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IMPACT OF EFFORT DEGREE DEVELOPED IN FINGERS-HAND-ARM ASSEMBLY, ON THE HAND DEXTERITY. CASE STUDY

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Abstract: *This paper presents some theoretical and practical aspects obtained from the analysis of upper limb movements under a controlled effort. For starters, the study of anatomical modeling of the upper limb components necessary to identify sensitive areas in terms of normal stresses and dynamic overstressing the joints respectively or gripping area. Design and development of experimental approaches that emphasize these effects on joints, range of motion or energy consumed during analysis constitutes the second part of the work. Also, a particular interest is given to how to determine the level of dexterity by inducing a controlled effort. In the third part of the paper are presented the results and conclusions obtained after applying the methodology designed on a casuistry identified in the experimental procedures.*

Key words: *effort, hand, MediTutor, range of motion, dexterity.*

1. Introduction

It is obvious to all that the human hand is a complex mechanism and with a diverse utility.

But beyond these issues, finger-hand-arm assembly (FHA) is closely correlated with the brain, both in evolution and in the personal development.

Therefore, to some extent, we "think" and "feel" with our hands and in turn, our hands contributes to the mental processes of thought and sensory development. In any mechanism, animate or inanimate, functional capabilities refer to features structure, but also to the nature and characteristics of the control system for single functions management or for functions available in multiple combinations.

The analysis of normal hand requires an understanding from sensorial and biomechanical points of view.

Hand fingers arm assembly (FHA) is symmetrical and balanced. FHA represents a system that allows the achievement of complex movements on each side and/or simultaneous from the entire human body.

The human hand has a wide range of possible functional abilities, but they can change with age, disease, and injury, and can vary from individual to individual and subsequently can affect a person's quality of life [13].

It is therefore very important to establish for each case, the procedure to ensure the best rehabilitation and recovery process in relation to all functional or structural factors.

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For this aspect, the first step is to achieve a structural modeling to know the load, shapes and limits of operation, but without subjecting the human subject to physical testing.

As shown in the paper [11] „there has been a significant amount of research on biomechanical simulations in the graphics community. A large portion of these efforts include physics-based and musculoskeletal systems. One of the greatest benefits of biomechanical studies is the realism that they add to the simulation".

In this respect, modeling and simulation of muscle activity was conducted according to numerous studies in the literature, in different ways or experimental approaches.

Design and simulation of a musculoskeletal system involves two components: bones (modeled as rigid bodies) and muscles (as modeled structures using *B-splines* functions).

2. Modelling the Human Hand

A geometrical model by *MakeHuman* software [14] was used to build the bone structure of the hand and necessary changes were made in the case study (human subject of 75 percentile category).

In this model it is considered that all the hand bones are passive rigid bodies and that their deformation, during simulation does not exist.

In the anatomical structure of the hand there are 16 passive rigid bodies that contain 30 bones and 25 muscles [11].

Biomechanically system of hand shows 16 degrees of freedom (DoF) and performs a series of movements for grasping, abduction, adduction, supination and pronation. As shown in the paper [11] "the B-splines in this simulation are used only for visualizing the muscle and managing its length. Unlike interpolating B-spline strands, the approximating uniform cubic B-splines are used to route the muscles along the bones. Since these are massless approximating splines, they have no dynamic properties (e.g., mass, velocity etc.) and are not considered to be strands" [11].

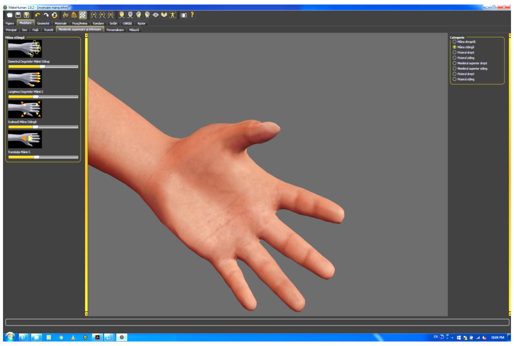

Fig. 1. *Modelling the human hand by MakeHuman software* [12]

A minimum of 4 control points are needed to create a single spline for using cubic B-splines. "Each muscle has **m** control points, where m > 4 and is an arbitrary number that varies for each muscle.

The following blending function is used to compute the uniform cubic B-spline for one uniform interval" [11]:

$$S_i(t) = \begin{bmatrix} t^3 & t^2 & t & 1 \end{bmatrix} \cdot \frac{1}{6} \begin{bmatrix} -1 & 3 & -3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 0 & 3 & 0 \\ 1 & 4 & 1 & 0 \end{bmatrix} \begin{bmatrix} P_i \\ P_{i+1} \\ P_{i+2} \\ P_{i+3} \end{bmatrix}. \quad (1)$$

Using open source software *Blender 3D viewing* it could modeling the geometric model built properly in relation to the size of the subject (Figure 1).

This simulation have revealed the limits of movement and respectively loading on joints and also the gripping parts of the system.

This determination comes to complete other applications where many authors have also customized the inverse kinematics algorithm to fit their specific applications [11].

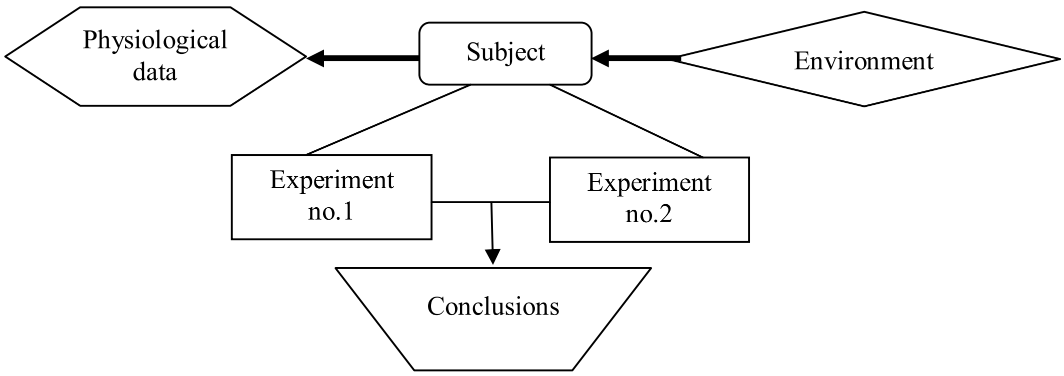

Fig. 2. *Experimental diagram* [12]

3. Experimental Setup

In order to develop and design an experimental methodology, it was analyzed the possibility of the problem discomfort jobs development at hand. It has found that this type of investigation requires the collection of initial data about the types of dysfunctions, about conditions of their appearance and about forms. Following these preliminary analyzes have chosen one human subject, that showing a discomfort of the fingers on his right hand after daily activities (including using the mouse for 8 hours a day), with no history of any kind trauma of upper limb.

To determine the causes of the problems two experiments were performed which required two different devices [5]. The experiments were conducted according to the following procedural diagram (Figure 2).

Fig. 3. *Dinamometers* [12]

In the **first phase** were highlighted physiological data of the human subject, it has provided a suitable space conducting experiments with controlled environmental conditions and set within normal limits.

In the *first experiment* it was used two dynamometers (Figure 3) for measuring anatomical and physiological forces of grasping action of poly-digit-palm and subtermino-side in different time periods.

In the *second experiment* it was used a mechatronic system type *HandTutor* - a comfortable glove with sensors for goniometer measuring of angles and to analyze the behavior of hand subjected to varying degrees of effort (Figure 4) [15].

Fig. 4. *HandTutor glove (front-back)* [12]

The system includes a software package for evaluation of various movement disorders of the hand and a set of tests for rehabilitation purpose.

The *HandTutor* system allows the evaluation extension/flexion of the fingers and wrist, right/left. *HandTutor* glove can be used for a multitude of actions among which we mention improving hand dexterity, disabilities recovery of the hands characterized by types limited the movements of the fingers and wrist due to muscle weakness, or decrease disorders of movement of the hand and of their trembling. [1, 2, 4, 10].

4. Results and Discussions

For the *first experiment*, it was used as tools, the analog dynamometer and pinch type. This experiment was conducted over a period of 14 days. The steps of this experiment are:

Morning just after waking (8:00 AM), the human subject was forced to sit in the chair, with hand resting on the handle and acts anatomically and physiologically palmar dynamometer (Figure 5).

Immediately after the first step, the human subject was instructed to act anatomically and physiologically pinch dynamometer type and corresponding data were recorded.

In the **evening** time (08:00 PM) were repeated previous steps, from morning.

Fig. 5. *Dynamic actions on hand* [12]

For the *second experiment*, it was used as tools the *HandTutor* sensory glove, a laptop and a container with sand, with different weights (3, 5, 8 and 10 kg).

The recordings were *Range of Motion* (ROM), *Finger Trace Motion Analysis* (FMA) and *Test the target* (TT).

The phases of the experiment are the following:

In the *initial phase* of the experiment number two were recorded, by using the *HandTutor* glove, the relaxed initial tests not subject to the induced effort. The recorded movements were the extension and flexion of the fingers.

In the *next phase*, the human subject was required to keep a container with sand in the right hand, during 5 minutes.

Immediately after the 5-minute effort, to the human subject was placed the sensory glove and subjected to test and record ROM active and passive doing the anatomical/physiological flexion and extension of the fingers.

After the moment when the hand was relaxed, for about 30 minutes (60 minutes if weights were 8 kg and 10 kg), human subject was asked to take container for 5 minutes for the next test, FMA by doing the normal flexion and extension fingers, repeatedly for 20 seconds.

Immediately after the 20 seconds, the human subject conducted a *target test* (TT).

Fig. 6. *Recording the hand movements with* HandTutor *system* [12]

In order do not influence the results of the experiments and to assess the behavior of the human subject's hand, records were made in 4 different days for each weight. A total of 45 records were achieved using *HandTutor* glove and was chased throughout the influence evolution of the effort degree on dexterity and handling by dedicated *MediTutor* tests type.

For each record, in each experiment it was necessary to conduct the calibration process (extension/flexion of the fingers and wrists) of the glove on the right hand, the one that was registered in both experiments.

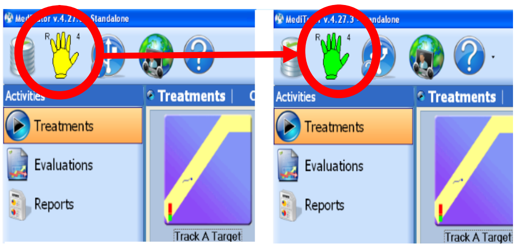

Fig. 7. *Calibration of the glove* [12]

Thus, from the analysis of clamping force (anatomical and physiological values measured in the morning and in the evening, along the 14-day of experiments) it emerges that the *anatomical average force* was ~34.07 daN - in morning time, ~42.86 daN - in evening time and *physiologic average force* was ~15.5 daN - in morning time and ~17.57 daN - in evening time (Figure 8).

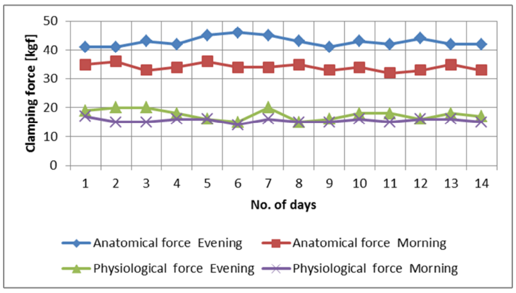

Fig. 8.*Clamping force measured by dinamometer* [12]

Therefore, the anatomic clamping force is defined as 2.44 times higher than physiological clamping force measured in evening time and respectively a ratio of 2.2 times higher compared to the same measurements, but in morning time.

The ratio between anatomic and physiological clamping force measured has value of 1.13 in the morning time and 1.26 in the evening time. These values show an increased clamping force, both anatomical and physiological (the evening compared to the morning time).

This indicates a sustained motor activity during the day that induces a degree of fatigue and tension in muscles of FHA assembly.

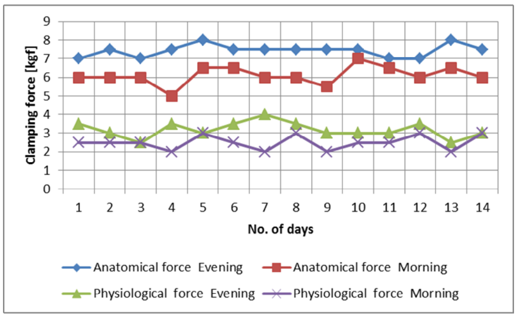

Fig. 9. *Clamping force measured by pinch* [12]

In the same context, the measured force by pinch dynamometer indicates a similar situation of clamping forces variations, but of course at lower limits because it acts only with three fingers (Figure 9).

For the *second experiment* there were three types of test in the dedicated software MediTutor: *Range of motion (ROM), Finger motion analysis (FMA)* and rehabilitation test *Track a target (TT)*.

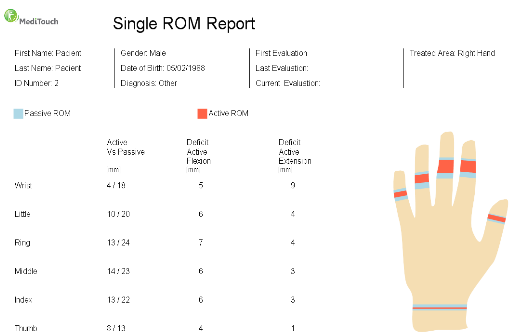

Fig. 10. *Example of ROM report* [12]

In the case of the first test ROM were made in total 15 records: 3 tests without weights and other 3 tests each, with 3, 5, 8 and 10 kg (Figure 10). Depending on the weight and the two types of recordings *passive ROM* and *active ROM* the analysis were performed movement displacements of fingers during 20 sec., after in his right arm was induced the effort with the weights (0, 3, 5, 8 and 10 kg) (Figures 11 and 12.).

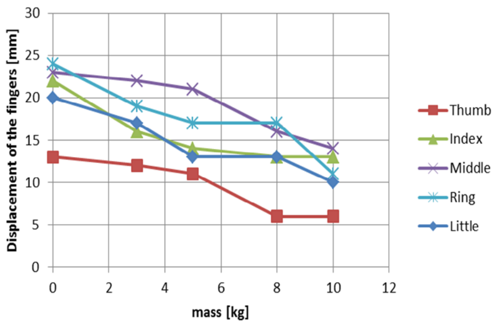

Fig. 11. *Movements of the fingers (ROM passive)* [12]

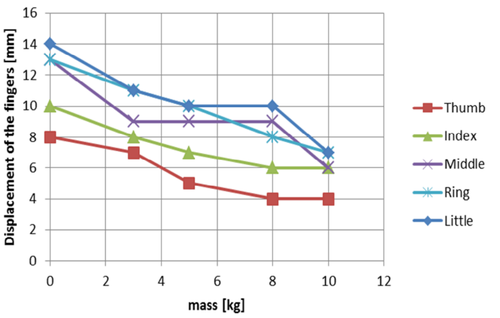

Fig. 12. *Movements of the fingers (ROM active)* [12]

It was followed the same procedure when registering FMA and were evaluated simultaneous movements of the fingers after they were exposed to the same degree of effort (Figure 13).

After all the tests, it was determined the frequency range (1.5-without load and 0.9-with load of 10 kg) of fingers movements.

These threshold values indicate a strong decline in the frequency of total motion of the fingers when FHA assembly was subjected to heavy loads, resulting in reduced capacity handling with precision.

This aspect is confirmed by rehabilitation test aimed to inducing dexterity evaluation score. Exercise has run for 1 minute after each step of testing ROM and FMA (Figure 14).

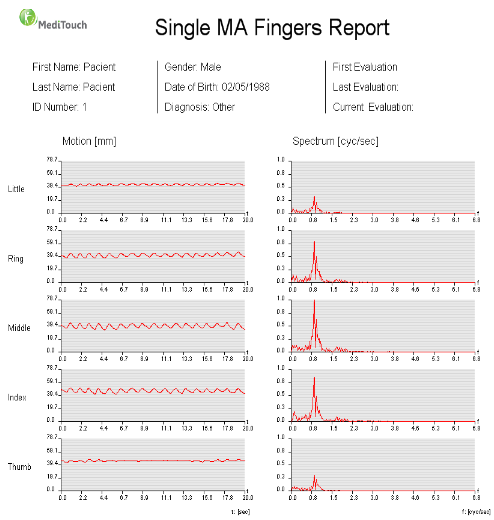

Fig. 13. *Fingers motion analyse report* [12]

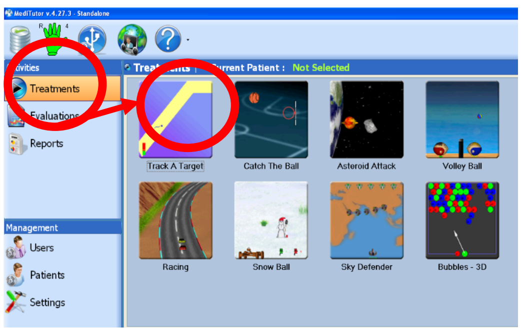

Fig. 14. *Exercise TT to evaluate dexterity* [12]

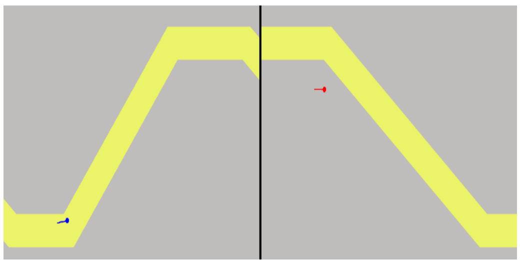

Fig. 15. *Testul Track a target* [12]

Track the target (TT) is a dexterity test involves tracing a path with a virtual ball performing extension and flexion movements of the fingers and wrist (Figure 15).

As a result, we get a score based on accurately tracking (on the route) or incorrect (outside) of a trajectory that can be established with linear or sinusoidal shape. The maximum score is 100 points.

The analyses of all records of this test reveal a constant decline in test scores determined by TT according with increasing of weight (Figure 16).

The difference between the first score of recording and the no. 3 recording is due to the impact of human subject to this type of testing and it is observed when he got used to work, the score is much better.

Therefore for a better assessment of the effort degree influence on dexterity it was provided in the procedure to use multiple TT tests to eliminate this aspect of *learning the test.*

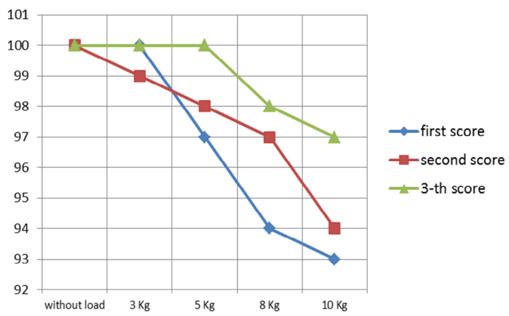

Fig. 16. *Diagram with scores of TT* [12]

The *MediTutor* software package contains more TT tests, with different degrees of difficulty and using them progressively may determine dexterity with greater accuracy and also, in same time, can eliminate the human subject adaptability to the same type of test.

5. Conclusions

In the analysis performed on the chosen case they were found the following aspects:

- It can be seen a link of proportionality between rehabilitation TT test and other measurements made with *HandTutor* glove. Thus, if the weight will increase the frequency of movements (fingers and wrist) and dexterity scores fall.
- It finds that if the mass of the object used to induce the strain on the whole FHA assembly is low, the frequency of motion of the fingers of the hand grows.
- Also the displacements of the fingers increse, leading to incresing their score to values close to the maximum. Therefore, to establish a mechanisms for rehabilitation of the hand discomfort, then recommend regular training of them.
- Regular training must be done with repetitive movements, with small weights, by performing oscillations with high frequencies and movements to anatomical limit.
- In the case of the first experiment (measuring the anatomical forces), it observed an increasing of them from morning untill evening time, with a percentage of 20%. For physiological force case, this one was lower in the morning than in the evening (increases with a percentage of 17% from morning to evening time).
- For the second experiment (using *HandTutor* sensory glove), it was observed that the most requested fingers in lifting weights are index, middle and ring fingers. The thumb and little finger does not contribute greatly to this type of movement, they only provide hand in tightening the closure, but they could see little difference displacements per weight basis [6-9].
- For the test ROM and for FMA was observed that the fingers have a gradually degree of solicitation of the muscles for each weight.
- The same situation for rehabilitation TT, the test scores were very close to the maximum, indicating that the human subject is not suffering from neurological disease on the right hand.

- Realizing these experimental analyses, it was found that the subject right hand discomfort is caused by the degree of fatigue arising from a daily effort he exerts.
- Therefore there is need for regular exercises to relax the joints of the fingers and hand and to stress relief and to mobilization of their muscles [3].

Acknowledgements

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