Chapter 2

Analysis for Objective Evaluation the Stress of the Hand

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Additional information is available at the end of the chapter

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Abstract

The hand is constantly in contact with products and therefore stressed differently. Heavy stress is the cause of unpleasant sensation and can lead to common hand diseases in the worst case. The chapter starts with the description of hand diseases and with methods to determination of hand stress. Subsequently, the chapter is continued with a literature review of hand stress analysis refer to objectively methods. In the main part, two objective methods are developed and presented to analyze the hand stress. These methods allow the simulation and the measurement of hand stress. Compared to the classical approach, the results of the objective methods show a higher accuracy in faster review of hand stress. Finally, the chapter ends with a discussion of the results and gives opportunities to improve the hand model and the measurement system.

Keywords: pressure pain threshold (PPT), pressure discomfort threshold (PDT), digital hand model, handle design parameters, hand stress, hand tissue strain, wrist strain, hand posture, Job Strain Index (JSI), strain variables, sensor glove, JSI-system

1. Introduction

1.1. Hand diseases

People are constantly in contact with products and thereby stressed differently. In particular, high power transmissions, short rest periods as well as incorrect postures influence the health [1]. In this case, typical diseases may occur due to high stress. In the worst case, diseases in the wrist, for example, arthrosis can be caused by an incorrect estimation. An arthrosis on the wrist leads to a painful restriction of the mobility of the wrist. An anomaly of the compressive stress in the wrist is being held responsible for the high joint wear and the joint pain. An arthrosis at the thumb saddle is called as rhizarthrose [2].

Figure 1 shows a deformed joint site. The symptoms can only be alleviated by minimally invasive joint cleansing or by the severing of painful nerve fibers. In a last step, there remains in some cases only a partial stiffening of the carpal bones—or the supply of individual finger joints by arthroplasty or prosthetic. In the case of joint cleansing, a needle is inserted into the joint capsule. If the injection is deeply injected into the thumb saddle joint, the palmar-extending tendon of the flexor carpi radials can be injured [3].

A novel therapy involves a stabilization by kinesio-taping. In addition to the massage effects, that stimulate the flow of blood and lymph. The elastic adhesive tape supports joint functions. The influence of the tapes on the tensions corrects muscular imbalances so that a balance between the muscle groups can arise again. The stimulation of the proprioceptors in the joints ensures a better sense of movement. By stimulating the receptors, pain in the joint is relieved [4].

1.2. Determination of hand stress

In the application of hand-held products, the user is under different stress factors. These stress factors cause in human's strains, depending on individual characteristics and abilities. Stress means the physical characteristics of the work situation, for example, a force transmission on the hand. Strain, in contrast, refers to the reactions such as hand pain [5].

In most cases monitoring methods are used to determine the hand strain. These monitoring methods are based on the scoring of certain stressful situations. Thereby valid low scores lead to low strain. But in the most monitoring methods the level of detail of the hand is

Figure 1. Computed-tomography of a rhizarthrosis.

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limited to few positions. Therefore, Job Strain Index (JSI) by [6] is often determined for the evaluation of the hand strain. With regard to the development of a system to objectify hand strain, this chapter focuses on the JSI method.

The JSI method was published by [6] and deals with the evaluation of hand strain. Thereto, a manual work was observed for 3 min, and a so-called Job Strain Index (JSI) was calculated. The determination of the JSI is based on the estimate of six strain variables and on the multipliers determined by those. The strain variable, intensity of exertion (IE) refers to the maximum effort that can be exerted by a human being [10]. Hand-dependent maximum gripping forces by [7] can help to determine the effort. The strain variables, duration of exertion (DE) and efforts per minute (EM) result from the formulas for the maximum effort. For the estimation of hand/wrist posture (HWP), angle limits for the wrist extension (E), flexion (F) and ulnar deviation (D) are specified. The comparison of the JSI with the limits shows the risks of the hand health. **Table 1** shows a template for determining the multipliers.

Rating	Exertion intensity	Exertion duration	Exertion frequents	Hand posture	Work speed	Work duration
1	Light (1)	<10% (0.5)	<4 (0.5)	Very good (1)	Very slow (1)	<1 (0.25)
2	Somewhat hard (3)	10–29% (1)	4–8 (1)	Good (1)	Slow (1)	1–2 (0.5)
3	Hard (6)	30–49% (1.5)	9–14 (1.5)	Fair (1.5)	Fair (1)	2–4 (0.75)
4	Very hard (9)	50–79% (2)	15–19 (2)	Bad (2)	Fast (1.5)	4–8 (1)
5	Near maximal (13)	80–100% (3)	≥20 (3)	Very bad (3)	Very fast (2)	≥8 (1.5)
JSI = EI × ED × EF × HP × WS × WD						

Table 1. Template of JSI-determination.

2. Literature review

2.1. Simulation-models to determine the hand stress

To provide early ergonomic criteria for product design, digital hand models can be used for the simulation of hand stress. Digital hand models are generated by computer representations of the hand and can be simulated using either the multibody systems method (MBS) or the finite element method (FEM). It is also possible to couple the methods of FEM and MBS. In contrast to MBS models, FEM models are deformable and can calculate mechanical stresses such as pressure in certain parts of the body. MBS models consist of rigid non-deformable bodies connected to one another by kinematic joints. Using the MBS method, it is only possible to determine the kinematics of the body and the contact forces. These data are used, for example, as input data for FEM simulation [8]. Often the hand models are simulated as part models because of their complexity. This includes, for example, simulating finger models. For example, [9] developed a combined FEM and MBS finger model of three finger segments with realistic bones, nails and soft tissue. In the dynamic simulation, the stiffness of the grip surface was varied and demonstrated in final results the decrease of the pressure distribution. The work [10] developed a FEM fingertip and simulated the pressure distribution on the fingertip when opening can a tab. The results revealed that over a large contact area pressure, distribution was reduced to the fingertip. With the thumb model the static pressure distribution for use of clip connections are simulated by [11]. These influences such as pressure level, material, geometry and position change of the clips are examined. This influence examination gives design proposals for clips [12]. Other digital hand models focus on realistic simulation. The work [13] presented a hand model for the simulation of non-linear contact deformations, in relation to realistic overlapping of the skin (**Figure 2**).

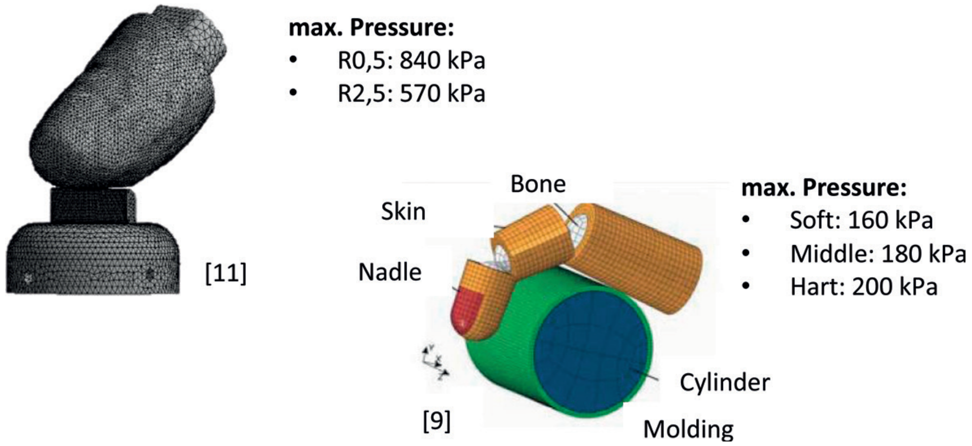

Figure 2. Example of hand models.

2.2. Support-systems to reduce the hand stress

In the context of the present work there exist sensor gloves to measure forces when gripping and using products. Some works are focused exclusively on the development of new sensor gloves. The research of [14] shows that the sensor gloves are exploring the relations between forces and other variables such as muscle tension [15], handling and feel [16] and the perceived gripping force [17].

Since 1991 are sensor gloves designed to measure forces in gripping and operation of handheld products. To measure the force distribution on the palm most sensor gloves have piezo (-resistive) sensors such as in Refs. [18, 19] or [20]. Due to the simple programming and low cost compared to capacitive sensors these are preferred. The force sensors are varying in the number and in the position on the hand and in their form. For the investigation of pressure distribution on the palm [21] develops a sensor system of six force sensors based on FSR sensors (FSR—Force Sensing Resistor). These resistive sensors are based on the measurement of the resistance change of semiconductor materials such as silicon. In applying three different shaped handles are pressed on the palm and then calculated from the force-measuring the pressure distribution.

To measure the hand posture there, exist optical methods and methods in which active sensors are attached to the hand [14]. This chapter deals with sensor gloves with active sensors, since optical methods require a complex experimental setup and capture only the movement and posture of the hand. Active sensors are placed in the design as a sensor glove directly to the hand and do not require complex experimental setup [22]. The sensor gloves are often equipped with fiber optic [23], strain gauges [24] or goniometers [25]. Through the further development of microelectronic sensors, circuits and batteries are designed with smaller size and weight. The data collection, processing and storage are done internally, or the data are transmitted to the computer externally via wireless protocols [26]. **Figure 3** shows new technologies with RFID to measure the time in relation of the motion.

Figure 3. Example of support-system by http://www.proglove.de (2017).

3. Simulation of hand stress

3.1. Comfortyping

The term "comforting" is an artistic word and has emerged from the composition of comfort and prototyping. Comfortyping is intended to function as a stand-alone simulation program, in which a digital hand model is included in the simulation environment. After importing a hand-held product as well as after selection of influencing variables, they should be calculated on the basis of their design proposals. A similar goal for assessing the ergonomics of the man-machine interface also exists as ergotyping of [27]. In contrast to this, the focus should be placed on the hand-arm system with Comfortyping. For example, it should be possible to deliver spline suggestions to the user, which can then be imported into the CAD system. For Comfortyping is a database with different influencing variables such as grip types, gripping forces as well as hand-type and handle-dependent material properties is required. The program should offer a choice of three hand types with little, much as well as medium subcutaneous fat content. The work of [28] differ fleshy, tendinous and normal skin types. In addition, it should be possible to automatically scale the hand models by percentile and gender. A snap function should allow the hand model to take the product automatically.

A first approach for Comfortyping was developed with Recurdyn (see **Figure 1**). Here the grip of an iron bender was taken and defined the reduction of pressure peaks as well as a homogeneous pressure distribution as a target function. The MBS/FEM program Recurdyn has an Autodesign function and can iteratively optimize geometries. In the example, a shape change handle was constructed with six cylinders and pressed onto the palm of the hand with 200 N. In addition, the handle was gripped with 50 N gripping force. The geometry and material properties from the hand (skin type dependent) and the force and movement conditions from the iron bender (product-dependent) were selected from the database. For the target definition, the reduction and homogenization of the pressure distribution was selected manually (**Figure 4**).

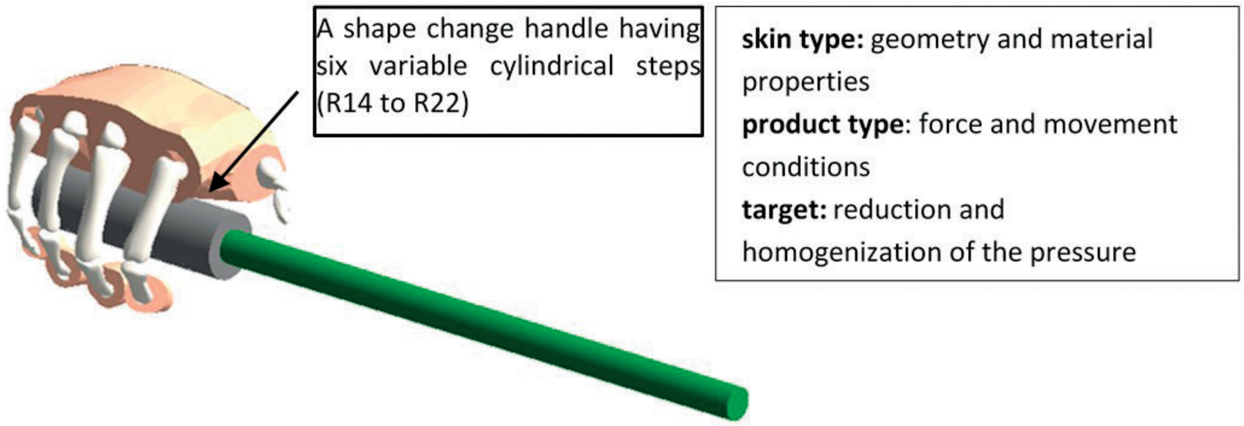

Figure 4. Comfortyping in RecurDyn.

3.2. Results

The results show before the optimization on the hand regions O and Q high pressure loads. The radius of all steps is R14. The pressure loads were redistributed to the hand center P with the optimization. For this purpose, the program changed the radius of the steps of the handle until a desired pressure distribution is obtained. To do this, the radius in the hand center changes to R22. This information is output as a spline into the CAD model of the handle. A pressure evaluation with different subjects confirmed the optimized grip shape as comfortable.

For comfort evaluation, the shape change handle was designed. The developed shape change handle consists of six spreader jaws, which can be moved by a threaded pin rotation. The threaded pins have right-hand and left-handed threads. The so-called entraining jaws spread the counter-jaw during an outward movement. To conceal the edges of the jaws, a rubber covering was applied. These six jaws have taken together the width of a male palm of the 50th percentile of about 95 cm. The whole mechanism was tested by FEM for strength and is made of ABS. Various tools can be connected to the shape change handle (**Figure 5**).

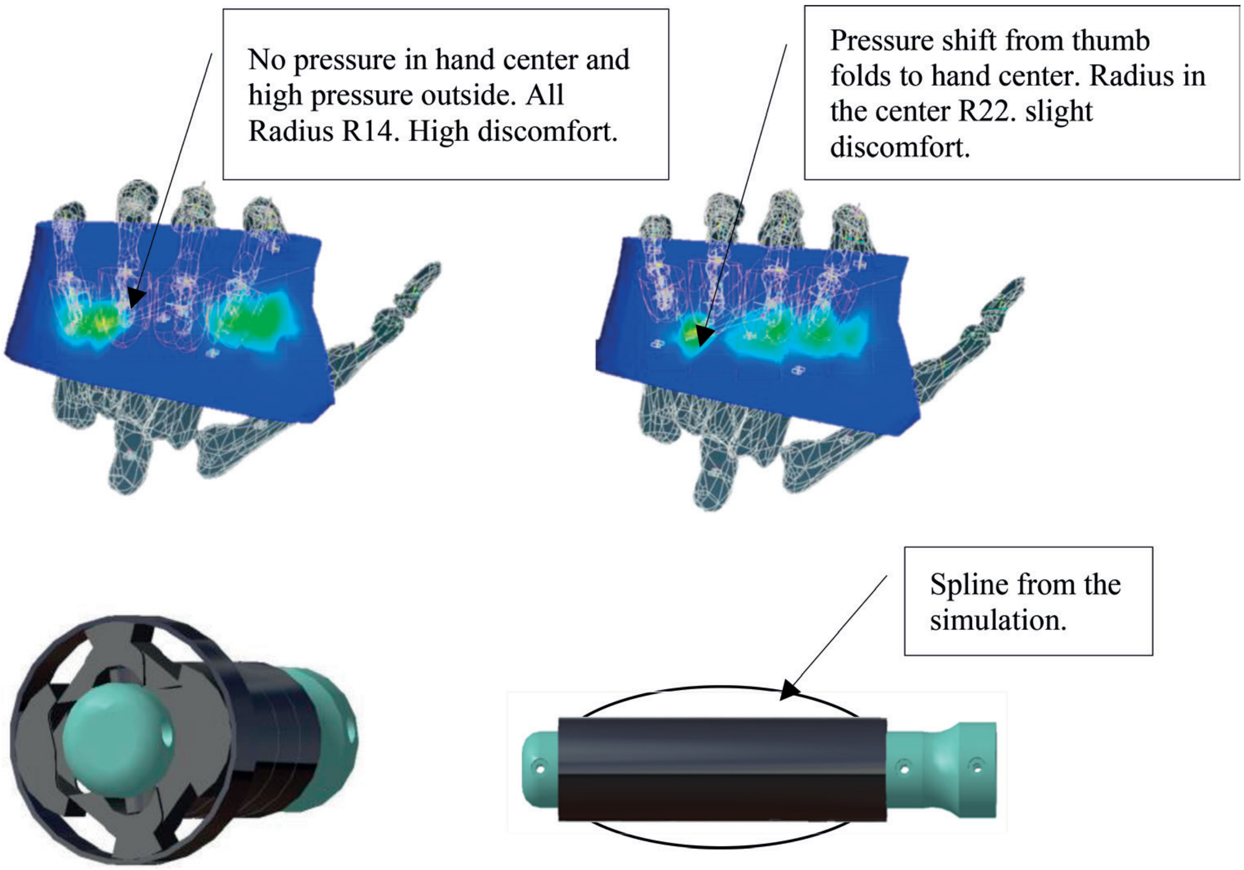

Figure 5. Results of Comfortyping.

4. Measurement of hand stress

4.1. JSI-system

The development of the JSI-System (Job-Strain-Index System) was made for a male person of the 50th percentile between 20 and 30 years (see **Figure 6**). As glove, a model (TouchGrip of UPIXX) in microfibre fabric was used. This remains firm in the fixed position of the sensors on the hand. For the sensors to measure the wrist angle ulnar and radial, a bending sensor (Interlink FSR 408) is mounted on the thumb side of the hand, at the level of the wrist. For the wrist angle, palmar and dorsal a potentiometer was used. To this on the back of the glove a sheet metal was sewn to attach the potentiometer. In the forearm a velcro strip was applied and on the velcro a sheet metal and a rod were attached. To measure the force distribution on the palm (thenar, hypothenar, palmar) and on the fingertips, were force sensors Interlink (FSR 402, FSR 400) adapted to the preparatory work of [21].

The wiring was led through a slot outwardly toward the back of the hand, so this could cause no hindrance on the palm. All signals of the sensors were lead to the microcontroller (Arduino MEGA 2560). The Arduino has been built with an LCD-Display in a plastic housing. Thus, it is possible to wear the evaluation system on a belt. For calibration, the raw data are transferred on the computer in Excel (PLX-DAQ: Parallax Data Acquisition Tool). Approximation

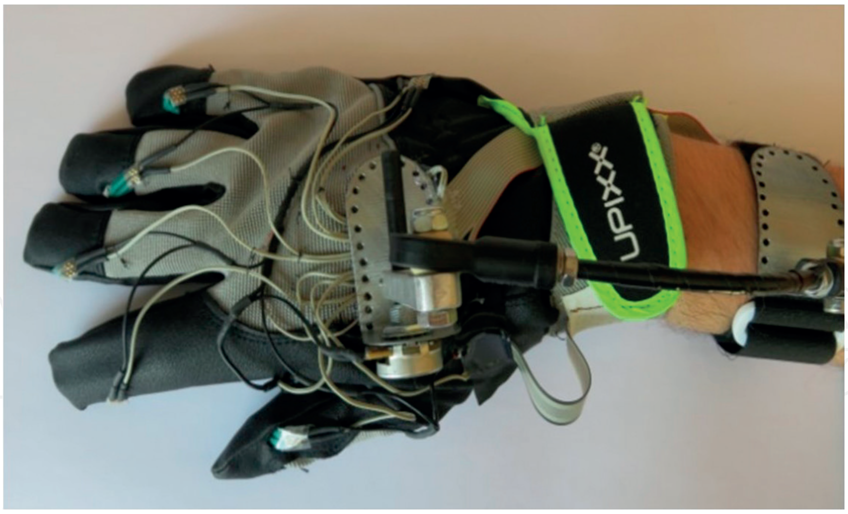

Figure 6. Prototype: JSI-system.

functions are derived from the raw data with the using of load cell and angle template. For the validation, several measurements by different forces and postures were accomplished. It was shown that the sensors measures are reproducible. For the evaluation of the JSI the measurements were compared with the limit values. The evaluation was performed in Excel according to the principle of the case distinction. Decisive for the strain variables are mainly maximum forces, angles and times [14].

4.2. Results

In the experiment, it shall be proven, if by using the prototype, the evaluation of the hand stress is faster and exacter than the classic JSI method. To show the applicability of the JSI-System, different strain cases are evaluated using the classic method and compared to the measured JSI. As an experiment angle bracket are assembled on Aluminum profiles in three different variations (see **Figure 7**).

Following work steps were performed:

1. Two slot nuts were placed in the slot.
2. One angle bracket was placed on the slot nuts.
3. Washers were placed on two bolts.
4. Both bolts were screwed into the slot nuts using an Allen wrench.
5. Both bolts were tightened with 20 Nm using a torque wrench

The experiment was performed in three variations to show the function of the JSI-System and the influence of force and angle on the result. In the first variant, the experiment is performed as described above. In the second variant during the tightening of the bolts using the torque wrench, a dorsal flexion of the wrist of about 45 degrees was provoked. Thereby the influence

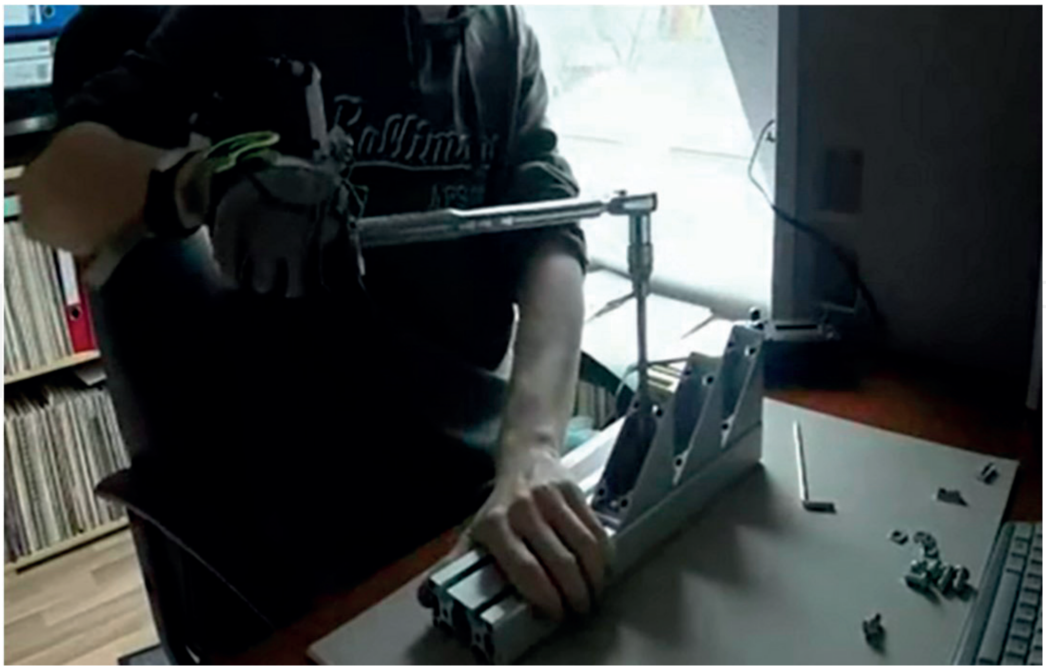

Figure 7. Experiment.

of the hand posture on the strain magnitude should be examined. In the third variant, the handle of the torque wrench was grabbed in the middle to increase torque and also the force. Here should be examined the influence of an increased force on hand posture and the intensity of the exertion [14].

For the purpose of a subjects study the experiments were filmed. One variant took about 3 min. The first variant was performed ten times to analyze the results of the JSI-System for measuring a similar task several times. The subjects were tested independently from each other and were assigned to perform the JSI evaluation using the videos from the three experiments. Apart from the videos the examiners got following information:

1. The speed of work were felt as normal.
2. For the evaluation 8 h of work per day were assumed.
3. The torque was about 20 Nm.
4. The lever in the first and second variant was 29 cm.
5. The lever in the third variant was 15 cm.

The evaluation of the JSI in the subject's study took about 10–15 min for each variant. The measurement took as long as the activity, therefore 3 min. The comparison between the subject's study (average of individual JSI ratings) and the measurement shows that the estimation is varying a bit from the measurement. The largest deviation arises in the third test variant. The highest hand stress emerges from the extreme hand posture in the second variant. Examiner 5, for example, tends to give higher estimations than examiner 3. For the repetition of the first variant a mean for the JSI of 1.055 with a standard deviation of 0.32 was measured. According to this, the spread lets us expect that the JSI measurements lay at 1.055 ± 0.32. The maximum spread is approximately ±0.5. These results indicate that during the experiments different influencing factors like the grip and strength of fingers, posture of hand and fingers etc. have influences on hand stress.

5. Conclusion

The literature review has shown that no digital hand models exist that are used for the simulation and analysis of influencing factors with respect to the pressure simulation. Either realistic skin deformation is simulated [13] or part models to study material investigation are used [9]. Here are no statements taken to the sensation of pressure. With the known hand models, a derating of the pressure distribution can be indeed proven; however, the inclusion of influences by [28] is ignored. With the help of the digital hand model, there is the ability to save subjects, expensive prototypes and pressure sensor mats in the development of hand-held products. The hand model can develop proposals for the design in a short time, and reduces the pressure load objectively. The comparison between the pressure simulation and pressure measurement showed that correct pressure loads are determined with the linear approach of the hand model. The literature review shows, in this context, such as the work of [10] that a linear material behavior on skin tissue can be assumed. However, the linear material behavior is permitted only for a certain range of forces and demands, for example, for the fingers typing e-modules. This effort can be eliminated in a non-linear material behavior. Since in most cases, skin damage due to shearing arises, for further development the expansion of the model for simulation of shear stress is recommended. Other criticisms of the model include the fixing of the metacarpals in the room. These ensure that the palm is immobile. In addition, the palm consists of a plurality of muscles which alter the mobility of the metacarpal bone. The application displays a new approach to produce an impact analysis. The results of the impact analysis can be implemented directly in the CAD model and give a product which produces low and evenly distributed pressure distributions on the hand tissues for the simulated factors. The impact analysis gives findings about which factors have an influence on the pressure distribution.

In summary, regarding the literature on the measurement of hand stress can be said, that there is no work, which uses a sensor glove to measure strain variables from the JSI method [14]. Very often sensor gloves with force sensors are used to obtain an indication of the power level, without taking the hand posture into account. In some works, such as [22], for example, only the movement or the hand posture for motion capture is measured with the sensor glove. Then the measurement data scored with RULA, without taking forces into account. None of the sensor gloves aims solely the ergonomic quality of a hand-held product. The developed JSI-System give an effective tool for assessing the hand stress based on JSI method. In addition, the examiners do not always have the same expertise and experience regarding the hand ergonomics and therefore evaluate differently. Regarding the standardization of JSI, with the JSI-System arises a potential for application in the industry. The JSI-System allows the comparison of hand-held products and processes together. A misjudgement of hand stress can be ruled out. The measurement of hand stress takes much shorter than with the classic JSI-rating. The validation has shown that all sensors provide reproducible measurements for the short-term application. Also, the state of the art shows the use of the piezo (-resistive) sensors. However, for the industrial capability and long-term use, the sensors should be examined more closely to know limits as power level and duration of sensors. For further development, it is also advisable to integrate a simple replacement of the sensors, because the sensors can be damaged by their sensitivity during continuous use. Other criticisms of the prototypes include obstructing the movement of the hand as well as the outsiders of wired sensors. With the JSI-System is shown that strain variables from monitoring methods may be measured. This also means that other methods such as LMM or RULA can be performed with the measurement method. The high training costs for more accurate results, which are recommended by [29], can be reduced with systems such as the JSI-System. The fact that compressive forces on the hand and finger surface can be measured by the JSI-System opens the possibility of a pressure reduction for comfortable design of hand-held products. The JSI-System, combined with the work of [21] can be used to assess the pressure distribution and influence factors.

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