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ORIGINAL ARTICLE

Optimizing web-accessibility for deaf people and the hearing impaired utilizing a sign language dictionary embedded in a browser

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Abstract Deaf people have certain problems navigating on the Internet. This is a subject, which has not received adequate scientific attention. Via an experiment with both deaf and hearing people, text was identified as a problem for deaf people when navigating on websites. A prototype of a website with an embedded sign language dictionary, which translates keywords to sign language, was developed and tested against the same website without the dictionary. This test revealed that deaf people who were given the sign language prototype completed a given task significantly faster than deaf people who were given the website without the dictionary. A final test showed that deaf and hearing people use the same number of metacognitive comprehension strategies when reading on websites, but the frequency of their usage was different. Deaf people make more use of a *search and match* strategy, which is a behavior this prototype supports.

Keywords Sign language · Deaf people · User driven innovation · Metacognitive comprehension strategies · Prototyping · Eye tracking

1 Introduction

This work was made in collaboration with Center for Deafblindness and Hearing Loss (Center for Døvblindhed og Høretab) in Aalborg, Denmark. They also helped with the requisition of deaf test subjects and made the preliminary observation, which this project is based on.

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By preliminary observations, it seemed that deaf people navigate on basis of words plus pictures and visual indicators when browsing websites. Furthermore, it seemed that deaf people misunderstand some of the web content, especially if the text and the pictures on the website do not match. From an interview with two deaf people, at Center for Deafblindness and Hearing Loss in Aalborg, it was clear that there was a consensus that deaf people, when looking at a website, would want to look at any picture they could, if the website provided such. Furthermore, they told that they quickly became bored when reading text, except simplified text. This information led to the presumptions that deaf people would be looking at pictures more than text, and that deaf people would have difficulties with the text element on websites.

The problems deaf people face on the Internet is a subject, which has not received adequate scientific research. The goal of this paper is to investigate the problems deaf people face on websites and explore possible solutions to such problems, which could help deaf people read content on websites as good as the average normal hearing person.

Most content on websites is based on text. Deaf people in general have a poor reading level, since text is based on oral language (Perfetti and Sandak 2000). Oral languages are foreign to deaf people, since their first language is sign language. Sign language is a nonverbal language, which is based on gestures with the body, face and primarily the hands. Sign language and how deaf people understand and use text are investigated in order to understand this subject and find a solution.

The first part of this article consists of theory, which explains sign language and how deaf people read and comprehend text. That is followed by the first experiment, where deaf people's reading skills on the Internet is investigated. In every experiment section, there will be

subsections in regard to subjects, materials, design and procedure, results and discussion. Following experiment I, there will be two sections concerning a focus group and prototype development. This will be followed by experiment II, where the prototype is tested. A theory section concerning metacognitive reading strategies will follow, which will be explored in experiment III. The results of the whole article will then be discussed, reflected and concluded upon in the last section of this article.

2 Sign language

There are many myths concerning sign language, e.g., that sign language is English spoken with the hands and that sign language is international. The surrounding language(s) and the attitude toward sign language influence the sign language (Engberg-Petersen 1998; Grosjean 2011). According to experts at Center for Deafblindness and Hearing Loss in Aalborg, bilingualism in relation to deaf people refers to that the first language most deaf people learn is sign language, followed, e.g., English as second language. Sign language is divided into three types of language: the sign language of the deaf people, sign-English (pidgin signed English) and English with supporting signs. Together with these three language types, other methods, which can be used, are: the hand–mouth system, the hand alphabet, etc. When signing in sign language, the illustrator is to set the scene in the locus, followed by the actual story, e.g., the sentence "the boy climbs up the tree." The tree is to be drawn first, followed by the boy and then the action climbs. An important thing when signing sign language is to emphasize the important words. When looking at the sentence from before, is the important thing the boy or that he climbs the tree? If it was the last, the sentence in sign language would be: climbs the tree, the boy climbs the tree. Simply to underline what is important in the sentence. In sign language, only present tense exists. To illustrate the past and the future, the drawer points backwards or forwards, respectively, when setting the scene. According to Lene Schmidt, sign language interpreter at Center for Deafblindness and Hearing Loss, for a person with sign language as first language it is very difficult to understand a sentence where the words of content are flexed grammatical, e.g., in past tense. This is not the only problem people with sign language as their first language face; they also have problems with idioms, compound nouns, wider terms and pronouns.

3 How deaf people read and comprehend text

According to Perfetti and Sandak (2000), reading is not a parallel language system, but closely related to the spoken language and its phonology. Spoken language is prior to written language—all children learn a native language, but not all learn how to read. Other important factors to reading are: reading experience and the automatic of reading and comprehension strategies.

Since written language is closely related to spoken language and its phonology deaf readers will have natural problems with reading. According to Perfetti and Sandak (2000), two findings indicate that deaf readers did not make use of phonological cues in spelling as much as hearing readers do. The first finding is that deaf readers did not make phonological spelling errors (skwrl instead of squirrel). The second finding is that the deaf children to a higher degree remembered silent letters when spelling compared to hearing children of the same age. Three studies show that deaf readers make use of phonology (Perfetti and Sandak 2000). The first study states that deaf readers can make use of phonology, when they have to judge if a sentence rimes (Hanson and Fowler 1987). The second study indicates that deaf readers can make use of phonology, when performing a naming task. When the deaf readers in this task had to name pseudo-words, they could read these pseudo-words accurately aloud. This is an indication that deaf readers can assemble phonology from letters (Leybaert 1993). A third study indicates that the memory for visual presented language relies more on its phonology, than its visual information, and studies indicate that it is the same with deaf readers (Perfetti and Sandak 2000). The conclusion is that some deaf readers make use of phonology, while others do not. It is suggested that if deaf readers do not use phonology, they make use of visual information, contextual information or use sign-based recoding. According to Perfetti and Sandak (2000), many deaf readers, like less skilled hearing readers, rely more on orthography and semantic information instead of phonological information. Some deaf readers make use of phonology, but how have they gained that access? According to Perfetti and Sandak (2000), there are some possible explanations: lip-reading and different forms of cued speech, where the speaker uses hand signals close to the mouth to distinguish both consonants and vowels. Perfetti and Sandak conclude that many deaf readers are cable of gaining access to phonology and use it when reading. The level of how well deaf readers are to access phonology may elevate their achievements in reading (Perfetti and Sandak 2000). According to Andrews and Mason, there are many possible explanations as to why deaf readers have difficulties in reading; it could be that the deaf reader has poor verbal linguistic skills or because there is a great difference between the structure in verbal language and in sign language. Another reason could be that the deaf reader does not have the same background knowledge about the different topics (Andrews and Mason 1991). These theories are the theoretical foundation for the experiments.

4 Experiment I

An experiment is made in order to find empirical evidence to verify or falsify the preliminary observation and presumptions. Furthermore, the goal is to generate measurable data and to pinpoint which web elements are difficult for deaf people to understand. The findings to these two rationales are to be the foundation for a solution to the problem(s) deaf people may face when browsing websites. These presumptions led to the research hypotheses. Hypothesis 1: "Deaf people will be looking more on pictures than text on websites compared to people with normal hearing". Hypothesis 2: "Deaf people will use more time on text heavy websites compared to people with normal hearing".

4.1 Methodology

4.1.1 Subjects

Seven men and three women suffering from deafness participated (all attending the Center for Døvblindhed og Høretab in Aalborg, Denmark). The mean age was 38.2 years (SD = 15.1). The reading abilities of the test subjects corresponded to the average pupil of the third or fourth grade in the Danish school system and one of them could not read at all. All have been deaf since birth.

Control group: Four men and seven women with normal hearing participated in a control experiment. The mean age was 30.6 year (SD = 14.8). All hearing test subjects had a normal level in reading. This was chosen because most websites, including important government websites, require a normal reading level. The goal of this article was to find out what problems deaf people face on such websites and find ways to help them understand the content of such websites as good as the average hearing person.

4.1.2 Materials

Selection of the test websites: three websites were chosen; one text heavy website (see Fig. 1), a website with a combination of text and pictures and instead of finding a website only with picture a compromise was made. Since it was impossible to find a website which only contained pictures, a website which mostly containing pictures, and minimum text, was chosen as the third test website.

4.1.3 Design and procedure

Experiment I was planned as a between-subjects experiment. Both groups of test subjects were given the same task on three different websites. Where the test subjects looked on the website and the completion times were compared between the groups. The order in which the test subjects received the websites was counterbalanced.

Only one test subject was tested at a time. The test subject sat in front of a monitor, which was connected to an eye tracker. The test subject was first given an introduction to the experiment. The deaf test subjects had the introduction translated by a sign language interpreter, which also translated the tasks for each website, if the deaf test subject requested it. The control group of hearing test subjects was given the introduction in oral by the facilitator and read each task on a piece of paper. After completing the experiment, both groups of test subjects were to answer some demographic questions, such as age and time of becoming deaf. The data were obtained via an eye tracker.

4.2 Results

The three different websites were each divided into areas of interest, and the fixations lengths were measured in seconds. This was done using the eye tracker software.

The analysis of the website containing pure text showed a difference between the deaf and the hearing test subjects. The deaf test subjects used in average 97.20 s on the task. This was compared to the hearing test subject, who in average used 29.09 s on the same task on the same text heavy website. The time differences between these two groups are illustrated in Fig. 2. These two time measurements seem significant different, and therefore, a t test was conducted. The p value was 0.045, showing that there was a significant difference between the two groups in task completion time.

The analysis of the website containing text and pictures showed a difference between the two groups as to what web elements they focused on the most. The deaf test subject in average used 5.90 s to look at pictures, and in average 16.76 s to look at text. This was compared to hearing test subjects, who in average used 10.00 s looking at pictures and in average 13.23 s looking at text.

The analysis of the website containing mostly pictures and a little text showed a slight difference. Again the deaf test subjects focused slightly more on text than the hearing test subjects. The deaf test subjects used in average 2.57 s to look at pictures and in average 2.76 s to look at text. This was compared to hearing test subject, who in average used 2.80 s looking at pictures and in average 3.93 s looking at text. The time difference between the deaf and hearing test subjects was so slight that it could have been a result of pure chance.

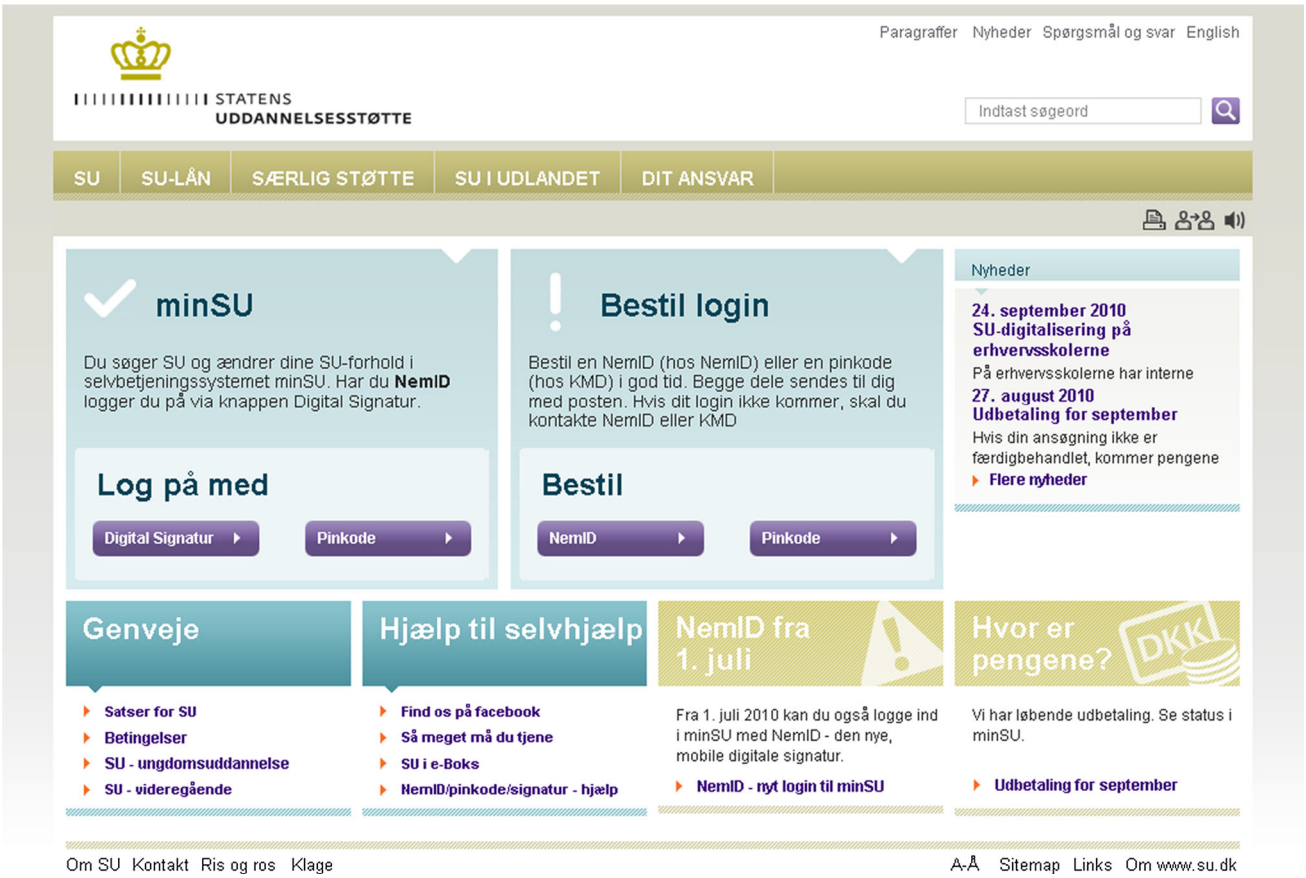

Fig. 1 A screenshot from the text heavy website, www.su.dk, as of 2011. This was/is a government website with information, instructions and forms on how to receive state benefits for people in the educational system

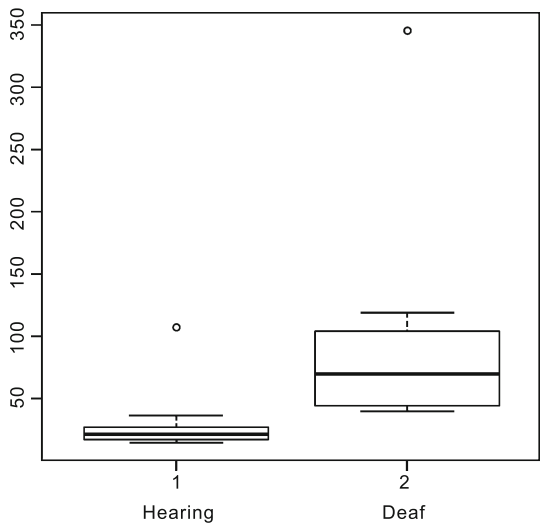

Fig. 2 *Box plots* for the normal hearing and the deaf test subjects in accordance with task completion time on the text heavy website

4.3 Discussion

Hypothesis 1 is falsified, since the deaf test subjects looked more on text and less on pictures compared to the hearing test subjects. This was in accordance with the website with an equal amount of text and pictures. In regard to the website which contained mostly pictures and little text, hypothesis 1 cannot be verified or falsified. This is due to that there was no noticeable difference between the two groups of test subjects in how much they focused on the different web elements. Hypothesis 2 is verified since the deaf test subjects used significantly more time to finish the task on the text heavy website.

The deaf test subjects in average looked more on text than on pictures on websites, compared to the hearing test subjects. This was contrary to the preliminary observations and the hypothesis made on the assumptions, that deaf people would be looking more on pictures than text on websites, compared to people with normal hearing. Furthermore, the experiment showed that in accordance with a more text heavy website, the completion time for the deaf test subjects was much longer compared to the hearing test subjects (29.09 s for the hearing test subjects and 97.20 s for the deaf test subjects). This result verified the hypothesis: "Deaf people will use more time on text heavy websites compared to people with normal hearing".

In accordance with the theoretical foundation, the experiment showed that the deaf test subjects made use of the strategy of finger spelling, when presented to a word they did not know. A concern regarding the experiment is the selection of the three test websites, since the website, which should only show pictures unfortunately contained a little text. Another concern is that some of the test subjects were familiar with some of the websites. The majority of the deaf test subjects knew the website that consisted mostly of pictures. Some of the hearing test subject knew the text heavy website, which was a government website. These two concerns were in mind when analyzing the data, but it is found that these concerns are trivial in relation to the purpose of this experiment, since all of the test subjects have experienced websites similar to the two, both in content and design. The results of the experiment revealed text to be the biggest problem for the deaf test subjects.

5 Focus group

Since the deaf test subjects have valuable knowledge and insight into what could help them to understand text better on websites, a focus group meeting was conducted with some of the deaf test subjects.

5.1 Methodology

5.1.1 Subjects

Six people suffering from hearing loss or deafness from Center for Døvblindhed og Høretab in Aalborg and a sign language interpreter.

5.1.2 Materials

Questions were prepared in advance that would help the deaf participants think of what could help them to better understand text on websites and to navigate easier online. Writing and drawing materials were also prepared if the participants choose to illustrate their ideas.

5.1.3 Design and procedure

Notes were taken by hand, since the questions and answers were translated to and from sign language. One of the authors was the interviewer and other one was the note taker. The participants were asked which solution they thought could make a difference to them, when navigating on the Internet and what would help them understand written text better.

5.2 Results

A couple of ideas were generated in the focus group:

- Idea 1: All websites on the Internet could be translated directly into sign language.
- Idea 2: Easy reading websites, where content could be written in a more understandable and easy way (from the deaf people's point of view).
- Idea 3: Highlighting difficult and meaningful words and then having the synonyms or antonyms for the word shown on screen.
- Idea 4: Highlighting of the word they do not understand and then having the word translated into sign language on screen.

5.3 Discussion

It would be impossible to translate all the words on the Internet into sign language. It would also be impossible to have all the text written content of the Internet be presented in an understandable and easy way. Highlighting the words and having their synonyms or antonyms shown, or having the difficult word translated into sign language, were the two ideas that were judged to be realistic to produce or simulate.

6 Development and design of a prototype

These two ideas, generated in the focus group, needed to be evaluated, in order to judge how usable they could be in accordance with an experiment and real life applicability. A way could be to embed the solution in a web browser as some sort of a dictionary. When the deaf reader would encounter a difficult word he or she could highlight the word and then have an instant synonym or antonym to the word in a pop-up window. The same solution could be used with the sign language solution, except that the pop-up window now should contain the word in sign language.

The two solutions were judged in accordance with the theoretical foundation of this project. And on the basis of that the synonym/antonym solution was not chosen to be developed further. This was due to the fact that the synonym/antonym solution was based on text and thereby oral language, which experiment I showed to be a big obstruction for deaf people online. Therefore, the solution containing sign language was chosen to be developed further.

To construct the sign language solution, a test website was to be developed together with video-recordings of different words translated into sign language. The test website was developed in HTML and inspired by local

government websites. A sign language interpreter, from Center for Deafblindness and Hearing Loss, assisted in identifying which words should be translated into sign language and subsequently translated the written words into sign language while being filmed. These video-recordings were converted to GIF files and added to the test website, see Fig. 3.

7 Experiment II

To test whether or not this solution could help deaf people on the Internet, two research hypotheses were put forward. Hypothesis 1: "Deaf people will find it easier to use a website, which translates difficult words into sign language compared to a regular website with no translation". Hypothesis 2: "Deaf people will use less time on completing tasks on a website, which translate difficult words into sign language, compared to a regular website with no translation".

7.1 Methodology

7.1.1 Subjects

Six men and five women suffering from deafness participated (all participants being regular guest or attendants at Center for Døvblindhed og Høretab in Aalborg, Denmark). The mean age was 44 years (SD = 15.37).

7.1.2 Materials

In order to test whether the sign language solution would work, two websites were produced: The website containing the sign language solution and the same website without the sign language solution.

7.1.3 Design and procedure

This experiment was planned as a between-subjects experiment. Six test subjects carried out the experiment on

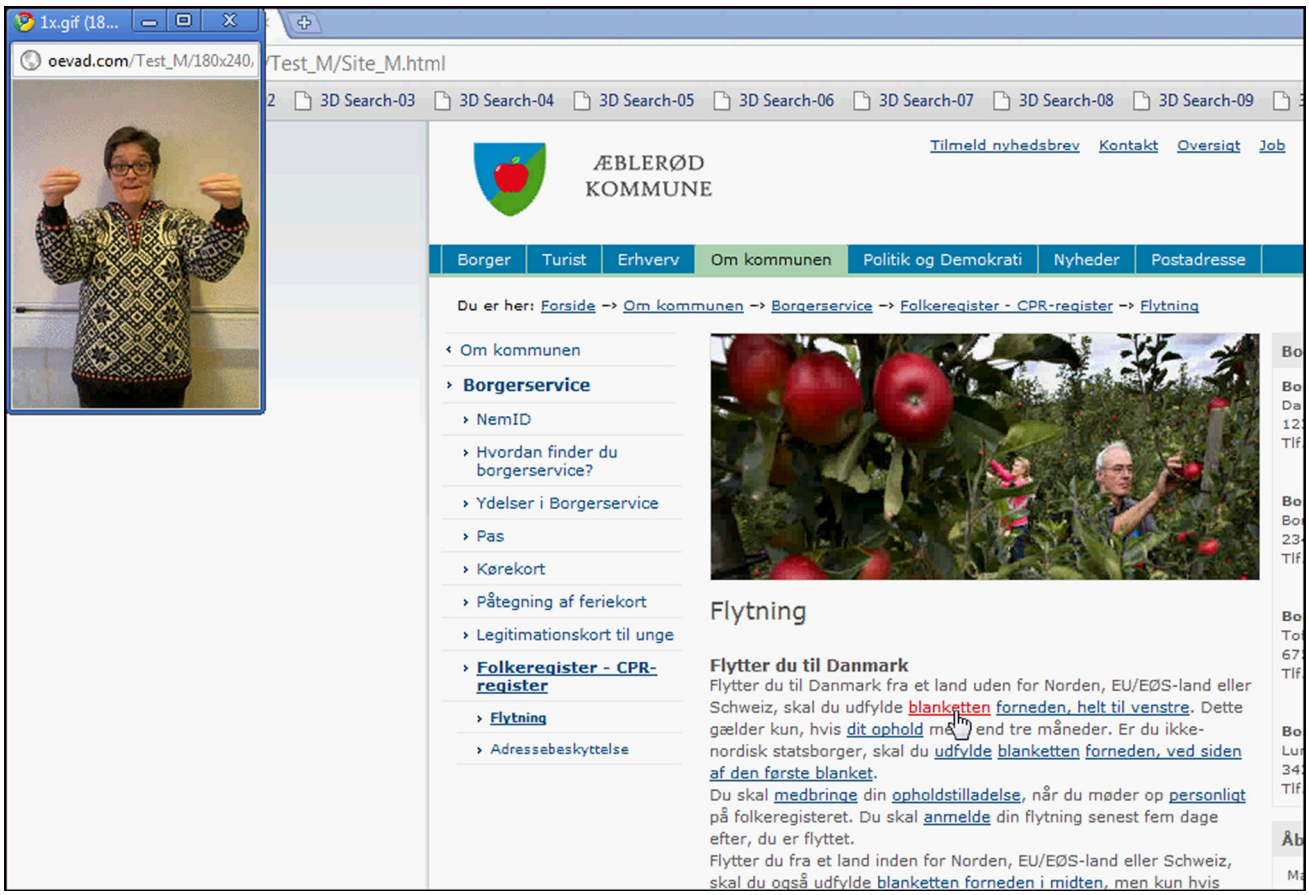

Fig. 3 Screenshot of the sign language solution, where the hyperlinks activated the animations/translations of the difficult words

the website with the sign language solution. Five test subjects carried out the experiment on the website without the sign language solution.

Only one test subject was tested at a time. The test subject sat in front of a laptop. The test subject was first given an introduction to the experiment, translated into sign language. A sign language interpreter screened the test subjects in order to have an equal amount of poor and better readers in both test groups. Both test groups were to find a specific form (out of five possibilities) on the website they were given. The test subjects were to identify the correct form based on the words they read on the pages, translated or not. The task was complete when the test subjects found the right form or after 5 min. After completing the experiment, the test subjects were to answer different questions relating to the test, e.g., "How easy was it to find information on the website?" The test subjects were to answer on a six point, forced choice likert scale. Furthermore, the test subjects were to answer some open qualitative questions in relation the experiment. Data concerning time were obtained via an eye tracker.

7.2 Results

Question number one asked the test subjects how easy they felt it was to find information on the website. As seen in Fig. 4, the test subjects who were given the website without the sign language solution have given answers distributed toward the answers: one, two and three corresponding to: "very hard," "hard" and "slightly hard". The test subjects, who were given the website with the sign language solution gave answers distributed toward four and five, corresponding to: "little easy" and "easy", see Fig. 4.

This distribution indicates that if the deaf test subjects were given the website with the sign language solution, they found it easy to find information. The deaf test subjects, who were given the website without the sign language solution found it difficult to find information.

Question number two asked the test subjects whether they felt they had an overview over the website, they were given. As seen in Fig. 4, the test subjects who were given the website without the sign language solution distributed their answers in two categories: one "very poor" and two "poor", see Fig. 4. The test subjects who were given the website with the sign language solution distributed their answers from one "very poor" to five "good", see Fig. 4.

This indicates that the deaf test subjects, when given the website with the sign language solution, had a feeling of having a slightly better overview of the website.

In accordance with the completion time for the task, there was a clear difference between the two groups. The group, which received the website without the sign language solution, used much more time on completing the task than the group, which received the website with the sign language solution. In Fig. 5, the difference between the two groups are illustrated with box plots. The mean time of the group which received the sign language solution was 92.83 s. The mean time of the group, which received the website without the sign language solution, was 159.40 s. These two completion time means seem significantly different. In order to test whether this was correct, a t test was initiated. The p value from the t test was 0.0021 and shows that the deaf test subjects were significantly quicker to understand and complete the task, if the difficult words were translated into sign language, as illustrated in Fig. 5.

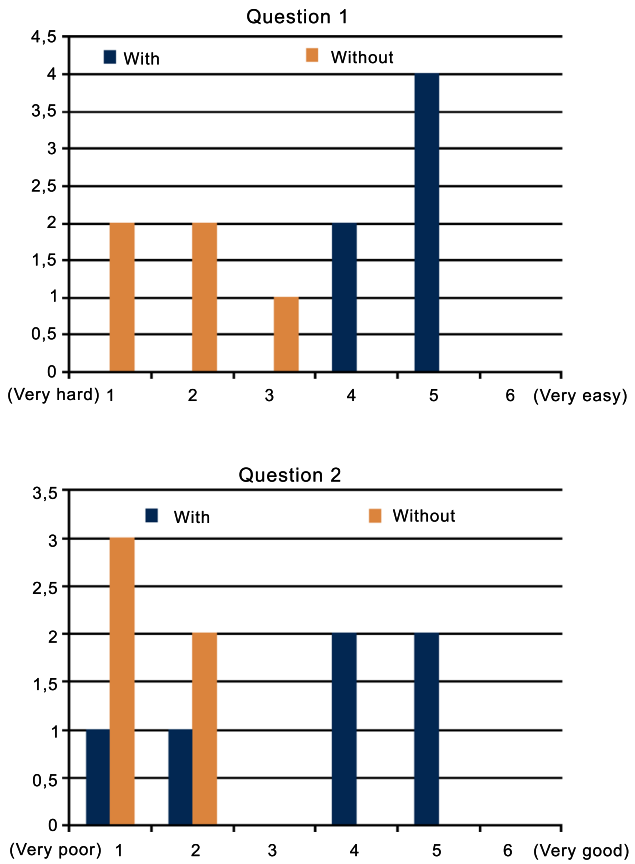

Fig. 4 Answers to question 1 on the *top* and the answers to question 2 is in the *bottom*

7.3 Discussion

Hypothesis 1 is verified since the deaf test subjects, who received the test website with the sign language solution, felt they found it easier to find information, compared to the test subjects who had received the test website without the sign language solution. Hypothesis 2 is verified since it was clear the deaf test subjects, who received the test website with the sign language solution, completed the tasks on the website quicker, compared to the test subjects

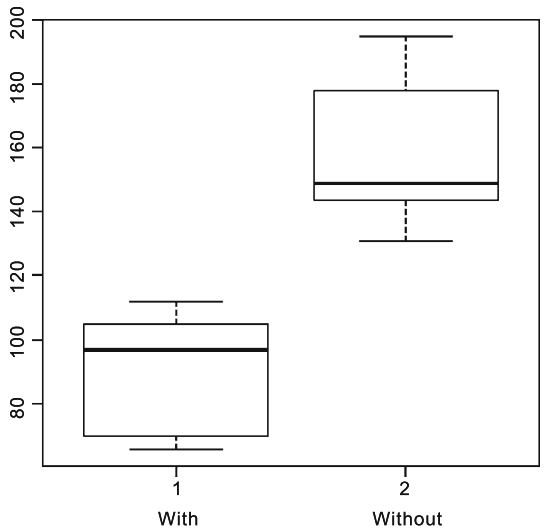

Fig. 5 *Box plots* illustrating the difference in task completion time between the group, which received the website with the sign language solution, and the group which received the website without the solution

who had received the test website without the sign language solution.

The prototype tested in experiment II simulated a sign language dictionary embedded in a web browser. All of the deaf test subjects, who tried the prototype expressed that such a solution would be a great asset to them on the Internet. The experiment also revealed that the deaf people in this experiment completed tasks quicker and gave them a better information-overview, when using the developed sign language solution.

The prototype worked well. But why the results turned out the way they did was unclear. The effect of the prototype needed a more in-depth theoretical explanation and empirical foundation. Metacognitive comprehension strategies, in accordance with deaf people, needed to be investigated in order give these results a theoretical explanation. This should lead to an experiment, which should provide this empirical foundation.

8 Metacognitive comprehension strategies

Experienced readers make use of metacognitive comprehension strategies when reading. Andrews and Mason conducted an experiment to identify which strategies both hearing and deaf test subjects used while reading a text. The test subjects received one sentence at the time and had to fill in a blank spot with the correct word. The test subjects had to self-report what they did to identify the correct word to be written.

From this, Andrews and Mason (1991) identified that both deaf and hearing readers make use of six different strategies:

- Background knowledge
- Rereading
- Looking backward in the text
- Looking ahead in the text
- Identifying contextual cues in the sentence
- Identifying cues from the title

Furthermore, Andrews and Mason (1991) identified that deaf readers in average used 3.8 different strategies, whereas the hearing readers used 4.7 different strategies. Both groups mostly used *background knowledge* followed by *rereading* the sentence and *looking back in the text*. The hearing readers used *identifying (contextual) cues* both in sentence and also from the title. *Looking ahead* in the text was rarely used in any of the two groups. An increase in the use of strategies in relation to the reading level was also identified: the better reader, the more strategies were used (Andrews and Mason 1991).

Delgado and González (2005) made a series of experiments to investigate deaf people's accessibility to the Internet. Reading comprehension abilities in deaf people in accordance with hearing people were investigated. In one of the experiments, both deaf and hearing test subjects were to navigate in an online newspaper, which had a hierarchical structure in three levels. In the analyses of the experiment, Delgado and González identified that the deaf test subjects to a high degree used one strategy more than the hearing test subjects. Namely:

- *Search and match* (Delgado and González 2005)

Delgado and González identified that the deaf test subjects, more than the hearing test subjects, had a behavior in which they scanned for the central and important words or contents of a website.

Furthermore, pictures are an essential and indispensable part of most websites. From the book "Eyetracking Web Usability" written by Nielsen and Pernice (2010), it was derived that:

- *Pictures* are used to gain comprehension

Especially, if the pictures have high contrast, colorful and highly related to the content of the website a picture helps comprehension (Nielsen and Pernice 2010).

Together this makes eight strategies, which deaf and hearing people might use when reading on websites.

All theory mentioned up until this point has given the theoretical explanation as to why the sign language solution tested in experiment II worked as well as it did. These eight metacognitive comprehension strategies were chosen to be the theoretical outset of a third experiment, which should provide the mentioned empirical evidence explaining why the prototype worked.

9 Experiment III

An experiment was planned to investigate as to which degree the eight mentioned strategies would be used by deaf people when reading on websites. This rationale and the theory led to the research hypotheses. Hypothesis 1: "There is a difference in the use of metacognitive strategies between deaf people and hearing people when reading web content on the Internet". This hypothesis was made to estimate whether there was a difference in strategy usage between hearing and deaf people. Hypothesis 2: "Hearing people use more metacognitive strategies than deaf people when reading web content on the Internet". This hypothesis was made to test whether Andrews and Mason was right when they pointed out that hearing readers in average use one more strategy than deaf readers. Hypothesis 3: "Deaf people use the strategy *search and match* more than hearing people when they read web content on the Internet". This hypothesis was made to test whether Delgado and González was right in their assumption, that deaf readers primarily uses the strategy of *search and match* when reading on the Internet.

9.1 Methodology

9.1.1 Subjects

Eight deaf male test subjects with a mean age of 36.5 year (SD = 7.69) from Center for Døvblindhed og Høretab in Aalborg, Denmark. All test subjects suffered from prelingual deafness and had a hearing loss above 80 dB. All test subjects had sign language as their first language and written Danish as second language.

Control group: Eight hearing male test subject with a mean age of 30.9 year (SD = 12.62) participated in the experiment. All test subjects had Danish as their first language.

All test subjects were screened via FVU-tests ("Forberedende Voksen Undervisning" or "Preparatory Adult Education" in English): a Danish test to derive a person's reading level (uvm.dk 2015). Six of the eight deaf test subjects had a poor reading level and the two remaining subjects had an insufficient reading level. All the hearing test subjects had a good reading level.

9.1.2 Materials

In order to test the strategy usage, three fictitious websites were constructed in three rising difficulty levels:

- Easy: A public postal information website. The text on the website was taken from exam papers intended for, but not yet used for, deaf students. The LIX number was 43. See Fig. 6.
- Medium: A news website, with a story about space exploration. The LIX number was 38. See Fig. 7.
- Hard: An official local government website with information about civil marriage. The LIX number was 44. See Fig. 8.

The difficulty levels of each of the three websites were based on subjective estimations on the sophistication and quantity of the content and technical words in the text of the websites. At the bottom of each of the three websites, the test subjects were asked one informational question about the content of the website they have just interacted with. This was done to ensure that the test subjects would actually read the text on the website. The websites were constructed to look like and have similar content, as found on typical and ordinary websites. The rationale being that a realistic setting would ensure a realistic and valid result. And by constructing the websites none of the test participants knew the websites beforehand.

9.1.3 Design and procedure

The experiment was planned as a between-subjects design experiment, in which both the test group and the control group were to interact with the same three websites in the same order: from easy reading difficulty to medium to hard reading difficulty.

Both test groups were given an instruction to the experiment and were told that they would be tested for reading strategies and that they should interact with the websites as they normally would.

The test subjects would finish their task on the website, when they had answered the question in the bottom of the page. Before the test subjects would go on to the text website, they would be asked whether there were any words in the text which they did not understand, and what they did to understand these words. This was done to see whether the strategies of *background knowledge* and *identifying contextual cues* in the sentence had been used by the test subjects. These two strategies were obtained in this way because they could not be extracted via the eye tracker. The strategies of *rereading, looking backward in text, looking ahead in the text, identifying cues from the title, search and match* and *pictures* were obtained via an eye tracker.

9.2 Results

The data from the eye tracker had to be classified before it could be analyzed in depth. The results from the experiment were obtained by watching, analyzing and counting the data. The final data from the experiment were the number of strategies used by both groups of test subjects.

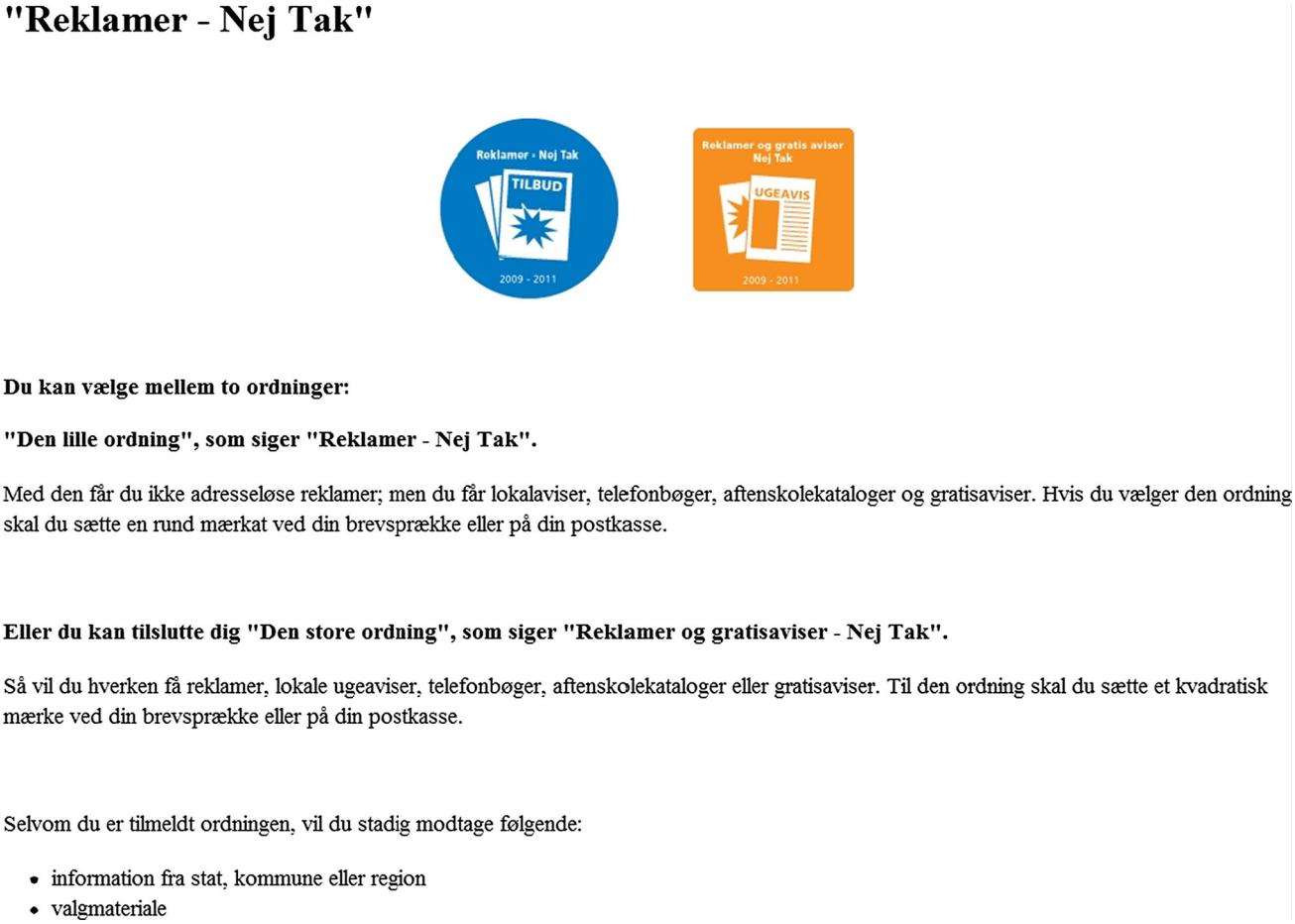

Fig. 6 Website with the easy reading level

9.2.1 Classification of the strategies

The reading strategies were classified in accordance with these specifications.

- *Rereading*: The strategy of *rereading* was counted, if the test subject had started reading a sentence and then started to reread the sentence, before having finished the sentence.
- *Looking Backward*: The strategy of *looking backward* was counted, if the test subject had read a complete sentence, but then jumped back to the start of the sentence.
- *Looking Ahead*: The strategy of *looking ahead* was counted, if the test subject jumped forward in the text to look for certain words. But this strategy would only be counted, if the jump forward in the text was within the vicinity of the sentence they started on, and if they jumped back to the vicinity of their starting-point.
- *Identifying cues in title*: The strategy of *identifying cues* was counted, if the test subject looked at the title on the website.
- *Identifying contextual cues in the sentence*: The test subjects were asked to the usage of this strategy by the experimenter. This strategy would be impossible to test directly with the eye tracker, since it would easily be mixed up with some of the other strategies.
- *Background knowledge*: To identify this strategy, the subjects were asked if they knew anything about the topic in advance.
- *Search and match*: The strategy of *search and match* was counted if the test subject looked across the whole or parts of the website in a search for certain words, headlines or pictures. This strategy was also counted, if the test subjects look around the whole website not looking for anything particular, but just to gain an overview.
- *Picture*: The strategy of *picture* was counted, if the test subject looked at the picture(s) on the website for a given period of seconds, in more than just a glimpse from a search. The idea being that the test subject obtained information about the content of the text from the information in, and context of, the picture.

Fig. 7 Website with the medium reading level

9.3 Analysis of the data

The strategies used by both groups on each website were counted and analyzed. The figures in this section represent the average usage of the strategies in the two groups in accordance with the three websites. It is the number of used strategies counted and summarized in accordance with each group and each of the three websites. None of the test subjects in any of the two groups reported that they had used background knowledge or contextual cues to understand the meaning of a word in any of the three websites.

9.3.1 Website with easy reading level

As shown in Fig. 9, the deaf test subjects mainly made use of two strategies: *identifying cues in the title* (38 %) followed closely by *search and match* (31 %). The hearing test subjects preferred the use of the strategy *looking backward in text* with a 36 % usage.

Both groups used the same number of strategies, just to a different frequency of usage. Both the hearing and the deaf test subjects used in average 4.9 strategies.

It can be seen that the deaf test subjects used the strategy of *search and match* more than the hearing test subjects. A two sample Wilcoxon test revealed that the difference was not significant (p value = 0.4586).

On the question in the bottom of the webpage, none out of the eight deaf test subjects answered correctly, while seven out of eight hearing test subjects answered correctly on the same question.

Test of the hypotheses.

Hypothesis 1 is verified, since there is a clear difference in the usage of the strategies between the two groups. Hypothesis 2 is falsified, since both groups used the same number of strategies. Hypothesis 3 cannot be either verified

Fig. 8 Website with the hard reading level

or falsified, since the difference in usage of *search and match* is not significant.

9.3.2 *Website with medium reading level*

As shown in Fig. 10, the deaf test subjects mainly made use of two strategies: *identifying cues in the title* (37 %) followed closely by *search and match* (33 %). Hearing test subjects preferred the use of the strategy *looking backward in text* (38 %).

Both groups used the same number of strategies, just to a different frequency of usage. Both groups used in average 5.1 strategies.

With a two sample Wilcoxon, it was calculated that the deaf test subjects used the strategy of *search and match* significantly more than the hearing test subjects (p value = 0.008168).

On the question in the bottom of the webpage, five out eight deaf test subjects answered correctly. The same number of hearing test subjects answered correctly on the same question.

Test of the hypotheses.

Hypothesis 1 is verified, since there is a clear difference in the usage of the strategies between the two groups. Hypothesis 2 is falsified, since both groups used the same number of strategies. Hypothesis 3 is verified, since the deaf test subjects use *search and match* significantly more than the hearing test subjects.

9.3.3 *Website with hard reading level*

As shown in Fig. 11, the deaf test subjects mainly made use of two strategies: *search and match* (37 %) followed closely by *identifying cues in the title* (30 %). Hearing test subjects preferred the use of the strategy *looking backward in text*, comprising 50 % of all the strategies used.

Both groups used the same number of strategies, just to a different frequency of usage. The hearing test subjects

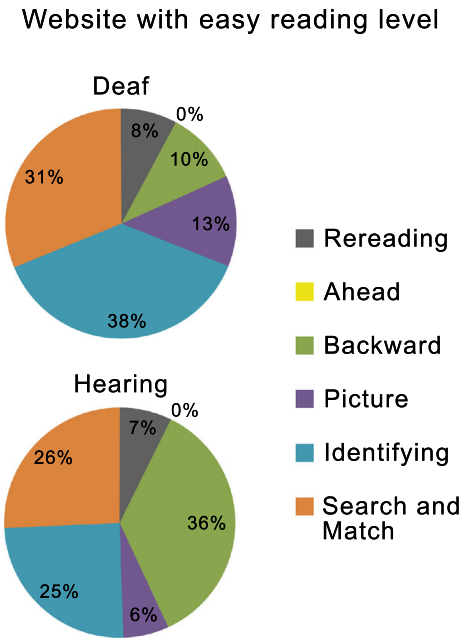

Fig. 9 Distribution of the strategy usage of each group on the website with easy reading level

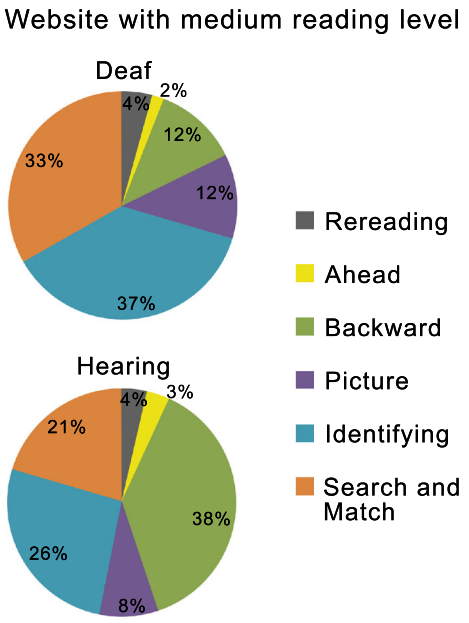

Fig. 10 Distribution of the strategy usage of each group on the website with medium reading level

used in average 5.1 strategies, while the deaf test subjects used in average 5.3 strategies. The difference between the two was insignificant (p value = 0.91), which means that there was no difference in the number of strategies used by both groups.

It can be seen that the deaf test subjects used the strategy of *search and match* significantly more than the hearing test subjects (p value = 0.02697).

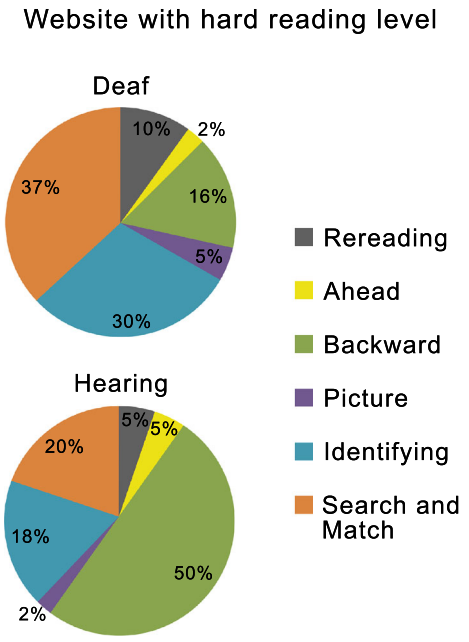

Fig. 11 Distribution of the strategy usage of each group on the website with hard reading level

On the question in the bottom of the webpage, one out eight deaf test subjects answered correctly, while seven out of eight hearing test subjects answered correctly on the same question.

Test of the hypotheses.

Hypothesis 1 is verified, since there is a clear difference in the usage of the strategies between the two groups. Hypothesis 2 is falsified, since both groups used the same number of strategies. Hypothesis 3 is verified, since the deaf test subjects use *search and match* significantly more than the hearing test subjects.

9.4 Discussion

The results of the experiment revealed that there is a difference in the use of metacognitive comprehension strategies, between the group of deaf test subjects and the group of hearing test subjects. Both groups used the same number of strategies, but the frequency of their usage was different. The hearing test subjects preferred the *strategy looking backwards in the text*. The deaf test subjects had two preferred strategies: *Identifying cues in title* and *search and match*. On the websites with the easy and the medium reading level, *identifying cues* was preferred slightly over *search and match*. Both strategies were much more preferred than the remaining six strategies. As the reading level was raised in difficulty, the more deaf test subjects used *search and match*.

The strategy of *search and match* was frequently used by deaf people, especially compared to hearing people. The

prototype had the difficult and central words of a difficult text highlighted, which signaled to the deaf person that the word could be translated into sign language. Thereby, the design of the prototype fits well with the Internet behavior of deaf people and their strategy usage of *search and match*.

9.5 Implications for design

The prototype developed in this paper simulated a sign language dictionary embedded in an Internet browser. The feedback from the deaf persons who tried it was all positive, and they expressed that such a solution could help them in their daily life. Furthermore, it was expressed that by only translating the difficult words, it helped them understand the overall text better, since it is usually the one or two difficult words that keeps them from understand the overall meaning of text on websites. The sign language solution is a prototype, and thereby it has many limitations. As the design of the system is now, the difficult words have to be manually identified and translated. If this design is to work more universally and in a broader context, it is worth looking into whether the system itself can identify the difficult words and translate them via animation. It is also worth looking into how the idea tested in this paper would work on smartphones and tablets.

10 Conclusion

The goal of this paper was to investigate what web elements deaf people use to gain information from websites, identify what problems they might face and to investigate solutions, which could help them read text on the Internet as well as the average hearing person. It was hypothesized that deaf people would be looking more on pictures and less on text, compared to people with normal hearing. A between-subjects experiment, with a group of deaf and a group of hearing test subject, was made on three websites, with various levels of text and pictures. An eye tracker showed that the deaf test subjects looked more on text and less on pictures, compared to the hearing test subjects. Furthermore, deaf people used significantly more time completing tasks on the text heavy website, compared to the hearing test subjects. From these results, text was identified as the main problem for deaf people on websites. The rationale being that written text is based on oral language, which again is based on sounds, which deaf people cannot hear. A focus group meeting generated the idea of a sign language dictionary embedded in a browser, which could translate a difficult word in text into sign language. This idea was made into a prototype. A second between-subjects design experiment was planned, with two groups of deaf test subjects, which had to perform the same task on a fictitious local government website. One group received the website with the sign language solution, while the other group received the same website without the sign language solution. The result of the experiment was that the group, which had received the sign language solution, significantly outperformed the other group in task completion time. The sign language solution worked well and as intended, but it was not yet known why. A further theoretical investigation into metacognitive comprehension strategies lead to eight strategies being identified as essential for reading and navigating on websites. A third between-subjects experiment was made, with one group of deaf test subjects and another group of hearing test subjects. Both test groups were to read the content of three fictitious websites, with a rising difficulty level. The results of the experiment, obtained via an eye tracker, showed that the deaf test subjects had two preferred strategies: *identifying cues from the title* and *search and match*. The easier the reading level of the website the more the strategy of *identifying cues from the title* was used. The harder the reading level of the website became the more the strategy of *search and match* was used by the deaf test subjects. The essence of the *search and match* strategy is to scan a website for the most important and central words or content. In the developed prototype, the central and most important words are highlighted, in order to signal to the deaf reader that these words can be translated into sign language. The observed Internet behavior of deaf people fits with the design of the prototype.

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