Ergonomic evaluation of body postures in order picking systems using Motion Capturing

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Abstract **— Industry 4.0 is ushering in a new era of digitization, automation of machines and also provides autonomy in industrial processes. Despite these advances the processes within order picking systems remain largely manual. Human cognitive and motor skills are difficult to replace and human flexibility is needed on the shop floor. It is well known that manual work requirements in intralogistics can lead to physical strain and in the long run to physical impairments such as musculoskeletal disorders. The aim of this article is to digitize the well-known ergonomics analysis tool Key Indicator Method (KIM) in order to obtain an automated evaluation and thus standardize the ergonomics assessment procedure in the future. For this purpose, a Motion Capture (MoCap) System will be used in a study where a manual picking process is simulated. With the help of the this system, the course of a joint angle on the example of the spine during picking is analysed. The results are assessed on the basis of existing ergonomic standards and guidelines. At the same time, the KIM is performed by two ergonomics experts to validate the results of the MoCap system and to check the suitability of the system for ergonomic analysis.**

Keywords — logistics, order picking, ergonomics, motion capturing, body postures, Key Indicator Method

I. NECESSITY OF ERGONOMICS ANALYSES IN INTRALOGISTICS.

The processes within a warehouse or a distribution center can vary from highly automatized to completely manual. Despite the development and implementation of Industry 4.0 technologies, there are still manual processes within a Warehouse. It is even expected, that the manual activities and therefore the number of employees will stay consistent in practice [1], [2]. Especially the processes within order picking systems remain often manual since the cognitive and motor abilities of humans are hard to imitate [3]. The process of order picking describes the compilation of items from a warehouse to serve customer orders. Due to an increasingly volatile costumers' ordering behavior, the design of the order picking system has to be flexible and be able to adapt to the changes in shorter time periods [4]. Combined with the increasing work intensity in order picking systems, up to more than half of the total operating expenses are in this process which leads to current research on measuring the influence of system design on the human body [4], [5]. Order picking systems can be divided into goods-to-person and person-to-goods systems. Previous research results in Germany show that employees in intralogistics often pull, push, lift and carry heavy loads at their workplaces [6]. Also working while standing and performing repetitive as well as manual activities are widespread work demands at the shopfloor [6]. Furthermore, warehouse workers often have to deal with working environmental conditions like wearing personal protective equipment, unfavourable climatic conditions or noise [6]. These characteristics of manual work demands in the intralogistics may lead to physical strains and in the long term to physical impairments such as musculoskeletal disorders [7], [8].

Ergonomics analyses offer the possibility to determine and evaluate frequent workloads. In addition, to assessing work demands and environmental conditions, an ergonomics analysis also makes it possible to record physical stresses and body postures. In this way, the risk of musculoskeletal disorders in the company can be reduced in the long term [9]. To analyze and assess the objective workload the best-known manual screening method in Germany is the Key Indicator Method (KIM) [10]. Different load types such as lifting/holding/carrying, pulling/pushing and work with hands can be assessed by an ergonomics expert. For this purpose, four key features such as duration/frequency, load weight, body posture and execution conditions are recorded, documented and evaluated according to ergonomics [10].

The aim of this article is to digitize the Key Indicator Method in order to obtain an automated evaluation and thus standardized ergonomics evaluations in the future. A motion capturing system (MoCap) will be used for this purpose. In a first study, a manual person-to-goods picking process with different removal heights of the goods is simulated. With the help of the MoCap system, the course of the joint angle of the spine is analyzed during picking and ergonomically evaluated on the basis of existing standards and guidelines. At the same time, the Key Indicator Method is carried out to validate the results of the MoCap and to check the suitability of the system for ergonomic analysis.

II. Overview of Ergonomics Analysis Tools and Motion Capturing Technologies

A. *Existing ergonomics analysis tools*

There are many different methods for ergonomics evaluation in industrial processes. One of the best-known manual screening methods in Germany is the Key Indicator Method (KIM) [9]. There are three different methods: Lifting, holding, carrying; pulling and pushing; physical workload during manual handling operations. The aim of the three KIMs is the analysis and evaluation of the objectively existing workload with one type of load handling each. The assessment is based on physiological, biomechanical and psychological assessment principles. The evaluation of the load is based on partial activities and is related to one working day. For the evaluation of the partial activities so-called key indicators are used: load weight; posture; frequency; duration or route; execution condition.

Within the research project "KoBRA" on normative management of physical work stress and risk [11], an overview of different assessment methodologies for ergonomics evaluation of physical workloads in industrial processes is given. The available methodologies are differentiated concerning the following aspects [11]:

- The assessment level of the methodology (rough screening, screening, expert method and continuous measurement)
- The type of physical stress, which can be evaluated with the methodology (manual handling, body posture, thrust force, repetitive tasks)
- The user group for which the methodology is suited

Following up on this detailed differentiation of assessment methodologies for ergonomics evaluation in industrial processes, the research project "ErgoKom" focuses the development and technical integration of an evaluation methodology for determining employee loads in order picking systems [7]. Within the project an assessment methodology especially designed for order picking systems was developed [7]. Based on the methodology "Multiple-load tool (MLT)", different characteristics and physical workloads in order picking systems are integrated to get a valid assessment methodology [7]. The MLT was developed in the above mentioned KoBRA research project and also contains parts of the KIM e.g. for the quantification of the body posture.

Applying this methodology in the order picking process can lead to subjective results since the body posture is assessed and evaluated by human experts. To specify the possible body postures in the order picking process, the classification of body postures has been detailed and adopted in the "ErgoKom" project [7]. Allocating different angle specifications (e.g. bending of upper body or abduction of upper arm) to the body posture score creates a more detailed and specific rating system [5]. The developed methodology is specified for order picking processes, but still paper based for industrial use. For this reason, the need for developing an automatic and real-time assessment methodology to detect and evaluate human motion is highlighted [5].

Besides the results of the described research projects, different ergonomic standards for the evaluation of human body postures and movements at work are available. Based on the DIN EN 1005-4 and the ISO 11226, the Institute for Occupational Safety and Health of the German Social Accident Insurance (DGUV) (IFA) classified angle ranges of different body postures and movements (head, torso, upper and lower extremities) according to the traffic light model [12]. The colour green means that body postures and movements are carried out ergonomically and therefore there is no need for action. The colour yellow means that the individual stress perception of the employees should be determined, as there is a risk of physical workload. The colour red requires a technical and/or organisational redesign.

B. *Existing MoCap technologies*

Over the past decades, various developments in MoCap technologies can be recognized [13]. Primarily driven by the entertainment and film sector, the performance in capturing body sequences has increased and hence the opportunities for using the technology in other fields like science or health [13]. There are different technical procedures for motion tracking such as optical, magnetic, mechanic, acoustical and inertial motion capturing [13, 14]. Advantages and disadvantages of each MoCap technology are given in Tab. I. The application of a technology is essentially based on the spatial environmental conditions in which the system is to be used.

TABLE I. Advantages and Disadvantages for Different Motion Capture Technologies [13, 14]

MoCap Technology	Advantages	Disadvantages
Optical	• High accuracy • Large capture environment • Participant free movement due to missing wiring	• Necessity of ○ constant visibility of the markers ○ post-processing ○ controlled light conditions
Magnetic	• No visual masking of sensors • Low purchase costs • Positions and orientations are available without downstream processing	• Possibility of electric or magnetic interference • Restricted movement due to wiring • Low frame rate
Mechanic	• No visual masking of sensors • No inteferences by metallic or magnetic objects	• No global translations • Restricted movement due to the exoskeleton
Acoustical	• Low cost and small sensors • Mobile use due to the low power cosumption	• Acoustical interferences possible • Limited range to about 50 meters
Inertial	• No visual masking of sensors • Small design	• No data about the position of the body in space available

MoCap Technology	Advantages	Disadvantages
		• Possible disturbances by the earth's magnetic field or other sources

III. Methods

A. Description of the used MoCap technology

The present laboratory study was conducted in the research centre of "InnovationLab Hybrid Services in Logistics" of the Chair of Materials Handling and Warehousing at the Technical University of Dortmund. One main field of research in this research centre are new human-machine interactions (HMI) in an Industry 4.0 environment. In this environment humans and machines can support each other in a shared working area [15]. The research centre essentially comprises the following reference and experiment systems [15]:

a) Reference systems: Optical reference system, radio reference system, laser project system, virtual reality system

b) Experiment systems: Robot systems, LR-WPAN and other wireless networks, networked computational system

For the laboratory study the optical reference system is used. The installed MoCap system consists of 38 cameras and is therefore one of the largest reference systems in Europe. Rigid or flexible objects must be equipped with markers for location and localisation. After calibration, the cameras can track and locate any object with markers in a volume of approximately 22m x 10m x 6m [15], [16]. The installed cameras are divided into 30 Vicon Vero 2.2 cameras with a resolution of 2.2 megapixels and a maximum of 330 frames per second and 8 Vicon Vantage V5 cameras with a resolution of 5 megapixels and a maximum of 420 frames per second. This enables ergonomics evaluation studies for postures and movements in a picking process without a human observer. In order to record the movement and posture data the test person wears an elastic suit on which 39 passive markers with a diameter of 25 mm are placed in a predetermined position. The markers reflect the camera's LED signals so that the position of each marker in a 3D space can be calculated using the Nexus motion capturing software. The Nexus Plug-In Gait biomechanical model generates kinematic and kinetic output data for each test person. Using the anthropometric data of each test person, the software calculates the angles of various body segments. The joint angles can be divided into three anatomical movements for the description of the position and position change of individual body parts:

- Flexion and extension of the body joints
- Adduction and abduction of one part of the body from/to the vertical axis of the body centre/limbs
- Internal rotation and external rotation.

B. Manual ergonomics analysis using KIM

To check the data of the MoCap system, the KIM regarding lifting, holding and carrying was used [10]. The KIM is a manual screening method that is applied to obtain a rapid assessment of work activity by identifying health risks. For this purpose, four key indicators such as duration/frequency, load weight, body posture and execution conditions were recorded, documented and evaluated regarding ergonomics [10]. Since the MoCap system can provide information on body posture in its current state of development, the key indicator body posture was of particular interest (Fig. 1). The assessment of the body postures for lifting/carrying/holding are classified by pictograms which offer a quick and easy assessment of the work activity. The characteristic posture of the load handling can be evaluated in each case for determining the weighting. There are four different classes of body postures with rating points from one to eight. For different postures a mean value can be calculated.

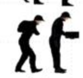
Characteristic body posture and load positions	Body posture and load position	Rating points
	• Upper body upright, not twisted • Load directly on body	1
	• Slight frontal or torsional movement of the upper body • Load directly on or close to body	2
	• Deep bending or wide front or slight frontal with simultanious torsional movement of the upper body • Load above shoulder or away from body	4
	• Wide front with simultanious torsional movement of the upper body • Load away from body • Kneeling or squatting	8

Figure 1: Classification of body postures and load positions in the Key Indicator Method (KIM) [10]

The other key features are also rated on different scales which evaluate the ergonomic conditions at a workstation. By adding the rating points for load weight, body posture and execution conditions with a subsequent multiplication with a parameter for duration/frequency the ergonomics expert gets a total score. The score is needed for identifying a physical overload that can be divided into four risk areas [10]. Area 1 and 2 correspond to the colour green according to the traffic light model. Risk area 3 is yellow and 4 means red.

C. Study design

To evaluate the posture of different persons, the tilt of the upper body during a simulated manual picking process was recorded and evaluated. For analyzing the tilt of the torso, a spinal column parameter was used to show flexion and extension of the joint point. In addition to the analysis of the MoCap system, the KIM was used for verifying the received joint angles data. Therefore, the workload according to ergonomic standards was evaluated with the MoCap system by measuring the joint angles as well as using KIM by two ergonomics experts.

The study sample consists of three students at the age of 22 to 29 years who had no practical experience in executing intralogistics processes. With a body height from 163 cm to 185 cm different physical conditions were taken into consideration. Due to the high manual handling effort, a simplified, standardized version of the order picking process was chosen as study design. The process started with walking to a storage location, positioning in front of the location and picking a defined number of small bags that were filled with granulate of 500 grams. To finish the process, the picked bags were placed in a container that was at a height of 90 cm (Fig. 2). In order to achieve a large variance in body postures and joint angles of the participants, different removal heights were implemented in the process: a low removal height of 30 cm, a medium removal height of 110 cm and a large removal height of 173 cm as can be seen in Fig. 2.

Figure 2: Experimenta order picking setup with with three different removal heights low, medium, high (left) and a storage location (right) (Source: Fraunhofer IML)

To ensure comparability between all test persons some rules had to be observed: a frontal positioning at the storage unit, at most three steps towards the storage unit, a one-handed pick with the dominant arm, a turn to the right, at most four steps towards the storage location and a one-handed put down with the dominant arm.

IV. Results

A. Results of using MoCap

All data records were processed using the Nexus software. Data gaps were filled with the rigid body fill and kinematic fill methods from Nexus and the dynamic Plug-In Gait model was calculated. Fig. 3 shows the real study environment and the digitalized body posture in the MoCap software. Based on the output of the dynamic Plug-in Gait model, all further evaluations were done. The Software MATLAB was used to process and plot the selected data which contained the spinal column angles for each frame.

The implementation of the traffic light model makes it possible to evaluate the ergonomic design of a process [12]. Using this model in both methods provides a basis for comparing the results of MoCap with the results of KIM analysis. To draw conclusions about ergonomic process design two parameters were used: The degree of the joint angle and its changeover time. According to the traffic light model an acceptable area (green) is defined from 0 to 20 degrees. Above 20 to 60 degrees the activities are in a conditionally acceptable area (yellow) and above 60 as well as below 0 degrees the activities are defined as unacceptable (red) [12].

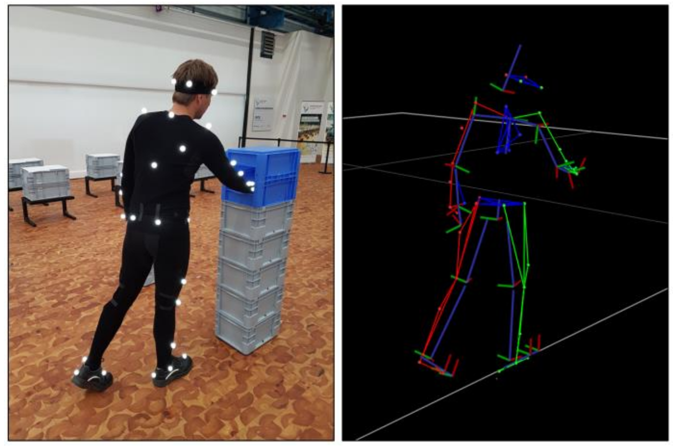


Figure 3: One test person who is picking items in the real environment (left) and in the MoCap software (right) (Source: Fraunhofer IML)

Table 2 gives an overview of the percentages of the spinal column angle according to traffic light model for each participant and removal height.

TABLE II. PERCENTAGES OF THE SPINAL COLUMN ANGLE PER TEST PERSON AND REMOVAL HEIGHT

	Removal height	**Green**	**Yellow**	**Red**
Person 1	Low	51,8	23,3	24,9
	Medium	81,4	0	18,6
	Large	47,5	0	52,5
Person 2	Low	48,9	19,9	31,2
	Medium	13,7	0	86,3
	Large	16,5	0	83,5
Person 3	Low	66,4	22,3	11,3
	Medium	78,9	0	21,1
	Large	67,7	0	32,3

It can be concluded that the physical load on a person's upper body depends on the removal height while picking items. The results show that the spinal column angle of persons 1 and 3 was mostly in the green angle range at the medium removal height. Thus, the inclination of the trunk was acceptable. In contrast, regarding test person 2, the angle of the spine was most often in the green area at the low sampling height. Furthermore, the item picking for test persons 1 and 3 at the large removal height proved to be not ergonomic. Here the spine angle was most frequently in the red range. For participant 2 picking at the medium and large removal height was equally not ergonomic.

It is noticeable that the spinal column angle in the medium and large removal height was never measured in the yellow angle range for all test persons. This can be explained by the fact that in the case of a back extension the angle goes into the negative range and is to be evaluated directly as unergonomic or red.

Furthermore, the ergonomics evaluation scheme is embedded and provides an ergonomic evaluation of the angle curves. Fig. 4 visualizes the joint angles of the spinal column for participant 1 at three removal heights (low, medium, large). At the low picking position, participant 1 showed a significant increase in the spinal column angle to 51.1° (upper graph). The other two figures show a variation of the spinal column angle by 0° at the middle and high removal height for test person 1. The average fluctuation between the minimum and maximum spinal angle is only 12°. At this point it becomes clear that the test person did not have to perform a significant flexion of the torso to reach the removal position at these two heights.

B. Results using KIM

In the following, the evaluation of KIM regarding lifting, carrying, holding is presented. The KIM provides a possibility to proof and validate the data of the MoCap analysis. KIM was used by two independent experts during the MoCap data was recording. The results show that both observers had uniform results in their assessment of the order picking activities. The explanation of the evaluation and the individual steps are therefore taken together. Tab. 3 shows the KIM total scores and the therein included body posture risk areas of all three test persons. These risk areas are used to enable the comparison between KIM and the processed MoCap joint angles of the spine column.

TABLE III. KIM TOTAL SCORES AND BODY POSTURE RISK AREAS FOR THE THREE TEST PERSONS PICKING AT DIFFERENT REMOVAL HEIGHTS

		Low removal height	**Medium removal height**	**Large removal height**
Person 1	KIM total score	30	12	30
	Body posture risk area	3	1	3
Person 2	KIM total score	30	18	54
	Body posture risk area	3	2	4
Person 3	KIM total score	30	12	54
	Body posture risk area	3	1	4

As seen in Tab. 3 the results regarding the body posture risk areas are for all three test persons and removal heights similar. The removal activities at the low removal height correspond to the risk area 3 (yellow), at the medium height to risk areas 1 and 2 (green) and at the large height to risk areas 3 and 4 (yellow and red). These results can be confirmed by the MoCap data for all three test persons, like Fig. 4 shows for test person 1. The different results for the large removal height arise because the KIM includes above shoulder work (Fig. 1) and the MoCap assessment only regards the joint angle of the spinal column.

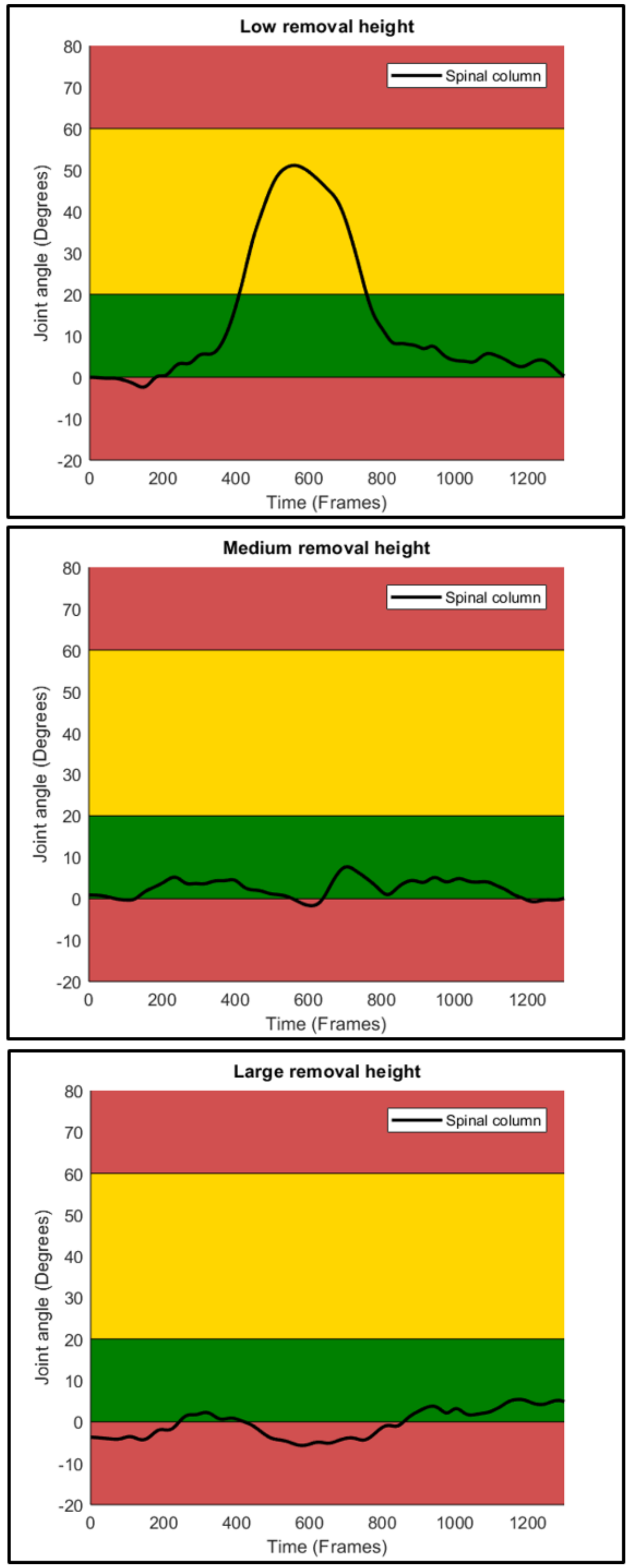


Figure 4: Joint angles for three different removal heights of test person 1 (top: low, middle: medium, bottom: large removal height) (Source: Fraunhofer IML)

V. Discussion and Conclusion

The comparison between the MoCap data and the results of the posture analysis using the KIM shows that it is possible to assess a manual handling process in intralogistics with MoCap data. Using the traffic light model for the ergonomic evaluation of the MoCap data revealed the problem that every negative joint angle is in the red area. Furthermore, the height and the execution of movement of the test person and also the marker placement on the suit are identified as having impact on the results. This can lead to unexpected results as seen in Tab. 2 (e.g. the percentage share of person 2 in the medium removal height is 86% in the red area). With that in mind, the comparison shows a great consensus bwtween the MoCap and KIM results. For further ergonomic evaluation using MoCap, the traffic light model has to be modified. The MoCap data showed a small deviation around the 0° range even with a natural walking movement of the test persons. Therefore, an additional yellow range between the green and red area could be added to buffer this kind of natural movements. Also, the marker placement needs to be done at a high accuracy to ensure valid data.

When looking at KIM it is notable that the MoCap system can only cover one part of the ergonomics assessment, namely the body posture. The time and load weighting as well as the evaluation of the execution conditions are not included here. In addition, the assessment with the MoCap data should include more body angles than the spinal column and these angles should also be included in the assessment. In order to evaluate work above shoulder height (as some results of KIM show), the shoulder angles should also be included. Only in this way, it is possible to guarantee a fully comprehensive assessment as with KIM. Nevertheless, detailed evaluations can be performed with the results of the MoCap data. The output of graphs, maximum and minimum values and a percentage distribution is possible. In future research the entire body can be visualized and evaluated during logistical activities by using MoCap technology. Furthermore, the use of force plates should be implemented to enable the measurement of forces of load weights on the body according to the KIM method. Concluding, MoCap technology offers a great potential to support the digitization of ergonomic evaluation in order picking systems. Especially the digitized ergonomic assessment of body postures is more accurate and faster than using KIM with human professionals.

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References

[1] D. Schlögl and H. Zsifkovits, „Manuelle Kommissioniersysteme und die Rolle des Menschen“, BHM Berg- Hüttenmänn. Monatshefte, vol. 161(5), pp. 225–228, May 2016.

[2] R. Michel, „2016 Warehouse/DC Operations Survey: Ready to Confront Complexity“, Supply Chain Management Review, pp S52–S59, Nov. 2016.

[3] E. H. Grosse, C. H. Glock, and W. P. Neumann, „Human factors in order picking: a content analysis of the literature“, Int. J. Prod. Res., vol. 55(5), pp. 1260–1276, May 2017.

[4] R. Manzini, Warehousing in the Global Supply Chain: Advanced Models, Tools and Applications for Storage Systems, London: Springer, 2012.

[5] K. Weisner and J. Deuse, „Assessment Methodology to Design an Ergonomic and Sustainable Order Picking System Using Motion Capturing Systems“, Procedia CIRP, vol. 17, pp. 422–427, Jan. 2014.

[6] V. Kretschmer, „Belastungsschwerpunkte von Erwerbstätigen in der Intralogistik“, Sicher ist sicher - Fachzeitschrift für Sicherheitstechnik, Gesundheitsschutz und menschengerechte Arbeitsgestaltung, vol. 12, pp. 536-540, 2017

[7] W. A. Günthner, J. Deuse, T. Rammelmeier, and K. Weisner, Forschungsbericht: Entwicklung und technische Integration einer Bewertungsmethodik zur Ermittlung von Mitarbeiterbelastungen in Kommissioniersystemen (ErgoKom), Garching: Lehrstuhl für Fördertechnik, Materialfluss, Logistik, Techn. Univ. München, 2014.

[8] M. Schmauder: „Ergonomie, was ist das?“, Sicher ist sicher - Fachzeitschrift für Sicherheitstechnik, Gesundheitsschutz und menschengerechte Arbeitsgestaltung, vol. 1, pp. 4–6, 2013.

[9] G. Caffier; U. Steinberg; F. Liebers: Praxisorientiertes Methodeninventar zur Belastungs- und Beanspruchungsbeurteilung im Zusammenhang mit arbeitsbedingten Muskel-Skelett-Erkrankungen, 1st ed., Bremerhaven: Wirtschaftsverlag NW Verlag für neue Wissenschaft GmbH, 1999.

[10] BAuA, Bundesanstalt für Arbeitsschutz und Arbeitsmedizin: Leitmerkmalmethode zur Beurteilung von Heben, Halten, Tragen. Dortmund, 2001, URL: https://www.baua.de/DE/Themen/Arbeitsgestaltung-im-Betrieb/Physische-Belastung/Leitmerkmalmethode/Leitmerkmalmethode_node.html.

[11] M. Kugler; M. Bierwirth; K. Schaub; A. Sinn-Behrendt; A. Feith; K. Ghezel-Ahmadi; R. Bruder, Ergonomie in der Industrie – aber wie? Handlungshilfe für den schrittweisen Aufbau eines einfachen Ergonomiemanagements, Darmstadt: Institut für Arbeitswissenschaft der TU Darmstadt, 2010, URL: www.kobra-projekt.de/page/handlungshilfe

[12] IFA, Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung, „Evaluation of physical work load in accordance with DGUV Information 208-033 (formerly BGI/GUV-I 7011) (Annex 3)“, 2015, URL: https://www.dguv.de/ifa/fachinfos/ergonomie/index-2.jsp

[13] A. Menache: Understanding Motion Capture for Computer Animation, Burlington, MA: Morgan Kaufmann, 2010.

[14] M. Kitagawa; B. Windsor: MoCap for artists: Workflow and techniques for Motion Capture, Burlington, MA: Focal Press, 2008.

[15] A. K. R. Venkatapathy, H. Bayhan, F. Zeidler, and M. ten Hompel, „Human Machine Synergies in Intra-Logistics: Creating a Hybrid Network for Research and Technologies“, Proceedings of the Federated Conference on Computer Science and Information Systems, vol. 11, pp. 1065–1068, 2017.

[16] C. Reining, F. M. Rueda, M. ten Hompel, and G. A. Fink, „Towards a Framework for Semi-Automated Annotation of Human Order Picking Activities Using Motion Capturing“, Proceedings of the Federated Conference on Computer Science and Information Systems, vol. 15, pp. 817–821, 2018.