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Effects of Information Content in Work Instructions for Operator Performance

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Abstract

Operators remain as important resources in complex final assembly. To sustain a multi-variant production, it is necessary for operators to manage high demands from a cognitive workload perspective. In such situations, work instructions can support operators cognitively. However, work instructions are often insufficient or unused in final assembly. In this paper, results from testbed experiments are presented where assembly work was supported by different types of work instructions with differing information content. Results indicate that operator performance in terms of perceived cognitive workload and information quality are affected by the presented content of information in work instructions.

Keywords: work instructions; information content; operator performance; final assembly; CPPS-testbed.

1. Introduction

With a growing amount of product variants in final assembly, the perceived complexity of shop-floor operators also increases [1-3]. Human labour, which remains inseparable from modern production systems [2, 4, 5], require cognitive support to manage the cognitive challenges of multi-variant production [6], which can be helped by improving both the quality of the provided information and the methods for providing said information [7]. When improving methods

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for sharing information, both visual [8] and digital [9] presentation, together with the accessibility of information, making it easier for operators to find the information [10] are important to consider.

Despite that early research on assembly instructions favours instructions where text and pictures are combined [11], work instructions are frequently text-only [12]. While these early experiments focus solely on time and quality for performance evaluation of one type of assembly [11], modern human-centered testbeds for multi-variant assembly work can facilitate experiments that have the possibility assess a variety of measurements [13].

Hence, this paper aims to assess operator performance in a testbed environment with multi-variant assembly, not only in terms of assembly quality but also operator workload. Furthermore, perceived complexity of work stations and quality of information in the work instructions are also assessed. These results are evaluated with regards to three types of work instructions.

2. Work Instructions

In theory, two approaches to manage the dissemination of information and knowledge within organizations, such as work instructions, exist: personalization and codification [14]. The personalization approach emphasizes human interaction to share information and the codification approach relies on documentation of information. Even though it is difficult to distinctively discern them in practice, many organizations use a combination of both extent [15]. An example could be that work tasks are instructed face-to-face between an experienced operator and a novice, while at the same time a documentation of said work tasks exists. While a face-to-face sharing of information can support the documented information, time for this type of interaction is often limited [16], thus making the documentation of work instructions more important. In creating such work instructions, it is important that the content of the presented information fit the intended end-user [17].

2.1. Design Principles for Information Presentation (DFIP)

Previous research has suggested six principles for how to design better presentation of information concerning assembly instructions, so called Design Principles for Information Presentation (DFIP) [18]. These six principles aim lower complexity for operator:

- 1. Choose a work task in the work place
- 2. Identify and support active cognitive processes in each sub-task
- 3. Analyse tasks based on how the operator perceives the work environment
- 4. Analyse tasks depending on cognitive limitations
- 5. Analyse tasks depending on individual differences and needs
- 6. Analyse tasks depending on placement of information content and carrier

Of these principles, number 2-6 were used to support the creation of the work instructions used in the experiments of this paper. Design principle number 1 was not applicable, since the work place was designed for these experiments.

2.2. Development of Work Instructions

For the experiments conducted in this paper, the work instructions were created for three different product variants [13]. Further, three types of work instructions were created for these product variants in the Casat software:

- Text and picture based instructions in Casat
- Text-only instructions in Casat
- Text and picture based instructions on paper, with the same information content as the text and picture based instructions in Casat

First, the text and picture based instructions in Casat were created and balanced for the three product variants and the three assembly stations. Then, the pictures were deleted for the text-only instructions in Casat, and finally, the information content of the text and picture based instructions in Casat were extracted to a paper version.

3. Experiment Set-up

The experiment set-up consisted of three manual assembly stations along a conveyor belt, which can be seen in Fig. 1. Each of the three assembly stations was equipped with a touchscreen monitor that displayed work instructions and the components necessary for assembling the product at that station [13]. The task that the test subjects conducted at the work stations were assembly of small LEGO models.

Fig. 1. The experiment set-up during one of the runs, with three manual assembly stations.

3.1. Assembly Quality (NPAC)

To assess the quality of the assembly work, the number of parts assembled correctly (NPAC), a non-negative integer, were calculated for each product [19]. While quality could be represented as the inverse of scrap rate or low deviation of product measurements, these concepts tend to focus on the quality of the production or the product. NPAC, on the other hand, focuses on the how well the assembly operator manages to perform.

In order to arrive at the NPAC value, the number of wrongly assembled components are subtracted from the number of components that the product consists of [19].

3.2. Operator Workload (NASA-TLX)

The cognitive workload of the test subjects for the assembly task during the experiments was assessed by using widely used NASA-TLX surveys, which contain six subscales with 21 gradations: mental demand, physical demand, temporal demand, performance, effort, and frustration level [20].

3.3. The Complexity Index (CXI)

CXI is a survey method used to assess perceived production complexity at a station level [21]. The method has been used at 17 stations, and was developed in 2011. In this experiment a smaller part of the CXI was used to investigate the impact of work variance and disturbance handling (two of the three areas in CXI). These questions include statements concerning work instructions, stress and available time and were recently used to investigate the relationships between empowerment and stress.

3.4. Information Quality

To assess the quality of the information provided to the test subjects, i.e. the assembly instructions, six attributes of information quality were used: comprehensiveness, validity, timeliness, accuracy, relevance, and accessibility [7]. Based on these six attributes, six statements were formulated, corresponding to the six attributes:

- Comprehensiveness: The instructions were sufficiently comprehensive for my assembly work (contained all necessary information).
- Validity: During my assembly work, I could trust that the instructions were correct.
- Timeliness: The instructions were presented at the right time (for me to perform my assembly work).
- Accuracy: The instructions were suitable for the task (assembly).
- Relevance: The instructions represented the reality.
- Accessibility: The instructions felt accessible, e.g. physical access, simple to navigate.

A survey with a five-level Likert-type scale for these six statements was created, ranging from 'fully disagrees' (1) to 'fully agrees' (5).

3.5. Participant Sample

In total, four experiment runs were conducted with three test subjects each. These 12 participants were recruited through advertisement on campus Lindholmen at Chalmers University of Technology. Further characteristics of the participant sample are listed in Table 1.

Table 1. Participant sample.

Sample	Experiment group
Percentage, male/female (no.)	83% male (10) 17% female (2)
Average age	29.1 years
Percentage, experience with assembly work (no.)	58% no experience (7) 25% 3-8 months (3) 8% 2 years (1) 8% no answer (1)
Percentage, experience with LEGO assembly (no.)	33% 1-5 years (4) 25% 6-14 years (3) 17% no or little experience (2) 17% more than 20 years (2) 8% no answer (1)

The four experiment runs were conducted with the same method, but with different types of work instructions, as listed in Table 2.

Table 2. The four experiment runs, and its instruction types.

Experiment run	Instruction types
X	Casat, text and picture
Y	Casat, text and picture
Z	Casat, text only
W	Paper, text and picture

3.6. Description of an Experiment Run

First, three test subjects arrived and were introduced to the experiments, both concerning the tasks itself and to the measurements and assessments. Then, for the experiment runs X, Y, and Z the test subjects were introduced to how to use the work instructions in the Casat software.

After the introduction, the test subjects were assigned to their first work station (1, 2, and 3), where they studied how to assemble the product variant (A, B, and C) for the assigned station using the paper instructions used in experiment run W. At this stage, the test subjects were considered novices from an experience perspective. When the test subjects reached a consensus on readiness to start the assembly work, they put the paper instructions aside and started using the instructions in Casat (except for experiment run W, where the test subjects kept the instructions), assembling nine products, with the variants in a pre-defined randomized order: C, B, A, B, B, C, C, B, C. After these assemblies, the test subjects filled out a NASA-TLX survey.

Then, the test subjects switched work stations by rotation, where the test subject starting at station 1 moved on to station 2, the test subject at station 2 moved to station 3, and the test subject at station 3 moved to station 1. At this stage, the test subjects were considered intermediates. The test subjects studied the instructions for the three variants of their new station and then assembled in the same order of variants as earlier. After these second round of assemblies, the test subjects filled out another NASA-TLX survey.

At last, the test subjects made a final rotation of work stations and repeated the process of studying instructions, assembling products, and filling out another NASA-TLX survey. During this rotation, the test subjects were considered as experienced.

After the three rotations, the test subjects filled out the survey concerning their perception of the information quality contained in their work instructions.

4. Results

The results obtained from the experiments assess assembly quality, operator workload, and information quality. The results from experiment runs X and Y were combined, as the same instruction type was used.

4.1. Assembly Quality (NPAC)

The quality of the performed assembly work was assessed with regards to instruction types and test subjects' experience during the experiment runs, which can be seen in Table 3. Assembly errors only occurred for the first round of assemblies, when the test subjects were considered novices, and only when the Casat software was used.

Table 3. Assembly quality (NPAC %), with regards to instruction types and experience of test subjects.

Instruction types	Novice	Intermediate	Experienced
Casat, text and picture (runs X and Y)	98.31%	100%	100%
Casat, text only (run Z)	98.94%	100%	100%
Paper, text and picture (run W)	100%	100%	100%

The maximum possible NPAC varies for the different stations, see Table 4 (first row). This difference was purposefully created to impose a difference of cognitive difficulty for the test subjects. The average NPAC across the three work stations can be seen in Table 4. The average NPAC for each of the stations signify the assembly quality, where the assemblies of station 1 were all assembled correctly, while for stations 2 and 3 there were some assembly errors. The percentage of assemblies that were assessed with the maximum NPAC value for each of the stations differs conceptually from the average NPAC, since one assembly error for one product entails error for that product. In Table 4, this means that 94.44% of the assembled products at station 2 had no errors at all.

Table 4. Two different approaches to use NPAC, with regards to assembly stations.

Station	Average NPAC of all assemblies	Percentage of assemblies that were assessed max NPAC
1 (max NPAC: 6)	6.00	100%
2 (max NPAC: 7)	6.94	94.44%
3 (max NPAC: 5)	4.99	99.07%

The assessed assembly quality of these experiments can be considered relatively high. The only assembly errors that occurred happened for novices using the Casat software at stations 2 and 3.

4.2. Operator Workload (NASA-TLX)

The workload of the operators was assessed between and after the three assembly rounds, and the average values for the subscales are presented in Table 5. Instead of weighing the NASA-TLX subscales, they are here studied individually. The subscale of performance was unclear for many of the test subjects and thus is not included in the results. In general, the text-only instructions resulted in a higher workload for the test subjects than the other two instructions types but required less effort. While text and picture based instructions for both Casat and paper version seem to be of similar value for many of the NASA-TLX subscales, temporal demands and effort are lower for the test subjects using the Casat software.

Table 5. NASA-TLX averages, with regards to instruction types.

Instruction types	Mental demands	Physical demands	Temporal demands	Effort	Frustration level
Casat, text and picture (runs X and Y)	3.83	3.47	4.42	4.83	3.58
Casat, text only (run Z)	7.22	5.22	6.67	4.11	4.89
Paper, text and picture (run W)	3.83	3.11	6.25	5.89	3.44

4.3. The Complexity Index (CXI)

For the CXI questions a difference between stations could be seen. A slightly higher CXI was found for station 2, see Table 6. All stations were perceived as moderate in complexity due to the area work variance. The statement that had the highest average was statement 3: Many variants are similar to one another regarding function and/or external surface at this station.

Table 6. CXI for station 1-3

Station	Complexity Index (CXI)
1	2.38 (moderate complexity)
2	3.19 (moderate complexity)
3	2.38 (moderate complexity)

4.4. Information Quality

The quality of the information, contained in the three instruction types, were subjectively assessed by the test subjects, with the average values presented in Table 7 for the six information quality attributes. In general, all attributes scored relatively high, close to the maximum value of 5. Only for text-only instructions, some attributes were lower than 4: comprehensiveness, accuracy, and accessibility, which could be expected, since these work instructions lacked pictures, could be considered less suitable for the task and were physically unwieldy. However, the text and picture based instructions for both Casat and paper version scored similarly, which can be because the same information content was presented, lack of experience of using Casat software, and the possibility to place the paper instructions of the three variants next to each other to gain an overview.

Table 7. Information quality averages, with regards to instruction types.

Instruction types	Comprehen-siveness	Validity	Timeliness	Accuracy	Relevance	Accessibility
Casat, text and picture (runs X and Y)	4.83	4.50	4.80	4.83	4.83	4.33
Casat, text only (run Z)	3.67	5.00	5.00	3.33	4.50	3.33
Paper, text and picture (run W)	5.00	5.00	5.00	4.67	4.67	4.67

Information quality was rated as very good in almost all runs. Only for the text-based instructions the information quality was rated slightly worse.

5. Discussion

The results indicate that the two facets of operator performance that are evaluated in this paper, assembly quality and operator workload, are affected differently by information content. Especially since that despite being instructed the same way, some test subjects tended to deviate in terms of standardized work. As an example it was seen that two operators pre-assembled tasks without asking for permission while other participants explicitly asked if it was allowed or not (during separate experiments). Although some results were as anticipated, some results were surprising.

The results on assembly quality remain relatively high, seemingly unaffected by information content (text and picture). The slightly lower percentage of assembly quality aligning with the use of the Casat software may be attributed to test subjects' inexperience of using the software as novices.

For the operator workload, the results from the NASA-TLX surveys indicated that the perceived workload that was higher for the text-only instructions and that pictures in work instructions comparably decrease cognitive demands and alleviates frustration among operators. This difference may be caused by that text-only instructions may require more focus during assembly work. However, since the data relies on three participants, further tests are needed.

Participants considered the stations to be moderately complex. This was mainly due to that variants were similar to one another. These results are relevant since it is important that the stations are not considered to be simple to work at (to make the assembly work realistic it should not be too easy to learn or work at the station). To be able to really study the impact of multi-variants assembly an increase in complexity is needed. This could be done through an increase in assembly variants.

Furthermore, from a quality of information content perspective, text and picture based instructions are preferred over text-only instructions, which is similar to the operator workload perspective. Concerning the accessibility of these instructions, it was possible for test subjects to place paper instructions of the three variants next to each other in order to get an overview of all three product variants, which was not possible with the in instructions in the Casat software. However, if the number of product variants increases and it becomes cumbersome to manually manage a larger number of paper instructions, a digital system for work instructions would better cognitively support operators.

6. Conclusion

Operator performance in terms of perceived cognitive workload can be improved, i.e. lowered cognitive workload, by including pictures to text instructions. In comparison to text-only instructions, perceived information quality is higher for text and picture based instructions. However, if the number of product variants increases, digitalized work instructions will be better than paper-based instructions in terms of accessibility for operators.

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