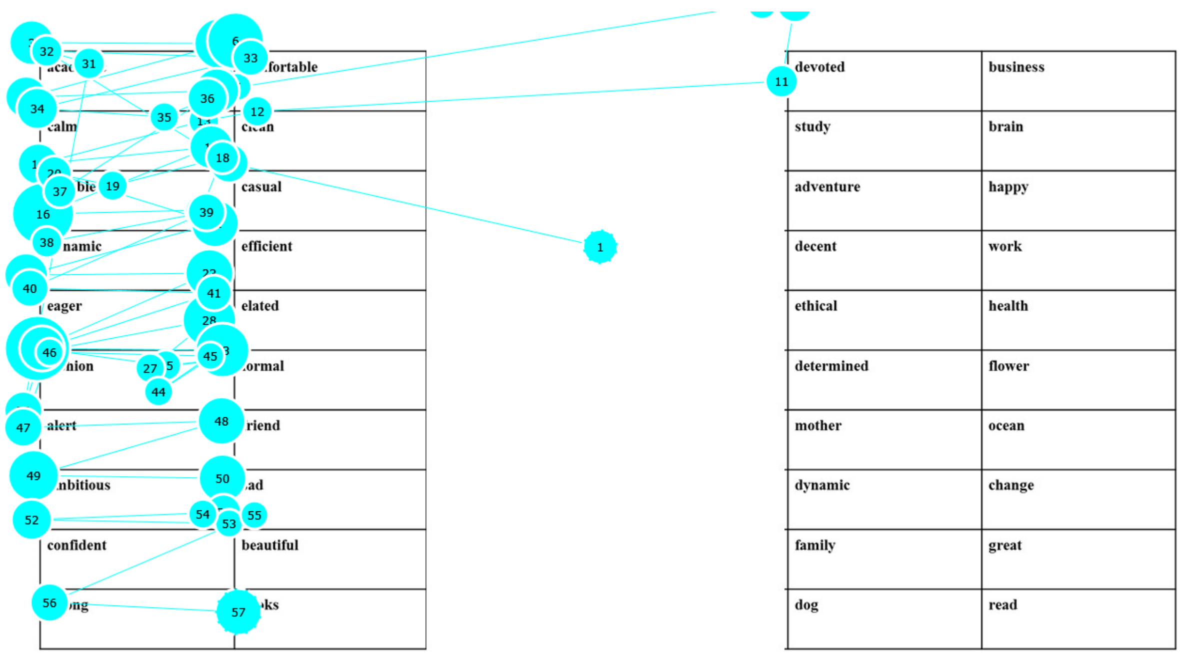
| ethical | health |
| determined | flower |
| mother | ocean |
| dynamic | change |
| family | great |
| dog | read |



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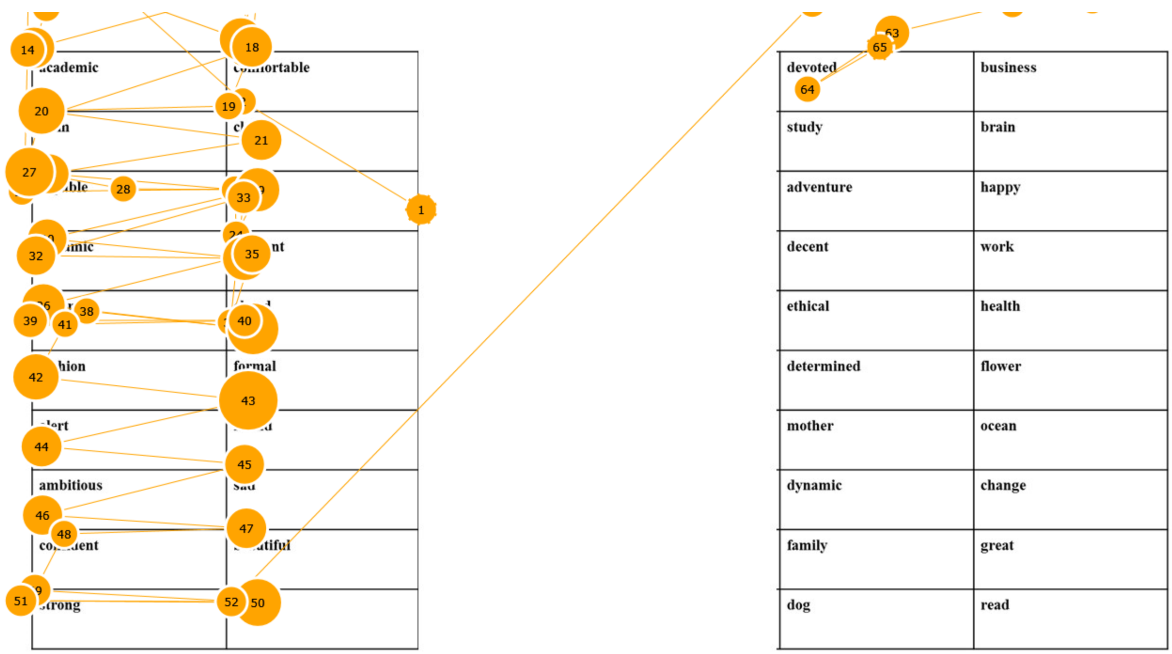
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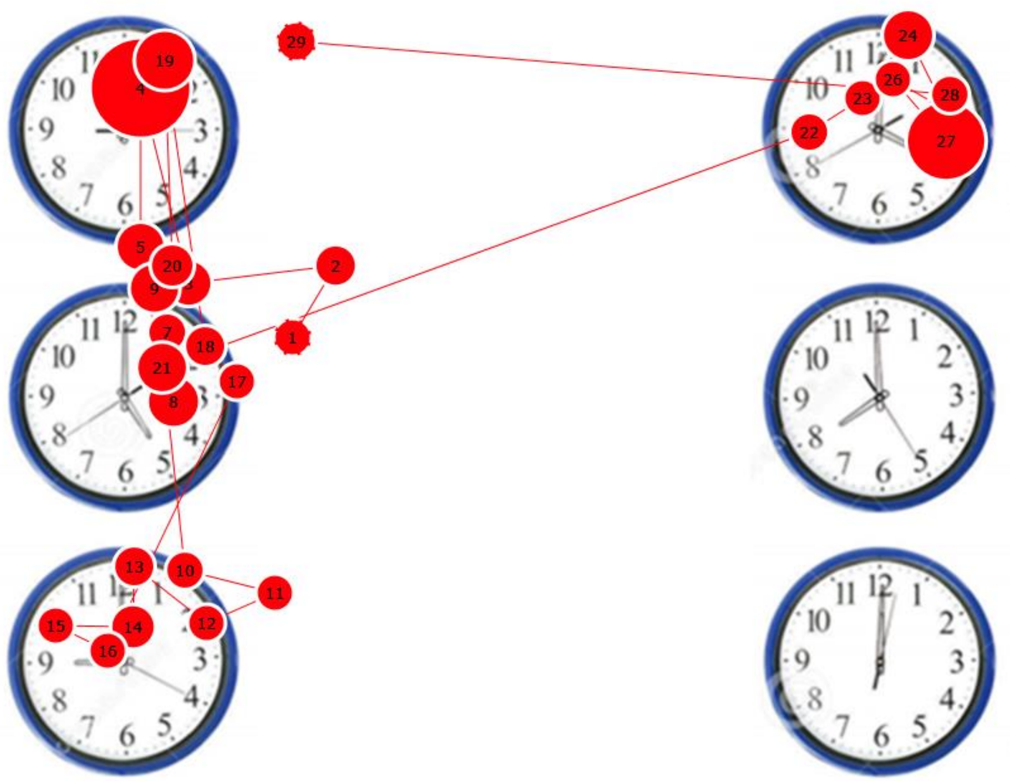

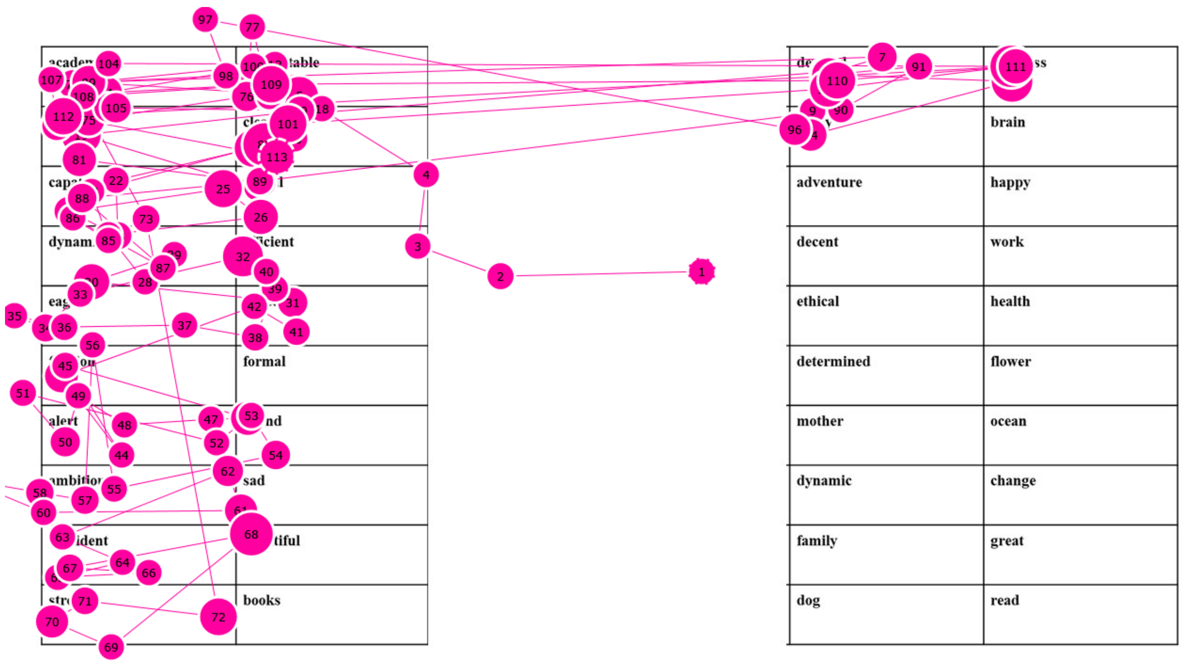
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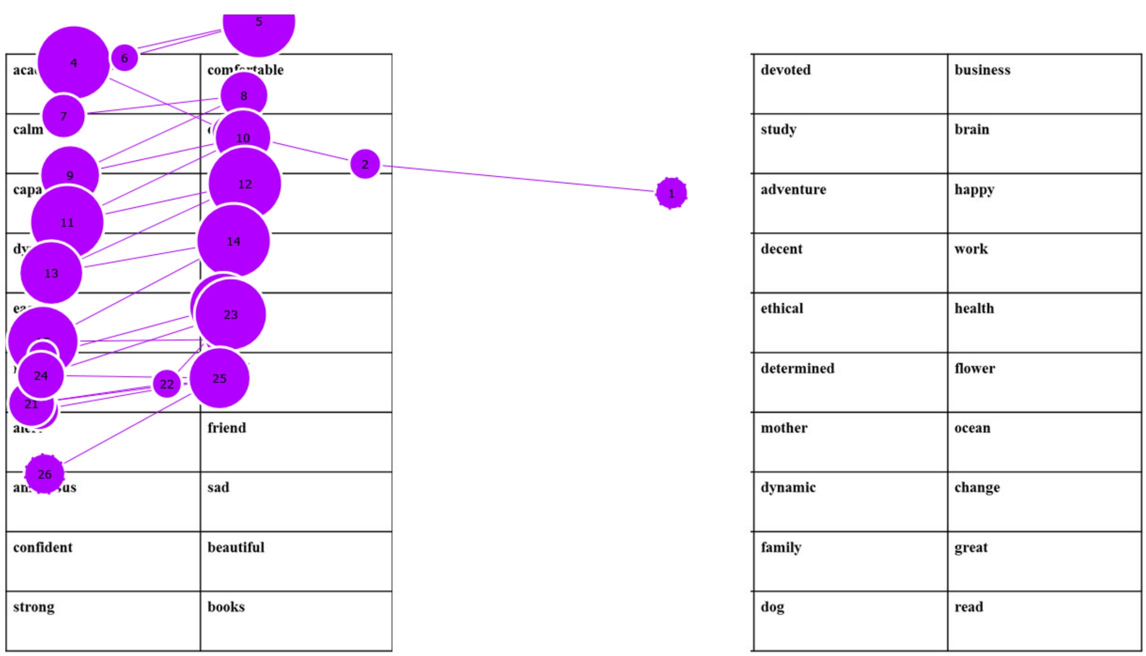
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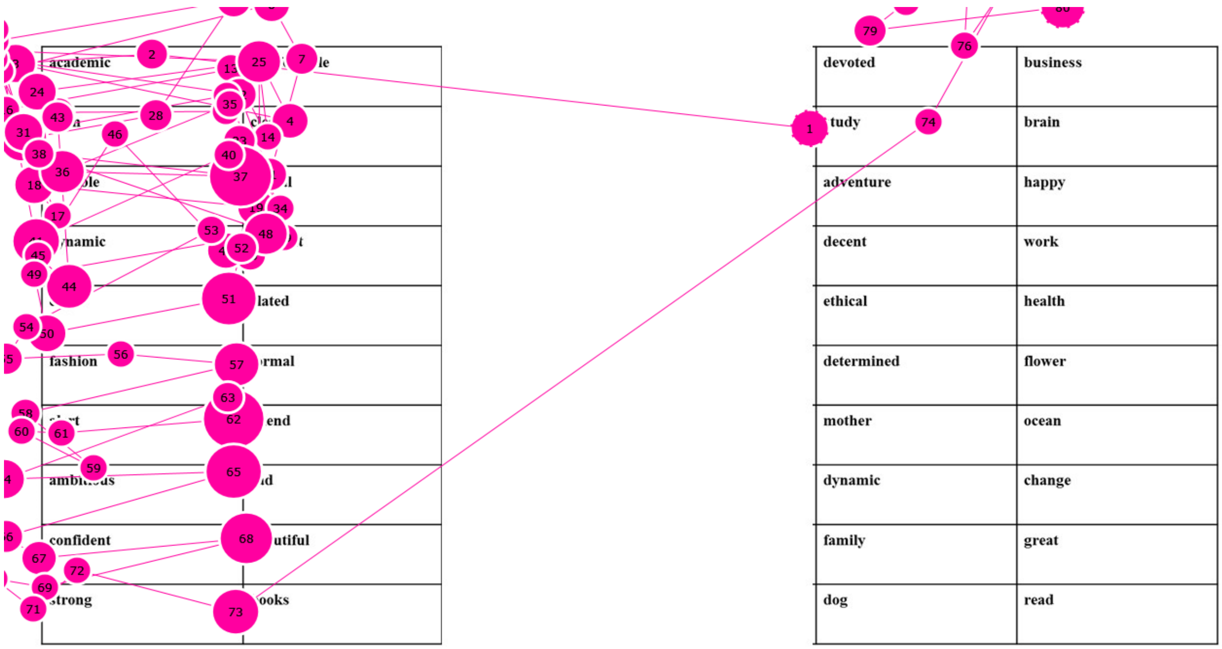
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