Effects of Menu Organization and Visibility on Web Navigation for People with Dyslexia

Helen Petrie, Ili Mahtar

Effects of Menu Organization and Visibility on Web Navigation for People with Dyslexia

Helen Petrie[1] and Ili Farhana Md Mahtar[1]
[1] Department of Computer Science, University of York,
York YO10 5GH, United Kingdom
{helen.petrie|ifmm500}@york.ac.uk

Abstract. People with dyslexia have reported difficulties with navigating websites, yet very little research has investigated the nature of these difficulties. This study investigated the effects of two aspects of web navigation, menu organization and visibility on the eye gaze behaviour, performance and preferences of dyslexic and non-dyslexic participants. Participants undertook four tasks on a website with either unified or fragmented main menu organization and either static or dynamic submenus. Dyslexic participants had significantly longer menu scanpaths (i.e. looked at more menu items), due to looking at more different menu items and revisiting more items in comparison to non-dyslexic participants. They also had more fixations and longer dwell times on submenus than non-dyslexic participants. They were also slower to select their first menu item and complete tasks. However, the perceptions of the different menu presentations did not differ between the two participant groups, although all participants preferred the unified menu presentation to the fragmented. Directions for further research to deepen the understanding and implications of these results are discussed.

Keywords: People with dyslexia, web navigation, menu organization, menu visibility, eye gaze patterns.

1 Introduction

People with dyslexia have difficulties in processing language, which manifests itself in difficulties with reading, writing and spelling [53]. However, people with dyslexia often have difficulties beyond language, and may also have difficulties with numbers, spatial orientation, hand-eye coordination, and short-term memory. Whether these additional difficulties are part of dyslexia, or relate to other conditions which co-occur frequently with dyslexia, is a subject of fierce debate [8, 32]. However, from a practical point of view, people with dyslexia do often have these additional difficulties and 5% - 10% of the population have dyslexia to a greater or less extent [51], depending on their native language [12]. For example, in the United Kingdom, it is estimated that 10% of the population have some aspects of dyslexia, with 4% of the population being severely affected [5, 31].

A growing body of research in HCI has explored the difficulties that people with dyslexia have with technology and how to use technology to support them in overcoming their difficulties. Most of the research has explored how to make text easier to read, both in terms of the presentation of standard typefaces [33, 35, 38-40, 42-44, 48, 49, 52] but also by developing new typefaces especially for dyslexic readers [7, 34, 37, 55]. Research has also investigated how to support writing and particularly spell-checking [13, 14], reading and producing mathematics [10] web search [21-23, 28], computer coding [25, 36] and the use of multimedia [3].

One area in which people with dyslexia have been shown to have difficulties is in the navigation of digital material. Freire, Petrie and Power [11] found that navigation problems were the second most common problem on websites for participants with dyslexia, accounting for 12.4% of all their problems. However, little research has been undertaken about the detailed nature of these problems and how web navigation might be improved for people with dyslexia, apart from some exploratory work by Al-Wabil and colleagues [1, 2]. On the other hand, there has been a considerable amount of research on how best to present web navigation for users in general [30]. Therefore, this study investigated the effects of two aspects of web navigation, the organization and visibility of menus with a sample of dyslexia participants and compared their performance, eye gaze patterns and opinions on a range of measures with a similar sample of non-dyslexic participants. We hope this will provide some initial useful results and stimulate further research on this topic.

2 Related Work

Most of the research in HCI for people with dyslexia has investigated how best to present text on screens for this user group. A number of different aspects of text have been investigated, including typeface [39], font size [33, 39, 40], character and line spacing [44, 48, 49, 52], line length [43, 48] and text and background colour [35, 38, 42]. A comprehensive review of this literature is beyond the scope of this paper, however current recommendations from this body of research are to use 18 point sans serif text with relatively short line lengths and wider vertical line and character spacing. Although there is much discussion about the possible effects of text and background colour on reading for people with dyslexia, there are no strong recommendations on this aspect of text presentation, as research results are mixed [35, 28,42]. In all, these recommendations do largely agree with recommendations which have existed for some years from user organizations which have probably been based on more anecdotal evidence [5].

Another area related to the optimal presentation of text for people with dyslexia has been the development of a number of typefaces which it is argued are easier for people with dyslexia to read, for example Dyslexie [7], OpenDyslexic [34], ReadRegular™ [37], and Sylexiad [55]. However, the current scientific evidence is that these typefaces do not improve reading speed or accuracy (most studies have used the sans serif typeface Arial as a comparison) and participants do not prefer them compared with standard typefaces [24, 16, 35, 39, 41, 56]. Most of this research has been conducted with children, although Rello and Baeza-Yates [39, 41] worked with participants with a wide range of ages (11 – 50 years).

Research has also investigated other areas of the use of digital technologies by people with dyslexia. For example, a number of researchers have investigated how dyslexic and non-dyslexic people conduct searches on the web. MacFarlane and colleagues [21-23] found that search behaviour of dyslexic and non-dyslexic web users is very different, with dyslexic users finding fewer relevant search returns in a given time and having very different eye gaze patterns. Morris et al [28] also found that dyslexic web users have difficulty identifying relevant search returns, perhaps because they are seeking pages which are not cluttered or dense in information. These differences in judgements of relevance were further supported by an online study.

Al-Wabil, Zaphiris and Wilson [1, 2] appear to be the only researchers who have investigated difficulties specifically in web navigation for people with dyslexia. In their first study [1] they interviewed 10 people with dyslexia about their experiences with web navigation. A number of interesting themes emerged, particularly that the interviewees did not find common navigational support tools such as breadcrumb trails and site maps very useful and that they preferred to navigate with the Back and Forward buttons on a website, as they could more clearly see the effects of their actions. On the use of menus for navigation, all interviewees stressed the importance of having menus consistent throughout a site, but opinions on dynamic menus differed. Some interviewees found them hard to interact with, while several interviewees found having dynamic menus reduced the visual clutter on a page which was helpful. In a second study, Al-Wabil et al [2008] investigated the eye gaze patterns of dyslexic and non-dyslexic web users in navigating three websites. Unfortunately, only two dyslexic web users participated and one of the control group of four non-dyslexic web users may have been an undiagnosed dyslexic (but was kept in the non-dyslexic group). However, the results suggested that the number of fixations, fixation duration and eye gaze patterns were different in relation to navigation between dyslexic and non-dyslexic web users.

While little research has investigated the performance or opinions of dyslexic web users with navigation and specifically menus on websites, there has been a substantial body of research on both aspects of web navigation for users in general, a recent review [30] covers 13 studies, without going into more unconventional and innovative menu types such as floating pie [46], radial [29, 47], flower [4] and leaf [45] menus. Some studies have found that there is no difference in performance between menus placed on the left or right of a webpage [9, 16], although left is now much more common, at least in English language websites. Similarly, some research has found [27] that static or dynamic menus do not affect performance or the perception of being lost. However, other research [19] has found that static menus are faster and easier (as measured by eye fixations) than dynamic ones, although this may interact with task complexity. Clearly a great deal more research could be conducted on this topic, although it may have little effect on web design fashions.

In this study we decided to investigate the effects of two aspects of web navigation for participants with dyslexia which had been investigated or mentioned in previous research, the organization and visibility of menus. The performance, eye gaze patterns and preferences were compared with a similar sample of non-dyslexic participants in order to investigate whether dyslexic web users would benefit from particular web menu presentations.

3 Method

3.1 Design

Participants navigated through a website about tourism in Canada and answered four questions, the answers to which were in different parts of the website. They were not allowed to use a search engine to find the answers. The order of tasks was counterbalanced.

The experiment had a 2 × 2 × 2 between-participants design with Participant Group (Dyslexic vs Non-Dyslexic), Menu Organisation (Unified vs Fragmented, see section 3.2) and Menu Visibility (Visible vs Dynamic, see section 3.2) as the between participants variables. The choice of these two variables in menu organization was motivated by the fact that they have been investigated with non-dyslexic web users [e.g. 19, 27], although no clear results have emerged as to which configuration is more appropriate. Thus our results contribute to the body of knowledge about non-dyslexic web users as well as dyslexic ones. In addition, dyslexic participants in [1] were asked to comment on static versus dynamic menus, although there was no consensus about whether they were helpful or difficult.

There were three groups of dependent variables: (1) eye gaze behaviour, (2) performance and (3) participants' opinions.

The eye gaze measures were divided into two further groups, menu scanpath measures and Areas of Interest (AoI) measures.

Menu scanpath measures. The menu scanpath is the sequence of fixations of the eyes as participants look at the menus on the webpages.

The measures taken were:

- total length of the scanpath (i.e. total number of fixations)
- number of different items in the scanpath (i.e. number of different places where the participant looked)
- number of revisits (i.e. number of places to which the participant returned). Thus, total length = number of different items + number of revisits.

In addition, the following eye gaze measures were taken for three Areas of Interest (AoIs): main menus, sub-menus and target menu item (the item the participant should follow to complete the task):

- First fixation duration in the AoI (measured in milliseconds, msec)
- Number of fixations in the AoI
- Mean fixation duration in the AoI (msec)
- Total dwell time in the AoI (msec)

The first fixation duration is thought to reflect the attention-getting property of an AoI, the number of fixations and number of revisits are thought to be good indicators of the importance of an AoI or its noticeability, while mean fixation duration and total dwell time are thought to reflect engagement of a participant with the AoI [6].

The performance measures were:

- Time from opening the page to first mouse click (whether it is the correct or wrong target) (measured in msec)
- Task completion time (measured in msec)
- Number of correct answers to comprehension questions

The participants' opinion measures were ratings on 7-point Likert items of the website in terms of 'ease of use', 'ease of remembering' and 'ease of learning'. A lower rating indicated a more positive opinion.

Ethics approval for this study was granted by Physical Science Ethics Committee of the University of York.

3.2 Participants

On recruitment, participants were asked to complete a validated screening tool for dyslexia [54] (see section 3.3). A total of 64 participants took part, 32 were classified as non-dyslexic and 32 as dyslexic. All participants were native English speakers with normal vision or vision correctable with spectacles.

The non-dyslexic group comprised 13 females and 19 males with ages ranging from 18 to 42 years ($M = 22.25$, $SD = 4.59$). Nineteen were undergraduate students, five were Masters students, five were PhD students (one was working part time) and three were employed. All of them had more than six years web experience (mean: 5.78, SD = 1.07, on a 7-point Likert item).

The dyslexic group were matched as closely as possible to the dyslexic group, they comprised 18 females and 14 males with ages ranging from 18 to 44 years ($M = 20.61$, $SD = 4.70$). Twenty-five were undergraduate students, six were Masters students and one was employed. All of them had more than six years web experience (mean: 5.32, SD = 0.98).

Participants were given a £10 Amazon gift voucher to thank them for participating in the experiment.

3.3 Materials and Equipment

The equipment set-up for the experiment is illustrated in Fig. 1. Participants used a wireless keyboard, a wireless mouse and a monitor to read and navigate the website and answer questions, while the researcher used a laptop. The laptop was connected to the eye tracker camera (SMI Red250 Mobile[1]), below the participant's monitor (via USB cable) and their monitor (via VGA cable). A Bluetooth USB dongle for the par-

[1] https://www.smivision.com/

ticipant's wireless mouse and keyboard were also attached to the laptop. Viewing distance between the participant and the monitor screen was approximately 60cm (see section 3.4).

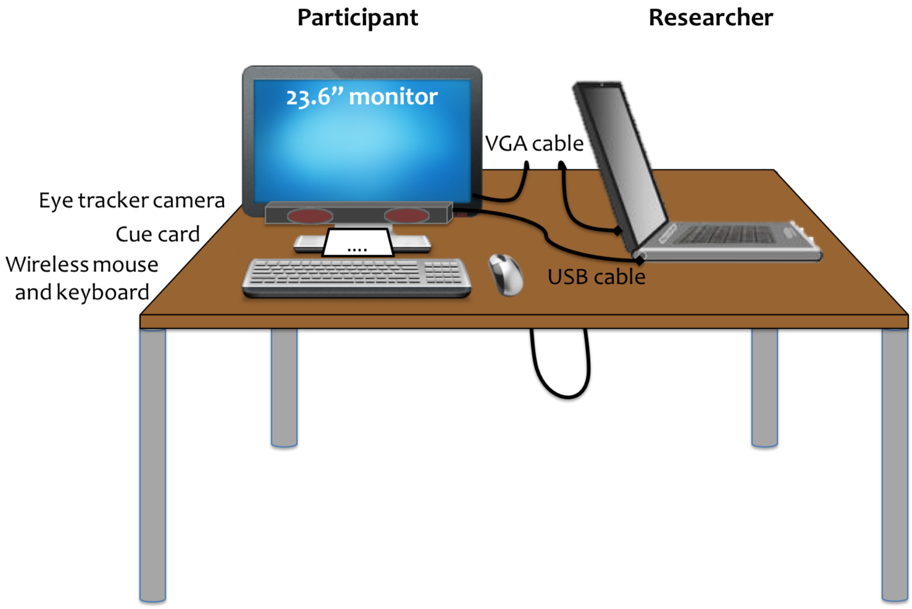

Fig. 1. Equipment set up

An online version of the Adult Self-Report of Dyslexia (ARQ, [54]) was used to establish whether participants were dyslexic or not, in addition to their self-report. The questionnaire asks information about reading habits, literacy and any dyslexia symptoms. Participants were categorised as non-dyslexic if their score was between 0 to 10, and dyslexic if their score was above 10.

An initial questionnaire collected information about participants' use of the web and demographic information.

Two web sites (a practice web site and an experimental web site) and five navigational tasks (one practice and four experimental tasks) were developed. Each task involved answering one multiple choice question with three answer options.

The experimental web site was about tourism in Canada, developed using content adapted from the Lonely Planet Canada web site[2] and [20]. Four versions of the experimental web site were developed, one each for the combinations of the Menu Organization and Menu Visibility variables. Menus were either Unified (located only on top of the page, see Figures 2 and 3) or Fragmented (split between the top and left side of the webpage, see Figures 4 and 5). Sub-menus were either Visible (visible to the participant at all times, see Figures 2 and 4) or Dynamic (appearing only when the participant hovered over with the mouse, see Figures 3 and 5).

---

[2] https://www.lonelyplanet.com/canada

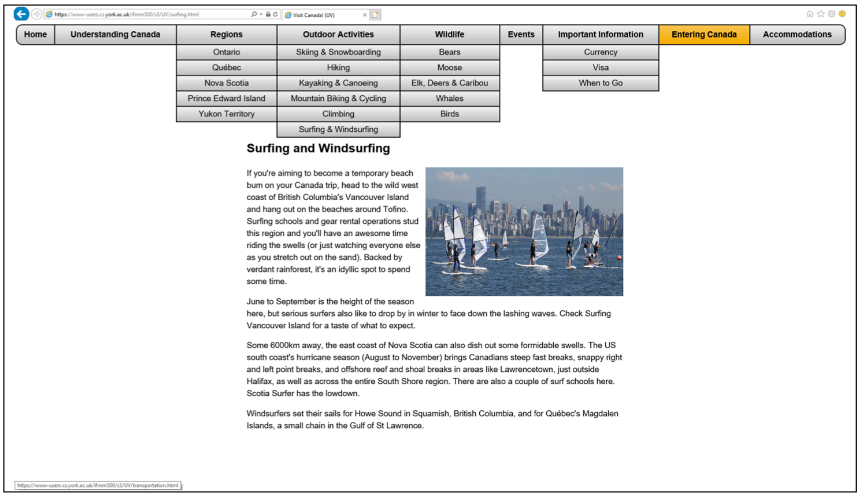

Fig. 2. Experimental website page with unified and visible menus

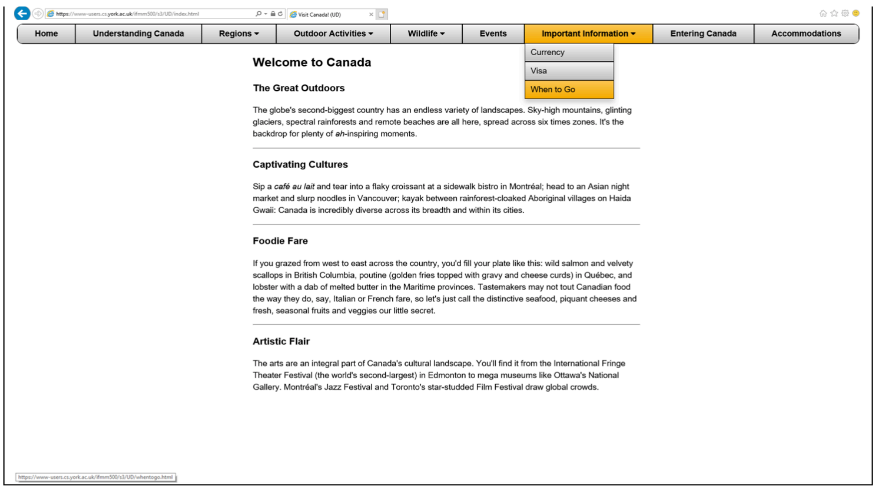

Fig. 3. Experimental website page with unified and dynamic menus

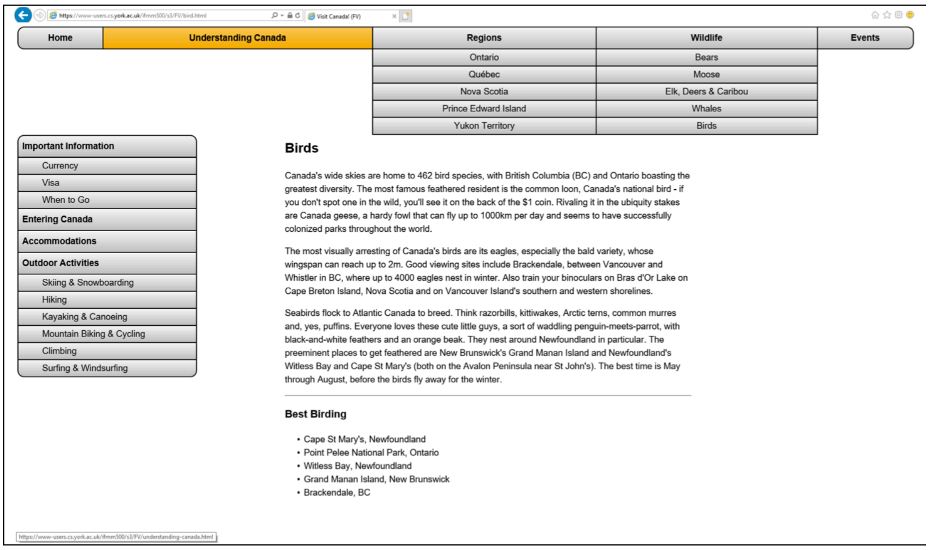

Fig. 4. Experimental website page with fragmented and visible menus

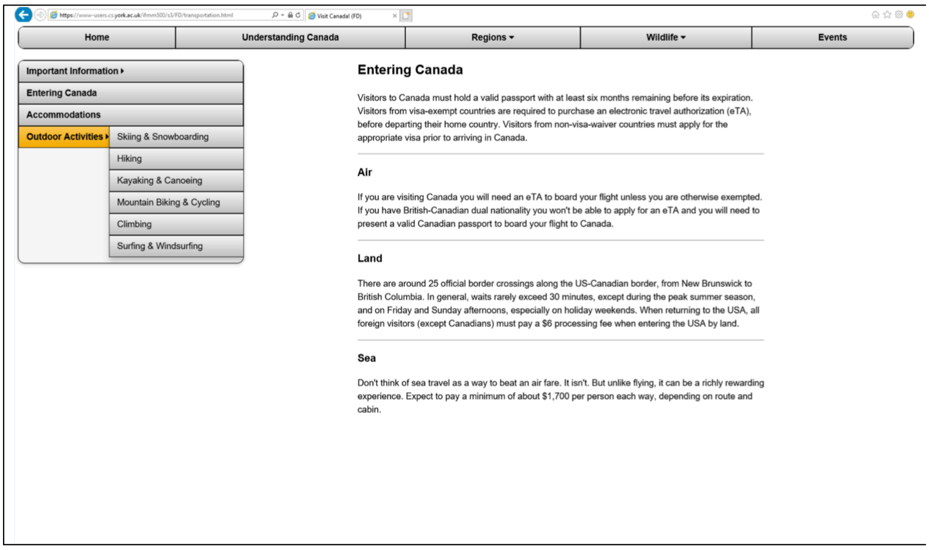

Fig. 5. Experimental website page with fragmented and dynamic menus

The text on the web pages was presented left-justified, 80 – 90 characters per line (not including spaces), font size 14 point, 1.5 line spacing, black on a white background. A limited number of images were included so as not to distract the participants too much from the text and menus. Menus had a linear gradient colour from light grey (#c1c1c1, RGB (193, 193, 193)) to very light grey (#f5f5f5, RGB (245, 245, 245)). When hovered over with a mouse, the menu item temporarily changed its background colour, a linear gradient colour from pure orange (#f8ac00, RGB (248, 172, 0) to soft orange (#fac754, RGB (250, 199, 84)). All menus, text passages and images fit into one screen on the monitor, so no scrolling was required to find information (that would have made the eye gaze analysis much more complicated).

A practice website was created with a very similar design to the experimental website, although the material was on a different topic, the biology of insects.

Questions were developed for participants to search for answers in the website. Multiple choice questions were used to make the task less onerous for the participants and easier for the researchers to score. A typical question was "How many official border crossings are there along the US-Canadian border?". A pool of 9 questions was generated and their difficulty assessed. Five participants (students and staff in the Deparmtnet of Computer Science) searched the website and answered the questions. After each question they rated how difficult it was to find the answer (on a 9 point Likert item, 1 = very difficult to 9 = not at all difficult) and indicated whether they had known the answer before viewing the website. Four questions from the pool were chosen, based on accuracy (all five participants were able to find the answer), difficulty (two questions were relatively easy, mean rating of 5.8, two questions were more difficult, mean ratings 7.0 and 7.6), and the fact that none of the participants knew the answer beforehand.

Small cue cards (9 cm x 12 cm) with the questions were created and placed below the participant's monitor as they tried to answer each question, so if the participant forgot the question, they could glance down and remind themselves of it.

A final questionnaire measured participants' opinion of the ease of use, ease of remembering and ease of learning of the menu structures on 7-point Likert items. It was decided not to use a standardized usability questionnaire such as the SUS as we wanted to specifically measure participants' opinions of the menus, not the whole website. All the standardized questionnaires considered were found to be too broad in their scope for the current study.

3.4 Procedure

Participants were asked to complete the ARQ before they came for their experimental session, in order to assign them to the appropriate participant group. The experiment session took place in a quiet room so participants could concentrate on the task (particularly important for the dyslexic participants). Participants were given a brief explanation about the purpose of the study and the tasks they were going to undertake. They were given a chance to ask any questions, before completing an informed consent form and the initial questionnaire.

Participants were asked to sit comfortably and adjust the height of the chair and the gap between their body and the desk. The monitor was then adjusted so the viewing distance from the participant to the screen was as close to 60cm as possible. Participants were asked to minimise head and body movement during the experiment to optimise the accuracy of the eye tracking equipment.

The eye tracking equipment was then used to calibrate and validate the participant's eye gaze. After a successful calibration, the participant was given a task on the practice website to familiarise them with the experimental procedure. They then moved to the experimental website and completed the four experimental tasks. The calibration and validation of their eye gaze was repeated at the beginning of each task. Questions were provided on screen, but also on a small cue card placed under the monitor (see Fig. 1), so if the participant forgot what they were looking for, they could glance at the card. The order of tasks was counter-balanced between participants. After all four tasks were completed, participants completed the final questionnaire, were encouraged to ask questions about the study and offered the Amazon gift voucher.

3.5 Data Preparation

Data were summed across the four tasks from each participant. Areas of Interest (AoIs) were created for the main menu, sub-menus and the relevant target menu item for each task and each version of the website. Data for first fixation duration in the AoI, number of fixations in the AoI, mean fixation duration for the AoI, total dwell time in the AoI, first time of mouse click, task completion time were all extracted from the eye tracking program.

For the menu scanpath analysis, each item in the main menu and sub-menus was allocated a code and the sequence of items visited was manually extracted from the eye tracking recording. Then the total length of the scanpath, the number of different items in the scanpath and the number of revisits to items were calculated. For example, if the sequence of items visited was ABCDEDEDC, the total length would be 9, the number of different items would be 5 and the number of revisits would be 4.

All dependent variables were visually analysed using histograms to check for normality of distribution. Outliers for all variables in eye gaze behaviour measures and some variables in performance measures (time of first mouse click, task completion time) were adjusted using the *winsorization* technique [15]. In this technique, outliers were adjusted if the values below or above than $Mean \pm 2SD$.

The majority of the data were normally distributed and the variances were homogeneous, so parametric statistics were used.

4 Results and Discussion

4.1 Eye Gaze Behaviour: Menu Scanpaths

2 x 2 x 2 ANOVAs were conducted with participant group (non-dyslexic and dyslexic), menu organisation (unified and fragmented) and menu visibility (visible and dynamic) as the between participants independent variables. The dependent variables were total length of scanpath, number of different Items in the scanpath and number of revisits.

On the ANOVA for total length (measured in number of items in the scanpath), there was a significant main effect for participant group with a large effect size, $F(1, 49) = 9.02$, $p = .004$, $\eta_p^2 = .15$. Dyslexic participants had significantly longer paths than non-dyslexic participants (mean Dyslexic: 25.79, SD: 17.11; mean non-dyslexic: 19.34, SD: 13.37). There was also a significant main effect for menu organization with a medium effect size, $F(1, 49) = 3.88$, $p = .05$, $\eta_p^2 = .07$. Scanpaths were significantly longer in the fragmented menu condition compared to the unified menu condition (mean fragmented: 24.05, SD: 16.20; mean unified: 20.87, SD: 14.88). No other effects were significant.

On the ANOVA for the number of different items in the scanpath, there was a significant main effect for participant group with a medium effect size, $F(1, 49) = 5.46$, $p = .024$, $\eta_p^2 = .10$. Dyslexic participants viewed more menu items than non-dyslexic participants (mean Dyslexic: 12.18, SD: 6.81; mean non-dyslexic: 10.47, SD: 6.35). No other effects were significant.

On the ANOVA for number of revisits, there was a significant main effect for participant group with a large effect size, $F(1, 49) = 9.06$, $p = .004$, $\eta_p^2 = .16$. Dyslexic participants made significantly more revisits to menu items than non-dyslexic participants (mean dyslexic: 13.37, SD: 10.95; mean non-dyslexic: 8.80, SD: 7.81). There was also a significant main effect for menu organization with a medium effect size, $F(1, 49) = 3.82$, $p = .05$, $\eta_p^2 = .07$. There were significantly more revisits in the fragmented menu condition compared to the unified menu condition (mean fragmented: 12.05, SD: 10.25; mean unified: 9.98, SD: 9.09). No other effects were significant.

These results show strong differences in menu scanpaths between the dyslexic and the non-dyslexic participants. Dyslexic participants had significantly longer scanpaths, so they looked at more items in the menus before making a selection than non-dyslexic participants. This was due both to the fact that they looked at significantly more different menu items and they revisited significantly more menu items than the non-dyslexic participants. So, they look around at more menu items and go back to items more before selecting a menu item to move to. Further research is needed to understand whether this is a robust effect and if so, why this is the case. Bylinskii et al [6] argue that the number of revisits to an item reflects its noticeability, however as this is a differential effect between dyslexic and non-dyslexic participants it could be that the dyslexic participants found the menu items more difficult to read or that they have a greater need to be sure of where they are going before they make a selection, as they are more worried about navigating through web pages. This behaviour certainly slows down their use of the web.

There was also an effect of menu organization on scanpaths for both dyslexic and non-dyslexic participants. Fragmented menu presentation resulted in significantly longer scanpaths and this was due to a significantly higher number of revisits rather than a greater number of different items visited (as there was no significant different in the number of different items visited). So, fragmenting the menu may create uncertainty in all web users, and they need to revisit items before making a selection. Only one of the previous studies found [25] investigated the pattern of scanpaths in relation to different menu organisation. Although it conducted interesting analyses, that study only investigated scanpaths in terms large areas of the web page, one of which was the menu. Thus, the researchers were not able to investigate how the menu organization affected the way in which participants interacted with components of the menu at a fine-grained level of individual menu items. Our results suggest that investigating the effects of menu structure in more detail could yield useful results.

4.2 Eye Gaze Behaviour: Areas of Interest

2 x 2 x 2 ANOVAs were conducted with participant group (non-dyslexic and dyslexic), menu organisation (unified and fragmented) and menu visibility (visible and dynamic) as the between participants independent variables. The dependent variables were first fixation duration, number of fixations, mean fixation duration, and dwell time, all for each type of AoI (main menu, submenus, target menu Item).

The ANOVA on first fixation duration (measured in msec) showed no significant effects for any of the AoIs.

The ANOVA on number of fixations for main menus showed no significant main effects but a significant interaction between menu organization and menu visibility, F (1, 56) = 6.17, p = .02, η_p^2 = .10. Fig. 6 shows that in unified menus there were more fixations with visible submenus, but with fragmented menus there were more fixations with dynamic submenus.

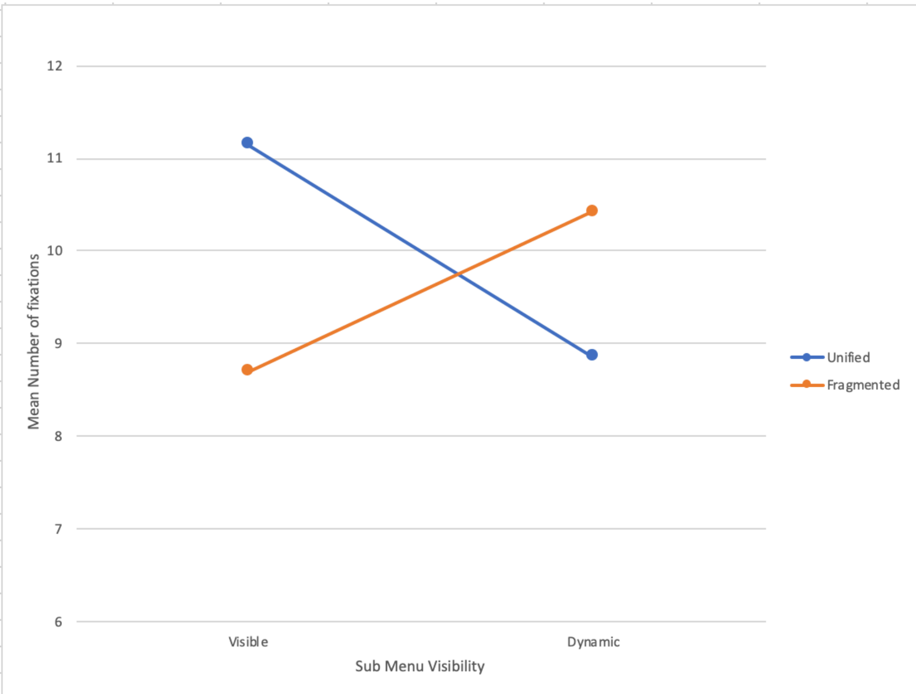

Fig. 6. Interaction for number of fixations between menu organization and visibility for main menu AOI

The ANOVA on number of fixations on submenus showed a significant main effect for participant group, $F(1, 56) = 5.69$, $p = .02$, $\eta_p^2 = .09$. Non-dyslexic participants had a significantly lower number of fixations on the submenus (mean: 9.94, SD: 3.86) than dyslexic participants (mean: 12.31, SD: 4.12).

The ANOVA on number of fixations on target menu items showed no significant effects.

The ANOVA on mean fixation duration (measured in msec) showed no significant effects for either main menus, submenus or target menu item.

The ANOVA on dwell time (measured in msec) showed no significant effects for main menus. However, the ANOVA for dwell time on submenus showed a significant main effect for participant group with a moderate effect size, $F(1, 56) = 4.19$, $p = .02$, $\eta_p^2 = .07$. Non-dyslexic participants had a significantly shorter dwell times on the submenus (mean: 2.58, SD: 1.13) than dyslexic participants (mean: 3.18, SD: 1.20).

The ANOVA on dwell time on target menu item showed no significant effects.

There were fewer interesting differences in the eye gaze measures related to AOIs than the overall scanpath measures. The first fixation duration, which it has been argued measures the attention getting property of an item [6], showed no significant effects. This is perhaps not surprising, as the experimental website was deliberately kept rather bland with mainly text, so there were not particularly attention-grabbing elements, particularly in the menus.

There were significant differences in the number of fixations on menu items, with dyslexic participants having significantly more fixations on submenus than non-dyslexic participants. However, the meaning of this result is not clear: in terms of interest in visual elements, more fixations are thought to indicate greater interest, but in terms of reading the text in menu items, more fixations are thought to indicate greater difficulty in reading. So, it may be that it was taking the dyslexic participants longer to read the text of the menu items.

There was also a significant interaction between menu organization and visibility on number of fixations (see Fig. 6), with unified menus with visible submenus having more fixations than with dynamic submenus, whereas for fragmented menus the number of fixations was reversed between visible and dynamic submenus. The first result makes obvious sense: if the main menu is all in one place and the submenus are visible, there will be more items to immediately look at, so more fixations will occur. However, the second result is more difficult to understand, why should dynamic menus create more fixations if the main menu is fragmented? Further research is needed to investigate whether this effect is replicable.

Mean fixation duration also showed no significant effects. However, overall dwell time on submenus showed a significant effect with dyslexic participants spending longer time on submenus than non-dyslexic participants. This result fits with the other results from the scanpath analysis and the number of fixations, that dyslexic participants are spending more time looking at the menus, particularly the submenus.

The two previous studies which investigated number of fixations in menu exploration [19, 25] did not conduct as fine-grained an analysis as presented here, so it is hard to make comparisons. Leuthhold et al [19] only investigated the number of fixations before the first mouse click and found dynamic menus produced significantly more fixations than simple menus. This is similar to our finding that there was a significant interaction for number of fixations between menu organization and visibility, but it does not help explain the interaction. As mentioned in the previous section, McCarthy et al [25] did not conduct an analysis below the whole menu structure, so their investigation of number of fixations is not comparable with ours. Further research is needed, both comparing dyslexic and non-dyslexic participants and the effects of menu organization and visibility on all participants, to establish whether these effects are robust.

4.3 Performance Variables

2 x 2 x 2 ANOVAs were conducted with participant group (non-dyslexic and dyslexic), menu organisation (unified and fragmented) and menu visibility (visible and dynamic) as the between participants independent variables. The dependent variables were time to first mouse click and task completion time as dependent variables. There was a ceiling effect in the number of correct answers to the comprehension questions, with most participants answering all questions correctly, so no analysis was undertaken on that dependent variable. However, this did mean that both dyslexic and non-dyslexic participants answered the questions very largely correctly.

On the ANOVA for time to first mouse click (measured in msec), there was a significant main effect for participant group with a large effect size, $F (1, 56) = 7.64$, $p < .01$, $\eta_p^2 = .12$. Non-dyslexic participants clicked sooner dyslexic participants (mean non-dyslexic: 5.56s, SD: 2.07; mean dyslexic: 7.41, SD: 3.18). No other effects were significant.

On the ANOVA for task completion time (measured in msec), there was a significant main effect for participant group with a large effect size, $F (1, 56) = 5.34$, $p =.02$, $\eta_p^2 = .09$. Non-dyslexic participants completed the tasks faster than dyslexic participants (mean non-dyslexic: 26.78 s, SD: 10.69; mean dyslexic: 32.97, SD: 10.88). No other effects were significant.

Not surprisingly, given the differences in the scanpath behaviour between dyslexic and non-dyslexic participants, there were also differences in performance between the two participant groups. Dyslexic participants were significantly slower in making their first mouse click and in completing tasks.

4.4 Participant opinions

Participants separately rated three aspects of the menu structures: their ease of use (EoU), ease of remembering (where items were, EoR) and ease of learning (EoL), each on a 7-point Likert item (with low ratings indicating most positive values). However, there were significant correlations between the three sets of ratings (EoU-EoR $r = .49$, EoU-EoL $r = .56$, EoR-EoL $r = .63$, all $p < .01$), suggesting they were measuring one underlying construct. Therefore, a mean rating (MenuRating) was calculated from the three ratings, which also creates a more robust measure.

A 2 x 2 x 2 ANOVA was conducted with participant group (non-dyslexic and dyslexic), menu organisation (unified and fragmented) and menu visibility (visible and dynamic) as the independent variables and MenuRating as the dependent variable. There was a significant main effect for menu organization with a large effect size, $F(1, 55) = 14.95$, $p = .00$, $\eta_p^2 = .21$. The unified menu organization was rated significantly more positively than the fragmented menu organization (mean unified: 1.90, SD: 0.82; mean fragmented: 2.82, SD: 1.01). No other effects were significant.

Interestingly the differences between dyslexic and non-dyslexic participants eye gaze behaviour and consequent performance did not lead to different opinions of the website. There were no differences between the groups in their ratings of the overall ease of use/remembering/learning the website. However, there was a significant difference in participants' ratings of menu organization, with the unified menu presentation rated significantly better than the fragmented presentation. There were no significant differences between ratings of the visible or dynamic submenus.

5 Discussion and Conclusions

This study investigated the effects of two aspects of web navigation, the organization and visibility of menu items on the eye gaze patterns, performance and preferences of dyslexic and non-dyslexic web users. A number of interesting results have emerged.

On the eye gaze measures, the scanpaths followed by participants showed significant differences between dyslexic and non-dyslexic participants and between fragmented and unified menu organization. Dyslexic participant had significantly longer scanpaths, which was due to both a significantly larger number of different menu items visited and a significantly larger number of revisits to menu items. Thus, the scanning behaviour of dyslexic and non-dyslexic participants was different. There were also significantly longer scanpaths for all participants in the fragmented menu conditions, which was due to a significantly greater number of revisits to items. Thus, fragmented menus slowed participants down as they revisited items before making a decision of where to go to next in the website.

On the analysis of eye gaze on specific areas of interest (AoIs), only the number of fixations and the overall dwell time (which are related as measures) showed significant effects. For all participants there was a significant interaction between number of fixations between menu organization and visibility, although the result was rather difficult to interpret and further research is needed. In addition, dyslexic participants made significantly more fixations and have significantly longer dwell times on submenus. Combined with the results that dyslexic participants had longer scanpaths than non-dyslexic participants, this shows that dyslexic participants are spending more time (and potentially effort) exploring the menus.

The differences between dyslexic and non-dyslexic participants in terms of eye gaze behaviour also showed themselves in the performance measures. Dyslexic participants were significantly slower in making their first mouse click on a webpage than non-dyslexic participants, not surprising given their scanpaths were significantly longer. In addition, dyslexic participants were significantly slower in completing the tasks, which may have been due to slower reading times of the texts as well as slower times to investigate the menus. There were no effects of the menu organization or visibility on the performance measures.

Finally, there were significant effects in participants' opinions of the menu organization, but no differences between dyslexic and non-dyslexic participants in their opinions. Overall, all participants were significantly more positive about the unified menus than the fragmented menus; there were no significant differences in opinions of visible or static menus.

The study has a number of limitations which need to be considered. The main limitation is that the participants, both dyslexic and non-dyslexic, were almost all university students. While this makes them comparable groups, it probably means that the dyslexic participants have learnt good coping strategies to deal with their problems, to have reached higher education. It would be interesting to collect a further sample of participants with more severe dyslexia and compare their data with the current samples and with a matched non-dyslexic sample. A further limitation is that only one website was used, so some of the results could be due to the particularities of this website and its menus. It is important to replicate these results with a range of websites. Using a number of websites would also allow for a within participants design, so that the participants could experience the different menu presentations and compare them. This was not possible in the current study, as once participants had undertaken the tasks with one menu presentation, they would know where menu items and information were and be to answer the questions very quickly.

Nonetheless, we believe these results are an interesting and useful first set of detailed results of the eye gaze behaviour, performance and preferences of dyslexic and non-dyslexic web users in relation to several aspects of menu organization on websites. The eye gaze data is time consuming to analyse and it seems that analysing the scanpaths yielded the most useful data with little extra information being added by analysing the number of fixations and fixations durations, although these are standard eye gaze measures in the research literature. Interesting future research could use a retrospective verbal protocol, showing the participant their scanpath after they have completed a task, and asking them to explain why they looked where they did. This would throw light on why the dyslexic participants looked at more menu items and revisited more items before making a selection. In turn, this could lead to guidelines for better menu organization for both dyslexic and non-dyslexic web users.

Acknowledgements

We would like to thank all the dyslexic and non-dyslexic participants in the study for their time and effort. We would also like to thank our colleagues in the Department of Computer Science for their help in establishing the difficulty of the questions for the study.

References

1. Al-Wabil, A., Zaphiris, P., Wilson, S.: Web navigation for individuals with dyslexia: an exploratory study. In Stephanidis, C. (ed.), Universal Acess in Human Computer Interaction, Part I, LNCS vol. 4554, pp. 593-602. Springer, Berlin-Heidelberg (2007).
2. Al-Wabil, A., Zaphiris, P., Wilson, S.: Examining visual attention of dyslexics on web navigation structures with eye tracking. In Proceedings of the International Conference on Innovations in Information Technology (IIT 2008), pp. 717-721 IEEE (2008).
3. Andresen, A., Anmarkrud, Ø., Bråten, I.: Investigating multiple source use among students with and without dyslexia. *Reading and Writing,* (in press).
4. Bailly, G., Lecolinet, E., Nigay, L.: Flower menus: a new type of marking menu with large menu breadth, within groups and efficient expert mode memorization. In Proceedings of the Working Conference on Advanced Visual Interfaces (AVI 2008), pp. 15 – 22 (2008).
5. British Dyslexia Association: Background. https://www.bdadyslexia.org.uk/about, last accessed 2019/2/2
6. Bylinskii, Z., Borkin, M.A., Kim, N.W., Pfister, H., Oliva, A.: Eye fixation metrics for large scale evaluation and comparison of information visualizations. In Proceedings of Workshop on Eye Tracking and Visualization (ETVIS 2015), pp. 235 - 255. Springer, Heidelberg (2015).
7. Dyslexie font. https://www.dyslexiefont.com/ Last accessed: 2019/1/15
8. Elliott, J.G., Grigorenko, E.L.: The dyslexia debate. Cambridge University Press, Cambridge (2014).
9. Faulkner, X., Hayton, C.: When left might not be right. Journal of Usability Studies, 6(4), 245 – 256 (2011).
10. Freda, C., Pagliara, S.M., Ferrero, F., Zanfardino, F., Pepino, A.: Dyslexia: study of compensatory software which aids the mathematical learning process of dyslexic students at secondary school and university. In K. Miesenberger et al (eds.) Proceedings of ICCHP 2008, LNCS vol. 5105, pp. 742 – 746, Springer, Heidelberg (2008).
11. Freire, A. P., Petrie, H., & Power, C. Empirical results from an evaluation of the accessibility of websites by dyslexic users. In Proceedings of the Workshop on Accessible Design in the Digital World. Lisboa, Portugal available at: CEUR-WS. Org (2011).
12. Goulandris, N. E. Dyslexia in different languages: Cross-linguistic comparisons. Whurr Publishers, London (2003).
13. Gregor, P., Dickinson, A., Macaffer, A., Andreasen, P.: SeeWord - A personal word processing environment for dyslexic computer users. British Journal of Educational Technology, *34*(3), 341-355 (2003).
14. Gregor, P., Newell, A. F.: An empirical investigation of ways in which some of the problems encountered by some dyslexics may be alleviated using computer techniques. Proceedings of the Fourth International ACM Conference on Assistive Technologies, ACM Press, New York (2000).
15. Hellerstein, J.M.: Quantitative Data Cleaning for Large Databases (2008) Last accessed: 2019/1/28 http://db.cs.berkeley.edu/jmh/papers/cleaning-unece.pdf
16. Kalbach, J., Bosenick, T.: Web page layout: a comparison between left and right justified site navigation menus. Journal of Digital Information, 4(1) (2003).
17. Kuster, S. M., van Weerdenburg, M., Gompel, M., Bosman, A. M.: Dyslexie font does not benefit reading in children with or without dyslexia. Annals of dyslexia, 1-18 (2017).
18. Leeuw, R.: *Special font for dyslexia?* Phd thesis, University of Twente. (2010).
19. Leuthold, S., Schmutz, P., Bargas-Avila, J. A., Tuch, A. N., Opwis, K.: Vertical versus dynamic menus on the world wide web: Eye tracking study measuring the influence of

menu design and task complexity on user performance and subjective preference. Computers in human behaviour*, 27*(1), 459-472 (2011).
20. Miller, K., Armstrong, K., Kaminski, A., Karlin, A., Lee, J., McCarthy, C., ver Berkmoes, R., Walker, B. and Tang, P.: Lonely Planet Canada. Lonely Planet (2017).
21. MacFarlane, A., Al-Wabil, A., Marshall, C., Albrair, A., Jones, S., Zaphiris, P.: The effect of dyslexia on information retrieval: A pilot study. Journal of Documentation*,* 66(3), 307-326 (2010).
22. MacFarlane, A., Albrair, A., Marshall, C.R., Buchanan, G.: Phonological working memory impact on information searching: an investigation of dyslexia. In Proceedings of the 4th Information Interaction in Context Symposium, pp. 27 – 34. ACM Press, New York (2012).
23. MacFarlane, A., Buchanan, G., Al-Wabil, A., Andrienko, G., Andrienko, N.: Visual analysis of dyslexia on search. Proceedings of Conference on Human Iinformation Interaction and Retrieval (CHIIR '17), pp 285 - 288. ACM Press, New York (2017).
24. Marinus, E., Mostard, M., Segers, E., Schubert, T. M., Madelaine, A., Wheldall, K.: A special font for people with dyslexia: Does it work and, if so, why? Dyslexia, *22*(3), 233-244 (2016).
25. McChesney, I., Bond, R.: Gaze behaviour in computer programmers with dyslexia – considerations regarding code style, layut and crowding. In Proceedings of EMIP '18, ACM Press, New York (2018).
26. Meindertsma, J.: The power of typefaces: Dyslexie. TXT, 8-9, 56-59 (2016).
27. Melguizo, M.C.P., Vidgay, U., van Oostendorp, H.: Seeking information online: the influence of menu type, navigation path complexity and spatial ability on information gathering tasks. Behaviour and Information Technology, 31(1), 59 – 70 (2012).
28. Morris, M. R., Fourney, A., Ali, A., Vonessen, L.: Understanding the needs of searchers with dyslexia. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18). ACM Press, New York (2018).
29. Murano, P., Khan, I.N.: Pie menus or linear menus which is better? Journal of Emerging Trends in Computing and Information Sciences, 6(9), 476 – 481 (2015).
30. Murano, P., Sander, M.: User interface menu design performance and user preferences: a review and ways forward. International Journal of Advanced Computer Science and Applications, 7(4), 355- 361 (2016).
31. National Health Service: Overview – dyslexia. https://www.nhs.uk/conditions/dyslexia/, last accessed 2019/2/2
32. Nicolson, R.: Dyslexia: beyond the myth. The Psychologist, 18(11), 658 – 659, (2005).
33. O'Brien, B.A., Mansfield, J.S., Legge, G.E.: The effect of print size on reading speed in dyslexia. Journal of Research in Reading, 28(3), 332 – 349, (2005).
34. Open Dyslexic. Last accessed 2019/1/29: https://www.opendyslexic.org/
35. Pijpker, C.: Reading performance of dyslexics with a special font and a colored background. Phd thesis, University of Twente (2013)
36. Powell, N., Moore, D., Gray, J., Finlay, J., Reaney, J.: Dyslexia and learning computer programming. In Proceedings of the 9th annual SIGSCE/SIGCUE ITiCSE Conference on Innovation and Technology in Computer Science Education (ITICSE '04). ACM Press, New York (2004).
37. Read Regular. Last accessed: 2019/1/29: http://www.readregular.com/english/intro.html
38. Rello, L., Baeza-Yates, R.: Optimal colour to improve readability for people with dyslexia. Text Customization for Readability Online Symposium, Available at: https://www.w3.org/WAI/RD/2012/text-customization/ (2012).

39. Rello, L., Baeza-Yates, R.: Good fonts for dyslexia. Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility, ACM Press, New York (2013).
40. Rello, L., Baeza-Yates, R.: How to present more readable text for people with dyslexia. Universal Access in the Information Society, 16(1), 29-49, (2015).
41. Rello, L., Baeza-Yates, R.: The effect of font type on screen readability by people with dyslexia. ACM Transactions on Accessible Computing (TACCESS), *8*(4), 15 (2016).
42. Rello, L., Bigham, J.P.: Good background colours for readers: a study of people with and without dyslexia. In Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessbility, ACM Press, New York (2017).
43. Rello, L., Kanvinde, G., Baeza-Yates, R.: Layout guidelines for web text and a web service to improve accessibility for dyslexics. In Proceedings of the International Cross-disciplinary Conference on Web Accessibility (W4A ’12), ACM Press, New York (2012).
44. Rello, L., Pielot, M., Marcos, M.-C., Carlini, R.: Size matters (spacing not): 18 points for a dyslexic-friendly Wikipedia. In Proceedings of the 10th International Cross-Disciplinary Conference on Web Accessibility (W4A ’13), ACM Press, New York (2013).
45. Roudant, A., Bailly, G., Lecolinet, E., Nigay, L.: Leaf Menus: Linear Menus with Stroke Shortcuts for Small Handheld Devices. In Proceedings of INTERACT 2009, pp 616 – 619, (2009).
46. Rubio, J.M., Janecek, P.: Floating pie menus: enhancing the functionality of contextual tools. In Adjunct Proceedings of the 15th Annual ACM Symposium on User Interface Software and Technology (UIST ’02), ACM Press, New York (2002).
47. Samp, K., Decker, S.: Supporting menu design with radial layouts. In Proceedings of the International Conference on Advanced Visual Interfaces, ACM Press, New York (2010).
48. Schneps, M. H., Thomson, J. M., Chen, C., Sonnert, G., Pomplun, M.: E-readers are more effective than paper for some with dyslexia. *PloS One, 8*(9), e75634.
49. Schoonewelle, A. Typographical support for dyslexics: the effect of textual alternations on dyslexics’ test scores. PhD thesis, Vrije Universiteit Amsterdam (2013).
50. Schulz, T. Internal validity in experiments for typefaces for people with dyslexia. In Proceedings of International Conference on Computers Helping People with Special Needs (ICCHP ’16). Springer, Heidelberg (2016).
51. Siegel, L.S.: Perspectives on dyslexia. Paediatrics and Child Health, 11(9), 581 - 587 (2006).
52. Sjoblom, A. M., Eaton, E., Stagg, S. D.: The effects of letter spacing and coloured overlays on reading speed and accuracy in adult dyslexia. British Journal of Educational Psychology, *86*(4), 630-639, (2016).
53. Snowling, M. J.: Dyslexia (2nd ed. ed.). Blackwell Publishers, Malden, MA (2000).
54. Snowling, M. J., Dawes, P., Nash, H., Hulme, C.: Validity of a protocol for Adult Self-Report of Dyslexia and Related Difficulties. Dyslexia, 18(1), 1-15 (2012).
55. Sylexiad Last accessed 2019/1/29: http://www.robsfonts.com/fonts/sylexiad
56. Wery, J. J., Diliberto, J. A.: The effect of a specialized dyslexia font, OpenDyslexic, on reading rate and accuracy. Annals of dyslexia, 67(2), 114-127 (2017).