Smart Digital Assistance Devices for the Support of Machine Operation Processes at Future Production Workplaces

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Abstract. Digitalization of production changes the scope of human-machine interaction, frequently leading to increasing informational load. The present article describes a study which investigated smart digital assistance (SDA) devices regarding usability, subjective strain, performance and reaction time while conducting a simultaneous machine monitoring and assembly task. Results reveal that subjective mental strain and reaction times were positively affected by means of SDA usage and showed significant differences independent from SDA type. Performance significantly increased when data glasses were used. Significant differences were further shown in usability when using smartwatch compared to data glasses. Findings show that SDA device implementation in industrial practice potentially has a positive benefit for productivity.

Keywords: automation, digitalization, human-machine interaction, production workplace, smart digital assistance, wearable devices

1 Introduction

Digitization and automation are significantly changing production systems [1, 2]. In the production sector, this change is reflected in concepts such as cyber physical production systems [1], the internet of production [3], or smart factories [4], amongst others. Consequently, technological limits of current system components are reached [5]. Spencer [6] outlines a struggle between the rationalization and extinction of many existing jobs and the creation of more self-determined jobs. Therefore, shaping the digital transformation and its effects on daily routines in production workplaces is a key element for current and future ergonomic research. In particular future work with production machines is affected by digitalization and automation, for instance in cases in which a higher number of tools and more frequent tool changes are required, which cause a shift in the machine operators' range of tasks [7, 8]. Furthermore, responsibility for multiple simultaneous and decentralized processes can cause high workload and strain to the workers [9]. In those cases, it seems likely that without additional support, the number of mistakes and duration of idle times increases, thus leading to decreasing overall productivity and system safety.

In order to address this challenge, smart digital assistance (SDA) devices, such as data glasses or smartwatches, can be used to support production workers in the depicted future working scenario [10]. The main advantage with regard to their wearability is given by the opportunity of constant accessibility to required information, e.g. about process states and sudden hazards [11]. SDAs thus offer the potential to reduce individual strain and workload, thereby positively affecting the quality of work and productivity in the long term.

For this reason, a study was conducted to investigate different SDA devices in the context of future machine operation tasks. The study aims at analyzing the impact of SDA device support on machine operation.

2 Method

2.1 Participants

A total of 33 subjects (14 female; 19 male) between the ages of 20 and 46 (AM = 26 years, SD = 4.6 years) took part in the study. They were recruited in the region Aachen, Germany. Subjects with existing visual impairments were excluded from the study. All subjects stated that they were more familiar with the mobile devices smartphone and tablet than with data glasses.

2.2 Experimental Design

The experiment followed a 2x3 (scenario x SDA) within-subject design. Scenarios were “remote monitoring of machines” (S1) and “notification of work progress” (S2). Used SDA devices were a tablet-computer (TB), smartwatch (SW) and data glasses (DG). Each combination of both factors is called “condition” in the following. A latin square was used to randomize conditions between subjects. The task of the test persons in the present study was the simultaneous performance of an assembly and monitoring task. Here it was emphasized that both tasks (assembly vs. monitoring task) were equivalent and both had to be performed with the same motivation. The monitoring task was divided into two conditions; "remote monitoring of machines" and "notification of work progress". Both the dismissing of alarms and process feedback required a user confirmation on the tablet. In the secondary assembly task, participants had to tighten and loosen screws on a prepared metal board with prefabricated boreholes by means of a cordless screwdriver. Dependent measured variables were subjective mental strain, usability, performance (number of screws), and reaction time (seconds). Subjective experienced strain was determined using the NASA-Task Load Index questionnaire [12]. Usability was assessed with the System Usability Scale (SUS) [13]. The performance value for each condition was determined based on the number of screws mounted in the assembly task.

2.3 Apparatus

To evaluate the selected use cases, a tablet-computer (HTC Nexus 9), a smartwatch (Sony 2), and a pair of smartglasses (Vuzix M100) were used. The tablet-computer simulated the human-machine interface of a production machine. The different devices were connected via Bluetooth, allowing for a non-restricted wireless use. A realistic simulation of a production setting was achieved using an application on the tablet on which the two operating scenarios "remote monitoring of machines" and "notification of work progress" were simulated. The first scenario included randomly occurring alarms (Alarm A, B, C, D), which were triggered for the observed machines and to which the participants had to react. In the second scenarios, participants had to react to notifications regarding the process of the observed machines. A 10 seconds countdown displayed the upcoming end of a process. In conditions with smartwatch or data glasses support, notifications in both scenarios were also displayed on the SDA device. In conditions with the tablet-computer, no additional informational support was offered and participants had to self-monitor alarms and processes.

2.4 Procedure

The experiment was carried out in a laboratory of the Institute of Industrial Engineering and Ergonomics of the RWTH Aachen University. One trial lasted approximately three hours. The experiment consisted of three blocks (SDA devices) within two trials (scenarios). After each block, participants answered a questionnaire to determine their subjective impressions.

Both scenarios were repeated three times using the different devices. In conditions with the tablet computer the task was to monitor the scenarios without additional SDA support. The two following conditions included an additional mobile SDA device – a smartwatch or data glasses – which displayed alarms (scenario 1) and process status (scenario 2). While preoccupied with the assembly task, participants had to monitor and react to the different scenarios using the respective device. Between the individual blocks, participants were given a rest period, to avoid physical and mental overexertion.

3 Results

The statistical analysis of the results was done on the basis of a repeated measures MANOVA at significance level of 0.05%. If the assumption of sphericity was violated, a subsequent Greenhouse-Geisser-Correction was conducted. Bonferroni post-hoc pairwise comparisons were used for univariate analysis. All data were included in the experiment (N=33). Reliability for the SUS scale was assessed with Cronbach's alpha.

Descriptive statistics are shown in Table 1. Means of NASA-TLX and reaction time were highest for the factor tablet and similar for smartwatch and data glasses. SUS mean values were lowest for the tablet and increased for the data glasses and smartwatch. The performance by the mean number of screws increased when using smart watch and data glasses.

Table 1. Descriptive Statistics. Means (Standard deviations) of dependent variables. Factor scenario: S1 = "Remote monitoring of machines", S2 = "notification of work progress", factor SDA: tablet = TB, smartwatch = SW, data glasses = DG, AM = Arithmetic Mean, SD = Standard Deviation. Best value of each dependent variable marked bold.

AM (SD)	Remote monitoring of machines			Notification of work progress		
	S1 -TB	**S1 - SW**	**S1 - DG**	**S2 - TB**	**S2 - SW**	**S2 - DG**
NASA-TLX	43.22 (16.33)	34.31 (14.58)	35.89 (14.73)	43.82 (51.21)	**32.82** (15.36)	34.58 (13.91)
SUS	61.92 (18.00)	**88.75** (13.89)	76.42 (15.49)	66.67 (19.42)	87.92 (13.83)	75.25 (21.11)
Performance [number of screws]	**58.07** 10.71	62.70 (13.99)	61.97 (13.20)	58.27 (12.00)	59.30 (13.39)	59.63 (11.97)
Reaction Time [sec]	17.33 (7.07)	5.66 (3.39)	6.14 (2.09)	9.97 (7.07)	**3.16** (1.26)	3.68 (2.38)

Results of the repeated measures MANOVA that included all dependent variables revealed a significant overall effect for scenario, V = .708, F(4, 26) = 15.763, p < .001, partial η^2 = .708, for SDA, V = .981, F(8, 112) = 13.49, p < .001, partial η^2 = .491, and for the interaction scenario*SDA, V = .272, F(8, 112) = 2.206, p = .032, partial η^2 = .136.

Univariate analysis reveals a significant main effect of reaction time for the factor scenario, F(1, 29) = 46.22, p < .001, partial η^2 = .614. For the factor SDA, it showed significant main effects of NASA-TLX, F(1.643, 47.65) = 14.187, p < .001, partial η^2 = .328, of SUS, F(1.625, 47.127) = 27.78, p < .001, partial η^2 = .489, of screws, F(2, 58) = 3.755, p = .029, partial η^2 = .115, and of reaction time, F(1.209,35.047) = 81.1, p < .001, partial η^2 = .737.. The main effect for the interaction was significant for reaction time, F(1.38, 40.026) = 7.64, p = .004, partial η^2 = .209.

Bonferroni-corrected pairwise comparisons for the factor scenario only show significant differences of reaction time, p < .001. The factor SDA revealed significant differences for NASA-TLX, for performance between the tablet and both, the smartwatch and data glasses, p = .001. SUS showed significant differences for all paired couples in SDA, p < .019. Performance was significant between tablet and data glasses, p = .03. Significant differences in reaction time were shown between the tablet and both, smartwatch and data glasses, p < .001.

For reliability analysis of the SUS, Cronbach's alpha was calculated for each condition to assess the internal consistency of the subscale for positive affect, which consists of ten items. The internal consistency of the questionnaire is satisfying, with Cronbach's alpha for positive affect: .787 < α < .902.

4 Discussion

4.1 General Discussion

The aim of the present study was to investigate if the use of SDA devices in machine operation scenarios supports the user whilst operating production machines. Therefore, SDA device support was examined in two machine operating scenarios: "remote monitoring of machines" and "notification of work progress". The present study indicates that the use of SDA devices as support for machine interaction can improve machine operation.

Results of the factor scenario show that the use of SDA support leads to a significant improvement of the reaction time in both factor levels. The extent of the improvement, however, differs between the scenarios, whereby the improvement for the factor level “notification of work progress” is significantly higher than the factor level “remote monitoring”. This leads to the conclusion that the support of SDA devices influences reaction times of an operator, depending on the current use case. Therefore, improvement of reaction time is not directly improved by using SDA devices, as this effect is mitigated by the specific implementation scenario.

Results concerning the factor SDA devices further reveal that the use of either a smartwatch or data glasses has a positive effect on mental strain and reaction capability, which was shown by decreasing NASA-TLX and reaction times. However, the differences between the two devices is small and showed similar tendencies. Consequently, the type of SDA device is likely to be interpreted as less relevant for subjective strain and reaction times than the fact that an SDA device is used at all. On this basis, it might be assumed that SDA support allows for more efficient work, since on the one hand, focus can completely be given to the secondary assembly task, and on the other hand, effort of the monitoring task is reduced.

Performance, however, achieved highest means and significant differences when using the data glasses. In contrast to this, the smartwatch did not show significant differences for this dependent variable compared to no SDA support. In this regard, it may be assumed that this fact might be attributed the advantage of the glasses, which allows hands-free usage and leads to a greater number of assembles screws in general, whereas information input when using the smartwatch requires a turning of the wrist.

Further, SUS results show that there is a difference in usability between offering support versus not offering support. For the support options, the smartwatch showed a higher usability compared to the data glasses. This difference may be attributable to the fact that wearing additional glasses is less comfortable than wearing a watch on the wrist. Also, near accommodation of the eye is required when watching the displayed information on the glasses screen.

However, the evaluated scenarios essentially differ in only a few factors. On the one hand, alarm resolution is slightly more complex, since it is necessary to differentiate between four different alarms that are displayed; on the other hand, in this use case the reaction is more urgent, since an alarm that occurs is likely to be resolved as soon as it is displayed. Concerning the processes, the displayed countdown might have left room for reaction. Based on these considerations, it is stipulated that the influence of mobile devices on the efficiency of the execution of an assembly task might increase with increasing complexity of the monitoring task or the relevance of the displayed information for the human-machine interaction.

4.2 Limitations

It has to be considered that the study was conducted with SDA devices featuring certain characteristics, which means that the transferability of the results to other devices of the same type (smartwatch, data glasses) or completely different mobile technologies is as yet unclear. Furthermore, other use case scenarios with different characteristics have to be investigated before a more general statement can be given about SDA support advantages.

5 Conclusion and Outlook

Since the benefits of a particular device do not significantly outweigh the benefits of one of the SDA devices, a case-specific catalog of requirements for the support system could be drawn up. This would also allow for individual user preferences to in be incorporated in the selection process.

The significant differences tested in all SDA devices of the SUS analysis make it clear that there is potential for the integration of existing consumer market technologies in industrial practice through mobile support with data glasses or smartwatch. Concerning usability, a smartwatch should be preferred over data glasses, which in turn would be preferable over no support according to the presented results. In case of a cognitively demanding task or one that requires quick reactions, SDA support is recommended without device preference. If performance is most important for a given task, a use case analysis should be conducted a priori, since SDA support offered no significant improvement in at least one of the tested scenarios.

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