Cognitive Assistance to Support Maintenance and Assembly Tasks: Results on Technology Acceptance of a Head-Mounted Device

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Abstract. This paper presents a study investigating the user acceptance (i.e. the perceived ease of use, willingness to use the system over time, and perceived usefulness) of a smart head-mounted device that can be used as assistive technology for maintenance and assembly. In particular, we focus on the head-mounted display named HMT-1 from RealWear. The uniqueness of this technology is, among other things, that it offers the possibility to fold away the display with the instructions, allowing more control over the appearance of assistive content than in other head-mounted displays. Overall, 48 participants took part in this interview study. They mentioned some advantages (e.g., that the hands are free and that one can see the instructions while working on something else at the same time) and disadvantages of the technology (such as usability issues). They also suggested that the technology is suitable for non-routine tasks and tasks of medium-to-high complexity. Our findings highlight that a cognitive assistive technology is perceived as positive when direct assistance is available (in the visual field of the worker) with a possibility to control the system.

Keywords: Technology acceptance · Work assistance · HMD · Cognitive assistance · Assembly · Maintenance

1 Introduction

Digital technologies are increasingly used in maintenance and assembly use cases with the aim of cognitively guiding employees. Thus far, various augmented reality solutions, instructions on mobile devices, or projections, such as in situ instructions, have been developed, implemented, and evaluated [1,9,12].

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A more recent example of cognitive assistive technology is the RealWear head-mounted tablet (HMT-1). The HMT version 1 device, depicted in Fig. 1, is a head-mounted device that provides visual information through a screen and auditory information through a headset and is suitable for workers requiring their hands to be free for tasks. It has been developed for industrial use, which is why the 380 g device can be combined with a safety helmet and safety goggles. This weight includes a 3250 mAh battery with an 8-h charge life. Active noise suppression of up to 90 dB is designed to ensure reliable speech recognition even in noisy environments. Furthermore, the HMT-1 is waterproof, shockproof, dustproof, and can be used in temperatures from −20 °C to 50 °C. The colour microdisplay with a resolution of 854 × 480 pixels can be worn over the left or right eye (realwear.com). A unique feature of this technology is that the cognitive support (i.e., the information that is displayed) can be physically retrieved or folded away. Thus, the user has good control over the display technology in his or her field of view, and can fold it away before becoming distracted or annoyed by the displayed information.

Fig. 1. A visualisation of the Head-Mounted Tablet 1 (right) and an illustration of the arm with the information given (left); copyright RealWear (2018)

The aim of this study is to investigate the acceptance of a head-mounted device named HMT-1, which can be used as cognitive assistance for assembly and maintenance. To investigate the technology acceptance it is essential to determine which aspects of the technology are perceived as useful and easy to use and which aspects of this device still require improvement. Within semi-structured interviews we could provide input for developers of head-mounted devices in designing the system but also for industries that aim to use head-mounted displays as assistance for their worker.

In the following sections, we describe the theoretical background of this study by focusing on empirical and theoretical research concerning technology acceptance. Next, we present the methodology of our interview study, including a sample description and the procedure of the study. In the findings section, we present the main findings of the interviews separately for the two core dimensions of technology acceptance: perceived ease of use and perceived usefulness. Lastly, we discuss these findings and review the limitations and ideas for future research. Within the practical limitations and conclusion section, we derive recommendations for the design, development, and implementation of cognitive assistive technologies in the context of assembly and maintenance work.

2 Background

2.1 Head-Mounted Devices for Cognitive Assistance

Industrial workplaces are increasingly digitised. In line with this, new technologies are being introduced to support employees in their work tasks. These technologies can support employees cognitively (e.g., by providing information about products or by supporting complex analyses) or physically (e.g., using robots or exoskeletons that support carrying heavy loads). For cognitive assistance, head-mounted devices have been developed, which are widely used to provide information to employees. This technology originated in 1950 and 1960 when Morton Heilig telesphere mask was patented [11]. A current innovation is the RealWear HMT-1 published in March of 2017, which has previously been introduced.

Previous research on user acceptance of HMDs has revealed differences in acceptance between usage scenarios [13] and differences in technology properties [8]. For instance, [13] analysed augmented reality smart glasses and their role in work assistance in electronics manufacturing in two use cases (order picking in warehouse logistics and assembly machine setup). They conducted a survey investigating the users' expectations in terms of usability, usefulness, and user acceptance. The findings demonstrated that the overall user expectations were more positive in the second use case than in the first case among all aspects of usability and acceptance. The authors explained these results with a task-technology fit approach (see also [4,5,7]). The results of this study highlight the necessity to consider potential properties of use cases in which new assistive technologies should and should not be used.

2.2 Technology Acceptance

Technology acceptance is usually assessed based on the widely acknowledged technology acceptance model (TAM; [3,14,15]). The model proposes two relevant variables predicting the intention to use technologies: i) perceived ease of use and ii) perceived usefulness. Perceived ease of use is described as the degree to which a user thinks that using the technology is free of physical and mental effort. Perceived usefulness describes that the user thinks that using the technology increases his/her task performance. Perceived ease of use and perceived usefulness are fundamental determinants of actual system use. The fulfilment of both is [3].

3 Interview Study: Method and Procedure

As part of a larger research study, we invited individuals to the *TU pilot factory Industrie 4.0* at the Vienna University of Technology (pilotfabrik.tuwien.ac.at/en) and asked them to assemble a workpiece using a screen or an augmented reality solution. After this task we presented the HMT-1 to these participants as another solution that can help with assembly. The participants were invited to a separate room where they had the opportunity to try it out. We then conducted interviews with them and asked them about their general impression and their assessment of the perceived usefulness and ease of use.

The sample consisted of 48 participants: 30 were female, and 18 were male. The age of the participants ranged from 18 to 44 years (M = 24.81, SD = 5.54). Regarding the highest level of education attained, 30 participants stated that they had passed the Matura/Abitur, and 18 indicated that they had obtained an academic degree.

The semi-structured interviews addressed the advantages and disadvantages, perceived usefulness, and appropriate work contexts for the HMT-1. The interviews lasted between 4 and 27 min (M = 11:53; SD = 4:02). The interviews were conducted by three interviewers (two of whom are co-authors) guided by the interview guidelines. All interviews were conducted in German. The interviews have been transcribed and analysed by summarising the content about the two technology acceptance dimensions: perceived ease of use and perceived usefulness. Based on the approach of Mayring's qualitative content analysis [10], we categorised the statements into broader categories that should cluster and represent the original statements properly.

3.1 Findings

In the following sections, we present the findings separately for the perceived ease of use and perceived usefulness. In terms of perceived ease of use we describe mentioned advantages and disadvantages of the technology; for perceived usefulness we describe despite statements about the general perceived usefulness also suitable use cases that have been mentioned by the study participants.

Perceived Ease of Use. Participants mention initial advantages and disadvantages of the technology which we have categorised into three categories: i) user experience, ii) ergonomics, iii) device characteristics. The following two tables (Table 1 and Table 2) summarise the advantages and disadvantages for these three dimensions. The numbers in parentheses indicate the frequency of the respective statement.

In general, the most frequently mentioned advantage of HMT-1 was that it is perceived as suitable in terms of the display (location) and the related adjustability. Participants for instance mentioned the advantage that the arm can be located directly in front of the workers' eyes (14 times). In connection to that, they reported that their field of view is unrestricted (5 times). They further highlighted the adaptivity and controllability (that the boom arm can be folded back and forth with one hand (10 times) and the possibility to move freely (10 times) as advantages.

Disadvantages primarily concern the hardware and quality of experience with respect to (media) the display abilities of the technology. For instance, 26 participants mentioned that the display is very small. Similarly, participants also

Table 1. Most frequently mentioned advantages; numbers in parentheses indicate the frequency

Category	Formulated advantages
User experience	Location: display is located in the worker's field of view (14)
	Adaptivity and control: the boom arm can be folded back and forth with one hand (10)
	Mobility: to move freely (10)
	Support: see instructions and do something else at the same time (6)
	Field of view: hardly restricted (5)
	Pleasure: funny and interesting (5)
Ergonomics	Comfort: pleasant wearing comfort (2)
	Individually adjustable (1)
Device characteristics	Broad application areas: Useful for several workstations (2)
	Input and output: voice control and sound reproduction (2)

Table 2. Most frequently mentioned disadvantages; numbers in parentheses indicate the frequency

Category	Formulated disadvantages
User experience	Quality: blurred, fuzzy, pixelated image (11), not possible to see the complete screen content (13), voice control (1)
	Familiarity: unfamiliar (6)
Ergonomics	Health: pressure on the head leading to headache (8 times), strenuous for the eyes (12)
	Discomfort: uncomfortable (5), annoying feeling to always have something on the head (4), always in the field of view (9)
Device characteristics	Hardware: display is very small (26)
	Physical stability: perceived as unstable (18)

mentioned disadvantages related to health at work, for example, that working with the small display may be strenuous for the eyes (12 times) or that the weight of the technology may lead to headache (8 times). Further, regarding the quality of the visualisation, participants mentioned that the image is blurred, fuzzy, and pixelated (11 times) or that the voice control is not precise enough (once). We want to mention here that participants did not evaluate the finished system with a visualisation that has been properly developed and tested; therefore, some of these statements are expected.

Perceived Usefulness. In terms of perceived usefulness, 15 participants reported that the device is useful. One participant stated, *"that it would enrich the workflow"* and that *'it gives the impression of efficiency'* (Participant ID 2). However, others did not assess the device as useful. For example, it was stated that *'in any case, it would hinder me more'* (Participant ID 42). We further asked participants about suitable use cases for HMT-1. A total of 34 suggestions were made. According to the interviewees, HMT-1 is appropriate for non-routine tasks and for tasks of medium-to-high complexity. Furthermore, it is considered practical *'when you have to manufacture something big and complex and have to move around a lot'* (Participant ID 10). In addition to the implementation of the technology in manufacturing (e.g. for quality control; participants with IDs 17, 29, and 30), it could also be used in logistics, for instance as a *'navigation device for truck drivers or for crane or forklift drivers in larger warehouses'* (Participant ID 23).

3.2 Discussion

In our interview study we investigated user acceptance of a head-mounted device called HMT-1, which is designed to support users by presenting information (e.g. visualizations) in the visual field. The information is shown on a foldable display. We had two main results that are relevant for both the assembly and the maintenance context. Firstly, we found that besides the possibility to move freely, the participants mentioned that it is of central advantage to have the display in their field of view, combined with the autonomy to decide where and when the visualization is given. In particular, the users reported that the position of the display and the adaptability and control of the extension arm to which the display belongs were mentioned as advantages. The ability to fold away the information distinguishes the HMT-1 from other HMDs. Thus, this technology allows to support the workflow while avoiding possible distractions or interruptions. The individual control of the employee is thus maintained, which has proven to be limited when using other HMDs (see e.g. [2]). Secondly, the results showed that HMT-1 contains functionalities that both support and hinder the workflow. These results are consistent with the results of the study reported by [8]. Therefore, as with any technology, when introducing the technology into an organization, it is necessary to invest time in considering appropriate work tasks in order to benefit from the technology. For example, the participants in this sample mentioned that HMT-1 is particularly suitable for non-routine tasks and tasks of medium to high complexity.

Limitation and Future Research. A limitation of our study is that the sample consisted mainly of students using the device for the first time, rather than assembly or maintenance workers. However, to create the industrial context, we integrated the study into a larger project that took place in a pilot factory. Still, our results only give a first impression of the acceptance of the technologies by non-professionals. A further limitation is that the technology was not tested with suitable ready-made software. The comments on the quality of the presentation are also due to this fact; however, the physical or display characteristics of the device (screen size, resolution, etc.) are also independent of content and have been mentioned negatively in this respect. Overall, the study results already give an indication of the perceived advantages and disadvantages of the technology and are thus valuable when it comes to further developing the technology. For further studies, we recommend conducting them with employees in real contexts. Thereby we suggest focussing on investigating for which specific use cases or working tasks this device can be supportive (for instance in terms of higher well-being, safety, productivity) and for which not.

Practical Implications and Conclusion. Our study provides recommendations to increase user acceptance in terms of perceived ease of use and perceived usefulness of the HMT-1. First, because the hands-free operability and the possibility to adapt and control the technology were described as particularly positive, we recommend maintaining this design. Second, we recommend focusing on a proper visualisation on the display. Third, we suggest - as for every technology that will be introduced at work - assessing suitable use cases and work tasks and defining when and how long the technology can and should be used. With these adjustments, we conclude that user acceptance can be increased and that the device can be beneficial for workers and organisations.

Finally, as regards the implementation of head-mounted devices in general, we recommend that the positive aspect of control over the technology should be maintained. For example, if organizations require employees to pretend to have their arm in front of their head at all times, these positive effects will disappear. As some ergonomic aspects have also been mentioned, we also recommend that the occupational physician be involved in the implementation. It is important to decide how and for how long the technology can and should be used. For example, maximum usage times can then be defined in cooperation (for further recommendations on how to implement assistive technologies see [6]). Such rules of use, appropriate for the specific workplace and workers, can minimise the potential negative effects on health and well-being and support comfort.

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