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The Effect of Pick-by-Light-Systems on Situation Awareness in Order Picking Activities

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Abstract

Pick-by-light systems are widespread in the industry, especially in order picking. Literature shows their potential to reduce picking-time and –errors as well as mental load. Using pick-by-light is also relevant for training processes since employees may tend to rely on these systems without consciously comprehending and processing the environment. Situation Awareness is a term referring to this fact and is analyzed in the study described in this article. The study took place in the learning factory “Center for industrial Production” at TU Darmstadt with N=31 subjects, who completed two order picking tasks: One of them assisted by pick-by-light and the other by pick-by-paper. SAGAT-based Situation Awareness showed no significant differences, whereas heart rate showed higher strain when using pick-by-light. NASA TLX showed a higher subjective strain using pick-by-paper.

Keywords: pick-by-light; order picking; learning; Situation Awareness

1. Introduction

1.1. Motivation

In recent years, the volume of products sold via e-commerce has increased steadily. At the same time, customers' expectations are shifting towards shorter delivery times, which results in major challenges for logistics and in particular

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for order picking [1]. Pick-by-light systems offer the opportunity to help facing these growing challenges. They are widespread in the industry in order to guide and cognitively support employees in finding and picking stock keeping units (SKU) [2]. Pick-by-light in this context means that light signals which are installed on the shelves guide the operator to his or her pick location [3]. The system is connected to a warehouse management system and is often combined with displays that indicate the number of picks of a specific SKU. Current research shows that this technical assistance not only is able to increase the pick frequency, but also significantly reduces the number of pick errors. Furthermore, first experimental studies show that the mental strain is reduced by a pick-by-light system in comparison to other guiding concepts, such as handheld devices or paper lists [2, 3]. However, it is uncertain to what extent the strong focus of employees on specific light signals has an effect on the Situation Awareness of the order picker.

Situation Awareness (SA) is defined as *"the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future"* [4]. Therefore, Situation Awareness in terms of the application of pick-by-light systems can be of great relevance with regard to two aspects in an order picking context.

On the one hand, a sole concentration on light signals can create a tunnel vision, so that the order picker no longer sufficiently perceives his surroundings. In addition to aspects of occupational safety, which are particularly relevant in warehouses (forklifts, warning lights, fragile goods), reduced SA can also affect the efficiency and quality of order picking [5]. For example, pick errors are not noticed or secondary tasks such as counting SKUs or inspecting the articles are executed incorrectly [6]. On the other hand, pick-by-light systems are often used in learning factories to instruct and train employees. In this context, SA could be critical as well. If the cognitive support reaches a level at which the order picker or the employee to be trained is no longer is attentive and stops concentrating on the different steps of the processes, the learning effect may decrease. In order to investigate the SA when using a pick-by-light system, order picking experiments were carried out in the learning factory "Center for industrial production" (CiP) of the TU Darmstadt and the SA during pick-by-light was compared with a pick list-based order picking.

1.2. Related Work

So far, there are no publications in which researchers directly investigate to what extent SA is influenced by a pick-by-light system. Several models exist for the description of SA - besides those of Adams, Pew & Tenney, Hancock & Smith, Bedny & Meister and Finnie & Taylor [7,8,9,10], the most widespread and the model used here is the one of Endsley (1988) [4]. This model of the SA originates from aviation, but is often adapted to other safety-critical applications [11] such as driving, air traffic control or the nuclear industry.

However, SA is now also finding its way into other sectors and has already been studied in the industrial or production context by a number of authors. Sneddon et al. (2006) for example analyzed SA on offshore oil-drilling platforms and by interviewing crew members found out that important contributing factors for a reduced SA are isolation, employee fatigue and stress [5]. Moreover, research shows that motivation, flow of information and the complexity of the process significantly influence the SA for field operators and control room staff in process industries [6]. SA in production planning and scheduling has also already been examined in a case study. In production scheduling, SA can be maintained by constantly interacting with other individuals and computerized control systems in a sociotechnical system [12]. Further, Landmark et al. (2019) state that SA is crucial for employees in modern production systems, due to the digital transformation in particular [13].

It is remarkable that SA has not yet been measured objectively (e.g. SAGAT) in industrial contexts in the existing literature, as it is often done in aviation or driving contexts. In each of these articles, subjective methods such as observations and interviews are used.

2. Materials and Method

An order picking setup was implemented in the CiP Learning factory at Technische Universität Darmstadt for this study (s. picture 1 left). The CiP learning factory was established in 2007 and represents the complete value stream of a pneumatic compact cylinder including machining, assembly and intralogistics. The study described here was executed at the material warehouse of the assembly.

The Pick-by-Light-System (PbL) used was an LED-based Wizard-of-Oz-System, which was controlled by the experiment manager. The LED lights were placed at the compartments of the warehouse shelf, which contain different parts varying in form, size and mass. A number line is mounted beneath the LED lights of each compartment indicating the number of parts that had to be picked from the compartment (s. figure 1 right). Each LED light is allocated to number of the number line. The PbL indicates the compartment and box by the position of the light and the number of parts to be picked by the number of lights shining at the respective compartment. Wizard-of-Oz in this configuration means that the system looks like a real working system to the operator and could be used as a real working system for the experiment. In fact, however, it was controlled by the test manager and would not be able to work independently connected with a warehouse management system [14]. There was no data processing and logic implemented. After picking the SKU the subjects confirmed by pressing a button and the next light appeared at the next compartment according to a preselected sequence. For the subjects of the study, no differences to a real working system were recognizable. In the experiment, the PbL was compared to a paper-based picking list. For each of the two test conditions (using PbL vs. using picking list) Situation Awareness was captured with a SAGAT-based approach [4]: The experiment was stopped at a distinct time, that varied and so was unpredictable for subjects. The subjects then left the warehouse and answered altogether 13 questions that were posed orally by the test manager. The question followed the approach of Endsley [15] and focused on perception and comprehension of the environment of the material warehouse and learning factory, the shelf, its compartments and parts and the task itself., e. g. which part has been picked recently, status of the pick-by-light system, or if a shining signal light in the background has been recognized. SA was assessed by the share of questions that could be answered correctly. Furthermore, heart rate data and NASA Task Load Index (NASA TLX) were captured to analyze objective and subjective strain of the subjects. Heart rate data were captured using breath belt and Varioport system. Subjective strain was assessed subjectively using NASA TLX questionnaire [16], which follows a twostep procedure: First subjects have to rate six strain-related subscales, e.g. mental demand or effort, using a Likert-scale within a 100-points range with 5-point steps. Then subjects weight these subscales by pairwise comparisons to asses which subscales are more important for the task. The result is a task load score between 0 and 100. NASA TLX was completed digitally on a laptop next to the experimental setup immediately after the experiments.

In total the experiment took 90 minutes for each subject After arriving at the experiment area the Varioport-system to capture heart data was attached to subjects and a sociodemographic questionnaire was filled out. After that, the task and the pick-by-light system and the paper-based picking-list were presented to the subjects. The subjects then carried out two different order picking tasks that represented the test conditions and took about 30 Minutes each: one order picking task was supported by the PbL and the other one had to be done according to a paper-based picking list. The sequence of these two tasks was alternated to balance out learning and fatigue effects. During each task heart rate data and SA were captured. After each task subjects filled out the NASA TLX to assess subjective strain during each task.

The captured data were Situation Awareness, average heart rate, heart rate variability and NASA TLX score for two conditions: Picking supported by the PbL and picking according to the picking list. For all of the depending variables there were two data sets that could be compared by analyzing differences of the group-based mean values using T-tests for connected samples and Shapiro-Wilk test for Gaussian distribution of the samples.

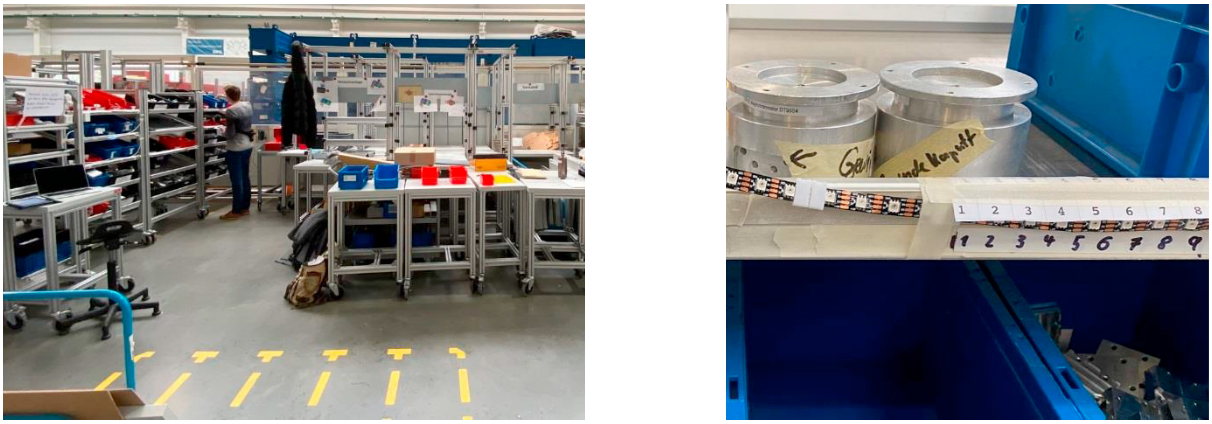

Fig. 1: Experimental setup in the learning factory (left) and prototype with number lines of one shelf compartment (right).

3. Results

In total, N = 31 subjects tested the two systems. The mean age of the sample is 22,9 years (*SD = 1,45*), which is a rather young collective, typical for studies in an university environment. A total of 13 subjects reported that they had no experience in order picking at all. Nine subjects had done order picking tasks in the industry as part of an apprenticeship or an industrial internship before. Twelve subjects were affected by visual impairments, e.g. myopia, farsightedness or corneal curvature. No subject reported deficits in the ability to concentrate.

Figure 2 shows the boxplots of the dependent variables, in which the data based on pick-by-light are located on the left side of each diagram and the data based on pick-by-paper are located on the right side. The left diagram shows heart rate data in beats per minute. The Situation Awareness score, which is the share of correctly answered environment- and task-based questions posed during the test runs, is displayed in the middle. The right diagram shows the NASA TLX score that ranges from 0 to 100. All diagrams also show the median values (horizontal line) and the mean values (black point). The Shapiro-Wilk test reveals a Gaussian distribution of the sample from which no outliers had to be removed.

The T-test statistics for heart rate data show a significant difference for the two test runs ($t = 3.43$, $p = .002$, $n = 31$) on a significance level of $\alpha = .05$. The heart rate for pick-by-light ($M = 93.32$, $SD = 13.43$) is significantly higher than that for pick-by-paper ($M = 90.62$, $SD = 12.40$). The effect strength according to Cohen [17] is r = .53 and thus corresponds to a strong effect.

There is no significant difference in the measurement of Situation Awareness ($t = -1.602$, $p = .119$, $n = 31$) on a significance level of $\alpha = .05$. The SA of pick-by-light ($M = .38$, $SD = .10$) do not differ significantly from the SA of pick-by-paper ($M = .43$, $SD = .13$). However, results show that subjects answered more questions correctly when using pick-by-paper.

NASA TLX data show that the subjective loads differ significantly between pick-by-light and pick-by-paper ($t = -.36$, $p = .025$, $n = 31$) on a significance level of $\alpha = .05$. The test participants felt a significantly higher load using pick-by-paper ($M = 50.59$, $SD = 16.22$) compared to pick-by-light ($M = 46.24$, $SD = 13.50$). The effect strength according to Cohen (1992) is r = .40, which corresponds to a medium effect.

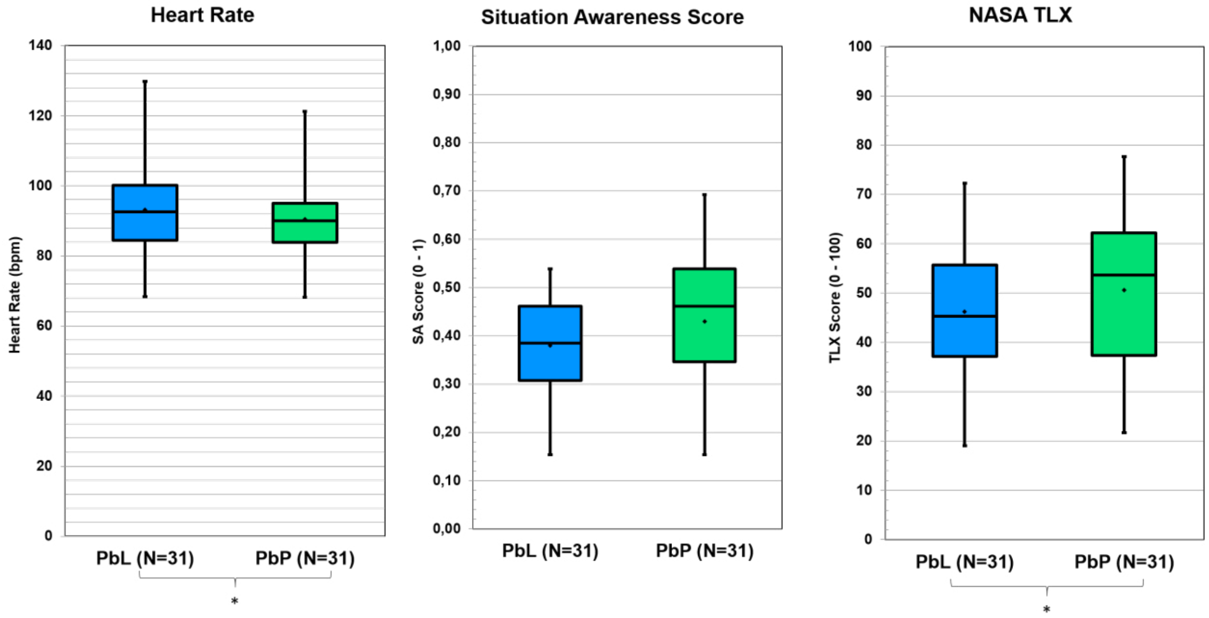

Fig. 2: Boxplots for the dependent variables of the study: Heart rate is shown in the left diagram, Situation Awareness score in the middle and NASA TLX score on the right side. Using pick-by-light is presented in blue and on the left side of each diagram, pick-by-paper on the right side and in green. Significant differences are designated witch "*".

4. Discussion

The study shows better Situation Awareness results for the use of paper based picking list compared to the pick-by-light system (though not significant). Subjects were able to answer more of the environment- and task-based questions correctly using pick-by-paper. Since the order of the questions sequence and the distribution of the questions to the two conditions varied, subjects were slightly more sensible for surrounding and task aspects using pick-by-paper. Since results did not differ strongly, however, it is not appropriate to warn of Situation Awareness problems using pick-by-light or even state the danger for a tunnel vision.

The tendency of the Situation Awareness results is supported by the heart rate results. The pick-by-light system shows a significantly higher objective strain. This suggests a more demanding task condition when using pick-by-light. This might be explained by the more intense provision of information and the higher amount of visual stimuli offered by the pick-by-light system that might as well bind visual capacity. Furthermore, confirmation steps after each SKU-picking might increase strain, since it intensifies the test situation.

However, results for subjective strain are contradictory. Subjects felt a significantly lower strain using pick-by-light which also supports findings in the literature [3]. An explanation might be that, when subjects are asked of strain, they express an assessment of the used systems as well. Following this, subjects evaluate the pick-by-light system more pleasant, more comfortable, or more interesting than the use of pick-by-paper. Moreover, some probands reported that they felt safer using pick-by-light. The TLX-subscales show that especially performance and frustration were rated better using pick-by-light. Subjects had the impression of being more performant using pick-by-light: Being able to pick more SKU while avoiding more faults. In addition, the higher frustration for pick-by-paper shows that they were rather insecure and discouraged when using pick-by-paper.

For learning factories, the results indicate two interesting aspects in particular: On the one hand, pick-by-light might offer the potential of easier and more enjoyable picking tasks. Especially employees in training situations might be motivated using pick-by-light. On the other hand, results show that pick-by-light might absorb more cognitive and visual resources. Employees might engage more intensely with task and environment using the picking list. Especially for training processes in learning factories, it is reasonable not to fully convert to pick-by-light.

5. Outlook

The CiP learning factory at TU Darmstadt did not previously contain a pick-by-light system for the material warehouse. The prototypical system used in the experiment will be adapted to the future demands of the learning factory and checked for implementation. It could be used for training processes that are not focused on intralogistics, e.g. process optimization of assembly, or for digitization training. If training focuses more on intralogistics paper based picking lists will also be used in the future to achieve a more intense training of task and process. An interesting aspect for future experiments is the combination of Situation Awareness and performance using pick-by-light-systems. Since these systems are often used for decreasing picking time and picking errors it could be assessed to which extent Situation Awareness influences performance.

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