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Potentials of an informational assembly assistance system for persons with cognitive disabilities—Results of a laboratory study

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Abstract
In Germany, individuals unable or not yet able to return to the general labor market due to disabilities are employed in sheltered workshops which are called WfbM ("Werkstätten für behinderte Menschen"). These organizations are required to earn the wages for the aforementioned group of people by offering market services. These services include, in particular, assembly activities. However, WfbM face the challenge that customer orders tend to become more complex, especially as a result of an increased number of product variants. This development not only has an impact on the work in WfbM, but also makes it much more difficult to achieve the desired inclusion of people with disabilities in the general labor market. Bearing this in mind, the research question addressed in this article can be stated as such: How far can the use of an informational assistance system compensate for performance deficits of people with disabilities in the context of assembly? The results of the conducted laboratory study show that the implementation of an assistance system can help to reduce existing barriers and challenges resulting from the mismatch between requirements of the general labor market and the performance characteristics of people with cognitive impairments.
Practical Relevance: For people with disabilities, the use of assistance systems opens up new opportunities for participation in the general labor market and thus makes an important contribution to implementing the requirements of the "Bundesteilhabegesetz" (a law to strengthen participation of people with disabilities in Germany).

Keywords Informational Assistance System · People with Disabilities · Manual Assembly · Image Processing System · Laboratory Study

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Potenziale eines informatorischen Montageassistenzsystems für Personen mit kognitiven Unterstützungsbedarfen – Ergebnisse einer Laborstudie

Zusammenfassung

In Deutschland werden Personen, die aufgrund von Beeinträchtigungen nicht bzw. noch nicht wieder auf dem allgemeinen Arbeitsmarkt tätig sein können, in einer „Werkstatt für behinderte Menschen (WfbM)“ beschäftigt. Diese Einrichtungen müssen die Arbeitsentgelte für den genannten Personenkreis durch am Markt angebotene Leistungen selbst erwirtschaften. Zu diesen Leistungen zählen vor allem Montagetätigkeiten. Allerdings stehen WfbM vor der Herausforderung, dass Kundenaufträge insbesondere infolge einer gestiegenen Variantenvielfalt tendenziell komplexer werden. Diese Entwicklung wirkt sich nicht nur auf die Arbeit in den Werkstätten aus, sondern hat auch zur Folge, dass die angestrebte Inklusion von Personen mit Unterstützungsbedarfen in den allgemeinen Arbeitsmarkt deutlich erschwert wird. Vor diesem Hintergrund wird in dem Beitrag der Forschungsfrage nachgegangen, inwieweit der Einsatz eines informatorischen Assistenzsystems Leistungsdefizite von Personen mit Unterstützungsbedarfen im Kontext der Montage ausgleichen kann. Die Ergebnisse der durchgeführten Laborstudie zeigen, dass die Einführung eines Assistenzsystems dazu beitragen kann, bestehende Barrieren, die sich aus der Inkongruenz zwischen den Anforderungen des allgemeinen Arbeitsmarktes und den Leistungsmerkmalen von Personen mit kognitiven Beeinträchtigungen ergeben, abzubauen.

Praktische Relevanz: Der Einsatz von informatorischen Assistenzsystemen kann Personen mit Unterstützungsbedarfen eine Teilhabe am Arbeitsleben ermöglichen und leistet damit einen wichtigen Beitrag zur Umsetzung des Bundesteilhabegesetzes.

Schlüsselwörter Informatorisches Assistenzsystem · Personen mit Unterstützungsbedarfen · Manuelle Montage · Bildverarbeitungseinheit · Laborstudie

1 Introduction

In Germany, individuals unable or not yet able to return to the general labor market are employed in sheltered workshops (Werkstätten für behinderte Menschen (WfbM), in literal translation “workshops for people with disabilities”). Their purpose is to enable integration and participation in working life and to promote the transition of suitable people to the general labor market via appropriate measures (§ 219 SGB IX). In total, there are over 700 main workshops in Germany with more than 3000 facilities, employing around 310,000 people with disabilities (Berg et al. 2023). Impairments are divided into physical, mental, and cognitive impairments, with people with cognitive performance impairments being primarily employed in WfbM—75.3% of the workforce in 2022 (Berg et al. 2023). Although these workshops are predominantly financed by the state, they must generate the wages for those employed in the working area themselves by offering services on the market (Section 221 (2) SGB IX). Many of the services offered are based primarily on simple assembly and packing activities for the industrial enterprises located in their respective region (Doose 2009). The tasks on which these activities are based are often characterized by large batches and thus high repetition frequencies as well as low work content, so that even people with cognitive impairments can learn these tasks and develop a routine. Workshops, however, are faced with the challenge that the number of variants of their customers' products is in many cases increasing and that more and more quality requirements must be taken into account. Case studies in the “SInnAssist” project have shown that people employed in WfbM are sometimes unable to take these increased requirements into account, resulting in assembly errors and complaints from WfbM customers. In addition, an increase in the complexity of assembly and packing tasks in industrial enterprises negatively impacts the intended goal of inclusion of people with cognitive impairments in the general labor market, meaning that transfers from WfBM to “normal” companies are often unsuccessful. The current transition rate in Germany is only around 0.16% per year, i.e., very few people with disabilities succeed in making the switch (Detmar et al. 2008).

2 State of research

Employees in multi-variant assembly have to absorb and process large amounts of information by continuously making decisions about the components to be assembled, and the tools or working methods to be used. The share of informational work in assembly tends to increase as more and more products are configured according to customer requirements and supplementary functions and thus components are integrated into products. Whereas manual assembly was for a long time considered primarily as an energetic work, in the present and future, the informational topics of assembly are to be emphasized. The design of manual assembly systems is therefore in the meantime to a large extent also a field of cognitive ergonomics (Hollnagel 1997; Bläsing et al. 2021).

Empirical studies point to multiple deficits in the informational design of manual assembly systems (Claeys et al. 2015). These incompatibilities between the information demand of the employee and the information supply in the work system lead, for example, to task interruptions, search processes or consultations with superiors, colleagues or designing engineers, which means that the share of contingency allowances in the production times increases (Hinrichsen and Bendzioch 2019). Incompatibilities cannot usually be avoided altogether, only minimized. Thus, according to the complexity-compatibility paradigm, an increase in complexity in a work system leads to a decrease in the effectiveness potential of ergonomic measures (Karwowski 2005). Typical incompatibilities between information demand and supply are referred to as "deficits" (Strasser 2021) or "gaps" (Hinrichsen et al. 2022). These typical incompatibilities can be highlighted using a model of human information processing (e.g., Schlick et al. 2018; see Fig. 1). The first incompatibility shown in the model may occur when the assembler lacks information ("missing data") to perform the next assembly step (Gap 1). It's also possible that the provided assembly instructions contain errors ("wrong data"—Gap 2). But even if all the required data or information is available and correct, the employee may not be aware of the information because it is, for example, included in a complex design drawing and overlooked ("no direct perception of the data"—Gap 3). If the employee perceives the required data, there may still be the problem of misinterpreting or complicated and time-consuming decoding of the data (Gap 4). And even if the data provided are interpreted correctly, distractions or inattention can lead to incorrect actions ("routine error"—Gap 5). If there is no feedback from the system (Gap 6), the error may not be corrected or uncertainties may arise that lead to additional activities (e.g., asking colleagues). In addition, individual gaps, for example Gap 4, arise from forgetting information (Gap 7) or interindividual differences in experience (Gap 8).

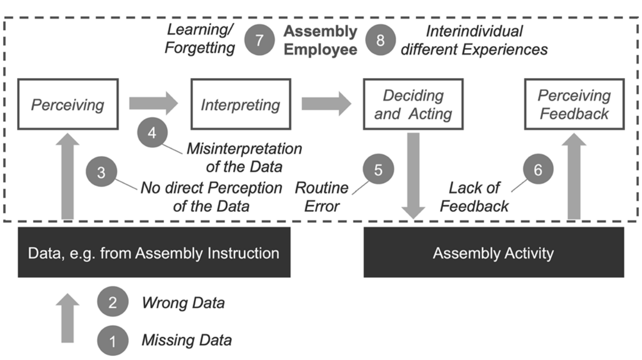


Fig. 1 Gap model of information processing in manual assembly (Hinrichsen et al. 2022, modified)

Abb. 1 Lückenmodell der Informationsverarbeitung in der manuellen Montage (Hinrichsen et al. 2022, modifiziert)

Ergonomically prepared information, in conjunction with informational assistance systems, can help to minimize or close individual gaps. In this respect, assistance systems aim to provide the right information at the right time and in the desired form (Claeys et al. 2015), so that it can be more easily absorbed and processed by the employee. For this purpose, assistance systems are configured in accordance with operational and personnel requirements. Key aspects that allow modification include the required hardware components, the user interface, and the connection to other IT systems (Hold et al. 2017). This way, for example, information can be output step by step via a screen. In addition, assistance systems offer the possibility of using various sensors, such as a vision sensor, to provide feedback on whether individual picking or assembly steps have been carried out in accordance with requirements. Assistance systems are described as adaptive if they can be tailored to selected characteristics of employees (e.g., changing the font size to compensate for a user's visual impairment; extent of support provided by the assistance system depending on the user's experience).

Informational assistance systems thus offer a non-negligible potential to further resolve the discrepancy between the requirements of the general labor market and the performance characteristics of people with cognitive impairments. A total of six studies could be identified that explicitly deal with the potential capabilities of informational assistance systems regarding people with disabilities (Table 1). The object of these studies were different display and output modalities of informational assistance systems in comparison to a control medium. Trial content included assembling Lego® assemblies (two of six trials), cutting parts for a jewelry box, inserting parts of a screw clamp into a machine, assembling five multi-outlet power strips, and mounting three metal rings on a metal rod. The total results are to be evaluated as positive. For example, using an informational assistance system predominantly leads to shorter execution times and fewer errors or better work results (Funk et al. 2015a, b; Aksu et al. 2019; Mark et al. 2021; Bendzioch and Hinrichsen 2023). However, the significance of these results is restricted or limited by the fact that the sample size is sometimes too small and/or the subjects in the experimental and control groups are identical (sequence effects). Furthermore, it can be seen from Table 1 that in some studies the comparison medium is not specified in detail, which makes it difficult to interpret the results. Similarly, only two studies consider an industrial assembly task (Mark et al. 2021; Bendzioch and Hinrichsen 2023), making it difficult to transfer the other findings to manual assembly. Although an industrial assembly is also used in the study by Funk et al. (2015a), the activity is not a con-

Table 1 Studies on the application potentials of information-based assembly assistance systems for people with disabilities
Tab. 1 Studien zu den Einsatzpotenzialen von informatorischen Montageassistenzsystemen für Personen mit Unterstützungsbedarf

Author	Assembly Task	Assistance Medium	Reference Medium	Participants (*Groups*)
Aksu et al. (2019)	Cutting process for a jewelry box	Information on a notebook	Not specified	$n=5$ *(2 groups of 5 persons)*
Bendzioch and Hinrichsen (2023)	Mounting five socket strips	Monitor with an image processing unit	Paper-based instruction	$n=20$ *(2 groups of 10 persons)*
Funk et al. (2015a)	Insert five components of a screw clamp into a machine	Projector for displaying pictures, videos, and contours	Verbal instruction	$n=64$ *(4 groups of 16 persons)*
Funk et al. (2015b)	Five Lego® assemblies with 6 to 48 parts	Projector with image processing unit	Information on a monitor	$n=15$ *(2 groups)*
Korn et al. (2013)	Lego® assembly with 8 parts	Projector and a monitor with a gamification approach	Information on a monitor	$n=60$ *(3 groups of 20 persons)*
Mark et al. (2021)	Mounting three metal rings on a metal rod	Combination of several assistance systems	Not specified	$n=7$ *(2 groups of 7 persons)*

ventional assembly operation, but merely the insertion of components into a machine. In addition, it should be noted that variant diversity, i.e., switching between different tasks, has only been considered in two studies (Funk et al. 2015b; Bendzioch and Hinrichsen 2023). However, given the trend that the complexity of assembly tasks is increasing, the cognitive transition from one task to the next should be understood as an essential skill or work requirement.

Overall, the analysis of existing studies clearly shows that there is a need for further research to better specify the potential use of information-based assistance systems for people with cognitive impairments in multi-variant assembly. A question that needs to be addressed in particular is the extent to which such a system is suitable for compensating performance deficits when compared with a control group of people without cognitive performance impairments, in order to give people with such an impairment better access to the general labor market in the future.

3 Objective

Existing mechanisms of prejudice or stereotypes about the performance of people with impairments—direct or indirect discrimination—make the transition to the general labor market more difficult (Kardorff et al. 2013). With this in mind, the existing research design of the previously mentioned study by Bendzioch and Hinrichsen (2023) is extended to include another group of people, individuals without cognitive performance limitations, to further explore the effects of an informational assembly assistance system. The research question to be specifically addressed is: To what extent can the use of an informational assistance system compensate for performance deficits of individuals with cognitive impairments (relative to a comparison group of people without cognitive performance impairments) in the context of multi-variant assembly? The study thus addresses the research gap outlined in the State of Research and is intended to provide information on improved inclusion through comparison with a control group (individuals without cognitive performance impairments).

4 Design of experiment and methodology

4.1 Research design

4.1.1 Support systems

In the experimental study, two types of assistance are used: An assistance system from the RICOH company and a paper-based assembly instruction—which is still common in many companies (Bannat 2014). The assembly assistance system—RICOH SC-10A (H)—is an image processing system, that offers a special feature by which the employee not only receives feedback on the error-free or faulty execution of each assembly step but is also shown instructions on how to execute the step. Assembly instructions can be created quite easily (without programming) via software. A screen serves as the output device for all information.

The information relevant to assembly is prepared with the same content and scope of information for both types of support (assistance system and paper manual). These are based on a step-by-step assembly instruction, which contains information on how to carry out individual operations and on the tools and materials required for each operation (see Fig. 2). Considering that assembly instructions often have deficits in practice (Hinrichsen and Bendzioch 2019), special attention was paid to making the step-by-step assembly instructions as user-centered as possible by involving employees from a workshop for people with disabilities in the design. In the instruction, for example, material retrieval is aided by highlighting the relevant container po-

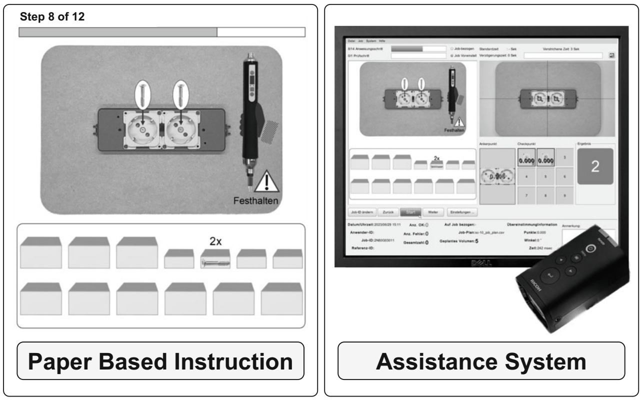


Fig. 2 Assistance systems used in research design
Abb. 2 Eingesetzte Unterstützungssysteme im Forschungsdesign

sitions in a true-to-scale illustration of the material supply (see Fig. 2).

As can be seen from Fig. 2, the information relevant to assembly is provided in the same form and to the same extent for both media, with the exception that in the case of the assistance system, additional feedback is output via the right side of the screen regarding the error-free or incorrect execution of an assembly step. This feedback takes the form of a live image recorded by the image processing unit, onto which the previously defined inspection features are superimposed. Only when all defined inspection characteristics match the stored reference image will information on the next assembly step be displayed on the screen. This ensures that, at the time of testing, the inspection characteristics defined for an assembly step, and with that the respective assembly operations, have been carried out without error.

4.1.2 Assembly task

In order to ensure applicability of the study results to industrial practice, the present study uses various products from one manufacturer for multi-variant power strips. These products are assembled in the laboratory but using original parts and tools. The object of the study are five different variants of a multi-outlet power strip (see Fig. 3). To simulate a multi-variant or customer-specific assembly, the products differ in their color design, making it difficult for the subjects to develop routines and requiring a "cognitive adjustment" from product to product.

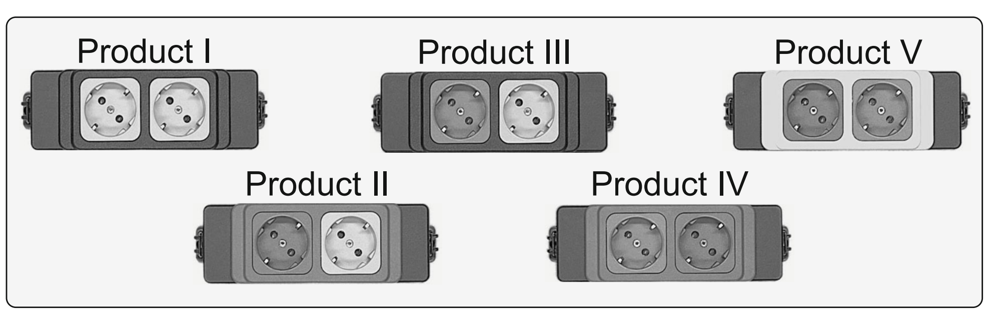
The order shown in Fig. 3 is binding for all test participants. This order was determined at random. A total of 18 individual parts are required per power strip assembly, with the test subjects having to distinguish between 13 different parts in the work system. In addition, the assembly task is notable for the fact that very different errors (e.g., incorrect positioning or mixing up of individual parts) can occur during its execution.

4.1.3 Experimental setup

The experimental procedure is carried out at a standing workstation sold by the company RK Rose+Krieger. The working surface of the assembly table has dimensions 1210×540 mm. The minimum working height is 933 mm. To ensure ergonomic posture, the workstation is height adjustable—400 mm lifting columns. Similarly, the workstation features two separable elements, the assembly table and the material supply rack (see Fig. 4). On the work surface of the assembly table, there is a wooden assembly fixture, designed to simplify handling and joining individual parts. The individual parts are supplied via grab containers arranged on two levels. To be able to clearly distinguish the grab containers and the parts stored in them from each other, a label with the material number and part designation is attached to each container.

For the assembly of the multi-outlet power strips, a torque-controlled screwdriver suspended from a tool balancer is available in the center of the work system, set to the appropriate torque and equipped with the correct bit. To ensure sufficient workplace illumination, it is equipped with an LED illuminant—approx. 2300 lm and approx. 5000 k. In addition, the workstation is shielded with a cover plate above the work system to prevent changes in illumination. The assistance system by RICOH described at the beginning is also firmly mounted above the work system (see Fig. 4). On the left side of the workstation a 19-inch screen is mounted at eye level, which displays the relevant assembly information as well as feedback from the assistance system. An additional IP camera is located above the workstation in order to minimize the influence of

Fig. 3 Assemblies according to the study design (Bendzioch and Hinrichsen 2023, modified)
Abb. 3 Baugruppen im Forschungsdesign (Bendzioch und Hinrichsen 2023, modifiziert)



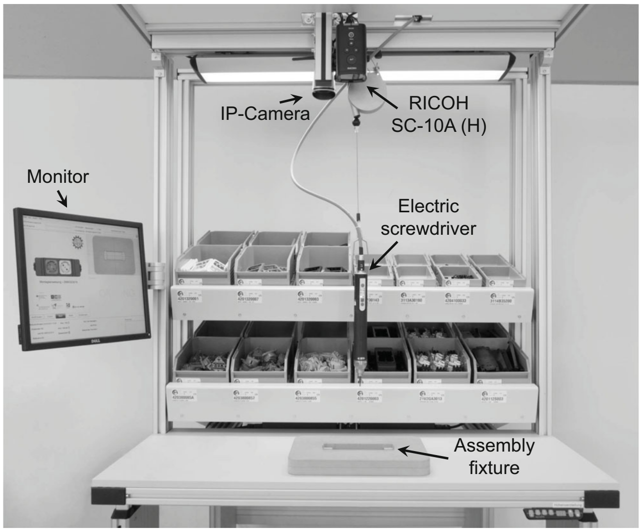


Fig. 4 Study setup (Bendzioch and Hinrichsen 2023, modified)
Abb. 4 Untersuchungsaufbau (Bendzioch und Hinrichsen 2023, modifiziert)

the test supervisor during the test procedure. With this, the test procedure can be monitored live via a separate screen at a sufficient distance from the test subject—approx. 3 m.

4.1.4 Independent and dependent variables

Based on the research design described above, this study uses two factors, each with two-factor levels, as independent variables—a two-by-two-factor research design. With the first factor, the type of support is varied in two levels: (1) informational assistance system and (2) paper-based information provision—control medium. The second factor comprises the distinction between two groups of individuals. The first group consists of individuals with cognitive impairments (experimental group) who work in a workshop for people with disabilities. The individuals in the second group have no cognitive performance limitations and act as a control group. Both groups are divided into two subgroups according to the research design—assistance system and paper-based instruction.

Whether and to what extent the two groups of individuals differ from and among each other due to the use of the information-based assistance system or the paper-based assembly instruction is examined based on the following dependent variables: Duration of assembly of a product (execution time), number of assembly errors, number of picking errors, assembly result (correct or incorrect) and mental stress. The characteristics of the dependent variables are recorded for the assembly of each multi-outlet power strip. How data on individual dependent variables are determined is described in Sect. 4.2.2.

4.2 General approach

4.2.1 Pre- and post-tests

Three different pre-tests and one post-test are used in the empirical study, which are described in more detail below:

Pre-test *Collection of personal data:* The personal data is collected using a questionnaire. In addition to questions on age, gender, and occupational status, the questionnaire also includes questions on the performance of assembly tasks and career prospects. Since it cannot generally be assumed that people with cognitive impairments can read, write, and calculate, this is queried as a basis for understanding the subsequent assembly instructions—basic understanding. In addition, subjects are asked to provide a self-assessment of their manual dexterity on a scale of 1 to 10, as well as information about their prior task-specific experience. Finally, the subjects also have to make a statement about their career prospects with a time horizon of three years, with the aim of highlighting differences between the groups of individuals.

Pre-test *Determination of visual acuity:* The required visual acuity is checked with a standardized eye test by Mißfeldt (n.d.). This test is an eye exam in A4 format, on which letters are shown in descending order of size. The smallest font size that must be read in the test is used as a reference or minimum visual acuity—labeling of the gripping containers. It should be noted at this point that individuals who have a visual aid must perform both the eye exam and the subsequent experiment while wearing it. The eye exam is considered as passed if the smallest font can be read aloud at a distance of 110 cm—the maximum distance in the experiment.

Pre-test *Determination of motor skills:* In addition to the subjective self-assessment of motor skills and manual dexterity, they are also checked with the aid of a reference model. The reference model is a Lego® car with 18 parts and is to be assembled in seven assembly steps. For this assembly, subjects receive paper-based instructions similar in scope and structure to those used in the subsequent main experiment. The pre-test is completed when the reference model is assembled without errors. The motor skills are evaluated based on the execution time required within one group of individuals and in comparison with the other groups.

Post-test *Determination of mental stress:* Subjectively perceived stress is recorded after each fully assembled multi-outlet power strip using a modified NASA-TLX questionnaire. For this purpose, the questionnaire of Hart and Staveland (1988) was adapted to the needs of the group of individuals so that it is easier to understand ("easy language"). Accordingly, the six items of the questionnaire are as follows: 1. Mental requirement—"Did you have to think a little or a lot?", 2. Physical requirement—"Did you have to move a little or a lot?", 3. Time requirement—"Did you have to hurry a little or a lot?", 4. Performance—"Did you do well or poorly on the task?", 5. Effort—"Did you have to exert a little or a lot of effort?", and 6. Frustration—"Did you get annoyed a little or a lot by the task?". The individual items are rated using a five-point Likert scale. Following Prabaswari et al. (2019), scores of 0 to 1.5 correspond to very low mental stress, 1.5 to 2.5 to low mental stress, 2.5 to 3.5 to medium mental stress, 3.5 to 4.5 to high mental stress, and 4.5 to 5 to very high mental stress.

4.2.2 Procedure

Before the start of an experiment, the participants are informed verbally and in writing about the procedure, the general conditions, and the study objective. Subsequently, the personal data are collected, and the motor and visual abilities are checked using the pre-tests described above. After completing these pre-tests, subjects will be randomly assigned to either the control medium (paper-based instructions) or the assistance system to perform the main experiment, assembling the five multi-outlet power strips. The introduction to the respective support medium takes place with the help of prepared documents, which are presented by the experimenter. In addition to the introduction to the respective support medium, the participants also receive instructions on assembly as well as on the use and function of the screwdriver. In addition, the height-adjustable workstation is set according to the subject's requirements.

Following the introduction and preparation of the main experiment, the multi-outlet power strips are mounted in the specified order (see Fig. 3). The assembly process as well as the time recording start with the call-up of the assembly instructions on the screen or the supply of the paper-based instructions and end with the completion of the last work step of an assembly. The required execution time is recorded by the experimenter using an Excel tool and refers to the complete assembly of a multi-outlet power strip. Errors during picking or assembly are recorded in a previously created error list with the following errors: Tool not used, component mounted in wrong position, wrong orientation of component, component not mounted, other error during assembly and wrong component grabbed (picking error). However, it must be considered that all errors are recorded, including those corrected during assembly or picking. The final assembly result for each multiple socket power strip is evaluated by the test supervisor based on defined criteria and also logged. During the period of assessment by the experimenter, subjects are directed to complete the post-test described earlier to determine subjectively perceived stress. This way, the questionnaire is completed by each subject a total of five times, so that a stress sequence is recorded across the assemblies.

4.2.3 Evaluation

The data collected during the experiment are analyzed both descriptively and by inferential statistical methods using the statistical program SPSS® 28. The focus is on the defined dependent variables, which are intended to reflect the influence of the assembly assistance system on the two groups of individuals compared to the control medium. Based on these variables and the chosen research design, test procedures suitable for the study of independent samples are selected depending on the distribution—Shapiro-Wilk test—and homogeneity of variance—Levene test—of the data set. Although the experimental design includes more than two stages, the test procedures used are, on the one hand, the t-test and, on the other hand, the Mann-Whitney U-test instead of an analysis of variance or the Kruskal-Wallis test. This ensures that only the test variables relevant to the study—e.g., experimental group assistance system vs. control group paper instruction—are considered. This is substantiated, on the one hand, by the different prerequisites of the two groups of individuals and the associated differences in performance and, on the other hand, by the fact that the control group—assistance system and paper instruction—was considered twice. Conditions that would, for example, be included in the Kruskal-Wallis test—rank sum calculation—and thus lead to a bias in the results.

For all tests performed, the significance level is $\alpha = 0.05$, with significant results ($p < \alpha$) divided into three classes: $0.05 > p > 0.01$ significant, $0.01 \geq p > 0.001$ very significant, and $p \leq 0.001$ highly significant. In order to substantiate the significance or influence of a significant result, the effect strength is further calculated using the correlation coefficient r. According to Cohen's definition (Cohen 1992), $r < 0.30$ corresponds to a weak effect, $0.30 \leq r < 0.50$ to a medium effect, and $r \geq 0.50$ to a strong effect. The inferential statistical results are supplemented by figures and tables on the location and distribution of the data using descriptive analyses.

4.3 Participants

A total of 20 subjects with cognitive impairments (7 women and 13 men) and 20 subjects without cognitive performance impairments (2 women and 18 men) participated in the empirical laboratory study (see Table 2). In total, 10 individuals from the respective group can thus be considered for each of the two condition combinations—comparison

Table 2 Personal data of the study participants
Tab. 2 Personenbezogene Daten der Versuchsteilnehmenden

	People with disabilities —*Experimental group*	Students and academic staff —*Control group*
Number of subjects	$n=20$ (7 women, 13 men)	$n=20$ (2 women, 18 men)
Age	M = 34.30 [years] SD = 14.34 [years]	M = 33.90 [years] SD = 14.37 [years]
Reading, Writing & Arithmetic	Basic understanding met	Basic understanding met
Line of work of the subjects	35% Assembly; 25% Vocational training; 20% Metalworking; 10% Joinery; 10% Textiles	55% Studies with a technical background; 45% Research and teaching
Assessment of own manual dexterity	M = 7.55; SD = 2.16 (on a scale of 1 to 10)	M = 7.90; SD = 1.33 (on a scale of 1 to 10)
Prospects for the next 3 years	35% No idea; 30% General labor market; 25% WfbM; 10% Pension	45% General labor market; 35% Continued employment at TH OWL; 15% (Doctorate) studies; 5% Pension

medium paper vs. assistance system. Both groups of individuals have a similar age structure: Experimental group M = 34.30 years (SD = 14.34 years) and control group M = 33.90 years (SD = 14.37 years). Subjects in the experimental group were drawn from typical work sectors within a workshop for people with disabilities (WfbM), such as assembly or joinery, while subjects in the control group were students and academic staff at the university. The examination of the reading, writing, and arithmetic skills showed that the prerequisites for carrying out the laboratory test were met in all subjects. Both groups of subjects rate their manual dexterity similarly (see Table 2).

While testing visual performance, it was confirmed that the participating subjects all had adequate vision. The answers to the question regarding previous experience with the experimental task revealed that all subjects had no experience with the assembly of multi-outlet power strips. However, differences between the groups of individuals were found in the examination of motor skills. This can be seen in Table 3, which shows that the execution time, on average (M), for assembling the Lego® reference model is significantly higher for the experimental group than for the control group. This difference also exists with respect to the standard deviation (SD). The large variation in execution times among the experimental group illustrates that the performance level of the subjects—due to individual limitations—is very different. Furthermore, it can be seen from Table 3, considering the assistance medium assigned later in the main experiment, that the execution times of the respective group using the assistance system tend to be slightly shorter (ex-post observation). For the control group, this difference proves significant using a t-test ($t(18)=2.114$, $p=0.049$, $r=0.445$).

Table 3 Execution time of the Lego® reference model using a paper-based instruction
Tab. 3 Ausführungszeit des Lego®-Referenzmodells unter der Verwendung einer papierbasierten Anweisung

	M [s]	SD [s]	Number of subjects
Experimental group			
Total	205.20	98.16	20
Assistance system	195.80	91.46	10
Paper-based instructions	214.60	108.52	10
Control group			
Total	82.95	18.52	20
Assistance system	74.90	15.07	10
Paper-based instructions	91.00	18.78	10

Further examination of the data set using a mean split (M = 144.07, SD = 93.24) also clearly illustrates the difference between the two groups of individuals with respect to the execution time of the Lego® reference model. Table 4 shows that all participants in the control group are below the overall mean value of 144.07 s, while only eight individuals in the experimental group are below this value.

The question therefore arises as to what these findings mean for the further conduct of the laboratory experiment. In principle, they reflect the current performance relationship of the two groups of individuals under the same general conditions and were to be expected given the specific limitations of the individuals from the experimental group. However, it must also be considered that the control group, which was assigned to the assistance system at a later stage, assembled the reference model significantly faster and can thus generally be classified as particularly efficient. Likewise, this grouping signifies that it tends to become more difficult for individuals with cognitive impairments to approach this group of individuals, even using an informational assistance system. Regardless, the results of the experimental group represent an expected range or spread in which the baseline level can be classified as approximately the same, considering the subsequent form of

Table 4 Distribution of test subjects based on the mean split
Tab. 4 Verteilung der Versuchspersonen auf Basis des mean-splits

	M [s]	SD [s]	Number of subjects
Mean-Split < 144.07 [s]			
Experimental group	121.00	15.42	8
Control group	82.95	18.52	20
Mean-Split > 144.07 [s]			
Experimental group	261.33	88.86	12
Control group	–	–	–

support. In this regard, the execution times of the Lego® reference model do not differ significantly from one another using the distribution-free Mann-Whitney U-test ($U = 44.000$, $p = 0.650$).

4.4 Hypotheses

Regarding the further quantification of the human-oriented and economic application potentials of an information-based assembly assistance system for people with cognitive impairments, a total of eight hypotheses were formulated and tested for their validity:

1. It is expected that the execution times of the experimental and control groups will be significantly lower than the respective comparison group with paper-based instruction due to the continuous feedback of the assistance system fitted with an image processing unit.
2. Regarding the number of picking or grabbing errors when picking up the parts to be assembled, it is to be expected that these do not differ significantly within a group of individuals—assistance system vs. paper instruction—due to the same information content or presentation format.
3. Given the automated error detection of the assistance system, the number of assembly errors of the experimental and control groups is expected to be significantly lower when using the assistance system than that of the respective comparison group with paper-based instructions.
4. With the postulated decrease in the number of assembly errors due to the use of the informational assistance system, it is also expected that the experimental group with the assistance system does not differ significantly from the control group with the assistance system.
5. Furthermore, the experimental group using the paper-based instruction is expected to cause more assembly errors than the control group using the paper-based instruction.
6. With the postulated decrease in execution times and assembly errors, it is further expected that the labor productivity of the experimental group with the informational assistance system is not significantly different from that of the control group with paper-based instructions.
7. It is also expected that the experimental group with paper-based instructions will achieve significantly lower work productivity than the control group with paper-based instructions due to the individual impairments.
8. Regarding the intensity of mental stress, it can be expected that the use of the informational assistance system will not lead to any additional mental stress for the experimental and control groups, since the information content of both forms of instruction—paper instruction and informational assistance system—is approximately the same and the assembly task remains unchanged.

5 Results

Regarding the first hypothesis, the influence of an informational assistance system on the execution time for the assembly of the five multi-outlet power strips is investigated. Due to the continuous feedback of the assistance system *(A)* equipped with an image processing unit, it can be assumed that the execution times of the experimental group *(E)* and the control group *(C)* are significantly lower than those of the respective comparison group with paper-based instructions *(P)*. The test of the established thesis is done with the distribution-free Mann-Whitney U-test. The test indicates that there is no significant difference between the use of the assistance system and the use of the paper-based instruction for both groups of individuals (experimental group: $U_{AE\_PE} = 36.000$, $p = 0.290$; control group: $U_{AC\_PC} = 32.000$, $p = 0.174$). This means there is no statistically significant difference between the use of paper-based instruction and the assistance system, so the first hypothesis must be rejected.

Descriptively, however, there is certainly potential for reducing execution times through the use of an informational assistance system (see Table 5). For instance, the standard deviations decrease significantly for both groups of individuals compared to the respective comparison group with paper-based instructions. For the assembly of the fifth product in the test group, for example, this is reduced from 101.57 to 53.12 s, which corresponds to a decrease of 47.70%. In addition, a reduction in execution time across all assemblies can be observed in both subject groups, despite variations in product configuration (see Table 5). By using the informational assistance system for the five products, the execution time can be reduced in total by 11.4% in the experimental group and 12.7% in the control group.

A sometimes-important aspect that influences the previously described execution times is the number of picking and assembly errors that occur during the assembly process. Regarding picking errors, it is assumed that subjects within a group of individuals do not differ significantly from each other due to the same information content and

Table 5 Average execution time of the multi-outlet power strips exemplified by products 1, 5, and 1–5 in seconds

Tab. 5 Mittlere Ausführungszeit der Mehrfachsteckdose am Beispiel der Produkte 1, 5 und 1–5 in Sekunden

		Product 1	Product 5	Product 1–5
AE—assistance system experimental group	M	404.90	254.50	1615.50
	SD	126.71	53.12	–
PE—paper-based instructions experimental group	M	520.50	277.70	1823.90
	SD	199.57	101.57	–
AC—assistance system control group	M	225.40	141.80	853.20
	SD	34.96	27.80	–
PC—paper-based instructions control group	M	260.20	177.10	976.90
	SD	66.45	47.48	–

presentation format—hypothesis 2. This assumption is confirmed by a non-significant result for both groups of subjects (experimental group: $U_{AE\_PE} = 47.000,\ p = 0.819$; control group: $U_{AC\_PC} = 46.500,\ p = 0.759$). Although the statistical test confirms the assumption of the second hypothesis, there certainly is, from a descriptive point of view, potential for the use of an assistance system. In this respect, Fig. 5 shows that through the use of the assistance system fewer errors were caused overall for both groups of individuals. Picking errors are reduced by 50.0% in the experimental group and by 55.6% in the control group compared to the respective comparison group with paper-based instructions.

Figure 6 shows the average number of assembly errors both for individual products and across all products. The diagram shows that the assistance system contributed to a significant reduction in assembly errors for both groups of test subjects. In addition, the assistance system contributes to a lower interpersonal dispersion of the number of errors compared to the respective group of subjects with paper-based assembly instructions. The postulated reduction in the number of assembly errors through automated error detection and the continuous feedback of the status of individual assembly steps (error-free/faulty) by the assistance system is already made clear by the diagram (see Fig. 6)—Hypothesis 3.

Further examination of the data set supports this finding with a significant effect for both groups of subjects, also using the Mann-Whitney U-test (experimental group: $U_{AE\_PE} = 11.000,\ p = 0.003,\ r = 0.661$; control group: $U_{AC\_PC} = 22.500,\ p = 0.035,\ r = 0.472$). Compared to the respective group with a paper-based instruction, the number of assembly errors decreases on average by 73.8% in the experimental group and by 63.8% in the control group.

The assumption in hypothesis 4 concerning the number of assembly errors is that the experimental group with the assistance system does not differ significantly from the control group with the assistance system. However, it can be seen from Fig. 6 that the control group makes significantly fewer errors. Statistically, a significant difference between the two groups is confirmed, so hypothesis 4 must

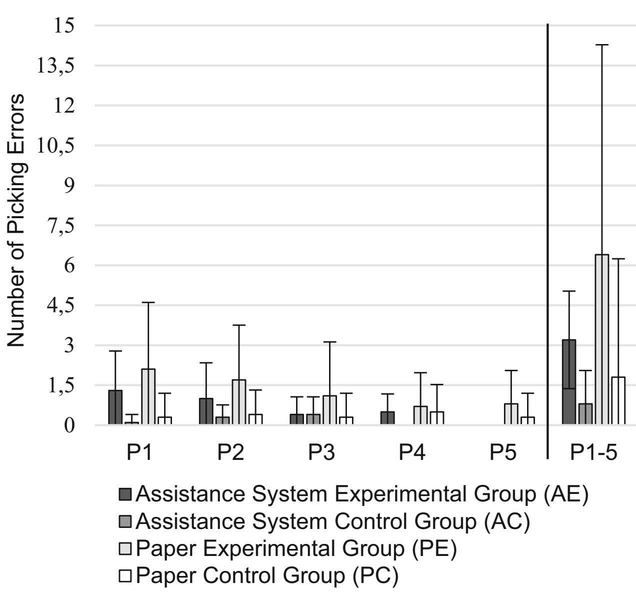


Fig. 5 Average number of picking errors at product level and across all products

Abb. 5 Durchschnittliche Anzahl der Kommissionierfehler auf Produktebene sowie über alle Produkte hinweg

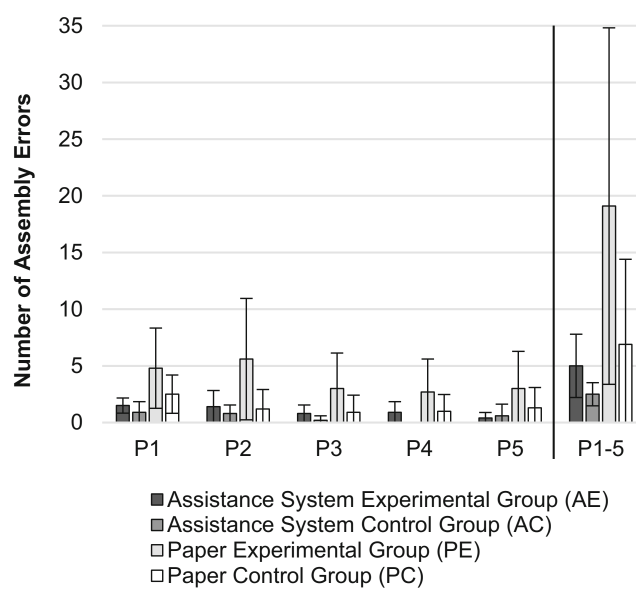


Fig. 6 Average number of assembly errors at product level and across all products

Abb. 6 Durchschnittliche Anzahl der Montagefehler auf Produktebene sowie über alle Produkte hinweg be rejected ($U_{AE\_AC} = 20.000$, $p = 0.021$, $r = 0.516$). In contrast, the assumption of hypothesis 5 can be confirmed by a further comparison between the experimental group and the control group, each with the paper-based instruction ($U_{PE\_PC} = 15.500$, $p = 0.009$, $r = 0.586$). Thus, due to the performance limitations of its members, the experimental group causes more assembly errors than the control group with paper-based instructions. This statement is supported by a non-significant cross-comparison between the experimental group with the assistance system and the control group with the paper-based instruction ($U_{AE\_PC} = 50.000$, $p = 1.000$). Thus, a comparison of the error frequency of the experimental group with an assistance system (AE) and the control group without an assistance system (PC) also shows that individuals with cognitive impairments using an assistance system cause fewer assembly errors than individuals without cognitive impairments who do not use an assistance system. This finding suggests that assistance systems are able to compensate for employees' cognitive impairments and can therefore be a key to inclusion and participation in working life.

In addition to the number of assembly errors that occurred during assembly, some of which were detected and corrected by the test subjects themselves, the absolute number of products assembled without errors was also recorded. As shown in Fig. 7, both groups of individuals were able to assemble almost all of the 50 multi-outlet power strips to be assembled without errors using the assistance system. Only one multi-outlet power strip in the test group was assembled incorrectly. The reason for this was a retroactive correction of an assembly step that had already been completed and checked by the assistance system. However, this subsequent change was detected by the assistance system during the execution of the last assembly step, so that the product was classified as defective. In contrast, the groups of individuals with paper-based assembly instructions were far from being able to complete the required quantity of good parts. Only 17 of the 50 products (34.0%) could be assembled without errors in the test group, while 32 of 50 (64.0%) could be assembled in the control group.

Labor productivity is a metric that represents the number of products assembled without errors in relation to the execution time spent on them. It is expected that the labor productivity of the experimental group using the informational assistance system will not differ significantly from that of the control group using the paper-based instructions—Hypothesis 6. To test the hypothesis, labor productivity was first determined using the previously mentioned calculation rule and tested using the Mann-Whitney U-test. According to this test, the groups mentioned above do not differ significantly from each other ($U_{AE\_PC} = 40.000$, $p = 0.450$), so that hypothesis 6 is confirmed. This result can also be shown very clearly in Fig. 8. According to this, the labor productivity of both groups (AE and PC) hardly differs from each other with regard to the assembly of the five products.

Furthermore, Fig. 8 shows that the assumption of the seventh hypothesis can already be confirmed descriptively. According to this, the experimental group with paper-based instructions achieves a comparatively low labor productivity compared to the control group with paper-based instructions. This assessment is confirmed by applying the Mann-Whitney U-test ($U_{PE\_PC} = 21.000$, $p = 0.027$, $r = 0.494$), which evidences a significant difference between the two groups. This demonstrates once again that the use of such an assistance system can lead to an equalization of performance in the intended target group. However, it is also clear that the provision of an assistance system for

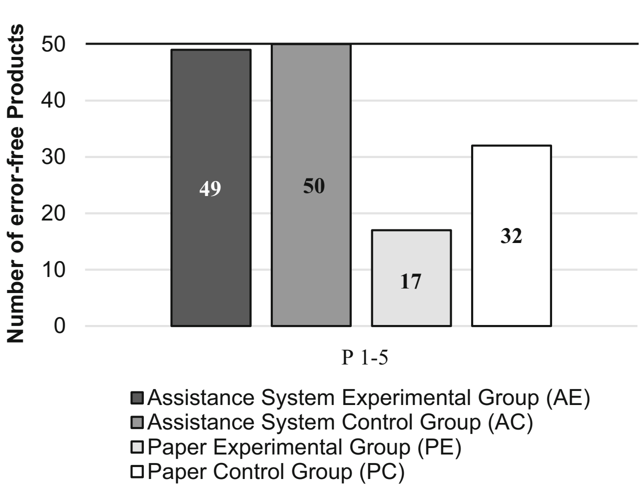


Fig. 7 Number of multi-outlet power strips assembled without errors
Abb. 7 Anzahl fehlerfrei montierter Mehrfachsteckdosen

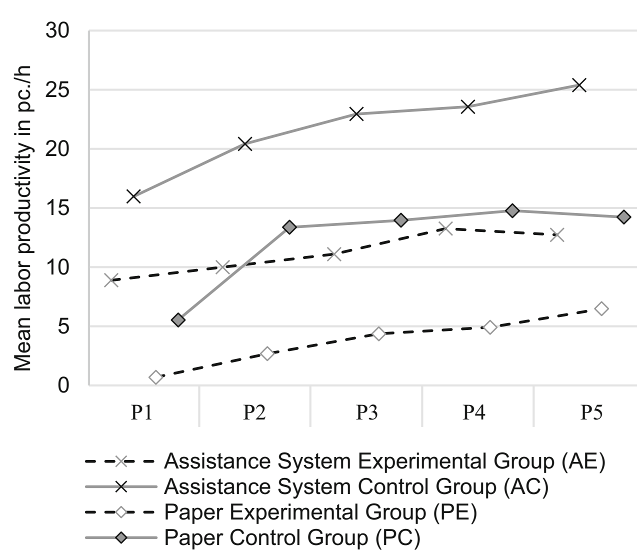


Fig. 8 Progression of labor productivity
Abb. 8 Verlauf der Arbeitsproduktivität

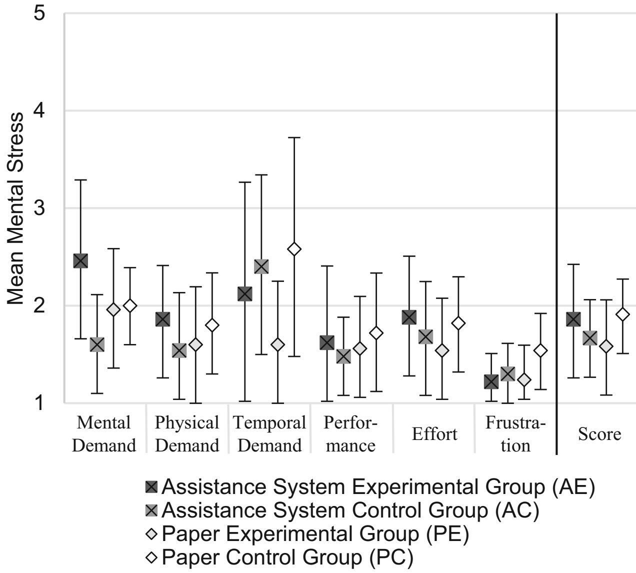


Fig. 9 Average perceived mental stress of subjects across products 1 to 5

Abb. 9 Durchschnittliche wahrgenommene mentale Beanspruchung der Probanden über die Produkte 1 bis 5

individuals without cognitive performance impairments has a positive effect on productivity as well, as evidenced by the significant difference between the two control groups ($U_{AC\_PC} = 6.000$, $p = 0.001$, $r = 0.744$).

With reference to the positive results and characteristics of the investigated assistance system so far, it remains to be clarified how its use affects the induced or perceived stress of the subjects—hypothesis 8. An examination of total stress calculated from the mean of the six items of the modified NASA-TLX questionnaire reveals no significant difference between the support systems used within one subject group (experimental group: $t_{AE\_PE}(18) = 1.124$, $p = 0.276$; control group: $t_{AC\_PC}(18) = -1.362$, $p = 0.190$). The assumption of the eighth hypothesis can thus be confirmed, which states that the use of an informational assistance system does not lead to any additional mental stress in the experimental and control groups. The underlying stress level here is in a low range between 1.6 and 1.9 on a scale of 1 to 5, regardless of the form of support and group of individuals, see Fig. 9 under the heading "Score".

6 Discussion and conclusion

The presented findings impressively show that adaptations to information provision in manual assembly can help to reduce existing barriers and challenges resulting from the mismatch between requirements of the general labor market and the performance characteristics of people with cognitive impairments. These potentials of using an assistance system become clear not only by the comparison within the experimental group itself (use of an assistance system vs. paper instructions), but especially by the control group considered in the research design, which consists of individuals without cognitive performance impairments. In the following, the results of the study about the individual hypotheses will first be discussed. Subsequently, general conclusions will be drawn for improved inclusion of people with cognitive impairments.

The results of the first hypothesis' testing show that for both groups of individuals, there are no significant differences between the execution times for assembling the five multi-outlet power strips depending on the support medium (assistance system vs. paper instructions). However, the informative value of this hypothesis is limited because the individuals using paper instructions do not receive automatic feedback on errors, therefore often do not recognize these errors and consequently—in contrast to the individuals using the assistance system—in many cases do not carry out (time-intensive) activities to correct errors. However, the results show that despite performing these troubleshooting activities, both the subjects in the experimental group and the subjects in the control group using an assistance system (AE and AC) required shorter execution times on average than the respective comparison groups (PE and PC) using paper-based instructions (–11.4% and –12.7%, respectively, see Table 5).

The importance of the labor productivity metric is clearly higher than that of the execution time, since labor productivity is based on the number of products assembled without defects in relation to the execution time spent on them. The consideration of products assembled defectively or without defects in the metric of labor productivity is also highly relevant from a customer perspective, since customers, while also considering costs and price, place primary importance on the quality of products. Therefore, it's especially the results on hypothesis 6 that are quite crucial in order to make statements about whether assistance systems have the potential to compensate for people's cognitive limitations by providing additional support and thus offer them new opportunities on the labor market.

The results for hypothesis 6 show that the automatic error detection of the assistance system in particular, enables the individuals with cognitive impairments (experimental group) to achieve approximately the same work productivity as the control group (individuals without cognitive impairments) using paper-based instructions (see Fig. 8). Since paper-based assembly instructions are still widely used in industrial practice (Bannat 2014), the introduction of assistance systems can therefore compensate for people's weaknesses and become an enabler for increased inclusion and integration of these people into the primary labor market. The positive influence of the assistance system on the metric of labor productivity results primarily from the number of products assembled without defects. For instance, using paper-based instructions, individuals with cognitive impairments were able to assemble only 17 of 50 products without errors, while using the assistance system resulted in 49 error-free products and only one product with errors (see Fig. 7). The number of errors during product assembly also decreases significantly with the use of the information-based assistance system (hypothesis 3, see Fig. 6). This positive effect of the assistance system is mainly due to the system's image processing unit, which provides continuous feedback to employees and therefore contributes to closing Gap 6 ("lack of feedback") (see Fig. 1).

Regarding the retrieval of components from the grab containers located at the workplace, there are, as postulated, no significant differences between the support media used within the two groups of individuals (hypothesis 2). Nevertheless, the results show that the use of the assistance system tends to lead to fewer errors than paper-based instruction, despite the equal information content of both forms of assistance. This result is probably due to the fact that the information on the screen was provided centrally and at eye level, while the paper-based instruction could be freely placed by the subjects. This option of choosing where to place the instructions also meant that the subjects' attention was no longer focused on the information provided, which was instead assumed to be known. This problem corresponds to Gap 3 ("no direct perception of the data") of the model in Fig. 1.

Furthermore, the study shows that using an informational assistance system does not lead to a significant increase in subjective perceived stress, despite the extraordinary increases in productivity. The results show a subjectively perceived stress level that is relatively low overall, regardless of the group of people and the support medium used (see Fig. 9).

A critical point to note is that the results of the laboratory study are only valid for the very specific work system used in the study. However, due to the continuing trend towards a greater number of variants and smaller batch sizes, there are a large number of work systems in Germany and other countries that are comparable to the described work system in terms of task complexity. Therefore, the study results certainly allow the conclusion that with the help of informational assistance systems, the chances of the affected group of people to find a job outside of workshops for people with disabilities, i.e., in a privately organized company, can be significantly improved. This finding is also supported by initial findings from a field study conducted at the manufacturer's premises for multi-outlet power strips. It can also be assumed that support technologies will continue to improve significantly over the next years. The use of artificial intelligence in particular will presumably help to ensure that information support can be adapted to individual needs to a greater extent. A follow-up study could therefore aim to investigate whether a dynamic provision of information in line with individual needs—including the possibility of using an active dialog with an AI-based assistance system—can further improve work productivity. However, the currently very low transition rate from WfbM to "normal" companies (see Sect. 1) indicates that not only work design—including the implementation of assistance systems—can have an influence on this transition rate, but also political and legal framework conditions. Therefore efforts should be made at different levels to take advantage of the benefits offered by inclusion for everyone involved—people with disabilities, companies, and society.

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References

Aksu V, Jenderny S, Kroll B, Röcker C (2019) A digital assistance system providing step-by-step support for people with disabilities in production tasks. In: Ahram T, Falcão C (eds) Proceedings of the AHFE 2018 International Conferences on Usability & User Experience and Human Factors and Assistive Technology, vol 794. Springer, Cham, pp 775–785 https://doi.org/10.1007/978-3-319-94947-5_76

Bannat A (2014) Ein Assistenzsystem zur digitalen Werker-Unterstützung in der industriellen Produktion (Dissertation. Technische Universität München, München)

Bendzioch S, Hinrichsen S (2023) Informational assistance system—A key to self-empowerment of persons with cognitive disabilities in manual assembly? In: Ahram T, Taiar R (eds) Proceedings of the 10th International Conferences on Human Interaction & Emerging Technologies (IHIET 2023): Artificial Intelligence & Future Applications. AHFE Open Access, New York, pp 548–556 https://doi.org/10.54941/ahfe1004061

Berg M, Stratmann A, Walter J, Weber M (2023) Neue Wege gehen – Jahresbericht 2022. Bundesarbeitsgemeinschaft Werkstätten für behinderte Menschen e. V. (BAG WfbM), Berlin (https://www.bagwfbm.de/file/1541/)

Bläsing D, Bornewasser M, Hinrichsen S (2021) Cognitive compatibility in modern manual mixed-model assembly systems. Z Arb Wiss 76:289–302. https://doi.org/10.1007/s41449-021-00296-1

Claeys A, Hoedt S, Soete N, Van Landeghem H, Cottyn J (2015) Framework for evaluating cognitive support in mixed model assembly systems. IFAC-PapersOnLine 48(3):924–929. https://doi.org/10.1016/j.ifacol.2015.06.201

Cohen J (1992) A power primer. Psychol Bull 122(1):155–159. https://doi.org/10.1037/0033-2909.112.1.155

Detmar W, Gehrmann M, König F, Momper D, Pieda B, Radatz J (2008) Entwicklung der Zugangszahlen zu Werkstätten für behinderte Menschen. ISB – Gesellschaft für Integration, Sozialforschung und Betriebspädagogik gGmbH, Berlin (https://nbn-resolving.org/urn:nbn:de:0168-ssoar-342577)

Doose S (2009) Berufliche Integration von Menschen mit Behinderung. In: Eberwein H, Knauer S (eds) Handbuch Integrationspädagogik. Beltz, Weinheim, Basel, pp 245–263

Funk M, Bächler A, Bächler L, Korn O, Krieger C, Heidenreich T, Schmidt A (2015a) Comparing projected in-situ feedback at the manual assembly workplace with impaired workers. In: Proceedings of the 8th ACM International Conference on PErvasive Technologies Related to Assistive Environments. Association for Computing Machinery, Corfu, pp 1–8 https://doi.org/10.1145/2769493.2769496

Funk M, Mayer S, Schmidt A (2015b) Using in-situ projection to support cognitively impaired workers at the workplace. In: ASSETS '15: Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility. Association for Computing Machinery, Lisabon, pp 185–192 https://doi.org/10.1145/2700648.2809853

Hart SG, Staveland LE (1988) Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. Adv Psychol 52:139–183. https://doi.org/10.1016/S0166-4115(08)62386-9

Hinrichsen S, Bendzioch S (2019) How digital assistance systems improve work productivity in assembly. In: Nunes IL (ed) Proceedings of the AHFE 2018 International Conference on Human Factors and Systems Interaction, vol 781. Springer, Cham, pp 332–342 https://doi.org/10.1007/978-3-319-94334-3_33

Hinrichsen S, Nikolenko A, Beckmann N, Meyer F (2022) Development of a new type of carousel-based compacted work system for mixed-model assembly in mechanical engineering. In: Proceedings of the 2022 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM). IEEE Xplore, pp 87–90 https://doi.org/10.1109/IEEM55944.2022.9989731

Hold P, Erol S, Reisinger G, Sihn W (2017) Planning and evaluation of digital assistance systems. Procedia Manuf 9:143–150. https://doi.org/10.1016/j.promfg.2017.04.024

Hollnagel E (1997) Cognitive ergonomics: it's all in the mind. Ergonomics 40(10):1170–1182. https://doi.org/10.1080/001401397187685

Kardorff E, Ohlbrecht H, Schmidt S (2013) Zugang zum allgemeinen Arbeitsmarkt für Menschen mit Behinderungen – Expertise im Auftrag der Antidiskriminierungsstelle des Bundes. Antidiskriminierungsstelle des Bundes, Berlin. https://www.antidiskriminierungsstelle.de/SharedDocs/downloads/DE/publikationen/Expertisen/expertise_zugang_zum_allg_arbeitsmarkt_f_menschen_mit_behinderungen.pdf?__blob=publicationFile&v=3

Karwowski W (2005) Ergonomics and human factors: the paradigms for science, engineering, design, technology and management of human-compatible systems. Ergonomics 48(5):436–463. https://doi.org/10.1080/00140130400029167

Korn O, Abele S, Schmidt A, Hörz T (2013) Augmentierte Produktion: Assistenzsysteme mit Projektion und Gamification für leistungsgeminderte und leistungsgewandelte Menschen. In: Boll S, Maaß S, Malaka R (eds) Mensch & Computer 2013 – Tagungsband. Oldenbourg Wissenschaftsverlag, München, pp 119–128 https://doi.org/10.1524/9783486781229

Mark BG, Rauch E, Matt DT (2021) The application of digital worker assistance systems to support workers with disabilities in assembly processes. Procedia CIRP 103:243–249. https://doi.org/10.1016/j.procir.2021.10.039

Mißfeldt M (n. d.) Sehtest mit Buchstaben. https://www.sehtestbilder.de/sehtest-ausdrucken-buchstaben.php. Accessed 2 Feb 2021

Prabaswari AD, Basumerda C, Utomo BW (2019) The mental workload analysis of staff in study program of private educational organization. In: Materials Science and Engineering—11th ISIEM (International Seminar on Industrial Engineering & Management. IOP conference series, vol 528. IOP, pp 1–6 https://doi.org/10.1088/1757-899X/528/1/012018

Schlick C, Bruder R, Luczak H (2018) Arbeitswissenschaft. Springer, Berlin, Heidelberg https://doi.org/10.1007/978-3-662-56037-2

Strasser H (2021) Compatibility as guiding principle for ergonomics work design and preventive occupational health and safety. Z Arb Wiss 76:243–277. https://doi.org/10.1007/s41449-021-00243-0