Technologie, procesy i systemy produkcyjne
Technologies, processes and systems of manufacturing
Engineer of XXI Century'2024

Evaluation of workload of a furniture industry worker using the CEIT system

Mateusz Gacek [1], Robert Drobina [2], Damian Kolny [3,*], Sabina Stypuła [4,*], Marcin Raczek [5,*]

[1] *Uniwersytet Bielsko-Bialski 43-300 Bielsko –Biała ul. Willowa 2, Wydział Budowy Maszyn i Informatyki, email: gacek.mateusz02@gmail.com*
[2] *Prof. UBB, dr hab. inż., Uniwersytet Bielsko-Bialski 43-300 Bielsko-Biała ul. Willowa 2, Wydział Budowy Maszyn i Informatyki, e-mail: rdrobina@ubb.edu.pl*
[3] *mgr inż., Uniwersytet Bielsko-Bialski 43-300 Bielsko-Biała ul. Willowa 2, Wydział Budowy Maszyn i Informatyki, e-mail: dkolny@ubb.edu.pl*
[4] *Uniwersytet Bielsko-Bialski 43-300 Bielsko –Biała ul. Willowa 2, Wydział Budowy Maszyn i Informatyki, email: S58010@student.ubb.edu.pl*
[5] *ATEPAA Group, 43-300 Bielsko-Biała ul. Wędrowców 112, email: marcin@atepaa.com*
* *Mateusz Gacek, gacek.mateusz02@gmail.com*

Abstract: In this study, an evaluation of worker load was conducted using the CEIT system. The analysis highlights the consequences of static load on employees, and specifies load limits that are in compliance with Polish legislation. Various types of grips and their ergonomic implications were also presented. Additionally, recommended and maximum load levels for individual phalanges were discussed, along with standards that limit the pressure exerted by machinery on workers. The design section of the study detailed the components of the CEIT system and its operating principles. This was followed by an analysis of the workload experienced by a worker in the furniture industry, providing insights into the physical strain involved in tasks such as furniture assembly. This work was developed in collaboration with ATEPAA Group and was conducted as a part of the VIP UBB student scientific circle, supervised by mgr inż. Damian Kolny.

Keywords: Workplace ergonomics, RULA, Load, Grip strength;

Ocena obciążenia pracy pracownika branży meblarskiej za pomocą systemu CEIT

Mateusz Gacek [1], Robert Drobina [2], Damian Kolny [3,*], Sabina Stypuła [4,*], Marcin Raczek [5,*]

[1] *Uniwersytet Bielsko-Bialski 43-300 Bielsko –Biała ul. Willowa 2, Wydział Budowy Maszyn i Informatyki, email: gacek.mateusz02@gmail.com*
[2] *Prof. UBB, dr hab. inż., Uniwersytet Bielsko-Bialski 43-300 Bielsko-Biała ul. Willowa 2, Wydział Budowy Maszyn i Informatyki, e-mail: rdrobina@ubb.edu.pl*
[3] *mgr inż., Uniwersytet Bielsko-Bialski 43-300 Bielsko-Biała ul. Willowa 2, Wydział Budowy Maszyn i Informatyki, e-mail: dkolny@ubb.edu.pl*
[4] *Uniwersytet Bielsko-Bialski 43-300 Bielsko –Biała ul. Willowa 2, Wydział Budowy Maszyn i Informatyki, email: S58010@student.ubb.edu.pl*
[5] *ATEPAA Group, 43-300 Bielsko-Biała ul. Wędrowców 112, email: marcin@atepaa.com*
* *Mateusz Gacek, gacek.mateusz02@gmail.com*

Streszczenie: W pracy dokonano oceny obciążenia pracownika za pomocą systemu CEIT. Przedstawiono konsekwencje obciążenia statycznego dla pracowników, standardy obciążeń, które są zgodne z polską legislacją. Przedstawiono także różne rodzaje chwytów i ich implikacje z perspektywy ergonomii. Dodatkowo, przedstawiono rekomendowane i maksymalne poziomy obciążeń dla poszczególnych paliczków oraz normy limitujące nacisk maszynerii na pracownika. W części projektowej przedstawiono skład systemu CEIT oraz zasadę jego działania. Następnie, dokonano analizy obciążenia pracownika branży meblarskiej przy

DOI: https://doi.org/10.53052/9788367652278.16

wykonywaniu działań związanych z montażem mebli. Praca powstała we współpracy z ATEPAA Group. Praca również jest realizowana w ramach kola naukowego VIP UBB – opiekun koła mgr inż. Damian Kolny.

Słowa kluczowe: Ergonomia stanowiskowa, Metoda RULA, Obciążenie, Siła chwytu;

1. Introduction

Following ergonomic guidelines when designing a product that interacts with the user or requires such interaction is not only considered good practice but more often, than not considered an obligation. The recurring issue of certifying the term "Ergonomic" is also not insignificant. Nevertheless, there are good practices in designing with ergonomics in mind, and it is worth at least becoming familiar with them, especially in the context of grips, which are the primary area of user interaction with a product. The most common group of products utilizing handles are tools, where a well-designed handle is more than just a place to hold onto. In truth, grip structure, along with the nature of the work performed dictates how much force will be inflicted upon the worker's hand. If such exposure is allowed to persist over a lengthy period of time serious damage may be dealt to the worker's posture or even skeletal structure itself. Thus, in order to effectively combat such harmful conditions, new methods were developed which aim to measure forces, posture angles, etc. By evaluating data gathered using these new technologies, engineers can more accurately create countermeasures to combat these hazards, thus improving working conditions and work effectiveness.

2. Static load as a common cause of injury

Static load occurs when there is no observable movement of the limb or torso, but the muscles involved are tense (they experience isometric contractions) and the force generated can counteract a force equal to the force of gravity. Therefore, no mechanical work is performed. However, increasing muscle tension is an active physiological process and places a significant load on the human body. Static work is more taxing compared to dynamic work with the same energy expenditure [1]. Static work is characterized by relatively low energy consumption, as a heavy static load results in a lower energy cost than performing light dynamic work. Unfortunately, under such conditions, despite the low energy demand, an oxygen debt develops in the muscles, and anaerobic processes become more important. As M. Wróblewska explains, this happens because: "In static work, due to prolonged contraction, the muscle becomes stiff, and the capillaries that supply blood are compressed, increasing the resistance to incoming blood flow. As a result, less blood flows through the muscle, the muscle tissue no longer receives essential nutrients, and the removal of metabolic waste is hindered. Blood flow reduction occurs when muscle tension exceeds 5% of maximum strength and becomes complete at around 50% of maximum strength" [1].

The impact of static load on the musculoskeletal system

The international term "Repetitive Strain Injury" (RSI) describes disorders that result from very frequent, low-intensity stimuli. While a single stimulus is not considered as a heavy load due to its low intensity, RSIs develop as a result of frequent repetition of monotonous motion sequences and insufficient recovery opportunities. From sports physiology, it is known that insufficient recovery is considered a cause of muscle and tendon injuries [2]. Injuries may heal better or worse depending on the capability of blood to reach affected muscles and how much load they are a subject to on a daily basis. Unlike muscles, tendon tissue is poorly vascularized [3], yet it must withstand significant loads in everyday life. This leads to relatively long recovery times. Micro-injuries at tendon junctions can lead to chronic discomfort as a result of minor damage and continuous, repetitive strain. For this reason, highly repetitive activities are suspected to cause tennis elbow or tendonitis [5,6]. Due to the limited evidence of effective treatment for tennis elbow and carpal tunnel syndrome, reducing strain and ergonomically optimizing the workplace is particularly important [4,7]. In general, prevention is much better than treatment [8]. In the physiological model of operation, a proper supply of oxygen and nutrients, as well as the removal of metabolites and CO2, which are produced in greater amounts if the muscle cell is subjected to some form of activity, must always remain in balance [9]. However, even with small static loads, nutrient exchange in the muscle cell is hindered due to active muscle tension [10]. A frequently cited theory regarding musculoskeletal disorders suggests a deficiency of muscle or tendon tissue as a result of sustained static load. In the long term, this leads to high susceptibility to injury due to reduced load resistance [11, 12]. With static load, venous return is also weakened. Veins are part of a low-pressure system, and their return function depends on muscle tension and relaxation.

Lifting standards and force limits for men and women relevant in work processes in 2024

Lifting standards in the workplace are an extremely important aspect of organizing work processes to ensure safe conditions for employees carrying out their duties. Labor laws precisely specify weight limits for objects that can be safely lifted by employees. Separate regulations apply to pregnant and breastfeeding women, as well as to young workers**.** The general standards regarding the maximum weight of objects lifted and carried by a worker are outlined in the Regulation of the polish Minister of Labor and Social Policy of March 14, 2000, concerning occupational safety and health in manual transport work and other tasks involving physical effort, referred to as the BHP regulation for manual work [13]**.** According to § 13, paragraph 1 of this regulation, the weight of objects lifted and carried by a single worker must not exceed [13]:

- For women: 12 kg for continuous work and 20 kg for occasional work;
- For men: 30 kg for continuous work and 50 kg for occasional work.

The weight of objects lifted by a single worker above shoulder height must not exceed [9]:

- For women: 8 kg for continuous work and 14 kg for occasional work;
- For men: 21 kg for continuous work and 35 kg for occasional work.

If objects are carried by a single worker over a distance exceeding 25 meters, the weight of those objects must not exceed [9]:

- For women: 12 kg;
- For men: 30 kg.

According to § 13, paragraph 4 of the regulation, if objects are carried by a single worker uphill over uneven surfaces, ramps, or stairs with a maximum slope of 30° and a height exceeding 4 meters, regardless of the distance, the weight must not exceed [9]:

- For women: 12 kg;
- For men: 30 kg.

If the slope exceeds 30° and the height exceeds 4 meters, the weight must not exceed [9]:

- For women: 8 kg for continuous work and 12 kg for occasional work;
- For men: 20 kg for continuous work and 30 kg for occasional work.

According to § 17, paragraph 1, objects exceeding 4 meters in length or 30 kg for men and 20 kg for women should be carried in teams, ensuring that the weight per worker does not exceed [9]:

- For continuous work: 25 kg for men and 10 kg for women;
- For occasional work: 42 kg for men and 17 kg for women.

It is prohibited to manually move objects in teams over a distance exceeding 25 meters or with a total weight exceeding 500 kg*for men and 200 kg for women (§ 17, paragraph 3).

When transporting objects as a team, the following must be ensured [9]:

- Selection of workers based on height and age, with supervision by an experienced worker designated by the employer;
- A minimum distance of 0.75 meters*between workers, using appropriate auxiliary equipment.

Transport of long and heavy objects should be done using auxiliary equipment to minimize lifting above ground level (§ 18, paragraph 2). If carrying such objects on shoulders is necessary, workers must [9]:

- Lift and lower the object simultaneously on command;
- Stand on one side of the object;
- Use personal protective equipment to protect their shoulders.

Along the limits listed above, legislators have imposed limits on forces generated by machinery that a worker can safely be subjected to. Table 1. contains quantitative maximum values for quasi-static and transient contact between humans and the robot system. This data does not take into account the use of personal protective equipment or anything beyond standard work clothing typical for each work environment [14].

Table 1. External actuator force limits, which can be experienced by a worker [14]

Place on the body or an affected area	**Specific area of body**		**Quasi – static contact (crushing)**		**Temporary contact (impact)**	
			Max. permissible pressure P_S (N/cm2)	**Max. permissible force F_S (N)**	**Max. permissible pressure P_T (N/cm2)**	**Max. permissible force F_T (N)**
Cranium and forehead	1	Center of the forhead	130	130	130	130
	2	Temples	110		110	
Face	3	Jaw muscles	110	65	110	65
Nape	4	Neck muscles	140	150	280	300
	5	Neck discs	210		420	
Back and shoulders	6	Shoulder joint	160	210	320	420
	7	Lumbar vertebrae	210		420	
Thorax	8	Sternum	120	140	240	280
	9	Chest muscles	170		340	
Abdomen	10	Stomach muscles	140	110	280	220
Pelivs	11	Pelvic muscles	210	180	420	360
Arms and elbow joints	12	Deltoid muscle	190	150	380	300
	13	Kość ramienia	220		440	
Forearms and wrists	14	Humerus	190	160	380	320
	15	Forearm muscle	180		360	
	16	Arm nerve	180		360	
Palms and fingers	17	The tip of the index finger D	300	140	600	280
	18	The tip of the index finger ND	270		540	
	19	The terminal joint of the index finger D	280		560	
	20	The terminal joint of the index finger ND	220		440	
	21	The tip of the thumb	200		400	
	22	The inner surface of the hand D	260		520	
	23	The inner surface of the hand ND	260		520	
	24	The outer surface of the hand D	200		400	
	25	The inner urface of the hand ND	190		380	

DOI: https://doi.org/10.53052/9788367652278.16

Knees and thighs	26	Thigh muscles	250	220	500	440
	27	Kneecap	220		440	
Shank	28	Halfpoint of the tibia	220	130	440	260
	29	Calf muscles	210		420	

Force limitations of a machine or a robotic system can be determined based on pain sensitivity thresholds at the human-machine interface in situations where such contact may occur. The premise of risk assessment for applications of collaborative robots with limited power and force is that accidental or intentional contact may occur between parts of the collaborative robot system and a human. The first issue to consider in the risk assessment is determining where on the human body such contact is likely to occur. This is crucial because different areas of the body have varying thresholds for tolerating biomechanical load without causing minor injuries. Biomechanical limits have been defined to prevent the risk of human injury in the event of contact with a robot. A critical area of the body is of course the face, forehead and skull where the threshold values are 65 N for force and 110 N/cm² for pressure. The technical specification outlines the need to adhere to these values and indicates which limits apply to specific body parts. The robot system should be designed to adequately reduce the risk to the operator, ensuring that the relevant threshold values for quasi-static and transient contacts, as determined in the risk assessment, are not exceeded [14]. The graph below (Figure 1) shows a correlation between time and force / pressure values and time, where time is the main limiting factor. If the measured force exceeds any of the boundaries the worker may suffer an injury.

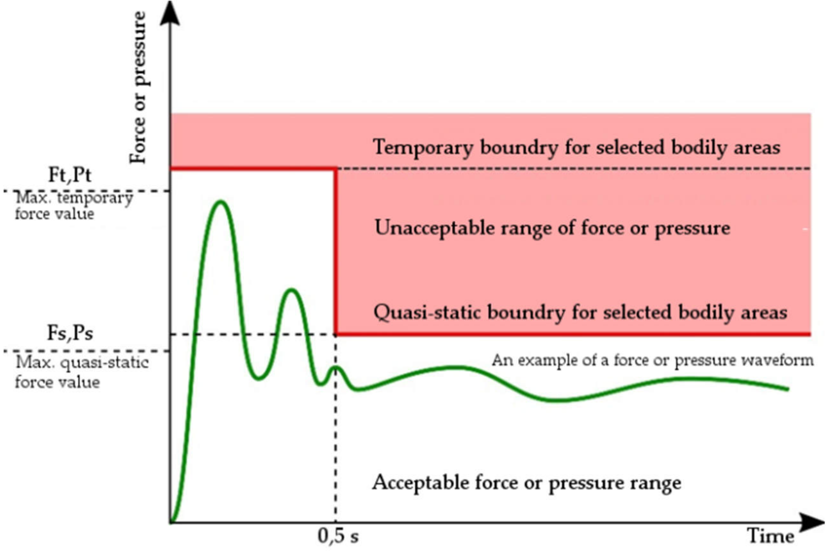


Figure 1. Force or pressure graph with outlined characteristics and unacceptable value boundaries [14]

If the robot's movement could result in pinching or immobilization of a body part between the robot and another element of the robotic cell, the robot's speed should be limited so that the system can respond to contact with the specific body part as shown in the diagram above [14].

3. Grips and phalange load

Three basic types of grip applications can be distinguished (Figure 2) [15]:

- Manipulating a product using a handle (such as but not limited to: rotating or twisting): In this case, the key factors are movement precision, wrist twisting, grip, and the most effective transfer of force from the hand through the handle to the product.
- Carrying a product using a handle: The focus here is on reducing the force exerted on the hand due to the product's weight while ensuring a secure grip.
- Pushing or holding a product using a handle: In this scenario, the primary concern is "cushioning" the impact of the product (e.g., due to shock) through the handle to the hand and reducing this impact force. Product manipulation is a secondary consideration.

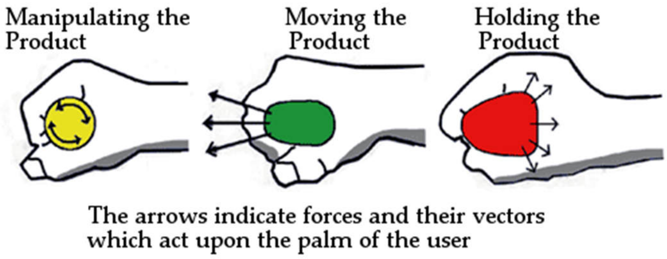


Figure 2. Different forms of manipulating an object by the use of grips [15]

Manipulation occurs through twisting only the wrist, the wrist and fingers, or just the fingers. A circular cross-section allows for all these movements. Its size depends on the product's purpose. For example [15]:

- Precise movements – for example: precision screwdrivers - a small cross-section is important here, as the torque required for tightening a screw is not large. In this type of application, typically two fingers are used: the thumb and the index finger, with the rest of the hand stabilizing the tool.
- Powerful movements – screwdrivers for construction work, bottle caps, levers, etc. In this case, a large handle cross-section is key, as it allows for greater torque (which comes directly from the hand's force and the cross-sectional radius). The load is distributed over a larger surface area, reducing the pressure felt on the hand and fingers.

At the same time, the cross-section size must ensure a secure grip, which is achieved when the thumb slightly overlaps the index finger with the hand clenched around the handle. For an adult, such a cross-section should have a diameter between 30 and 40 mm (Figure 3, 4).

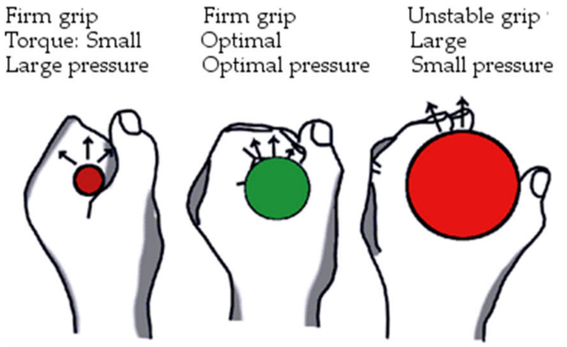
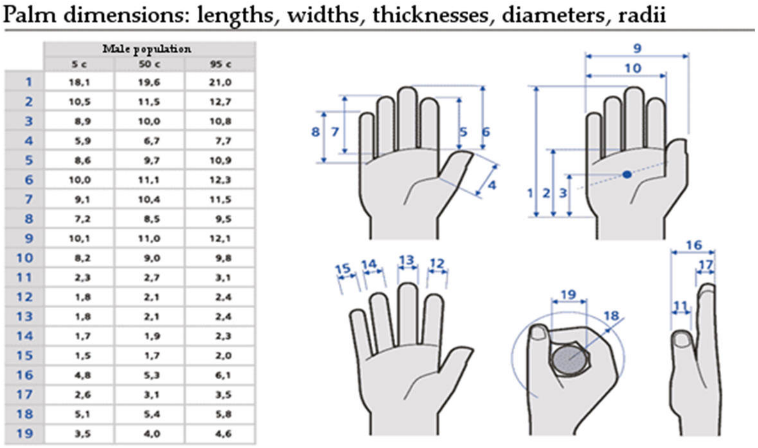


Figure 3. Visual evaluation of grip ergonomics [15]



Palm dimensions: lengths, widths, thicknesses, diameters, radii

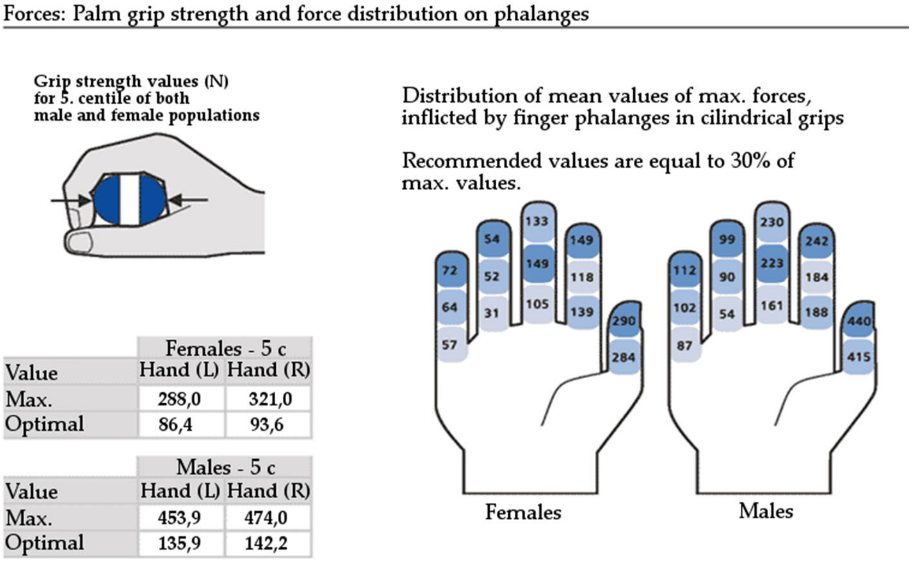
	Male population		
	5 c	50 c	95 c
1	18,1	19,6	21,0
2	10,5	11,5	12,7
3	8,9	10,0	10,8
4	5,9	6,7	7,7
5	8,6	9,7	10,9
6	10,0	11,1	12,3
7	9,1	10,4	11,5
8	7,2	8,5	9,5
9	10,1	11,0	12,1
10	8,2	9,0	9,8
11	2,3	2,7	3,1
12	1,8	2,1	2,4
13	1,8	2,1	2,4
14	1,7	1,9	2,3
15	1,5	1,7	2,0
16	4,8	5,3	6,1
17	2,6	3,1	3,5
18	5,1	5,4	5,8
19	3,5	4,0	4,6

Figure 4. Hand dimensions across different centiles of the male population [16]

This is a convenient approach to designing product-related loads for everyone. On the other hand, when there is a need to carry heavier weights, logic suggests that this task will be reserved for the larger and stronger portion of the population, specifically men between the 50th and 95th percentiles. Hence, the cross-section size should be as follows (Figure 4, dimension number 18) [15]:

- For weights less than 5 kg – row 19 from Figure 4, 5th percentile: the diameter of the default circular cross-section can be smaller than 30 mm.
- For weights up to 10 kg – row 19 from Figure 4, 50th percentile: the diameter of the default circular cross-section should range between 30 and 40 mm.
- For weights over 10 kg – row 19 from Figure 4, 95th percentile: the diameter of the default circular cross-section should range between 40 and a maximum of 45 mm.

Strength loads that can be experienced safely are also specified. Each phalanx may experience different force values during work and as such, they can handle different maximum loads. It is noteworthy, that depending on the dominant hand, it is more capable of withstanding higher loads (Figure 5).



	Females - 5 c	
Value	Hand (L)	Hand (R)
Max.	288,0	321,0
Optimal	86,4	93,6

	Males - 5 c	
Value	Hand (L)	Hand (R)
Max.	453,9	474,0
Optimal	135,9	142,2

Figure 5. Hand dimensions across different centiles of the male population [15]

4. Conducting measurements using the CERAA System

The evaluation of finger pressure strength in a production worker's hand at a furniture manufacturing company involves assessing the forces exerted on the worker's phalanges (finger bones) during a particular production phase. The study focuses on a production worker performing furniture assembly during one stage of the manufacturing process. Specifically, the article analyzes the process of furniture assembly, such as installing hinges on cabinets, using tools – hammer and power tools – such as a drill. The tasks are repetitive and monotonous. When using a hammer, the wrist area is primarily burdened due to the transmission of vibrations from the tool to the gripping area. In the case of the drill, vibrations are transferred not only to the gripping area but also to the individual phalanges of the hand. The goal of the study is to determine the peak forces exerted on the individual phalanges of the worker's hand during these tasks. To measure these forces, the CERAA Glove system (Figure 6) was used, which allows for the identification of pressure forces applied to the hand. This device captures detailed data on how much strain is placed on the fingers during repetitive assembly tasks, such as when hammering or using power tools. By understanding the peak forces, the study aims to provide insights into the ergonomic risks involved and suggest ways to minimize potential strain or injury to workers' hands during the furniture assembly process.

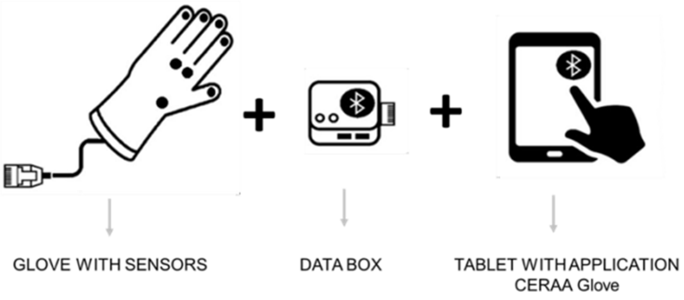


Figure 6. Components of the CERAA Glove system [17]

The measurement process involves the use of a mobile application that enables the assessment of forces acting on the hand, forces applied to sensors, and forces on the phalanges, using predefined grips. The process includes several key steps:

- Force Assessment: Measurement of the forces exerted on the worker's hand and fingers during specific tasks, with data collected through sensors placed on the hand.
- Ergonomic Evaluation: A detailed analysis of the results from an ergonomic perspective to assess the impact of the forces on the worker's health and performance.
- Video Analysis: The collected data is complemented by video footage of the worker's tasks, allowing for a more thorough understanding of the movements and actions leading to the measured forces.
- Result Verification: The results can be reviewed and verified to ensure accuracy and consistency.

The study is supported by industry standards that provide guidelines for assessing ergonomic risks and the safe limits of forces exerted on the hand during repetitive tasks [17]:

- STN EN 1005-1+A1 Safety of machinery. Human physical performance. Part 1: Terms and definitions.
- STN EN 894-3+A1 Safety of machinery. Ergonomics requirements for the design of displays and control actuators. Part 3: Control actuators.
- ISO/TR 12295:2014 - Ergonomics -- Application document for International Standards on manual handling (ISO 11228-1, ISO 11228-2 and ISO 11228-3) and evaluation of static working postures (ISO 11226).
- DIN 33411-1 - Physical strengths of man; concepts, interrelations, defining parameters, Standard by Deutsches Institut Fur Normung E.V. (German National Standard), 09/01/19.
- BGIA-Report 3/2009 – Der montagespezifische Kraftatlas, Institut fur Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (Assembly specific Atlas, German Labor Accident Insurance Institute).

In order to operate the CERAA system, the user needs to understand what the system consists of and how it defines grips (Figure 6) [17]:

- PRECISION GRIPS:
- Index finger (grip A) – touch / perpendicular pressure on the distal phalanx of the index finger (part closer to the nail).
- Thumb (grip B) – application of perpendicular pressure with distal phalanx of thumb.
- Index finger and thumb (grip C) – pincer (gripping the distal phalanx of thumb and forefinger, while they are put against each other).
- POWER GRIPS:
- Thumb and two fingers (grip D) (grip of the thumb with index finger and middle finger, index finger and middle finger are side by side against the thumb).
- Thumb and four fingers (grip E) (gripping the object by all fingers, the palm has a passive role).
- Palm (gripped hand) (grip F) (palmar grip) – application of pressure by the entire palm (all fingers and palm are active). It is an intense grip of all the fingers it is as if the user wanted to grip a ball. The thumb provides force opposition and all fingers are slightly bent in all their joints.
- Fist (grip G) called force grip (the thumb and the other 4 fingers are against each other in order to maximize palm contact and grip strength) – the provides opposite pressure to the other fingers and secures the gripped object firmly.
- Pliers (grip H) (the object is pressed between thumb and the index finger or the ring finger).

Additionally, depending on the worker’s gender, type of load, posture type and the grip being used, person using the application must define the following entry data: (Figure 7).

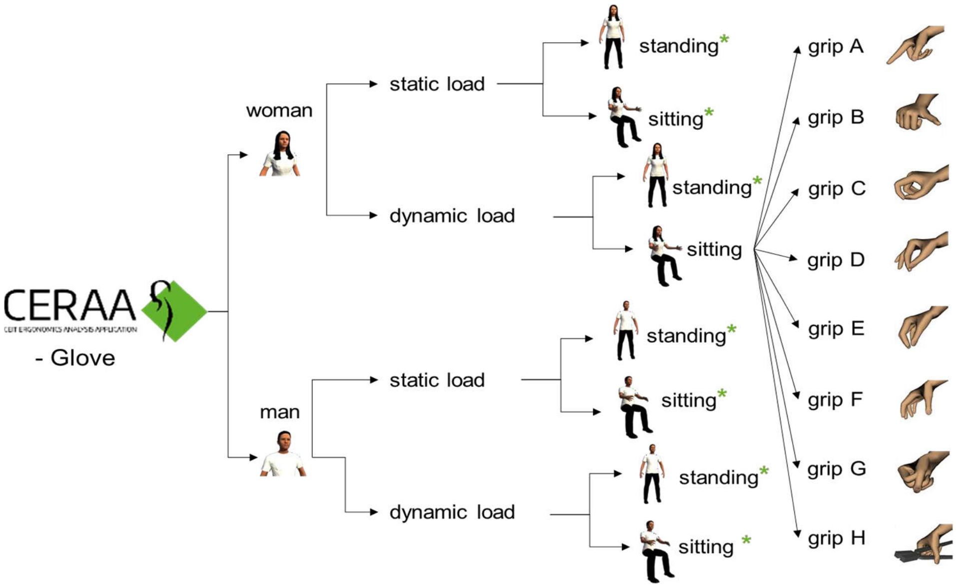


Figure 7. CERAA Glove application trait decision tree [17]

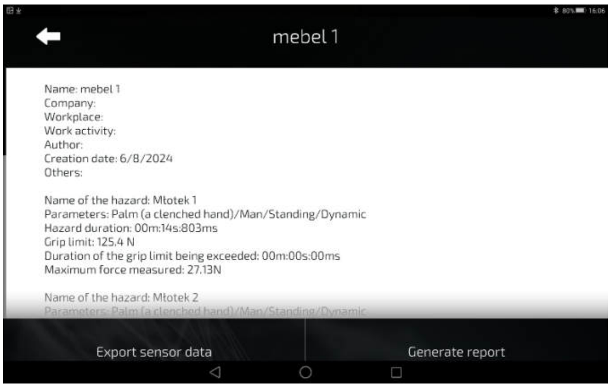
The symbol "*" in the diagram indicates the next level of categorization, which includes grips A-H (similar to the case for women – dynamic load – seated position – grips A-H). These choices correspond to the maximum acceptable force for each grip type. In practice, this means that different types of grips (A-H) are evaluated based on their specific characteristics, and each grip has a distinct acceptable force limit. The force limits take into account factors such as gender, posture (e.g., seated or standing), and the type of load (dynamic or static). By selecting a specific grip, the system will determine the maximum force that can be safely applied in that particular scenario. In order to perform measurements and evaluate loads while using the CERAA system the user must do the following [15]:

1. Turn on the application and select the CERAA Glove module (Figure 6).
2. Create a project or select an existing one.
3. Fill in all appropriate information relevant to the project (project name, company, workplace, work activity, author).
4. Turn on the data box, put it onto the worker's right arm around the bicep area, put on the glove and plug it into the data box (Figure 6.).
5. Make sure that the data box is connected to the application via Bluetooth, it should connect on its own at the very moment the data box is turned on.
6. Point the tablet camera at the worker and record the process undergoing evaluation.
7. Once the sufficient amount of data is collected the recording can be stopped and evaluation may begin.
8. In order to evaluate, the user must open the project file defined earlier and fragment the video onto operations performed by the worker that will undergo evaluation. Time and traits (Figure 7) for these operations must be specified. After that a force graph will appear at the bottom of the screen for the designated time frame with the name of the operation (Figure 8 - 9)

Figure 8. CERAA Glove application force evaluation time selection screen

Figure 9. CERAA Glove application complete evaluation

1. For each evaluated segment the user will have to specify information presented on Figure 7.
2. The user may now repeat step 8 and 9 to evaluate the entire video clip
3. Once the user is satisfied with the evaluation, a report may be generated (Figure 10.)


mebel 1

Name: mebel 1
Company:
Workplace:
Work activity:
Author:
Creation date: 6/8/2024
Others:

Name of the hazard: Młotek 1
Parameters: Palm (a clenched hand)/Man/Standing/Dynamic
Hazard duration: 00m:14s:803ms
Grip limit: 125.4 N
Duration of the grip limit being exceeded: 00m:00s:00ms
Maximum force measured: 27.13N

Name of the hazard: Młotek 2
Parameters: Palm (a clenched hand)/Man/Standing/Dynamic

Figure 10. CERAA Glove application report generation screen

Below are the results of the measurements conducted as part of the force evaluation (Figures 11-13). These figures present detailed data from the analysis of forces exerted on the worker's hand and phalanges during the furniture assembly tasks using both a hammer and an electric drill.

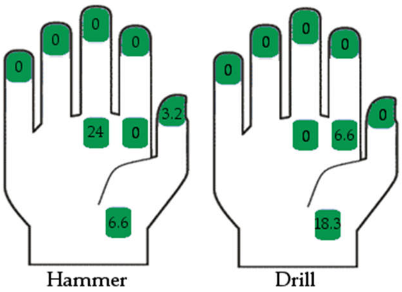


Figure 11. CERAA Glove sensor placement with max force values measured during the evaluation

Analyzing the data from Figure 11, the following conclusions can be made:

- When operating a hammer, the posture was defined as standing, dynamic, with a clenched fist grip. As a result, the maximum allowable force was set at 125.4 N (Figure 12). The maximum total measured force was 27.13 N, while the greatest force acting on a phalanx was recorded on the proximal phalanx of the middle finger, measuring 24 N. According to applicable standards (Figure 5), the maximum pressure on the individual phalanges falls within acceptable limits. However, it is recommended that the worker performing this task should be equipped with appropriate gloves to protect against the transmission of possible vibrations to the gripping area and forearms.

Figure 12. CERAA Glove hammer force evaluation

- When using a power tool such as an electric screwdriver, the pressure distribution on individual phalanges has a completely different nature. The posture was defined as standing, dynamic and with a clenched fist grip. In the case of using a hammer, the forces acted in a dynamic and impactful manner. However, when using a drill, the nature and method of vibration transmission is not characterized by impulsive or impact vibrations but rather by continuous vibrations, ranging from zero to pulsating. In this case, the maximum allowable force was set to 41.8 N (Figure 13). The maximum value of forces measured was 23.7 N, which falls well within the acceptable limits.

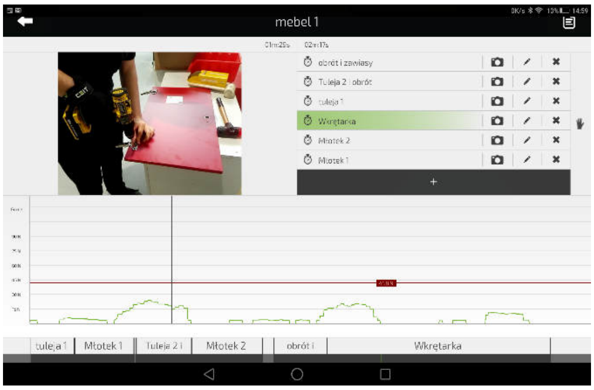


Figure 13. CERAA Glove drill force evaluation

- In cases where no force was detected — the sensors displayed 0 N — the pressure on the sensors was so minimal that they did not register any pressure. Nevertheless, regardless of the sensor readings, it is important to consider that minimal forces may still be present.

5. Results

- The conducted research confirmed that the use of the CEIT system for force evaluation is highly beneficial.
- The data obtained from the CEIT Glove allows for the detailed identification of pressure forces on select individual phalanges of the hand. This provides knowledge that enables engineers to design optimal work process as well as the appropriate selection of protective gloves for tasks involving hand tools, safeguarding workers from the transmission of vibrations.
- Modern hand tool design can benefit from tools that assist in the design process. Knowledge of the type and magnitude of forces transmitted from the tool to the gripping parts of the hand allows for better tool design. As a result, vibration transmission can either be eliminated or reduced to levels that minimize strain on the user.
- The results presented in this study reflect real-world working conditions, providing employers with a more complete understanding of the physical strain on workers and thus enhancing workplace safety standards.
- The focus on workplace ergonomics, including tool ergonomics, leads to more efficient and safer work. This can significantly reduce the strain associated with the use of certain hand tools, making tasks easier and less physically demanding.

Reference

1. Wróblewska M., Ergonomia, Skrypt dla studentów, Politechnika Opolska, Opole 2004, str. 191., tłumaczenie własne
2. Güllich, A. & Krüger, M. (Hrsg.) (2013). Sport: Das Lehrbuch für das Sportstudium. Berlin, Hei- delberg: Springer. [p. 446, 193].
3. van den Berg, F. & Arendt-Nielsen, L. (2010). Angewandte Physiologie (3. Aufl.). Stuttgart: Thieme. [p. 151].
4. Kaufmännische Krankenkasse (Hrsg.). (2008). Beweglich?: Muskel-Skelett-Erkrankungen-Ursa- chen, Risikofaktoren und präventive Ansätze. Berlin, Heidelberg: Springer. [p. 126 f.].
5. Deutsche Gesetzliche Unfallversicherung (DGUV). (2016). DGUV Information 208-033, 1–44. [p.14-17, 24, 25].
6. Walker-Bone, K., Palmer, K. T., Reading, I. C., Coggon, D. & Cooper, C. (2012). Occupation and epicondylitis: A population-based study. Rheumatology, 51(2), 305–310. [p. 4].
7. Barmer Gmünder Ersatzkasse (GEK). (2012). Heil- und Hilfsmittelreport 2012. Siegburg: Asgard Verlagsservice GmbH.
8. Hennies, G. (1998). Basiswissen medizinische Begutachtung: Rechtliche und inhaltliche Grundla- gen des ärztlichen Fachgutachtens. Stuttgart: Thieme. [p. 36].
9. Becker, M., Hettinger, T. & Wobbe, G. (1993). Kompendium der Arbeitswissenschaft: Optimierungsmöglichkeiten zur Arbeitsgestaltung und Arbeitsorganisation. Ludwigshafen (Rhein): Kiehl. [p. 111, 161].
10. Reneman, R. S., Slaaf, D. W., Lindbom, L., Tangelder, G. J. & Arfors, K.-E. (1980). Muscle blood flow disturbances produced by simultaneously elevated venous and total muscle tissue pressure. Microvascular Research, 20(3), 307–318. [p. 315].
11. Hagberg, M. (1984). Occupational musculoskeletal stress and disorders of the neck and shoulder: A review of possible pathophysiology. International Archives of Occupational and Environmental Health, 53(3), 269–278. [p. 271].
12. Visser, B. & van Dieën, J. H. (2006). Pathophysiology of upper extremity muscle disorders. Journal of Electromyography and Kinesiology, 16, 1–16.
13. https://poradnikpracownika.pl/-jakie-sa-normy-dzwigania-w-zakladach-pracy, 20.09.2024, tłumaczenie własne
14. https://bezpieczenstwowsystemachsterowania.pl/2020/11/granice-sil-i-naciskow/, 20.09.2024, tłumaczenie własne
15. https://www.konstrukcjeinzynierskie.pl/index.php?option=com_content&view=article&id=2434:ergonomia-uchwytu-produktu&catid=190, 20.09.2024, tłumaczenie własne
16. Gedliczka i in., Atlas miar człowieka. Dane do projektowania i oceny ergonomicznej. Warszawa, CIOP 2001, s. 8.
17. CERAA Glove Application Manual, 2024