POSSIBILITY OF AUTOMATED ERGONOMIC EVALUATIONS IN VIRTUAL REALITY ENVIRONMENTS

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The aim of the present research was to create a method for detecting the position and motions of the wrist and fingers at work, to design and create an experimental device to measure and evaluate the training task. Therefore, the issue of finger motions was searched, and the evaluation method was proposed. The experimental device used an optical device for motion monitoring, the so-called Leap Motion, which exports the measured data to a virtual environment created in the Unity3D development environment. This environment enables to read the required partial turning of the individual elements of the hand using the script. The training task consisted of a simple assembly. The evaluation is presented in this article.

KEYWORDS

ergonomics, hand, fingers, camera, automated analysis, work-related musculoskeletal disorders

1 INTRODUCTION

The hand, wrist, and arm form a complex and sensitive structure that can be easily overloaded due to physical work [Berlin 2017]. The complex structure of the hand should not be overloaded by unnecessary bending. Sometimes, even common work activities can cause health disorders called MSDs (work-related musculoskeletal disorders). In the article [Berlin 2017], the following factors are identified for the onset of MSDs:

- excessive force applied
- precise pressure on a small area
- repetitive tasks
- extreme positions during work
- vibration
- incorrect design of hand tools
- cold and heat

As this article deals with the issue of ergonomics in light equipment production, it is focused on the factors causing Cumulative trauma disorder (CTD) acting continuously over an extended period of time. CTDs can develop from improper work positions, repetitive tasks or excessive force applied.

The aim of this article is to design an automated method for evaluation of the position of the wrist and fingers at work, to design and create the experimental device for measurement, and evaluate the training task – the assembly in machine production in an industrial enterprise.

2 DANGEROUS WRIST AND FINGER POSITIONS

Motions that the hand can perform include supination and pronation motions (bending of the wrists and fingers), flexion and extension, and radial and ulnar deviations (bending of the wrist to the side) [Tortora 2004].

Another important function of the hand is the grip [Berlin 2017]. Depending on the level of accuracy required for a given task, the hand may occupy different functional positions. In the functional resting position of the hand, the pressure on the blood vessels, nerves and tendons passing through the carpal tunnel is the lowest, the muscles are relaxed, the fingers are slightly curved and the wrist is straight. As the strength and the ability of accuracy of the hands decrease dramatically when working at the extreme ends of their range of motion, working tasks should be performed as close as possible to the resting position of the hands [Clark 2003]. In the case of frequent deviations of individual parts to the extreme position, damage may occur.

For further evaluation, the standard designation of the individual finger joints will be used, see Fig. 1:

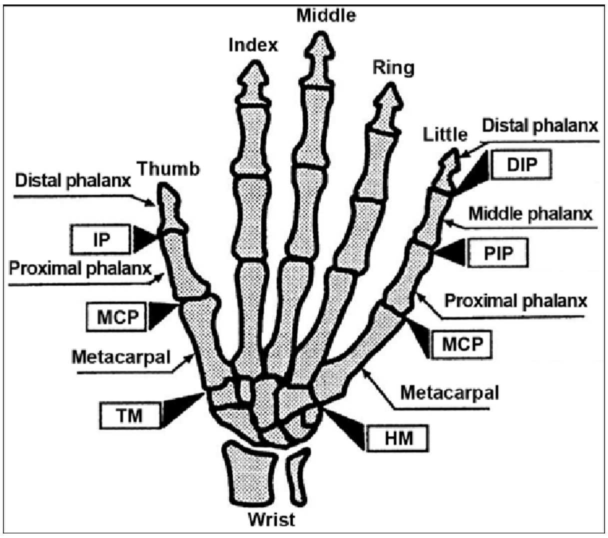


Figure 1. Designating the individual joints of the fingers [Li 2011]

3 CUMULATIVE TRAUMA DISORDER OF FINGERS AND WRIST

Cumulative trauma disorder (CTD) is a term for various disorders of the musculoskeletal and nervous systems that are caused by repetitive tasks, forceful exertions, mechanical compression or sustained postures. [Ibgal 2017]

These disorders are as follows:

Occupational carpal tunnel syndrome (CTS) is a medical condition due to compression of the median nerve as it travels through the wrist at the carpal tunnel [Burton 2014]. The main symptoms are pain, numbness and tingling in the thumb, index finger, middle finger and the thumb side of the ring finger.

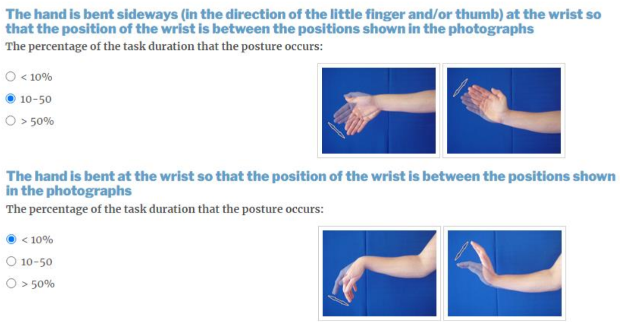
Tendinitis or Tenosynovitis - Tendinitis is most often caused by repetitive motions or overload. Symptoms of tendinitis are pain at and around the tendon. The pain may gradually increase or be sudden and severe [Helliwell 2003]. Tenosynovitis is an aseptic inflammation of tendons and tendon sheaths caused by minor traumas, which arise due to their mutual friction during an excessive number of movements in forced positions. [Luopajarvi 1979]

4 METHODS FOR EVALUATION OF THE POSITION AND MOTIONS OF THE WRIST AND FINGERS

The results of several research papers dealing with ergonomic issues can be used to evaluate the motions of the wrist and fingers. The methods to be used in this article will be presented below.

4.1. HARM method

The Hand Arm Risk Assessment Method (HARM) is a posture-based tool. This tool was developed in 2007-2009 for the risk assessment of arm, neck or shoulder pain development. [Douwes 2012]. It assesses ergonomic risks to the hands, arms, shoulders, and neck for hand- and arm-intensive tasks lasting more than one hour. The assessment is performed for one isolated working task at a time and includes six categories; duration, the most active hand during the working task, strength, posture, vibrations and other risk factors. For these categories, a risk score is assessed and then compiled. From the point of view of the wrist and its posture, the following parameters are important (sideways bending of the wrist by + - 20 °), see Fig. 2.


The hand is bent sideways (in the direction of the little finger and/or thumb) at the wrist so that the position of the wrist is between the positions shown in the photographs

The percentage of the task duration that the posture occurs:

- ○ < 10%
- ● 10-50
- ○ > 50%

The hand is bent at the wrist so that the position of the wrist is between the positions shown in the photographs

The percentage of the task duration that the posture occurs:

- ● < 10%
- ○ 10-50
- ○ > 50%

Figure 2. Screenshot of the HARM assessment form [TNO 2021]

4.2 DEG method

The DEG method is part of the Delphi system (DBS); it is a checklist system for production line designers. [Delphi Ergonomics Council, 2009] The design ergonomics checklist (Fig. 3) should be used by designers as early as possible during the designing process.

The purpose of the design ergonomics checklist is to standardize and simplify the process of gathering the acquired knowledge and integrating it, together with the known guidelines for ergonomics, into new designs. The designer should focus on identifying any item that could lead to a high level of risk of injury and / or suboptimal performance.

The following values are set for the wrist in this ergonomic standard.

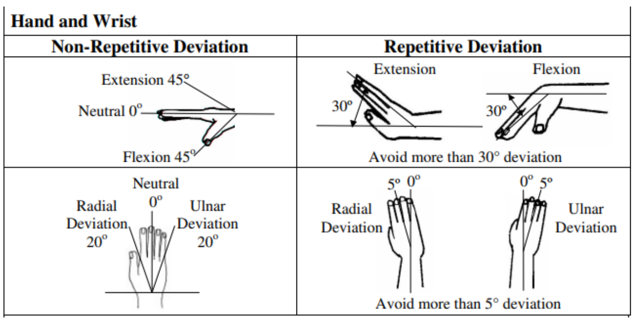


Figure 3. Screenshot of DEG assessment [Delphi Ergonomics Council, 2009]

Based on these methods, a set of criteria for evaluating the motions and position of the wrist and fingers was created. These criteria can be seen in the following figure 4.

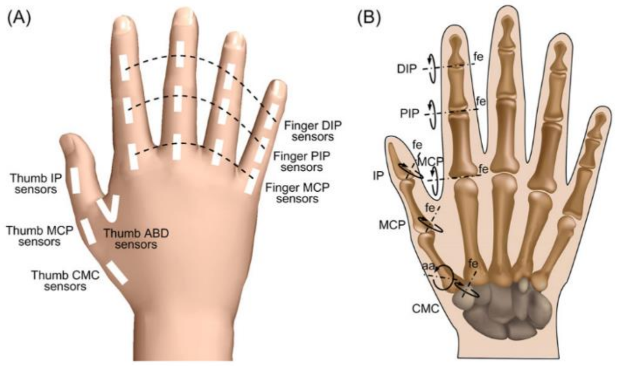


Figure 4. CyberGlove sensor placement and corresponding kinematic model of human hand. [Liu 2016]

5 TESTING DEVICE

To obtain the individual angles of partial bending of the joints of the hand, it is possible to use various measuring devices, such as gloves enabling hand tracking, MS Kinect, an optical sensor integrated, for example, in a mobile phone. A disadvantage of these devices is either their high cost when used for screening measurement in an industrial plant (gloves) or low measurement accuracy.

Therefore, a device for testing the position of the wrist and fingers at work was developed. The basic element of this device is Leap Motion (Fig.5), which can use sensors to detect the motions of hands and fingers without the need for touch [Kapicioglu 2021] or other contact [Jia 2022]. This small peripheral is connected to a computer via USB and, when placed upwards, captures the area above it. According to the manufacturer, the accuracy of the device is 0.01 mm, according to [Akkar 2022] and [Niechwiej-Szwedo 2018], this accuracy was measured [Weichert 2013] and adjusted to approx. 0.2 mm, which is completely sufficient for our cases, since our required accuracy was in the order of 10 mm.

Figure 5. Leap Motion sensor

Previous studies [Tuma 2018], were also focused on the sensing and ergonomics of the whole body, so it was obvious to use the Kinect sensor for this research as well.

The reason why another technology was selected is as follows: Based on the specifications of Kinect or Leap Motion, it can be observed that the two products are fundamentally different. While Kinect is designed to capture and detect the entire torso of human, Leap Motion focuses only on the detection of hands and fingers. At the same time, each device uses a different space sensing technology. While Kinect works on the principle of emitting and post-processing of infrared light - it measures the depth map of the environment around it, Leap Motion processes software images taken by an infrared camera. However, if we compare only the scanning range, we find that Kinect can scan test persons from a distance of 0.5m from the sensor up to a distance of 5m.

6 DESCRIPTION OF THE STUDY

- The simple assembly of four components was tested in the study. The components were placed in their defined positions (screw, nut, washer, larger nut), see Fig.6. The sequence of movements was as follows:
- Grasping the screw with the left hand (right-handed)
- Grasping the larger nut with the right hand
- Fixing a larger nut on the screw
- Grasping the washer
- Fixing the washer on the screw with the larger nut
- Grasping the nut
- Fixing the nut onto the screw with a light tightening
- Placing in the end position

In the case of assembly, it was not necessary to evaluate the lateral orientation, as the components are laterally identical except for the screw. The components were loosely placed on a horizontal plate. Therefore, it was not necessary to remove components from, for example, a box or other containers.

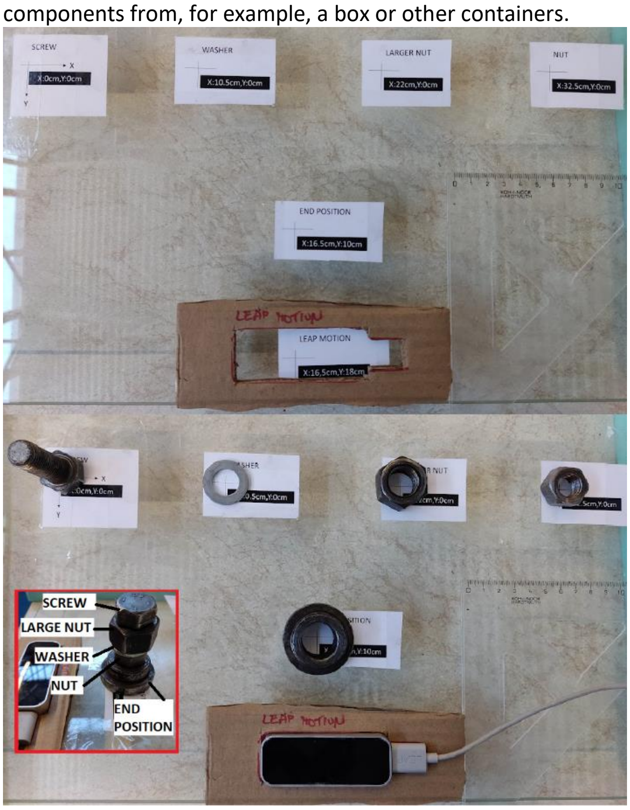


Figure 6. Study workplace with simple assembly

The study was performed with 5 testees aged from 26 to 42 years. Participants first tried the study without measurement and then performed only one measurement without repetition. The aim was a verification study to find out whether the given technology is suitable for this type of measurement and not the planned experiment.

The study monitored the motions of the hands (hand, palm, individual fingers) using a Leap Motion sensor. During the measurement, the left and right hands were evaluated separately. Unity 3D (2019.2.8f1) was chosen as the development environment, where the Leap Motion Core module was implemented; this allows for reading the position and a partial turn of individual elements (hand, palm, individual finger joints), see Fig.7.

The main disadvantage is the calculation of the angle itself. The initial calculation of the angle of the individual joints was correct, but in a different quadrant. In the angle range from 0° to approx. 15°, the calculation was correct, but when this interval was exceeded, the values were overturned, e.g., from 20° to 360°-20°, even though the correct angle value is displayed in the Inspector section of the Unity environment, which would cause significant complications in evaluation. Everything described above is caused by the so-called Gimbal Lock. Another difficulty was a change in the sign of the angle. The negative values of the angles in the case of the finger joints were caused by singularities when scanning with the Leap Motion sensor and, above all, they are difficult to achieve during manual assembly, so they were neglected. Negative values of the angles between the wrist and the palm do not need to be considered either, since we only deal with the range of angles to all sides, as shown in the HARM method above. Therefore, the following line was inserted into the script.

If the absolute value (angle between joints) is > 180°, subtract the value 360°.

Another complication in the calculation is the angle reading itself in Unity. Reading is done in Quaternions, but for better representation the values have been converted to Euler angles. This recalculation was performed before the actual calculation of the individual angles.

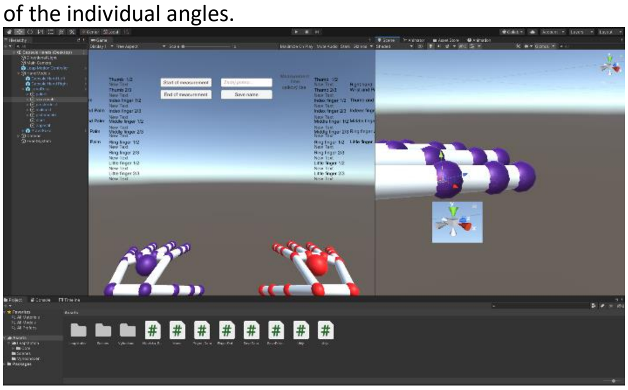


Figure 7. Unity 3D development environment– orientation of axes (e.g. left Index finger)

7 EVALUATION OF STUDY

Using a script, the partial turn along the three axes between the individual elements was read. This record (Fig.8) was further saved to csv. file for further evaluation.

Next, intervals of values from zero angle to 90° were divided by 5° using the script. In the case of the DEG method, see above, we assess the current angles. According to the Harm method, the measurement involves the density of values in the areas above the limit. In the case of our study, both methods were included.

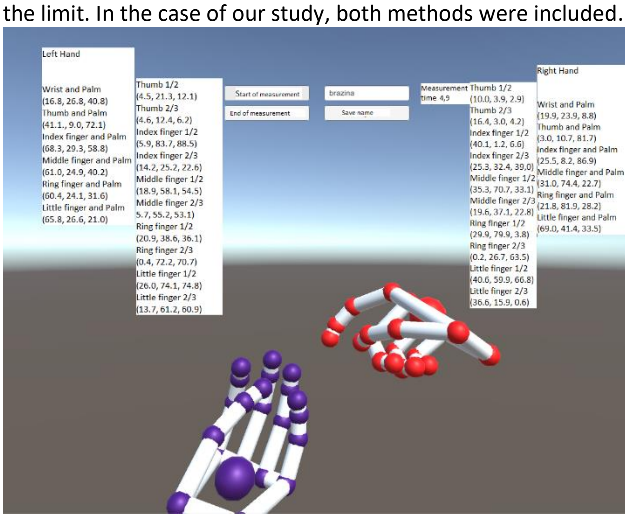


Figure 8. Screenshot while measuring the angles

As part of the measurement evaluation, the average of all participants' measurements for individual angles of partial turn was performed.

In an experiment involving five subjects, the movements of all finger and wrist joints were measured. Thus, for each participant, the angles of all 16 joints were measured over time. For each joint of each participant, it was verified that the measurements were compared to both the maximum angle that should be achieved for that joint (if specified) and then it was verified that the movement did not exceed the frequency of unnatural angles for that joint throughout the operation.

Thus, with a single measurement, it can be verified that the proposed workstation layout meets the requirements of both the DEG and HARM methods.

For schematicity, we present here only one monitored angle, see Fig.9. In cumulative graph is showed the frequency of individual angles of partial turn of the monitored joints. In the case of DEG method, it is 65 % of all values within the given limit for wrist extension and flexion for non-repetitive motions. In the case of repetitive motions, this would only be 40 % of all angle values.

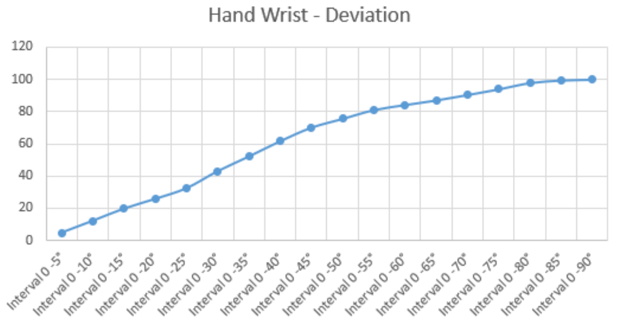


Figure 9. Percentage distribution of values according to the interval for bending the palm versus the wrist of the left hand

The presented evaluation methodology proved that the cumulative ergonomic load during repetitive motions can be determined using optical sensing and the evaluation of bending angles of tiny parts of the hand.

8 DISCUSSION

Even with such a simple assembly operation, it was possible to test the proposed method of measuring the angles. It was found out that the use of the Leap Motion sensor is fully sufficient for measuring the assembly operation in this manner.

The proposed measurement procedure has several major advantages over the conventional methods used for measurements (EEG, sensing gloves, video assessment). The measurement is inexpensive and does not require special apparatus for measurement. There is also no restriction of hand movement and the results are probably more representative. Also, the operator does not have to be burdened by the teacher-student syndrome, where, for example, during an EEG measurement under the supervision of a researcher, he or she may perceive the whole situation differently from the normal work and may be motivated to perform the work in a different way than he or she normally does, thus distorting the measurement results.

Regarding the accuracy of the automatic ergonomic assessment, it can be speculated that the proposed method will have higher accuracy than the method based on EEG measurements. On the other hand, the most accurate method (ergonomic gloves) burdens the operator and reduces the relevance of the results.

The currently frequently used method where the ergonomic specialist evaluates the captured video sequence frame by frame and evaluates the movement manually is very slow and the accuracy of the evaluation is low because it is burdened by the subjective evaluation of the specialist.

Another advantage may be the so-called agile design of the experiment, where it is very easy for researchers to perform the creation of measurement scenarios. This makes the described method suitable for deployment in the early design phase of a manufacturing operation. As a result, ergonomics can be better integrated into production preparation.

A disadvantage of the measurement by the proposed method is the occurrence of situations in which the hand joint is overlapped by another part of the hand or component, resulting in a measurement failure. This shortcoming could be eliminated by taking multiple readings of the hand from different positions, by deploying a different measurement procedure (glove, EEG measurements). For the purpose of this paper, we used a software approach, since we found during the analysis that such dropouts only account for a very small part of the measurements (up to 2%), the dropouts were not included in the result by using a script that filtered out such outputs.

In the event that the assembly operation is repeated for a long time, it is clear from the evaluation of individual finger motions that it would place an excessive burden on the operator. In particular, the wrist, the index finger and the middle finger would be loaded and would suffer from a wide range of motions and an unnatural position.

9 CONCLUSION

The article deals with a virtual environment that enables real-time scanning of the hand and fingers using the Unity3D development environment and the Leap Motion device. In this environment, the automatic evaluation of individual angles was further programmed for ergonomic evaluation of the assembly process in real time. A study in the form of a simple assembly was tested on a group of five testees. The purpose of this article is to show the feasibility of the system, which has been proven. The methods selected for the evaluation (DEG, HARM) were used as an example. It is possible to use other ergonomic methods for evaluation, their comparison would be purposeful in the future article.

The data obtained in this experiment were compared for each participant and for each joint. The quality of the measurements was verified in terms of the availability of the measurement data and its consistency.

Future measurements would be well advised to focus on verifying the accuracy of the measurements with other commonly used ergonomic techniques (ergonomic gloves, EEG). The experiment should also be conducted for more participants to allow for detailed statistical analysis of the measurements.

To improve the quality of the output data, further sensitivity analyses of the different subsystems of the equipment need to be performed. Another impact to the measurement is also the skill of the operator who performs the assembly. The total assembly time was not included, but only the individual angles, where, in the case of a longer time, there were almost no differences compared to shorter assembly times.

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REFERENCES

[Akkar 2022] Akkar, A. et al. Evaluation of Accuracy of Leap Motion Controller Device. Springer International Publishing, 2022, pp. 391-402.

[Berlin 2017] Berlin, C. and Adams, C. Production ergonomics: designing work systems to support optimal human performance. London: Ubiquity Press, 2017.

[Burton 2014] Burton, C, et al. Diagnosing and managing carpal tunnel syndrome in primary care. The British Journal of General Practice, 2014, Vol. 64, No. 622, pp. 262–263.

[Clark 2003] Clark, D.C. Common acute hand infections. Am Fam Physician, 2003, Vol.68, No.11, pp 2167–2176.

[Delphi Ergonomics Council, 2009] Design-In Ergonomics Guidelines. 2009. [online] [24.6.2022] Available from<https://www.delphisuppliers.com/vendor_documents/delphi-h/BlueBook/07%20Environmentatl-Health-Safety-Ergonomics-Industrial%20Hygiene/7B%20Ergonomics/Design%20in%20Ergonomics%20Guideline.pdf>

[Douwes 2012] Douwes, M. and De Kraker, H. HARM overview and its application: Some practical examples. Work, 2012, Vol. 41, No. 1, pp. 4004-4009.

[Helliwell 2003] Helliwell P.S. et al. Towards epidemiological criteria for soft-tissue disorders of the arm. Occup Med (Lond), 2003; Vol. 53, No. 5, pp. 313-319.

[Ibgal 2017] Iqbal Z.A. and Alghadir, A.H. Cumulative trauma disorders: A review. J Back Musculoskelet Rehabil, 2017, Vol. 30, No. 4, pp. 663-666.

[Jia 2022] Jia, L. et. al. Non-trajectory-based gesture recognition in human-computer interaction based on hand skeleton data, 2022, Multimedia Tools and Applications, pp. 20509-20539

[Kapicioglu 2021] Kapicioglu, K. et. al. A Touchless Control Interface for Low-Cost ROVs, OCEANS 2021: San Diego, 2021 pp. 1-6.

[Li 2011] Li, K. et al. Development of finger-motion capturing device based on optical linear encoder. Journal of Rehabilitation Research and Development, 2011, Vol. 48, No. 1, pp. 69-82.

[Luopajarvi 1979] Luopajarvi, T. et al. Prevalence of tenosynovitis and other injuries of the upper extremities in repetitive work. Scandinavian Journal of Work, Environment and Health, 1979, Vol. 5, No. 3, pp. 48-55.

[Niechwiej-Szwedo 2018] Niechwiej-Szwedo 2018, E. et al. Evaluation of the Leap Motion Controller during the performance of visually-guided upper limb movements, 2018, [online] [24.6.2022] Available from<https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0193639>

[TNO 2021] Hand Arm Riskbedömningsmetod (HARM). [online] [24.6.2022] Available from<https://www.fysiekebelasting.tno.nl/en/>

[Tortora 2004] Tortora, G. J. and Grabowski, S. R. Introduction to the human body: the essentials of anatomy and physiology. New York: Wiley, 2004.

[Tuma 2018] Tůma, Z. et al. Verification of HTC Vive deployment capabilities for ergonomic evaluations in virtual reality environments. In Safety and Reliability – Safe Societies in a Changing World. 1. London: Taylor and Francis group, 2018. s. 309-313. ISBN: 9781351174657.

[Weichert 2013] Weichert, F. et. al. Analysis of the Accuracy and Robustness of the Leap Motion Controller. Basel: Sensors, pp. 6380-6393.

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