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R. A. Goehlich
Airbus, Manufacturing Engineering, goehlicr@erau.edu

M. H. Rutsch
Airbus, Airbus Medical

I. Krohne
Airbus, Innovation & Development Manufacturing Technologies

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R. A. Goehlich[1], M. H. Rutsch[2] und I. Krohne[3]

[1] Airbus, Manufacturing Engineering
Robert.Goehlich@airbus.com

[2] Airbus, Airbus Medical
Moritz-Henning.Rutsch@airbus.com

[3] Airbus, Innovation & Development Manufacturing Technologies
Ingo.Krohne@airbus.com

Abstract

The incidence of musculoskeletal disorders in workplaces with difficult ergonomic conditions is increasing. Today, there is a growing market for technical support systems that avoid repetitive strain on the musculoskeletal system. We have been observing two (parallel) lines of development: on the one hand, the development of exoskeletons supporting shop floor operators and, on the other hand, the development of collaborative robots for the creation of hybrid teams. The focus of our research is the combined application of exoskeletons AND collaborative robots for shop floor operators in the aerospace industry. Our approach is to analyze various scenarios to understand which tasks should preferably be executed either with a collaborative robot, with an exoskeleton, or by a human without assistance from any support systems such as an exoskeleton or robot. In order to pursue this idea of modular and selective support system solutions, tool availability has to be ensured without increasing the required infrastructure. In a first step, we have developed a prototype of a tool adapter that enables the application of a tool either by connection to a robot, an exoskeleton, or the tool being held by the operator, and allows very fast coupling and decoupling within seconds. This concept will enable the realization of the proposed simultaneous use of exoskeletons and robots.

Kurzzusammenfassung

Magisches Dreieck: Mensch, Exoskelett und kollaborierende Roboter-Szenario

Muskel-Skeletterkrankungen an Arbeitsplätzen mit schwierigen ergonomischen Bedingungen nehmen zu. Aktuell entwickelt sich der Markt für Körperassistenzsysteme, die monotone Belastungen für das Muskel-Skelettsystem reduzieren, weiter. Wir nehmen zwei Richtungen in der Entwicklung war: Mitarbeiter werden bei ihrer Tätigkeit durch Körperassistenzsysteme O-DER kollaborierende Roboter unterstützt. Bei unserer Untersuchung konzentrieren wir uns auf die kombinierte Unterstützungsstrategie. Unsere Vorgehensweise ist es verschiedene Szenarien zu analysieren, um für die jeweiligen Teiltätigkeiten die passendste Unterstützung, entweder mit einem Exoskelett, einem Roboter oder ohne, anzubieten. Grundlage dieser Strategie stellt ein neu entwickelter Universaladapter mit einer Schnellkupplung dar, der ein Halten des Werkzeuges durch Roboter, Exoskelett oder den Menschen ermöglicht.

Keywords

Collaborative robot, exoskeleton, aerospace industry, human, wearable support systems

1 Introduction

Motivation.

Musculoskeletal disorders have been understood to occur in connection with work for hundreds of years. Today, there is a growing fear in Europe and elsewhere about the impact of work-related musculoskeletal disorders on employee well-being and health. Musculoskeletal disorders are considered to be a major cause of sickness absence. Although many explanations have been discussed in the past few decades regarding underlying mechanisms for the development of nonspecific musculoskeletal symptoms, definitive knowledge is still incomplete [Slu01].

Problem.

In today's production environment, the operator typically can decide to use either (1) an exoskeleton, (2) a cobot, or (3) no support for a specific work package (i.e., a set of tasks) to be carried out on a shop floor. The disadvantage is that usually this decision must be made before the tasks are executed, and once option 1, 2, or 3 has been selected, the operator will have to stick to his or her choice without having the chance to switch to a different option easily while executing the tasks.

Research Question.

This leads us to our research question (RQ): “How should a system be designed and processed to enable soft switching between the use of an exoskeleton, cobot, or no support during operation?”

Content.

The next section provides a brief review of literature regarding human, exoskeleton, and cobot scenarios. Section 3 describes our method including a visualization, measurement, and approach to verify this scenario. Following a results and discussion section, we will conclude our paper with recommendations.

2 Literature Review

Human.

Ergonomic conditions involving repetitive strain can cause musculoskeletal disorders. One well-known potential explanation at the muscular level is the Cinderella hypothesis, according to which the lack of recovery from repeated recruitment of the same motor neuron units causes complaints and fatigue when the same forces and movements are activated in a repetitive manner according to the criteria document for evaluating the work-relatedness of upper-extremity musculoskeletal disorders [Slu01].

Insights regarding general body postures are provided by a study conducted by Fritzsche assessing the postures of employees working in a vehicle assembly shop. The Rapid Upper Limb Assessment (RULA) risk score calculates the severity of a given posture with regard to work-related musculoskeletal disorders. Following the detection of risk factors, the ergonomic workplace conditions were improved. As a result of this study, the “risk score” has decreased, causing productivity to increase by 3.6%. In the future, investigating psycho-social factors and heart rate variability might become relevant to understanding this mechanism [Fri14].

Exoskeleton.

Typically, exoskeletons are stand-alone systems. Their advantage is that they can be operational in a minute and are very reliable and robust. However, the disadvantage of this characteristic is that an exoskeleton allows only few interactions with the environment. A selection of various exoskeleton types shows that typical exoskeletons are also limited to supporting only some areas of the body (e.g., foot, leg, pelvis, main body, arm, hand) and rarely cover the entire body [Goe16].

Collaborative Robot.

In principle, classical automation approaches and their application in confined spaces mean safe robotic operations based on physical separation or close coexistence. Generally, different standards and regulations such as ISO

15066 [ISO16] must be considered when implementing human-robot interaction.
Collaborative robotics, in the proper sense of the term, means real human-machine interaction. In the context of this work, the application of cobots is aimed at improving the ergonomic conditions. This could mean that robotic manipulation with its strength takes over the main loads while the human cooperator is in a guiding role [Mör12], or even that the human and the machine handle the same part simultaneously or share the same tool. Obviously, the close interaction of humans and robots involves safety hazards that must be identified [Vas13].

3 Method

As mentioned above, the general idea is to introduce types of support systems like exoskeletons and cobots enabling easy and highly flexible adaptation to different working conditions or personal preferences. This requires a human-machine interaction as well as a human-exoskeleton connection and even an exoskeleton-machine interface.
In addition to the technical interface definition, it is important in this scenario to define standardized indicators in order to select the right or even best human-exoskeleton-cobot combination focusing on ergonomic and process-related optimization. Any down selection and analysis must be supported by adequate measurements and validation methods, which are today especially concerning the benefits of exoskeletons at the beginning.

3.1 Scenario: Human, Exoskeleton, Cobots

Usually, support systems are considered independently from automation solutions. This is often due to the fact that the design of end effectors and tools is different depending on whether they are used by robots or humans. Moreover, as mentioned above, specific safety measures have to be taken into account for human-robot interaction. Nevertheless, the associated benefits regarding ergonomics and production are considered to be significant. Hence, a scenario for human-exoskeleton-machine interaction is created.

Figure 1 shows a concept where a tool that was used by a cobot is handed over to a human wearing an exoskeleton [Goe17]. The tool is connected directly to the exoskeleton without the intermediate stages that would be required in case of not using the tool adapter (such as grasping the tool, disassembling it from the robot end effector, carrying the (heavy) load, and connecting the tool to the exoskeleton).

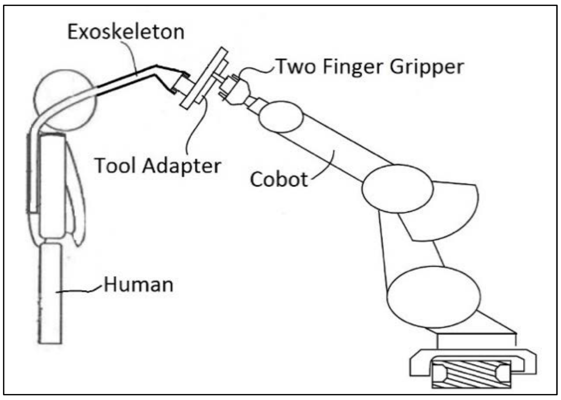

Figure 1: Soft switching of a tool between cobot and exoskeleton

3.2 Measurement: CUELA

The posture analysis is performed using the CUELA system (Computer-unterstützte Erfassung und Langzeit-Analyse von Belastungen des Muskel-Skelett-Systems) [computer-assisted recording and long-term analysis of musculoskeletal loads] established at the Institute for Occupational Safety and Health of the German Social Accident Insurance (Institut für Arbeitsschutz (IFA); Sankt Augustin, Germany). The system is composed of different sensors (accelerometers and gyroscopes for the head, arms, legs, back; potentiometers for back torsion). At the beginning of the data capturing session, all body angles are adjusted to an upright standing posture. As a result of this processing, movement artifacts are low [Ell09, Ell00]. The CUELA system allows to measure body postures continuously including kinematic data of the trunk and the lower and upper limbs. The general purpose of the CUELA measurement technique is to document the motion range and movement intensity during the performance of daily work tasks.

3.3 Approach: Standardize

One way of achieving an objective and valid workspace assessment is to apply the Key Indicator Method as described for example in [Klu17]. For example, such indicators typically include [Bun12]:

- Body posture,
- Hand/arm posture,
- Loads and frequencies,
- Working conditions,
- Work organization, and
- Head tilt inspection.

Having this methodology in mind, it is obvious that a system for classification and validation is necessary for human-exoskeleton-cobot interaction as well as for linking the technology selection to an ergonomic assessment. Nevertheless, this task is not an easy one especially with the aim of tool interchangeability. Therefore, a method of classification within the magic triangle has been drafted to support task allocation.

Figure 2 illustrates the magic triangle with a process brick that can be easily allocated to one of the “executors” and switched over to a different one while in process.

To verify our approach, we suggest the following arrangement of samples: the first group includes operators who do not use any support systems (human); in the second group, we observe operators with body assistance systems (exoskeleton); and the third group focuses on cobots (collaborative robots).

In addition to purely ergonomic key indicators, the magic triangle investigation required the definition of process-related and technical classification indicators, considering typical strengths and weaknesses for each group. For example, these include the agility but also the load handling limitations of humans, the required fast set-up time, and potential comfort issues of exoskeletons as well as the load capabilities and lack of accuracy of cobots.

Depending on a given task, different combinations of capabilities are required. Thus, based on the magic triangle approach, the best combination of the human-exoskeleton-cobots can be selected.

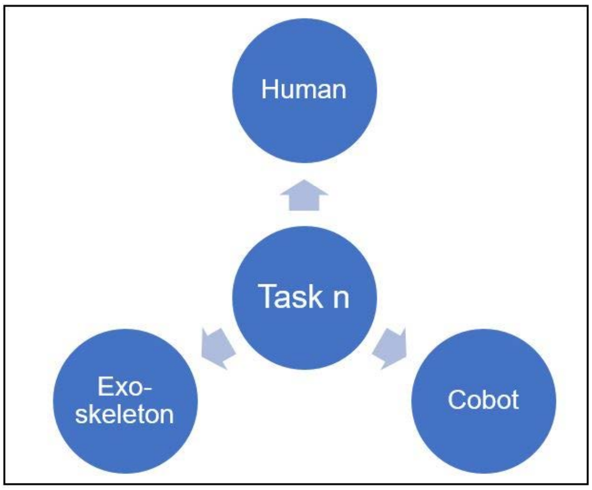

Figure 2: Magic triangle

4 Results

We conducted various trial tests for typical aircraft production tasks at laboratory level and organized our lessons learned concerning human, exoskeleton, and cobots in Table 1. In summary, we observed that:

- the operator without any support system is superior for a wide range of specific tasks,
- the exoskeleton support allows operators to perform tasks involving heavy loads (in a way that is less harmful to their health), but also affects the user’s comfort and freedom of movement, and
- the cobot support is primarily suitable for performing repetitive tasks.

In particular, as shown in Table 2, we observed that the magic triangle approach is more suitable for some process bricks than for others.

Table 1: Classification of major lessons learned from using the magic triangle approach

Task performed by	Impact	Probability	Rank (I*P)
Human (no support)			**= 5**
+ Quick tool grasping	***	**	+6
+ Agile movements	*	*	+1
+ Short instruction	*	*	+1
+ No maintenance	*	**	+2
- Heavy loads	**	*	-2
- Risk of failures for repetitive tasks	***	*	-3
Exoskeleton			**= 1**
+ Flexible to adapt to various geometries	**	*	+2
+ Fast set-up	**	**	+4
- Repetitive tasks are mitigated but not eliminated	*	*	-1
- Less comfort (weight, inflexible, skin transpiration)	**	**	-4
Cobot			**= 1**
+ Simple connection with tool	***	*	+3
- Heavier weight of end effector	*	*	-1
- TCP less accurate	*	*	-1

Note: The assumed task is to install a component, e.g., a raceway or bracket by means of a screw driver. The values are estimates based on observations.

Table 2: Classification of suitability of the magic triangle to selected tasks

Tasks	H	E	C
Transportation of a component	-	-	+
Holding of a component	-	+	+
Transportation of a tool	-	+	+
Holding of a tool	-	+	+
Use of the tool	+	+	-
Quality check	+	-	+

Note: H = human (without support); E =exoskeleton; C = cobot

5 Discussion

Overview.

Proposing new processes and novel tool-related designs triggers fruitful discussions among researchers, managers, and operators. Our discussion for this study focuses on a process comparison, the limitations we identified in our approach, and possible scenarios for verification.

Process Comparison.

Figure 3 shows a contrasting juxtaposition of the state-of-the-art process versus our magic triangle approach.

The state-of-the-art process is to cluster tasks (e.g., tasks 1 and 2) and assign an executor (e.g., an exoskeleton supports a human); any system change (e.g., a cobot supports a human for task 3) requires costly changeover time (marked with an arrow), leading to inflexibility.

In contrast, the magic triangle process reduces or eliminates these changeover times and allows agile reactions (e.g., task 1 is executed by a human alone, task 2 is executed with the support of an exoskeleton, while task 3 is executed with the support of a cobot).

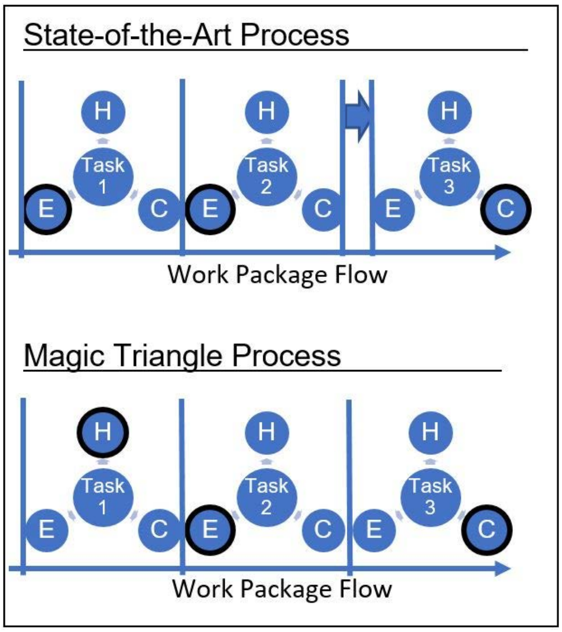

Figure 3: State-of-the-art versus magic triangle process

Note: H = human (without support); E = exoskeleton; C = cobot

Limitations.

We see major limitations in measuring the effectiveness of our magic triangle strategy with regard to ergonomic improvements (i.e., healthier working conditions), cost reductions (i.e., less changeover time of cobots), and agility of production (i.e., increased modularity, flexibility of cobots and exoskeleton use). This is due to the bias caused by:

- **Perception of operators varies** from “robot is a helpful assistance” to “robot is competing with my skills”, which results in different motivation levels and work results,
- **Scenarios vary** because some tasks are repeatable while other tasks change continuously, and
- **Individual preferences vary** in terms of how specific tasks are to be executed, as operators have developed different skills and levels of craftsmanship.

Possible Scenarios.

A selection of possible scenarios and our assumptions are describing the application of the magic triangle process. A deeper analysis will require to implement the described standardization and classification rules in this study. The following scenarios will give an insight if the magic triangle approach is leading into the right direction.

Scenario A. The production of cable loops is performed in pre-assembly shop floors. Cables are bundled with cable ties. The employees are working on desks, temporary they can use a chair. We assume that the CUELA measurement might show ergonomic conditions, which are convenient. The workers have to grasp the cable tie quickly in order to manufacture the cable loop.

This state-of-the-art process could be improved by applying the magic triangle. For example, by partly switching on a cobot the number of failures for repetitive tasks can be decreased. Moreover by having a good cobot adjusting it is possible to increase the productivity rate.

Scenario B. Painting of the underside of a fuselage comprise that the employees have to work with their hands across the head for hours by handling the spray gun. We assume that the CUELA measurement might show an increase of the ergonomic strain in these workplaces.

The magic triangle approach could show that the golden way is the use of an exoskeleton, which decreases the strain for the shoulder. But there are some work place areas, where employees have less space. Therefore, a soft switching to a “no support” process has to be considered.

Scenario C. Rivet tools are used to connect different parts of the fuselage. These tools are heavy with a typical weight between 5 to 7 kg. We assume that the CUELA measurement might summarize that workers who have to perform work packages with those tools have a high strain for their body.

Cobots cannot being applied in every section of the fuselage, e.g., the tail top, due to their limited reach. A magic triangle process analysis could propose a soft switching from the cobot support to the “no support” and/or to the “exoskeleton” support process.

6 Conclusion

The implementation of a simultaneous combination of exoskeletons, robots, and humans without support systems allows job rotation not only between employees but also by the same person using different support systems depending on individual habits. According to the Cinderella hypothesis, we expect a lower strain on the motor neuron units, reducing fatigue and health problems. Moreover, according to Fritzsche, improved ergonomic working conditions can increase productivity.

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References

[Bun12] Bundesanstalt für Arbeitsschutz und Arbeitsmedizin: Key indicator method for assessing physical workload during manual handling operations (Worksheet incl. detailed instructions), 2012. Retrieved from https://www.baua.de/DE/Themen/Arbeitsgestaltung-im-Betrieb/Physische-Belastung/Leitmerkmalmethode/pdf/KIM-manual-handling.pdf?__blob=publicationFile&v=2

[Ell00] R. Ellegast and J. Kupfer: Portable posture and motion measuring system for use in ergonomic field analysis. Ergonomic software tools in product and workplace design. Stuttgart: K. Landau, 2000.

[Ell09] R. Ellegast, I. Hermanns and C. Schiefer: Workload assessment in field using the ambulatory CUELA system. Digital human modelling. Germany, Berlin: V. G. Duffy, 2009.

[Fri14] L. Fritzsche, J. Wegge, M. Schmauder, Ma. Kliegel and K.-H. Schmidt: Good ergonomics and team diversity reduce absenteeism and errors in car manufacturing. In: Ergonomics, Vol. 57(2), pp. 148-161, 2014.

[Goe16] R. A. Goehlich, I. Krohne, R. Weidner, C. Gimenez, S. Mehler and R. Isenberg: Exoskeleton portfolio matrix: Organizing demands, needs and solutions from an industrial perspective. In: Proceedings of Zweite Transdisziplinäre Konferenz zum Thema Technische Unterstützungssysteme, die die Menschen wirklich wollen, pp. 147-156, 2016.

[Goe17] R. A. Goehlich, T. Kuhrt and I. Krohne: CoExoBot – Tool connector for exoskeleton and collaborative robot. Hamburg, Germany: Airbus, 2017.

[ISO16] ISO/TS. Robots and robotic devices – Collaborative robots: ISO 15066:2016. Geneva, Switzerland: International Organization for Standardization, 2016.

[Klu17] A. Klussmann, F. Liebers, F. Brandstädt, M. Schust, P. Serafin, A. Schäfer, H. Gebhardt, B. Hartmann and U. Steinberg: Validation of newly developed and redesigned key indicator methods for assessment of different working conditions with physical workloads based on mixed-methods design: a study protocol. In: BMJ Open 2017;7:e015412, Projektnummer: F, 2333, pp. 1-13, http://dx.doi.org/10.1136/bmjopen-2016-015412, 2017.

[Mör12] A. Mörtl, M. Lawitzky, A. Kucukyilmaz, M. Sezgin, C. Basdogan and S. Hirche: The role of roles: Physical cooperation between humans and robots. In: The International Journal of Robotics Research (IJRR) 31.13, pp. 1656-1674, 2012.

[Slu01] J. Sluiter, K. Rest and M. Frings-Dresen: Criteria document for evaluating the work-relatedness of upper-extremity musculoskeletal disorders. In: Scand J Work Environ Health, Vol. 27, pp. 1-102, 2001.

[Vas13] M. Vasic and A. Billard: Safety issues in human-robot interactions. In: IEEE Int. Conf. on Robotics and Automation (ICRA), pp. 197-204, 2013.