REPETITIVE LIFTING TASKS IN LOGISTICS – EFFECTS ON HUMANS AT DIFFERENT LIFTING TASK DURATIONS

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A volunteer study at the Chair of Ergonomics (TUM) investigates which cardiovascular effects on the human body are to be expected from repetitive lifting movements at different load times, and which requirements arise accordingly with respect to different lifting task durations by using the cardiopulmonary exercise testing (CPET) method. Two different weight classes and three different load times are combined with a conventional lifting task. In addition to the acquisition of objective data, such as oxygen consumption (V'O_2/kg) or heart rate (HR), the subjective stress using the Borg RPE scale is determined and analyzed. 27 test persons (M=27.6 years, SD=±3.1) participated in the study. At 70.4% less than three quarter of the participants in the test were men. Both the objective and subjective data show significant differences between the mentioned weight classes. A load time of more than 10 minutes for analyzing manual handling tasks by using CPET is recommended.
Keywords: Lifting task; load; stress; strain; cardiopulmonary exercise testing; CPET; oxygen consumption

INTRODUCTION

Assistance systems for supporting manual load handling are to be used in production and logistics systems for some time. Such support systems don't only include cranes and manipulator systems. For manually handled load weights of up to 30 kg, research interest exists only for quite some time for assistance, such as exoskeletons and other body-worn systems, as studies have shown that, in particular, manual, repetitive tasks combined with unfavorable postures cause diseases of the musculoskeletal system (Spallek et al., 2010). In addition, discomfort in the back area is caused, which ultimately results in absenteeism (Jäger & Luttmann, 2005). Also, organs of the cardiovascular system can be affected by this kind of work (Bongwald et al., 1995; Löllgen et al., 2010). The reason is that during the manual handling of heavy loads, a large part of the skeletal muscles is activated. At the same time, the skeletal system is loaded by internal and external forces. To maintain the muscle function, an increased oxygen supply of the muscles is required, which is regulated by the bloodstream and respiration. In particular, long-term activities put stress on the cardiovascular and respiratory system (Bongwald et al., 1995).

APPROACH FOR RESEARCH

Innovative assistance systems like exoskeletons and body-worn lifting aids need to be evaluated in a practice environment before launch. For this reason, the cardiopulmonary exercise testing (CPET) method is increasingly used to evaluate such body worn systems. In summary, it can be said that the results, which were determined using cardiopulmonary exercise testing in the field of medicine or sports, are not transferable to working tasks. Furthermore, there is the problem that many different approaches exist for the examination of the stress by using cardiopulmonary exercise testing in the field of work. Also, in the field of exercise and load duration different approaches exist. Therefore, in a study at the Chair of Ergonomics (Technical University of Munich, TUM), the influence of different lifting task durations on the stress of people in working tasks is investigated. In particular, conventional lifting and carrying procedures are analyzed in the field of the manual handling of loads in logistics by the combination of three different load times with two different weight classes.

METHOD

Test Environment

Workplace. The test environment is a replicated logistics workplace in a laboratory of the Chair of Ergonomics, which has two shelf assemblies. To comply with laws regarding the ergonomic workspace, a distance of 150 cm between the two shelves is respected (see Figure 1). In order to standardize the picking up and depositing of the boxes loaded with weights for all volunteers, shelves of 75 cm height are used. Another reason is there are not always different height settings of conveyor belts or shelves available in reality. The distance and altitude measurements are comparable to a study carried out in a task analysis for daily work of retailing (Knott et al., 2014). To ensure comparable lifting movements, blue markers are attached to the two opposing shelves, which are used as a placeholder for packages. For the experimental setup a chair also exists in the laboratory that is used as a resting place during the regeneration phase.

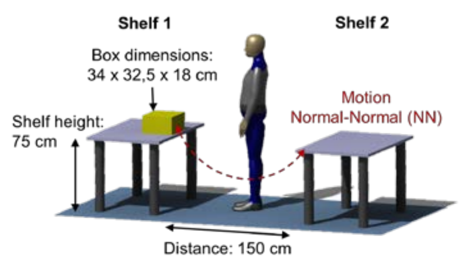

Figure 1: Schematic illustration of the logistics workplace with dimensions at the Chair of Ergonomics (TUM)

Load dimensions and weights. The dimensions of the size 4 DHL-Express packages used in this study have the following dimensions: length 32 cm, width 34 cm, height 18 cm. These dimensions correspond to the average size according to the above mentioned task analysis. With regard to package weights, two different weight classes are used with the abbreviations in Table 1. In order to obtain an optimum weight distribution, iron weights and water-filled boxes are used for the weight class "6.5 kg". The choice of package weights is also based on the above-mentioned task analysis. Visually no differences between the packages of 0 kg and 6.5 kg can be seen. This ensures that the volunteers have no expectations regarding the weights before starting the test.

Table 1: Package weights

	Tare weight	**Average weight**
Weight	0.375 kg	6.5 kg
Abbreviation	0 kg	6.5 kg

Task

Lifting task. Depending on the condition, the test person has the task of lifting and carrying a box with a defined weight of either 0 kg or 6.5 kg from shelf 1 to shelf 2 or from shelf 2 to shelf 1. To simulate the work of manual picking as realistically as possible in the laboratory, a rotation of 180 degrees is included in every movement. In addition, the test subject is asked to bring the package from shelf height to abdominal height during the carrying phase and lowering the box again to table height.

Lifting technique. The lifting technique must be carried out in accordance with ergonomic principles. That means picking up the box perpendicular to the body level is required. The picking up and depositing of packages in a rotated body posture is not allowed.

Lifting frequency. To achieve a realistic simulation of the situation at the replicated logistics workplace, a lifting frequency of six movements per minute is determined. According to Kiparski (1989), this number of movements corresponds to frequent lifting situations in industry. The beat is presented using a metronome (Metronome Plus, mm systems UG & Co. KG, Gießen/Germany).

Lifting task duration. The following three different load durations are used in this study: 3 repetitions, 10 minutes and 15 minutes. The study examines which stress exists at the different load times. In addition, the issue should be clarified which load period is required as a minimum load duration to obtain meaningful results.

Measurement Systems and Instruments

CORTEX MetaMax® 3B. To collect and analyze respiratory data the mobile cardiopulmonary exercise testing system MetaMax® 3B (CORTEX Biophysics GmbH, Leipzig/Germany) is used in combination with the software CORTEX MetaSoft® Studio. The device measures breath-by-breath data, stored on the device and transferred to the computer by Bluetooth connection. By using a shoulder strap and a mask attachment, the system is attached to the body of the test subject (see Figure 2). In particular, a comfortable and tight fit of the mask has to be ensured. Hygiene guidelines according to the manufacturer's user manual have been complied (CORTEX, 2014).

CORTEX MetaSoft® Studio. The software offers an intuitive data collection that corresponds to ergonomic principles with regard to usability. By using the software, the device MetaMax® 3B is prepared for the measurement recording. For this purpose, a 30-minute warm-up of the device and calibration procedures has to be considered.

POLAR® H7 Heart rate sensor. The hardware also includes a system for measuring the heart rate (HR), which is fixed below the subject's chest by using an elastic belt. The data is also transmitted via Bluetooth to the CORTEX MetaSoft® Studio software. Consequently, synchronous data analysis is possible.

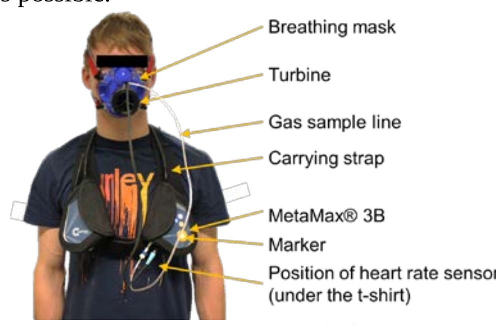

Figure 2: CORTEX MetaMax® 3B attached on a test person

GoPro HERO2. For a more detailed analysis of irregularities in the objective data collected by using the CPET system, the recording of a video camera is used. For example, data during which there was talking or coughing can be eliminated from the data set in order to avoid distortions in the results.

BAPPU-evo. To record the environmental conditions at the laboratory workplace, the measurement device BAPPU evo (ELK GmbH, Krefeld/Germany) is applied. The recording of this data is used to verify comparable environmental conditions in the laboratory during the test series.

Anthropometric Measuring Tool. To determine the body measurements, the anthropometric measuring tool is applied. In particular, body height, shoulder height, arm and leg lengths are recorded in addition to the weight.

Demographic questionnaire. Personal data are collected by a specially designed questionnaire. In addition to information on the age, gender and smoking habits, health status and fitness level are collected. Also, the experience in the field of manual handling of loads is requested.

Borg RPE scale. The subjective assessment of stress of the individual subjects during the conditions is determined via the standardized RPE scale according to Borg (1970). The goal is to compare these data with the objective data measured by the CPET system and the heart rate sensor.

Test Procedure

The experiment was carried out at the replicated logistics workplace at the Chair of Ergonomics (TUM) described in Figure 1. Figure 3 summarizes the procedure of the study, which lasts about 100 minutes. After welcoming and introducing the participant to the study by presenting information of the test procedure, formalities for voluntary test participation and a consent for collecting video and audio material is carried out. At the same time the subject is asked to eat a chocolate bar MARS® (45 g, Mars Inc.) in order to ensure comparable blood sugar levels between the individual test subjects. In addition, it is guaranteed that the carbohydrate reserves are not empty. After acquisition of body measurements using the anthropometric measurement tool, the chest strap for measuring the heart rate as well as the cardiopulmonary exercise testing system is attached to the participant. The former will be moisturized with water for better contact and checked for a good fit in order to prevent transmission errors. The system and the breathing mask must be positioned comfortably in order to interfere with the following working conditions as least as possible. To acclimatize to breathing with the breathing mask, which does not interfere according to the manufacturer, a 5-minute adaptation phase follows while sitting on the provided chair. Meanwhile, the demographic questionnaire is answered.

Before the recording of the test data is started, the experimental procedure will be explained to the test subjects. To ensure a standardized experimental procedure, the procedure is read to the subjects.

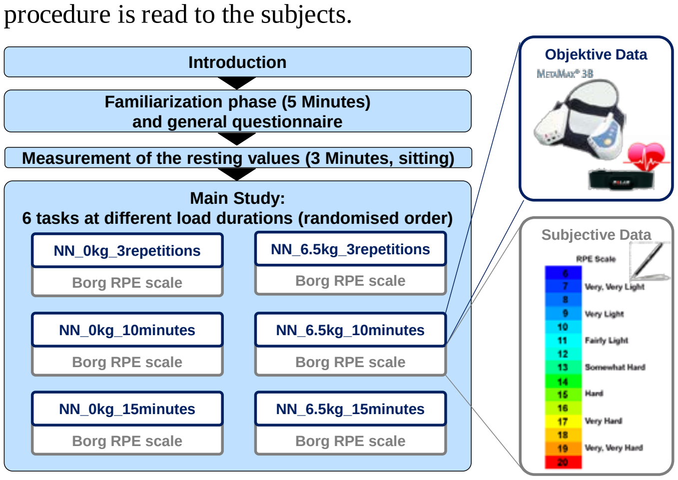

Figure 3: Test Procedure

As can be seen in Figure 3, the test starts with a resting phase. This takes three minutes and is based on previously performed research (see Knott et al., 2015). In this case, the subject is in a seated position without moving in any way. The resting phase is used for later comparison of the measured parameters between the conditions with and without the load. In parallel, the measurements of the GoPro HERO2 and the BAPPU-evo are started by the investigator. During the load condition in the study, a lifting movement has to be carried out at the described logistics workplace from a shelf to a second shelf. After picking up a box from a height of 75 cm, the subject performs a rotational movement of 180 degrees and carries the box a distance of 150 cm. During the transportation phase, the box is handled symmetrically and the upper and fore-arms form an angle of 90 degrees. Afterwards, the package is stored again at 75 cm height (see Figure 1). In total, six experimental conditions are carried out, in which both the weight (0 kg or 6.5 kg) as well as the load duration (3 repetitions, 10 minutes, 15 minutes) is varied. To avoid learning effects, the individual test conditions are performed in randomized order. Before each test task, the subject begins in the starting position. This is located in the middle of two opposed shelves. In order to detect the beginning and end of the individual conditions, the marker located on MetaMax® 3B (orange button) is pressed. In order to standardize the conditions for all test subjects, a metronome is used and provides signals for a lifting frequency of 6 packages per minute. The metronome beats 12 times per minute. Each signal a box is either received or stored. To regenerate, a five-minute break will take place after each condition. Simultaneously, the subjective assessment of stress by using the RPE scale according to Borg is used after each experimental condition during the break. Since the test persons may not speak during the trials, the personal stress based on the Borg RPE scale is collected by pointing the index finger on the scale. In addition, the next test condition is explained to the subject during the break. After the last regeneration break, the measurement systems are removed. Following this, the test subjects have the opportunity to express comments and suggestions before thanking them and handing out a small present for their voluntary participation.

RESULTS

Data Collection and Statistical Data Analysis

The preparation of the data of the demographic questionnaire, the RPE scale according to Borg, the BAPPU-evo measurement system and the objective measurements are carried out by using Microsoft Excel 2010. All subjects received an individual subject number. Thus, an anonymized data preparation and subsequent data evaluation is guaranteed. Furthermore, data generated by the MetaSoft® Studio software are filtered for the relevant respiratory parameters and transferred to Excel sorted by subject number and experimental parts. Since the cardiopulmonary exercise system works with the breath-by-breath technology, the data of the subjects for each breath are available. For comparison of the individual test parts, average values of the parameters are calculated for each condition (3 repetitions, 10 and 15 minutes). In order to analyze the experimental data statistically using the software SPSS (IBM, version 22), the following conditions must be met.

For the comparison of data sets, the arithmetic mean is basically generated for each part of the experiment for the test participants. For this purpose all values are summed up for one condition and then divided by the number (Bortz & Schuster, 2010). In order to get information about the dispersion of the calculated mean values, the standard deviation is calculated as described in Bortz & Schuster (2010).

As part of the statistical analysis, a test to eliminate an outlier was carried out according to Johnson et al. (1994). In addition, a test regarding normal distribution was conducted according to the Shapiro-Wilk test by using SPSS (IBM, version 22). In the case of an existing normal distribution, a t-test for paired samples is used, while in the case of absence of normal distribution the Wilcoxon test is calculated (Bühner & Ziegler, 2009). As part of the analysis of the hypotheses, a significance level of $\alpha = 5\%$ is used. Since all hypotheses of the study are non-directional and the participants are not different between the test parts, two-sided tests in the program SPSS by IBM (version 22) are applied. Thus, the following situations arise. For a p-value > α, the result of the investigation is not significant and the null hypothesis is retained. If the p-value ≤ α, however, the result is significant, which means the null hypothesis has to be rejected. In the case of a p-value > α, and thus the associated retention of the null hypothesis, this nevertheless does not suggest that this is true. However, it can be said that the test study is not sufficient for the rejection of the null hypothesis (Bortz and Schuster, 2010).

Test Sample

The test sample consists of a total of 27 subjects. After successful recruitment in the field of mechanical engineering, the test subjects are mostly scientists and student assistants. 19 men (70.4%) and eight women (29.6%) participated in the study with an average age of $M_{age} = 27.6$ years ($SD_{age} = \pm 3.1$). Regarding the body size and weight, the sample has an arithmetic mean of $M_{height} = 182.13$ cm ($SD_{height} = \pm 8.27$ cm) and $M_{weight} = 78.46$ kg ($SD_{weight} = \pm 10.74$ kg). Only one test subject smokes a pack of cigarettes per day. The frequency distribution of doing sports per week has its maximum at 44.4% (twelve subjects) in the area of two to three times of sports per week. 7.4% (two participants) do not engage in sports, while 29.6% (eight people) do sports once a week. Five subjects (18.5%) are active in sports more than three times per week. In addition, the test subjects were able to make statements about the perceived health condition. None of the volunteers saw himself in the field of competitive sports. With two test participants, the group "not trained" is also only very weakly represented. Twelve participants assessed their fitness level as "normal", whereas 13 persons decided for the classification "trained". None of the 27 participants were working in the field of load handling at the time of the study. The level of experience in the field of load handling reflects a low value. As verification for the environmental conditions of the laboratory tests, the data of the BAPPU-evo system is used. For this purpose, the average of the two major criteria (average temperature and humidity) was created. According to Kroidl et al. (2010), the measured average value for temperature of 22.7°C and the mean of the humidity of 44.8% can be attributed to the laboratory test.

Objective and Subjective Results

It was already demonstrated in Knott et al. (2015) that three repetitions for meaningful results for the evaluation of the stress in working activities are sufficient by using the Oxygen Consumption ($V'O_2$/kg) and the Heart Rate (HR), but there is also an increase after three repetitions. With this study it should be determined whether a load of 0 kg shows significant differences to a condition with 6.5 kg (Hypothesis 1) and at least which exercise duration is required (Hypothesis 2). In relation to the objective data, the following parameters will be considered in more detail: oxygen consumption per body weight $V'O_2$/kg [(ml O_2/min)/kg], heart rate HR [beats/min] as plausibility data and the Respiratory Exchange Ratio RER [-]. As a subjective parameter for comparison, the mean value of the RPE scale according to Borg (1970) is used. In both the objective and subjective values, no outliers could be determined according to Johnson et al. (1994), who set the outlier threshold to 3.5.

Hypothesis 1: Parameters show differences at different weights for 10 and 15 minutes. As shown in Figure 4a, the t-test results in a significant difference between the different weight classes for the parameters oxygen consumption ($V'O_2$/kg) at a significance level of $\alpha = 5\%$ for both 10 minutes ($t(26) = -14.621$; $p = .000 < .05$) as well as for 15 minutes ($t(26) = -14.888$; $p = .000 < .05$).

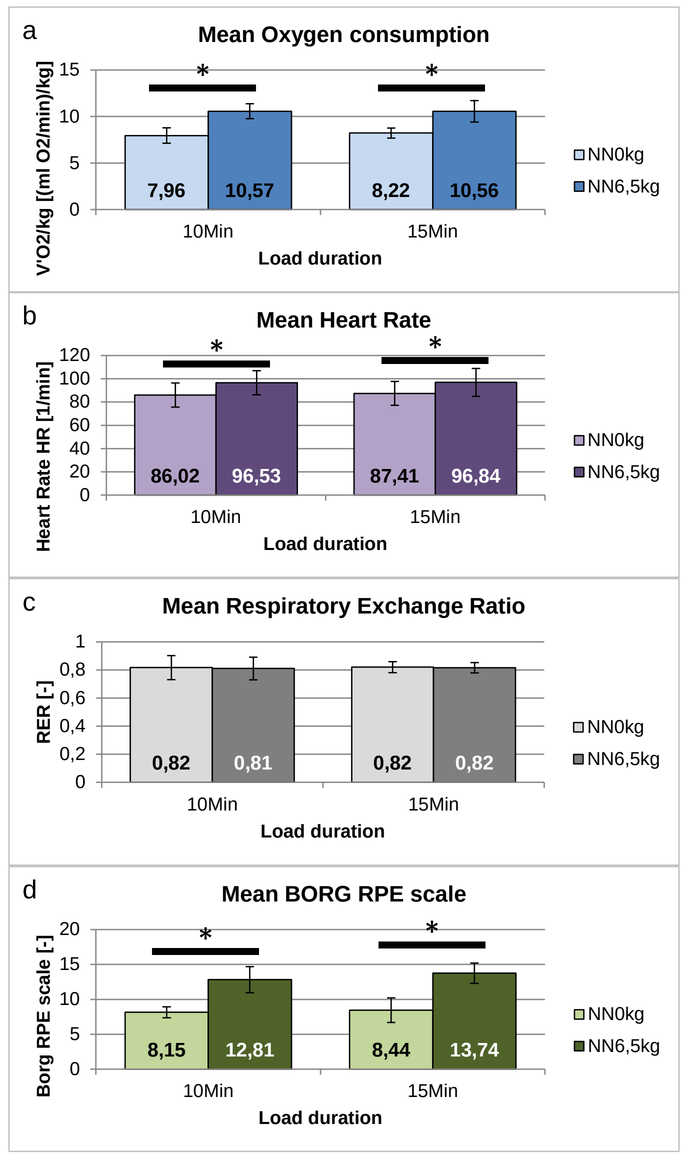

Figure 4: Comparison of the average values and standard deviation in the different test conditions (a: $V'O_2$/kg; b: HR, c: RER; d: Borg RPE)

The same results for the heart rate parameter (HR), as shown in Figure 4b (10 minutes: $t(26) = -7.016$; $p = .000 <$

.05; 15 minutes: $t(26) = -8{,}646$; $p = .000 < .05$). Consequently, in the case of oxygen consumption and heart rate, both exposure durations can be used for evaluation because a significant difference between the two weight classes could be detected. In contrast, however, the t-test for the RER parameter yields non-significant results (see Figure 4c). RER at a higher weight class corresponds to the values of the lower weight class. Accordingly, in this case the RER value is not sensitive enough to make statements regarding the assessment of stress in different activities (10 minutes: $t(26) = 1.059$; $p = .299 > .05$; 15 minutes: $t(26) = .704$; $p = .487 > .05$). However, while the RER shows no meaningful results, the average of the subjective assessment according to Borg confirms the remaining objective results by using the Wilcoxon test (10 minutes: $z = 4.554$; $p = .000 < .05$; 15 minutes: $z = 4{,}553$; $p = .000 < .05$; see also Figure 4d).

Hypothesis 2: Parameter differences at different load durations at 0 kg and 6.5 kg. With the existing normal distribution of the test sample data, a t-test for dependent samples for the parameters $V'O_2$/kg and HR and the Wilcoxon test for Borg-RPE values shows the following results (Table 2):

Table 2: Statistical analysis of hypothesis 2

t-Test V'O$_2$/kg	***df***	***t***	***p***
0 kg	26	-2.949	.007 *
6,5 kg	26	0.070	.945

t-Test HR	***df***	***t***	***p***
0 kg	26	-0.927	.363
6,5 kg	26	-.356	.724

Wilcoxon Borg-RPE	***z***	***p***
0 kg	-1.157	.247
6,5 kg	3.075	.002*

DISSCUSSION AND SUMMARY

In Knott et al. (2015) it has been suggested that a higher load duration may result in more meaningful results for RER. Hypothesis 1 shows, however, that even after 10 or 15 minutes, no differences between different weight conditions are available for RER. Only a decrease of the values in comparison with three repetitions is recognized. All other parameters such as oxygen consumption, heart rate and the RPE value according to Borg show significant differences in stress for different weight classes both at 10 and at 15 minutes. Regarding the second question of which exercise duration is at least required, durations of at least 15 minutes are recommended. This is due to the result of the significant difference at 0 kg. In addition, the type of the task is crucial. In this study, a rather simple activity was investigated. In follow-up studies, this statement should be checked for laboratory conditions with a longer lifting task duration and a task at a higher level of reality.

The aim is to obtain conditions for a methodology for evaluating stress in working situations with the results obtained. For example, this methodology could be applied in the evaluation of support systems in the field of the manual handling of loads. Currently body-worn lifting aids and exoskeletons are increasingly being developed to counteract the above-mentioned problems. The assistance system of the project consortium "Lifting Aid" has active drives in the upper extremities as well as passive elements in the back and leg area to preemptively protect against musculoskeletal disorders. For evaluation regarding stress reduction, the cardiopulmonary exercise testing will be used.

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REFERENCES

Bongwald, O., Luttmann, A., Laurig, W. (1995). Leitfaden für die Beurteilung von Hebe- und Tragetätigkeiten. Retrieved from http://www.dguv.de/Projektdatenbank/ffff0119/pr9119.pdf, checked on 8/5/2014.

Borg, G. (1970). Perceived exertion as an indicator of somatic stress. Scandinavian Journal of Rehabilitation Medicine 2(2), pp. 92-98.

Bortz, J., Schuster, C. (2010). Statistik für Human- und Sozialwissenschaftler. ISBN: 978-3-642-12769-4. Berlin: Springer.

Bühner, M.; Ziegler, M. (2009). Statistik für Psychologen und Sozialwissenschaftler. ISBN: 978-3-8273-7274-1. München: Pearson Studium.

CORTEX (2014). Handbuch MetaMax® 3B. Version MetaMax® 3B-R2. Revision e / 22.09.2014.

Jäger, M., Luttmann, A. (2005). Der "Dortmunder Denkansatz" zur biomechanischen Analyse der Wirbelsäulenbelastung bei Lastenhandhabungen. In Zeitschrift für Arbeitswissenschaft (59), 2005/3, pp. 249-262.

Johnson, N.L., Kotz, S., Balakrishnan, N. (1994). Continuous univariate distributions Vol.1 (Continuous univariate distributions, vol. 1, 2nd ed.) New York: Wiley.

Kiparski, R. (1989). Physiologische und biomechanische Untersuchungen zur Ermittlung der Beanspruchung beim repetitiven Heben von Lasten. Doctoral Thesis. Technische Universität Berlin. Fachbereich Konstruktion und Fertigung.

Knott, V., Kraus, W., Schmidt, V., Bengler, K.(2014). Manual Handling of Loads Supported by a Body-worn Lifting Aid. In Proceedings of the 3rd International Digital Human Modeling Symposium DHM 2014, Odaiba, Japan, 20-22 May 2014.

Knott, V.C., Mayr, T., Bengler, K. (2015). Lifting Activities in Production and Logistics of the Future – Cardiopulmonary Exercise Testing (CPET) for Analyzing Physiological Stress. In Procedia Manufacturing 3, pp. 354-362. doi: 10.1016/j.promfg.2015.07.173.

Kroidl, R., Schwarz, S., Lehnigk, B. (2010). Kursbuch Spiroergometrie. Technik und Befundung verständlich gemacht. ISBN: 978-3-13-143442-5. Stuttgart: Georg Thieme Verlag.

Löllgen, H., Erdmann, E., Gitt, A. (2010). ISBN: 978-3-540-92730-3 Ergometrie. Belastungsuntersuchungen in Klinik und Praxis. Heidelberg: Springer Medizin Verlag. doi: 10.1007/978-3-540-92730-3.

Spallek, M.; Kuhn, W.; Uibel, S.; van Mark, A.; Quarcoo, D. (2010): Work-related musculoskeletal disorders in the automotive industry due to repetitive work – implications for rehabilitation. In J Occup Med Toxicol 5, p. 1-6. doi:10.1186/1745-6673-5-6.