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Where to Display What? Using AR to Improve Work Performance

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ABSTRACT

Augmented reality (AR) is emerging as a next-generation interactive technology with the ability to display information in the immediate field of vision (i.e., near-eye display). This study investigates the interplay between information provision channels and information types on worker performance. A field experiment reveals that workers who follow instructions shown on AR glasses achieve higher work attentiveness and work performance than workers who receive this information on a mobile phone. Moreover, the effects of AR on work performance are moderated by information type. When the instructional information is highly dependent on the physical context, AR is more helpful in improving work performance. However, when the information is highly complex, the superiority of AR is weakened. This work contributes to the IS and HCI literature by revealing the value of AR in industrial organizations, and the boundary conditions for which AR affects worker performance.

Keywords

AR smart glasses, mobile phone, worker performance, information dependency, information complexity.

INTRODUCTION

Recent advances in high-speed communication and computing platforms have generated a strong demand for deeper human–digital interactions beyond traditional flat-panel displays. Augmented reality (AR) can be defined as a technology that can combine the computer-generated content and the real world in real-time (Azuma et al., 2001). It is predicted that the average annual growth rate of the global AR industry from 2020 to 2024 will be about 66%, and the market scale will be close to 240 billion by 2024.[1] As part of the digital transformation effort, organizations are increasingly adopting AR to provide instructional information accompanying tasks such as training and inspection (Li et al., 2022). For example, DHL warehouse workers wear AR glasses when they locate, scan, sort, and move inventory, which increases productivity by 25% compared to using handheld scanners or referencing paper forms.[2]

AR glasses display information in people's direct field of view (i.e., near-eye display; Lee et al., 2019), which affords the users to remain in contact with their surroundings.[3] However, despite the potential advantages of AR, mobile devices—such as cell phones and pads—are still popular digital tools used in industrial workplaces. While AR and mobile devices are both able to provide real-time instructions, they differ in the way information is delivered—that is, AR displays near-eye information, while the mobile display is usually beyond the direct field of view. Thus far, there has been a lack of a nuanced understanding of how these different information channels affect users' information processing and when the potential benefits of the new form of information delivery via AR can be more or less prominent. Very few studies have empirically investigated how AR, as compared to traditional mobile devices, may affect worker performance in industrial workplaces.

In this paper, we ask the following research questions: (1) what is the effect of AR, as compared to mobile, on users' information processing and performance, and (2) how does this effect differ depending on the type of information presented? More specifically, we focused on users' work attentiveness and work performance. Work attentiveness refers to the extent to which people pay attention to work-related details (Watson, 2000), while work performance reflects how well a worker is executing work-related activities (Parida and Kumar, 2006). We draw on attention theories, which suggest that humans have limited processing capability and explains how we allocate attention to different information. In our context, where users process information displayed on AR glasses or mobile devices while working, their task performance may be affected by how they switch attention between the physical environment and virtual information, as well as by how they integrate information into the tasks. We expect that workers who follow the instructions shown on AR (compared to mobile) devices will achieve higher work attentiveness and work performance.

[1] https://www.statista.com/statistics/591181/global-augmented-virtual-reality-market-size/

[2] https://www.dhl.com/global-en/delivered/digitalization/dhl-successfully-tests-augmented-reality-application-in-warehouse.html

[3] Another type of AR device is head-mounted displays (HMDs), such as Hololens, which project digital information onto physical objects and allow users to directly interact with the information. HMDs are viewed as promising for some business applications but are not yet ready for large-scale adoption due to their poor portability.

Furthermore, we distinguish between different types of information in terms of information dependency (low vs. high) and information complexity (low vs. high). Information dependency refers to the extent to which information is associated with the physical context (Steffen et al., 2019). Information complexity reflects the amount of information that be processed (Wood, 1986). We expect that information type moderates the effects of AR on work performance. Specifically, when the instructional information is highly dependent on the physical context, AR will be more effective in improving work performance. However, when the information is highly complex and, hence, more difficult to process near-eye, the positive effect of AR compared to that of mobiles will be weakened.

We collaborated with China Southern Airlines, the third largest airline in the world, and conducted a field experiment in the context of aircraft maintenance. We first compared the conditions of the instructional information shown on AR versus mobile and found that AR led workers to focus more on the task and inspect the aircraft more standardized. We also designed information on varying levels of dependency and complexity and assessed the moderating role. The results largely confirm our expectations.

The primary contributions of our work are as follows. First, this work contributes to the recent, though limited, work that investigates the use of AR by revealing how AR glasses, as compared to mobile, may change worker performance in industrial organizations. Second, it contributes to IS and HCI literature by investigating the boundary conditions for which AR affects worker performance, distinguishing different types of information. Moreover, the empirical evidence of this work cautions AR adopters and designers that despite the large display possibilities that AR brings, the best performance can only be achieved when considering the context in which the information is shown and the complexity of the information.

RELATED WORK

AR has been increasingly applied in the context of the industrial workplace (e.g., Wuttke et al., 2022), e-commerce (e.g., Hoffman et al., 2022), and medical treatment (e.g., Elmi-terander et al., 2020). In particular, AR is often used in the industrial workplace to provide real-time instructions on assembly, maintenance, and training. One major stream of research focuses on designing and implementing an AR system in these contexts. For example, Chen et al., (2015) designed an AR tool to assist in the assembly of a gearbox, which offered the part list and assembly instructions at the workstation by retrieving its production schedule. Choi and Park (2021) implemented an AR system for offshore plants, by optimizing the image recognition arithmetic the system is able to guide the construction workers to quickly navigate to onboard destinations and intuitively install and inspect outfitting parts.

More recently, a few scholars have investigated how AR changes users' work performance. For example, a study in the context of surgery compares clinical operations (i.e., screw placement) between AR-based technique and freehand, which shows that AR leads to higher screw placement accuracy compared to the freehand (Elmi-Terander et al., 2020). Wuttke et al. (2022) find using AR increases workers' productivity by 43.8% compared with using paper-based instructions because AR provides real-time, step-by-step instructions. However, workers who are supported by AR are less likely to remember and internalize the knowledge and thus perform worse after AR instruction is removed.

Our study differs from prior work in the following ways. First, compared to prior research (e.g., Chen et al., 2015; Choi and Park, 2021), we focus on exploring the values of AR in industrial organizations through a large field experiment. Second, we go beyond investigating the value of information per se (e.g., Wuttke et al., 2022). By comparing with mobile displays, we study how AR's near-eye display affects worker performance and its boundary conditions.

THEORETICAL BACKGROUND AND HYPOTHESES

In this section, we will develop hypotheses related to how AR affects workers' attentiveness and performance in the industrial workplace as compared to mobile and how these effects differ for different types of information.

The Main Effects of Information Channel

In industrial workplaces, workers need to follow instructions to complete tasks. The instructions, that were previously shown on paper, are now shown on either AR or mobile devices, providing real-time information to guide workers throughout their operations. We first compare the effects of providing real-time instructional information during the task via traditional mobile devices versus via AR on work attentiveness, that is, the degree to which workers are concentrated on work. With AR, information is displayed near-eye, which is also close to the physical objects users are working on. According to Lee et al. (2019), this allows users to notice the information without consciously switching away from the physical task at hand. Hence, users' attention to the working context is preserved.

However, when information is present on a mobile device, which is often separated from the physical objects users are working on, users will need to actively turn their attention away from the task at hand to access the information. Accordingly, although the task and information provided are highly related, users will have to split their attention between the two sources of information (i.e., physical objects and mobile screens). As attention theories suggest, managing attention switch between discontinuous, separate information sources consumes working memory resources (Barrouillet et al., 2004). Thus, users will have fewer working memory resources left to control and focus their attention on the tasks on hand. Therefore, we propose that,

H1: *Workers who follow instructions shown on AR (compared to mobiles) will achieve higher work attentiveness.*

As the information from AR or mobile provides instructions for users' on-site operations, whether users can accurately comprehend the information and thus follow it to carry out the work is key to achieving good work performance. As mentioned earlier, when information is provided through AR, users are able to scan it without switching their attention away from the current physical task. The provision of information near-eye enables users to process the information in the context of the related task environment (e.g., just beside the physical objects), which likely leads to improved understanding and internalization of information. Users will thus tend to incorporate what they have been instructed into their task execution, facilitating work performance.

In contrast, when information is provided through mobile, the information is spatially separated from the task context. This means that more cognitive resources are required to control the transition of attention between different information sources, memorize information from the mobile device, and integrate it into the related task context (Oberauer, 2019). This will lead to reduced efficiency and effectiveness of processing and comprehending information as compared to information provision via AR. This consequently causes barriers for users to standardize their operations based on the instructions. Therefore, we propose that,

H2: *Workers who follow instructions shown on AR (compared to mobiles) will achieve higher work performance.*

The Interplay Between Information Channel and Information Type

We further argue that the effect of information channels on work performance will be moderated by the type of information being provided (i.e., information dependency and information complexity). We refer to information dependency as the dependence of information on the physical context in which the information is embedded—that is, the degree to which the information is related to the participant's immediate physical surroundings (Steffen et al., 2019). If the information is closely associated with the physical objects, such as pointing to specific components that need to be checked during the work process, the need to understand the information in context increases. With AR, since information is delivered in the users' field of view, thus seamlessly integrated with the physical context, users can process and comprehend the information in the working context and follow the instructions while working. We thus argue that the advantage of AR in facilitating information comprehension and work performance is especially prominent when the information delivered is highly dependent on the physical context. In contrast, the information delivered on mobile devices is detached from the working context, which may cause difficulties for users in relating the instructions to the physical work on hand.

However, when the information delivered is less dependent on the specific working context, the cognitive resources needed to integrate the instructional information into the task context are largely reduced. With less strain on cognitive capacity, the difference between AR and mobile information channels is also likely diluted. Therefore, we propose that,

H3: *When the dependency of information on the physical context is higher, the positive effect of AR over mobile on users' work performance is stronger.*

Another information type that may moderate the effect of the information channel is information complexity, which refers to the amount of information that needs to be processed (Wood, 1986). Information complexity is a theoretically and practically important concept that has been studied in various contexts (e.g., Elmi-terander et al., 2020). We argue that, while AR is expected to facilitate information processing by integrating information into the related physical context in the same field of view, its effect will be weakened when the complexity of the information becomes higher. This is because an increase in information complexity implies an increase in users' visual and cognitive load. In this case, users will have to turn their attention directly to the information in order to fully process and react to it. Therefore, the fluency of processing information delivered via AR and integrating it with the physical context significantly decreases.

However, with mobiles, while the amount of information to be processed increases, the influence of information complexity in users' cognitive processing is less prominent than with AR because people are experienced in processing various information on mobiles and are thus less sensitive to the complexity of information. Hence, when processing complex information, the advantage of AR over mobile technology in integrating information with tasks is less prominent. Therefore, we propose that,

H4: *When the information is more complex, the positive effect of AR over mobile on users' work performance is weaker.*

METHODOLOGY

Research Context

We collaborated with China Southern Airlines and conducted a randomized field experiment at a major airport in central China. We tested our hypotheses with high external validity in the field of aircraft maintenance. Aircraft maintenance requires a robust regimen of scheduled servicing, inspection, and testing activities for every aircraft in service. While safety and performance are the primary goals of aircraft maintenance, an effective maintenance program also maximizes the resale value of the aircraft and prevents losses due to downtime. A visual inspection task of a Boeing 737-800 was chosen as our experimental task. As the company is in the process of transitioning to non-paper operations, it is rolling out AR and mobile programs that contain pre-coded sequences of steps and operational instructions about each step, which mechanics are required to follow. The information could be shown on AR devices, mobile devices, or both.

We used GLXSS SE AR glasses, which are produced by the AR solution provider LLVISION.[4] These AR glasses have a near-eye screen for displaying information close to one eye (i.e., around 2 cm). In our experiment, all mechanicians wore AR glasses that were connected to a 5-inch touch-screen mobile phone secured to one arm with a strap (see Figure 1). During the visual inspection task, the title of each step—consisting of the name of the area being inspected—was displayed on both the AR glasses and the mobile phone. The users could proceed to the next step by swiping the touch screen of the phone. Alternatively, they could also use a simple voice command (i.e., "move to next step").

Figure 1. AR Glasses and A Mechanic Wears the AR Glasses

To investigate the effect of the AR device vs. that of the mobile phone, we manipulated the delivery of real-time instructional information for 9 selected steps (out of 53). These steps were identified based on a pretest with more than 100 mechanics and represented the procedures in which they tended to make mistakes. In fact, these steps covered more than 80% of the mistakes in visual inspection tasks for transit aircraft made in the past. In the mobile condition, the instructional information for these steps was displayed only on the mobile. In the AR condition, real-time instructional information was displayed only on the AR glasses. The instructions were the same across the two conditions.

To investigate the moderating role of information type, we manipulated the instructional information in two dimensions: the level of information dependency on physical context and the level of information complexity. The design of information type was discussed with domain experts (e.g., mechanics, and engineers). Specifically, low-dependency information was manipulated as a textual instruction to tell workers what they should do (e.g., "please inspect this area carefully"). This information was relevant for all the steps, not just for a specific inspection area (see Figure 2, Type I). Conversely, high-dependency information includes a textual instruction specific to the area being inspected—that is, the key operation components in this area are identified and labeled in an image (see Figure 2, Type II). Information complexity was manipulated by the number of operations highlighted in an instruction. Specifically, while low-complexity information highlights only one key operation in a given step (see Figure 2, Type II), high-complexity information highlights multiple operations within this step (see Figure 2, Type III).

Ideally, since these two dimensions are orthogonal, we should adopt a 2 (dependency: high vs. low) × 2 (complexity: high vs. low) design, which implies four conditions. However, the type of low-dependency and high-complexity information implies that we should provide a large chunk of non-contextual information at each step, which has limited value and is not practical in such a context. Accordingly, we included only three information conditions in the experiment.

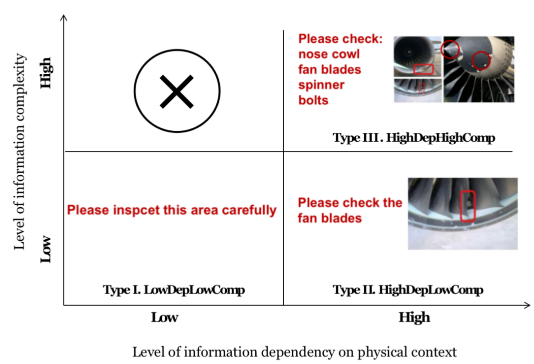


Figure 2. Information Type Provided at Step 20 (i.e., the front area of left engine)

Overall, a 2 (information channel: AR glasses vs. mobile phone) × 3 (information type: Type I vs. Type II vs. Type III) mixed-design field experiment was conducted to test our hypotheses. The information channel was manipulated as a between-subject factor, while the information type was manipulated within-subject—that is, every subject conducted the experimental task for three rounds, receiving one of the three types of information treatment in each round. The order of the three types of information was randomly determined for each mechanic.

In the end, 66 mechanics were recruited to participate in our experiment, with 31 and 30 subjects assigned to the AR condition and mobile condition, respectively. All the mechanicians on the airline's aircraft maintenance team were males. Their average age was 29.38 years, and their

[4] https://www.llvision.com/glxss-se.html

work experience ranged from 1 years to 16 years. They were generally not very familiar with AR (3.90 out of 7) but were very confident in using new IT tools (6.01 out of 7). We uncover no significant differences associated with these variables between mobile condition and AR condition.

Before we began our field experiment, we collected basic background information from all of the subjects and familiarize them with AR glasses through two-week training sessions. The main experiment was conducted in three rounds from November 21 to December 15, 2021, with each round lasting eight days. During the task, the subjects' AR glasses recorded a first-perspective video. The videos were used for the subsequent analysis of the subjects' work performance. After the visual inspection task, the subjects filled in a questionnaire that measured their perceived attentiveness, fatigue, etc.

Measurements

Work attentiveness was measured as the proportion of attentive inspection duration, calculated as the time spent inspecting the aircraft divided by the total duration of the task (which included the duration of looking around in work-irrelevant directions, irrelevant chatting with others, etc.). This was coded from the first-person perspective video. To strengthen the validity, we also measured the subjects' self-reported work attentiveness in the post-experiment questionnaire on a seven-point Likert scale (e.g., "I fully concentrated on the visual inspection task"; Kizilos et al., 2013).

Work performance was measured in two ways: visual performance and action performance. We measured visual performance as the number of inspected key components. Within the steps with instructional information, 12 key components were identified. We used YoloV5, a well-performing machine learning algorithm, to identify the key components from each subject's first-perspective video. Specifically, prior ergonomic research suggests that individuals' foveal field of view (FOV) ranges from 15° to 20° (Lee et al., 2019), which means that when people pay attention to an object, it is usually located within this field of view. Thus, we labeled the area within 20° in the horizontal direction and 15° in the vertical direction as the foveal FOV of the first-perspective video. To analyze the video, we extracted 5 pictures per second for further analysis. According to the maintenance manual, the key components should be inspected for more than 2 seconds; we thus extracted every 10 successive pictures as an analysis unit. Therefore, if the central coordinate point of the identified component was located in the foveal FOV in at least 10 consecutive pictures, it was recorded as 1, which means the component was deeply inspected, and otherwise as 0. As there were 12 key components, we summed up the number of attentively inspected components, resulting in a rating of visual performance from 0 to 12.

Second, we used action performance as a proxy. Specifically, squatting to inspect the side or lower covers of components is a very important action in our experimental task, which ensures that the components can be fully inspected. Six of the nine instructed steps should have been inspected by squatting. This measure was derived from analyzing the first-person video. Two research assistants were recruited to code the videos independently. Specifically, in a step that required squatting, if a subject did squat, the event was recorded as 1, otherwise as 0. As there were six steps in total, we summed up the number of squats, resulting in a rating of action performance that ranged from 0 to 6. In Table 1, we summarize the above measures for our two dependent variables.

Dependent Variables	Measures	Data Source
Work attentiveness	Proportion of attentive work time	Video
	Self-reported work attentiveness	Questionnaire
Work performance	Visual performance: number of inspected key components	Video
	Action performance: number of squatting actions	Video

Table 1. Summary of Measures

RESULTS

Results on Work Attentiveness

We conducted 2×3 repeated-measures analyses of variance (ANOVA) on different measures, which were with information channel as between factor and information type as within factor. We first looked at the objective measure, the proportion of attentive work time. The results of between-subject analyses show that subjects acquiring information from the AR glasses (M_{AR}=0.950) concentrated more on their maintenance work than those acquiring information from the mobile phone (M_{mobile}=0.926, $p<0.01$, $F[1,59]=11.21$, $p<0.01$, $\eta^2=0.17$). However, we do not find the interaction effect between information channel and information type.

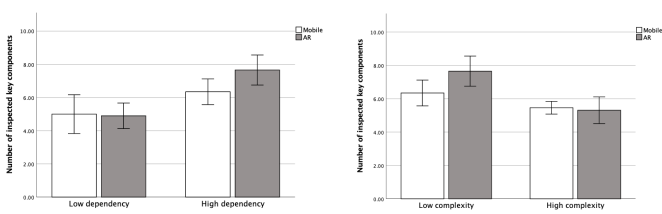
Turning to self-reported attentiveness, the results were consistent with the objective measure, that is, subjects in the AR glasses condition (M_{AR}=4.58) perceived higher attentiveness than those in the mobile phone condition (M_{mobile}=3.81, $F[1,59]=7.541$, $p<0.01$, $\eta^2=0.13$). Furthermore, there is no significant interaction effect. Overall, H1 is supported.

Results on Work Performance

We then conducted repeated-measures ANOVA on the measures of work performance, respectively. In terms of visual performance, we do not find a significant main effect of the information channel on the number of inspected key components ($F[1,59]=0.785$, $p>0.1$, $\eta^2=0.01$).

Furthermore, we analyzed the moderating effects of information dependency by contrasting Type I and Type II. The results revealed a marginally significant interaction effect between the information channel and information dependency ($F[1,59]=3.346$, $p=0.073$, $\eta^2=0.06$). To clarify the nature of this interaction, we further analyzed the main effect of information channel for high and low dependency information, respectively. The results show that when the information was highly dependent on the physical context (i.e., Type II), the AR glasses facilitates subjects to visually inspect more key components ($M_{AR}=7.65$) than the subjects in the mobile condition ($M_{mobile}=6.34$, $t[59]=2.230$, $p<0.05$, Cohen's $d=0.60$). However, when the information dependency was lower (i.e., Type I), there is no significant difference between the two conditions ($M_{mobile}=5.00$, $M_{AR}=4.89$, $t[59]=0.155$, $p>0.1$, Cohen's $d=0.04$, see Figure 3a).

We then analyzed the moderating effect of information complexity by contrasting Type II vs. Type III. We also find a significant interaction effect between the information channel and information complexity ($F[1,59]=5.147$, $p<0.05$, $\eta^2=0.09$). As we reported in last paragraph, when the information was less complex (i.e., Type II), the subjects in the AR glasses conditions inspected significantly more key components than those in the mobile condition. However, when the information complexity is higher (i.e., Type III), there is no significant difference in the number of inspected key components between the AR and mobile conditions ($M_{AR}=5.46$, $M_{mobile}=5.31$, $t[59]=0.337$, $p>0.1$, Cohen's $d=0.09$, see Figure 3b).



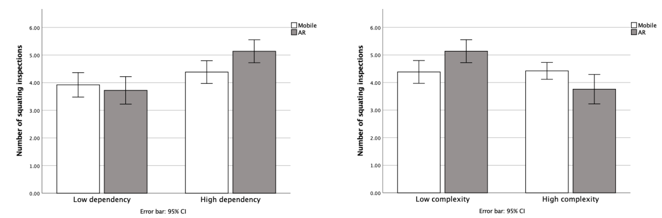
(a) **(b)**

Figure 3. Plots of Interaction Effects on Visual Performance

Turning to the second measure, action performance, the main effect of information channel on squatting inspections is not significant ($F[1,59]=0.051$, $p>0.1$, $\eta^2=0.001$). Therefore, H2 is not supported.

By contrasting Type I and Type II, we find a significant interaction effect between the information channel and information dependency ($F1,59]=4.532$, $p<0.05$, $\eta^2=0.08$). Further analyses showed that when the information was highly dependent on the physical context (i.e., Type II), the AR glasses condition leads subjects to perform significantly more squatting actions ($M_{AR}=5.14$) than the mobile phone condition ($M_{mobile}=3.48$, $t[59]=-2.640$, $p<0.05$, Cohen's $d=0.71$). However, when the information dependency is lower (i.e., Type I), there is no significant difference in the number of squatting actions between the two conditions ($M_{mobile}=3.92$, $M_{AR}=3.72$, $t[59]=0.155$, $p>0.1$, Cohen's $d=0.16$, see Figure 4a). Therefore, H3 is supported.

Moreover, there is also a significant interaction effect between the information channel and information complexity ($F[1,59]=9.256$, $p<0.01$, $\eta^2=0.15$). When the information is less complex (i.e., Type II), the AR glasses condition leads to significantly more squatting actions than in the mobile conditions. However, when the information complexity is higher (i.e., Type III), squatting actions in AR condition ($M_{AR}=3.76$) turns to be less than those in mobile condition ($M_{mobile}=4.42$, $t[59]=2.100$, $p<0.05$, Cohen's $d=0.58$, see Figure 4b). Therefore, H4 receives support.



(a) **(b)**

Figure 4. Plots of Interaction Effects on Action Performance

CONCLUSION

This study investigated the interplay between information provision channels (AR glasses vs. mobiles) and information types on employees' work attentiveness and performance. A field experiment revealed that when the information was provided through AR glasses, it helped improve employees' work attentiveness more than when a mobile was used. The information type also moderated the effects of AR glasses on employees' work performance. Specifically, when the information was highly dependent on the physical context, the AR glasses were more helpful in improving employees' work performance compared with the mobile condition. However, when the information was highly complex, the near-eye display on the AR glasses raised difficulties in understanding the information, which weakened the positive effect of the AR glasses compared to the mobile in improving work performance.

Implications of Findings

This research has several theoretical and practical implications. Firstly, we contribute to current AR research by highlighting the value of AR smart glasses in improving worker performance in industrial organizations. This study focuses on the fundamental difference between AR and traditional mobile devices and suggests that near-eye displays may facilitate users to process virtual information and physical work surroundings integrated, which then improve their work performance. Secondly, we contribute to IS and HCI literature by revealing the potential contingency factors related to the effects of AR glasses. We suggest that the information type can affect how people process information on AR. Specifically, the superiority of AR is strengthened when information is highly dependent on physical context but is weakened when information is highly complex.

Understanding the values of AR glasses is extremely helpful for industrial practitioners, who have long been seeking innovative ways to facilitate worker performance. Based on the current study, the message to practitioners is that compared with mobile devices, AR glasses can be an effective tool to improve users' capability of integrating instructions with the task in the physical world, especially when the provided information is highly dependent on the physical context, which further improves their work performance. The empirical results also caution AR designers that despite the large display possibilities that AR brings, the best performance can only be achieved when considering the context in which the information is shown and the complexity of the information.

Limitations and Future Research

We acknowledge that this study has some limitations. First, because of the novelty of AR, the subjects in our study had little experience with this technology. Therefore, some of the effects we demonstrated might change as users become familiar and habituated with AR. Second, we focused on a near-eye display AR device, which is the most widely used AR format. However, other emerging AR technologies, such as see-through AR—which can overlay the virtual information in the physical context instead of on a near-eye screen—remain to be further investigated.

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