Differences in Web-Interaction Styles of Hard-of-Hearing and Hearing Persons

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Abstract

Our aim is to design web-based interactive materials for the hard-of-hearing based on an adequate understanding of their interaction style. Recently, computer-based support for the hard-of-hearing has expanded with the development of a web-based interaction environment. The web is a promising medium for designing materials for the hard-of-hearing, because it allows information providers to control the presentation of its content. Currently, however, the issue of how the hard-of-hearing interact with the web is inadequately studied. We believe computer-based support for the hard-of-hearing will improve with a better understanding of their interaction with computer-based materials. Our experience in using traditional class materials suggests that the way the hard-of-hearing interact with web-based materials may differ from methods employed by hearing persons. Our study began with detailed observations of how the hard-of-hearing use the web by tracking eye movement and hyperlink selections, and comparing the results with those of hearing persons. Eight hard-of-hearing and ten hearing subjects participated in the experiments. Their ages ranged from 19 to 22 years. All subjects were regular Internet users. Our first paper (Namatame at al., 2004) discussed our eye-tracking experiment to demonstrate behavioral differences between hard-of-hearing and hearing persons when using web-based materials, with the preliminary conclusion that the hard-of-hearing exhibited a less strategic scan pattern, and shallower and more intuitive text-processing. These findings suggested that the design of web-based materials, which currently considers only textual or image substitutes for auditory information, is insufficient for the hard-of-hearing. This paper describes a follow-up study along with the initial study (Namatame et al., 2004), reinforcing the above conclusion. We further discuss implications of the results to design guidelines.

1 Introduction

Traditionally, the primary focus of computer-based support for the hard-of-hearing relied on computer-generated images of sign language and real-time text annotation. These are the primary means for the hard-of-hearing to access auditory information. Examples of such studies include Jensema et al. (2000a, 2000b) who investigated the use of TV captions for the hard-of-hearing. However, we believe that this approach has limited utility considering that only a small portion of the hard-of-hearing, 10 to 20%, can use mother-tongue sign language, and the understanding level of textual information of the hard-of-hearing is inferior to that of a hearing person's. We have supporting evidence for this claim from our experience in using traditional class materials.

Recently, computer-based support for the hard-of-hearing has expanded with the development of a web-based interaction environment. For example, Barman et al. (2002) initiated a web-based science program for deaf students called the "SOAR-HIGH Project." The web is a more promising medium for designing educational materials for the hard-of-hearing than traditional, less interactive educational media since it allows us to control content presentation. However, our experience in using traditional class materials suggests that the hard-of-hearing would interact differently with web-based materials than hearing persons. Currently, the issue of how the hard-of-hearing interact with the web is inadequately studied. We believe computer-based support for the hard-of-hearing will improve when we better understand their interaction with computer-based educational materials. Our study began with detailed observations of how the hard-of-hearing use the web by tracking eye movement and hyperlink selections and comparing the results with those of hearing persons.

2 Eye-Tracking Experiment

This section describes the initial eye-tracking experiment (Namatame at al., 2004) and the follow-up experiment.

We plan to develop web-based materials that will incorporate similar tasks currently performed on the web, including on-line shopping, browsing, information searching, and manipulating objects. Web-based tasks are performed interactively, requiring comprehension of information provided on the computer screen as it relates to the task goal, and the selection of an appropriate action, typically clicking on a link to another page. We suggest that the hard-of-hearing would perform these processes differently from hearing persons. In this section, we describe a preparatory study aimed at understanding web-interaction processes of the hard-of-hearing by observing their eye movement while performing web-based tasks.

2.1 Subjects

Eight hard-of-hearing and ten hearing participated in the experiments. Five of the eight hard-of-hearing participated in the new follow-up experiment. Their ages ranged from 19 to 22 years old. All subjects were regular Internet users.

2.2 Procedure

Each subject was asked to accomplish a task that included an information search and object manipulation on an experimental web site. Instructions for the task were given to the hard-of-hearing subjects using sign language and an announcement page, and to the hearing subjects using voice and an announcement page. The tasks were performed on a PC by clicking links on the pages.

2.3 Equipment and Stimuli

Subjects' eye movements were measured using a head-mounted eye tracking system, EMR-HM8 of NAC Inc. The task images were projected on a flat screen 150cm in front of the subject. The projection window size was 90cm wide by 75cm high with the viewing angle of 33 degree horizontal by 27.5 degree vertical. The data sampling rate was 60 Hz.

2.4 Task

The task was to locate a page that described car model Z4, and to choose a favorite color for it. The subjects were given the following instruction: "Please choose your favorite color for the car model Z4." The task was performed on an experimental web site modified from an actual automobile web site. Figure 1 illustrates the top page that consisted of five columns, four content columns and one news column, and a field at the bottom of the page. Content columns had a heading at the top, a picture with promotional text in the middle, and a list of topics at the bottom. An important feature of this specific page was that the contents were organized vertically. Successful task performance required correct understanding of the page layout since the column boundaries were not clearly defined. To reach the color determination page, the subjects should follow one of the following three routes. When the subject selected a wrong link, however, an error page was returned and they were forced to press the "Back" button of the browser (or the back button on the page) to begin again.

Route 1 consisted of selecting either Link 1, which is the heading of the second column labeled Products or selecting Link 2 in the topic list labeled by Index under the Products heading, both of which lead to the correct intermediate page, Products Index. This route is considered an indirect route because it requires comprehension of the meaning of the label to select on the top page. To select one of these links, the subject must infer that the term Products or Index under the Products heading implies car model, which is part of the task description. The subject should then select the BMW Z4 on the Products Index page to open the Z4 Information page where the color combination is to be selected to accomplish the subtask. These two selections, selecting BMW Z4 and color combination, are trivial because both are part of the task description.

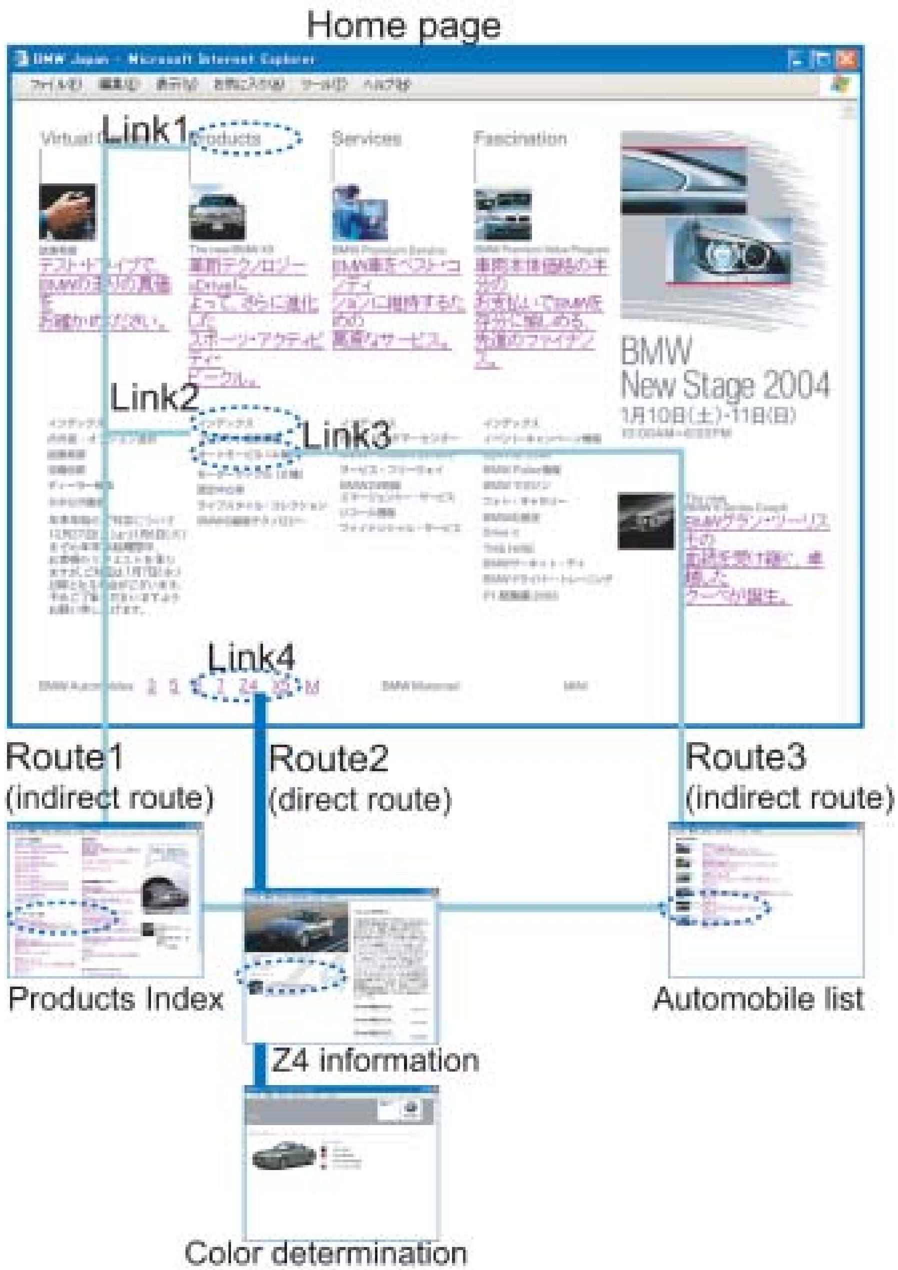

Figure 1: Experimental task and routes to the Color Determination page

Route 2 consists of selecting Link 4 in the model-name field labeled by Z4, which leads to the Z4 Information page. This route is considered a direct route because there is no inference required of the subjects to select the link.

Route 3 is an indirect route, consisting of selection of Link 3 labeled by Automobile in the topic list under the Products heading, followed by selection of the BMW Z4 link on the Automobile List page. This follows the Z4 Information page.

Two of the three routes (Route 1 and 3) required deep understanding of the labels when selecting them because the labels were only semantically similar to the designated goal description, whereas the last one (Route 2) required only a literal pattern matching since it is labeled by “Z4.”

3 Results and Discussion

The results from the initial experiment and the new follow-up experiment were consistent, reconfirming the following previous finding.

There are two aspects in which the performance of the hard-of-hearing significantly differed from that of the hearing subjects.

- *First, the level of textual information used by the hard-of-hearing was shallower than that used by the hearing subjects.*
- *Second, scan paths of the hard-of-hearing were not as strategic as those of the hearing.*

In this section, we first report the basic results in Section 3.1 and then examine the results from the viewpoints what the subjects selected (Section 3.2) and how the subjects selected the items (Section 3.3) in order to show differences between the performance of the hearing subjects and that of the hard-of-hearing.

3.1 Basic Results

Table 1: Basic performance measures obtained from hearing subjects: Total time necessary to select the correct link, the number of errors, the label on the selected link, and the route number (see Fig. 1).

Subject ID	Total Time	Number of Errors	Selected Item	Route Number
d	0:00:54	0	Z4	2
e	0:01:19	2	Products	1
f	0:01:10	1	Index	1
k	0:02:31	6	Automobile	3
l	0:00:45	1	Z4	2
m	0:01:17	1	Z4	2
o	0:00:20	0	Z4	2
p	0:01:45	4	Z4	2
q	0:04:03	7	Z4	2
r	0:01:52	7	Automobile	3
Average	**0:01:27**	**2.6**		

Table 2: Basic performance measures obtained from hard-of-hearing subjects: Total time necessary to select the correct link, the number of errors, the label on the selected link, and the route number (see Fig. 1)

Subject ID	Total Time	Number of Errors	Selected Item	Route Number
a	0:02:40	16	Z4	2
b	0:01:58	9	Z4	2
c	0:03:01	3	Z4	2
g	0:03:07	1	Z4	2
h	0:03:20	6	Z4	2
i	0:01:53	1	Z4	2
j	0:04:32	2	Z4	2
n	0:00:57	1	Z4	2
Average	**0:02:42**	**4.9**		

Tables 1 and 2 demonstrate basic performance measures observed in the experiments from hearing subjects and hard-of-hearing subjects. The main observations were as follows. The average time necessary to select the correct link was significantly longer for the hard-of-hearing (2 minutes and 42 seconds), compared with that for the hearing

(1minute and 27 seconds). The average number of errors for the hard-of hearing was 4.9, significantly greater than the average of 2.6 errors for the hearing. The hard-of-hearing consistently selected the link "Z4," whereas the hearing subjects selected not only the link on the direct route "Z4" but also the links on the alternative indirect routes "Index," "Products," or "Automobile."

3.2 Differences in What was Selected

In this section, we examine the nature of items the subjects selected in order to provide evidence to support our first claim that the level of textual information used by the hard-of-hearing was shallower than that used by the hearing subjects.

3.2.1 Correct Selections

It is intriguing that, as depicted in Table 2, all the hard-of-hearing subjects consistently selected the link labeled "Z4" on Route Number 2, which matched exactly the description of the task "Please choose your favorite color for the car model Z4." In contrast, the hearing subjects selected a variety of items. Although six of ten hearing subjects selected "Z4" on Route Number 2, two others selected "Products" or "Index" on Route Number 1, and two selected "Automobile List" on Route Number 3. The term "Product" or "Automobile List" (Route 3) has a semantic relationship with the knowledge concerning "Z4" (i.e., "Z4 is one of the automobile products of BMW"), which would make the subjects believe that the link "Products" or "Automobile List" should contribute to advancing the task. The term "Index," however, has no semantic relationship to the description of the current task but functions as the entry point to access the contents it represents, which is "Products" in this case. Thus, the label "Index" should have been considered to represent "Products Index."

In summary, all the subjects who selected "Index," "Products," or "Automobile List" should have recognized the semantic closeness of these terms to the description of the current goal. This assessment played an important role for them to select one of these links. People who do not utilize the semantic-relatedness assessment when selecting a link would select Z4, as the hard-of-hearing subjects of our experiment did.

3.2.2 Correct and Incorrect Selections

The subjects selected many wrong links, including image and text links. We conjectured that the subject selected an image link without the deep consideration necessary to derive the meanings of the image. It is clear from Fig. 1 that the images on the page did not seem to convey any specific meanings, but when a subject selected a text link, he/she usually would have selected it intentionally. We conjectured that the subject selected a text link by applying one of the following three strategies: 1) select a text link that has a matching label, 2) select a semantically related text link, or 3) select a text link randomly. We can infer which strategy the subject might have chosen by examining the nature of the selected links. The subject who selected the text link labeled "Z4" would have selected that link because it literally matched the description of the goal; when the subject selected one of the following links, we judged that he/she selected it because of semantic closeness of the link label to the description of the goal;

- In the first column: the heading labeled "Virtual Center", "Index", "Interior/Exterior Options"
- In the second column: the heading labeled "Products", "Index", "Automobiles"
- In the third column: the heading labeled "Services", "Index", "Lifestyle Collections"
- In the fourth column: the heading labeled "Fascination", "Index", "Photo Galleries"

When the subject selected the other links, we considered that he/she selected them randomly, with little intellectual consideration.

Figure 2 shows the proportions of the types of link selections, categorized in terms of 1) selecting semantically related link (semantic information), 2) selecting matching label "Z4," and 3) selecting the other text links and image links including static pictures and dynamic animations (non-semantic information). A prominent feature is that the hearing subjects selected text links that conveyed semantic information more often than the hard-of-hearing did, 49% versus 21%. Conversely, the hearing-impaired subjects selected non-semantic information (i.e., image links and other links) more often than the hearing subjects did, 62% versus 36%. It is clear from this result that the hearing more frequently used semantic information when selecting a link than the hard-of-hearing did.

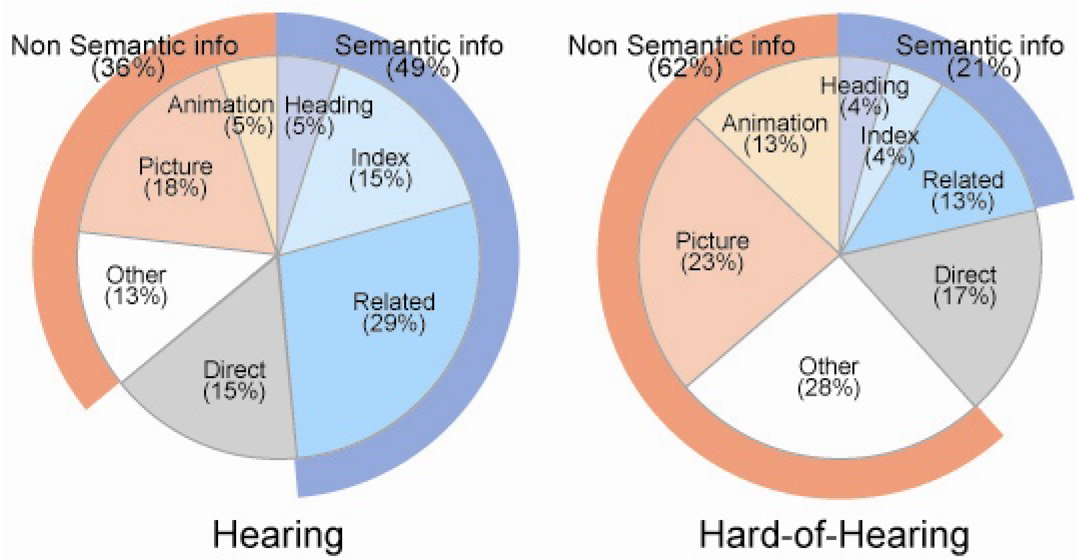

Figure 2: Differences between the types of links that the hearing subjects and the hard-of-hearing selected.

3.3 Differences in How the Item was Selected

In this section, we examine the eye-tracking experiments from the viewpoint of how the subjects scanned the page before selecting the correct link. We first present the results concerning scan paths in order to demonstrate the differences between those of the hearing subjects and those of the hard-of-hearing subjects. Then we examine the time used to select a link, and compare the patterns of the time courses between the hearing subjects and the hard-of-hearing subjects.

3.3.1 Scan Paths

Figure 3 display the results of eye fixations. The circles correspond to the positions on which the subjects' eyes fixated. The circle size is proportional to the duration of fixation.

Figure 3 (A) and (B) compares the scan paths from a hearing subject (left) and a hard-of-hearing subject (right). Both accomplished the task with comparable times (54 seconds for the hearing and 57 seconds for the hard-of-hearing), and both selected the same link, "Z4." Figure 3 (C) and (D) reveals the same comparison for a hearing subject (left) and a hard-of-hearing subject (right) who committed one error, accomplished the task with comparable times (77 seconds and 113 seconds), and eventually selected the same correct link "Z4." The subjects represented in Figure 3 (A) and (B) accomplished the task faster than those represented in Figure 3 (C) and (D).

Figure 3 indicate that the hearing subjects and the hard-of-hearing subjects used apparently different scan paths in search of "Z4"; fixation points from the hearing ((A) (C)) looked vertically aligned, consistent with the page's structure, whereas those from the hard-of-hearing ((B) (D)) did not show a coherent pattern.

3.3.2 Time and Error

Figure 4 plots the time it took for subjects to select a correct link as a function of number of errors. The data points from the hearing subjects are plotted in filled squares, and those from the hard-of-hearing subjects in filled circles. As is clear from the figure, the data from the hearing subjects exhibited a high correlation (R=0.85) between the time and the number of errors, whereas the data from the hard-of-hearing had no correlation (R = –0.02). This result implies that the hearing subjects might take a certain amount of fixed time before selecting an item, whereas the hard-of-hearing subjects might not use such a strategic search method when carrying out a web-based task. This finding is consistent with the results that demonstrate differences in search paths, depicted in Figure 3.

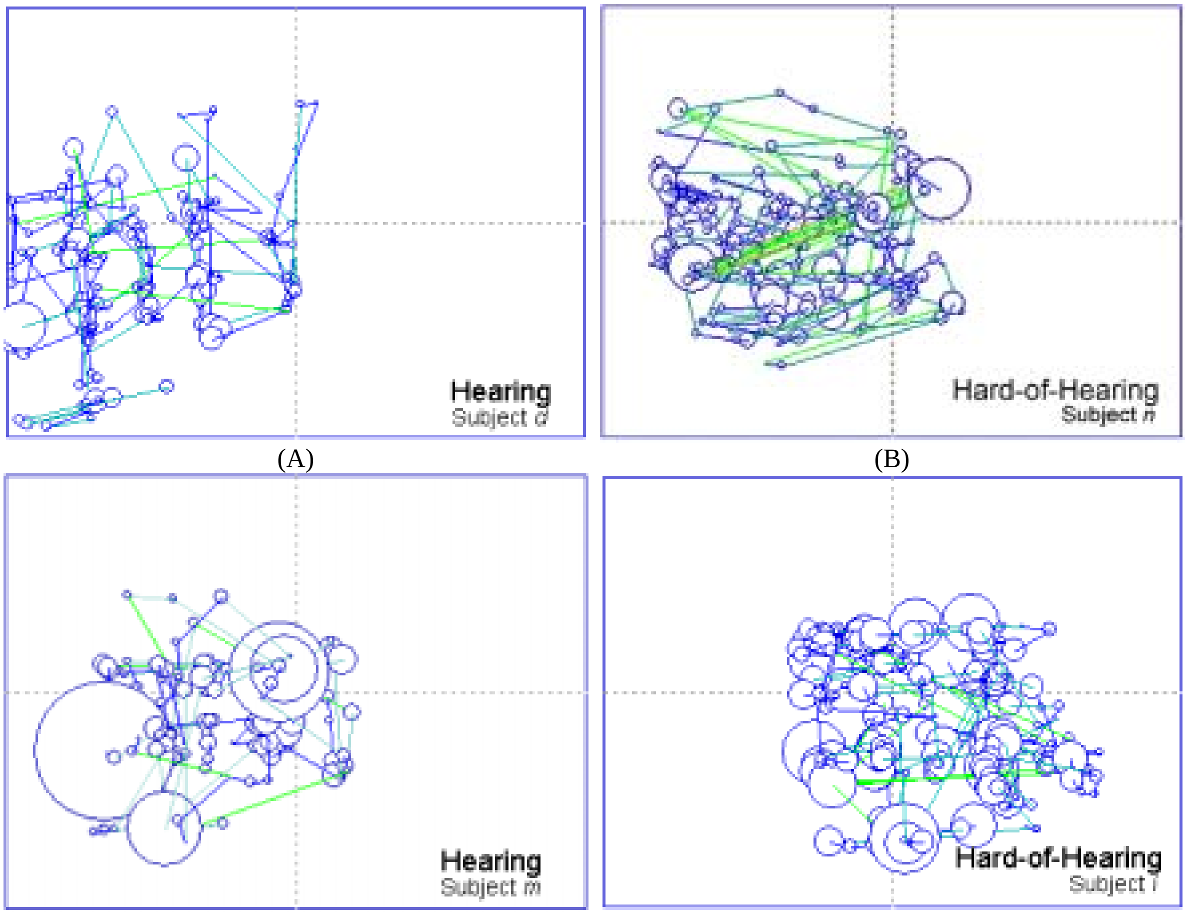

Figure 3: Fixation points of the subjects who selected “Z4”

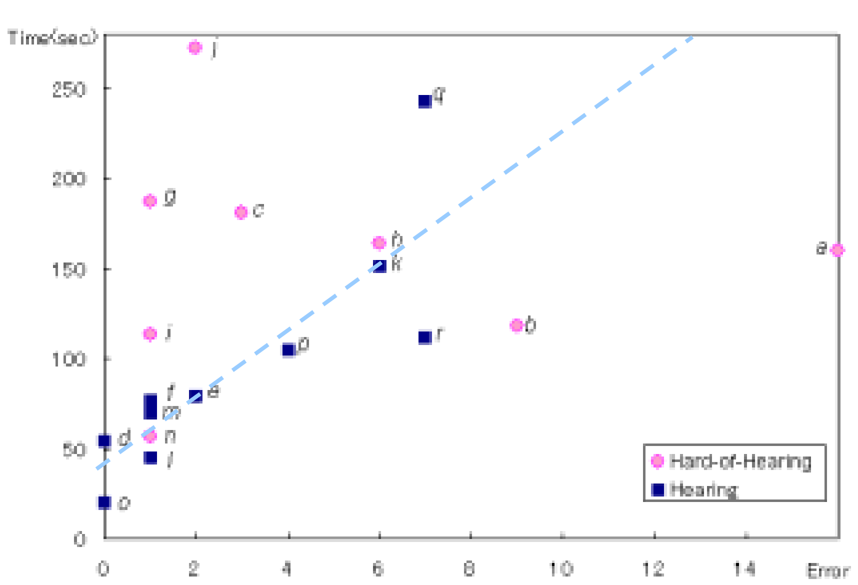

Figure 4: Relationship between the time to select a correct link and the number of errors

4 Discussion: How Guidelines Deal with Hard-of-Hearing Users

Our experiments clearly demonstrated that the interaction style of the hard-of-hearing differs from that of the hearing. This finding has significant implications for the current guidelines for the hard-of-hearing. In this section, we examine whether the current guidelines for the hard-of-hearing are sufficient in light of the results of our experiments.

- Principle 1: Content must be perceivable.
  - Guideline 1.1 Provide text alternatives for all non-text content.
    - Who Benefits from Guideline 1.1 (Informative)
      - People who are deaf, are hard of hearing, or who are having trouble understanding audio information for any reason can read the text presentation or have it translated and presented as sign language by assistive technology.
  - Guideline 1.2 Provide synchronized alternatives for multimedia.
    - Who Benefits from Guideline 1.2 (Informative)
      - People who are deaf or have a hearing loss can access the auditory information through captions.
  - Guideline 1.3 Ensure that information, functionality, and structure are separable from presentation.
  - Guideline 1.4 Make it easy to distinguish foreground information from background images or sounds.
    - Who Benefits from Guideline 1.4 (Informative)
      - Individuals with hearing impairments that limit their ability to hear all of the frequencies of speech can make out the words from the sounds they can hear because they are not mixed with residual sounds from the music.
- Principle 2: Interface elements in the content must be operable.
  - Guideline 2.1 Make all functionality operable via a keyboard or a keyboard interface.
  - Guideline 2.2 Allow users to control time limits on their reading or interaction.
  - Guideline 2.3 Allow users to avoid content that could cause photosensitive epileptic seizures.
  - Guideline 2.4 Provide mechanisms to help users find content, orient themselves within it, and navigate through it.
  - Guideline 2.5 Help users avoid mistakes and make it easy to correct them. [level 2 guideline]
- Principle 3: Content and controls must be understandable.
  - Guideline 3.1 Ensure that the meaning of content can be determined.
  - Guideline 3.2 Organize content consistently from “page to page” and make interactive components behave in predictable ways.
    - Who Benefits from Guideline 3.2 (Informative)
      - Using captions to note changes in speaker is beneficial for individuals who are deaf or hard of hearing and who may be unable to discern changes in speaker for audio-only presentations.
    - Editorial Note from Who Benefits from Guideline 3.2 (Informative)
      - We are looking for a word to replace “page” that applies across technologies. For visual applications, “screen” would apply, but would not apply for speech-based technologies such as VoiceXML.
- Principle 4: Content must be robust enough to work with current and future technologies.
  - Guideline 4.1 Use technologies according to specification.
  - Guideline 4.2 Ensure that user interfaces are accessible or provide an accessible alternative(s).

Figure 5: Excerpt from W3C Working Draft 19 November 2004 (WCAG20-20041119) relevant to designing websites for hard-of-hearing.

4.1 W3C's WAI Recommendations

W3C has established guidelines for the standard WEB technology to be used in building websites. Designers of web-based materials should refer to web design guidelines from W3C's WAI and the US Government Section 508. The guidelines are described under principles, accompanied with explanation on who benefits from it. Figure 5 shows the excerpt from W3C Working Draft 19 November 2004 (WCAG20-20041119) that are relevant to designing websites for hard-of-hearing.

4.2 Design Guideline Implications for the Hard-of-Hearing

Principle 1 suggests that providing alternatives to audio information is the key to web accessibility for the hard-of-hearing. The US Government Section 508 suggests that the web should attach synchronized captions for hard-of-hearing people as audio, video, and multimedia material. The primary focus of web materials and computer-based support for the hard-of-hearing is the provision of computer-generated images of sign language and real-time text annotation. These are the primary means for the hard-of-hearing to access auditory information. Almost all the currently used guidelines involve the substitution of audio information as the only aspect of web-based interaction. These techniques are appropriate for Principle 1. However, our experiments clearly demonstrated that the style of the hard-of-hearing to access text information differs from that of hearing-persons, and not all hard-of-hearing persons use sign language. Thus, the current use of guidelines for the hard-of-hearing may be seriously limited.

From the viewpoint of web material designers, it is technically easy to conform to Principle 1. We simply need to provide substitutes for auditory information. In contrast, Principle 3 indicates that "content and controls must be understandable." This principle is important because web-based tasks are performed interactively, requiring comprehension of information provided on the computer screen. However, the guidelines say only what to do, but not how to do it.

We do not know how to make the content understandable to the hard-of-hearing because we do not have enough knowledge to make it possible. Our experiments did clearly demonstrate that the hard-of-hearing's interaction style differs from that of hearing persons. Therefore, our research is relevant to Principle 3. However, our finding is not sufficient; the results of our experiments indicate that special considerations are necessary to design understandable materials on the web.

Another criterion for designing useful web pages has been suggested by Ivory et al. (2001). Guidelines for operationalizing web design are unclear, so the methodology to derive statistical models from expert-rated empirical data has been developed. However, these criteria would have limited utility when designing web pages for the hard-of-hearing because they have nothing to do with the hard-of-hearing's special needs that necessitate superordinate guidelines.

Specific guidelines that also consider behavioral characteristics for the hard-of-hearing must be warranted. If new guidelines are established, they should have applicability for individuals with behavioral characteristics similar to those of the hard-of-hearing.

5 Conclusion

From the analysis of the eye movement and link selection data, we determined two aspects in which the performance of the hard-of-hearing significantly differed from that of the hearing subjects.

The interaction style of the hard-of-hearing persons differed from that of hearing persons.

- The hard-of-hearing had lower text comprehension than the hearing subjects.
  - The hearing subjects exhibited variety in terms of the items they selected, but all the hard-of-hearing subjects consistently selected the link labeled "Z4."
  - When selecting a link, the hearing more frequently used semantic information than the hard-of-hearing did.
- Scan paths of the hard-of-hearing were not as strategic as those of the hearing subjects.

- The hearing subjects' scan paths appeared vertically aligned, consistent with the page's structure, whereas those of the hard-of-hearing did not show a coherent pattern.
- The subjects' strategic movements while searching for the desired information involved viewing the category titles on a page in order and seeing the characters in category groups sequentially from the top. Many strategic movements were observed in the hearing subjects, but not in the hard-of-hearing subjects.
- The hearing subjects took a certain amount of fixed time before selecting an item, whereas the hard-of-hearing subjects did not have such a strategic search method.

Our results suggest Principle 3 is not sufficient and must be supplemented by at least the following two statements in order to consider hard-of-hearing persons appropriately.

- Label expressions of hyperlinks should be intuitively understandable, based on the following supporting evidence:
  - all the hard-of-hearing subjects consistently selected the link labeled "Z4," and
  - the utilization of the semantic information was low.
- Structure of contents should be visually understandable, based on the following:
  - the scan paths did not have a coherent pattern, and
  - the hard-of-hearing subjects might not have a strategic search method.

We plan to continue this line of experimental research with an increased number of subjects and a wider range of web-based tasks with the following two goals in mind. The first is to design web-based interactive materials that are understandable for the hard-of-hearing. The other is to provide suggestions that would contribute to guidelines that consider the behavioral characteristics of the hard-of-hearing. We believe our future research should also have wide applicability for individuals with behavioral characteristics similar to those of the hard-of-hearing.

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