Ergonomic study regarding sport training - Push-ups simulation and analysis

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Abstract

Some of the most common and helpful physical exercises used in sport training are the push-ups. Their biomechanics is analyzed in the paper and the author also gives an ergonomical study of this particular exercise with a complete simulation of the process.

Key words: *ergonomic, sport, push-ups, analysis*

Acknowledgment

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Rezumat

Unele dintre cele mai comune și folositoare exerciţii fizice utilizate în antrenamentele sportive sunt flotările. Biomecanica lor este analizată în prezenta lucrare, autorii oferind, de asemenea, un studiu ergonomic al acestui exerciţiu special, cu o simulare completă a procesului.

Cuvinte cheie: *ergonomie, sport, flotări, analiză*

Menţiune

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Introduction

Today, exercise has become more important and prevalent in the daily routine of many people. Different types of work-out routines result in different benefits to the individual. Push-ups are a common type of exercise that do not require the use of any exercise equipment; this means that it can be done virtually anywhere. Push-ups are an excellent exercise to strengthen the upper body because they are safe, effective, and require the action of several muscle groups to be performed properly. Push-ups are performed in a prone position, using only the hands and toes to support the body weight. While in this position, the individual pushes off the floor with the hands to lift their body, maintaining a straight line between the shoulders, hips, and feet. Once full elbow extension is reached, the individual then slowly lowers himself to the floor. When performing a push-up, the horizontal adductors and the elbow extensors will be active throughout both the ascent and descent of the push-up. During the ascent phase, these muscles must work against gravity in order to produce elbow extension and horizontal adduction of the shoulder. During the descent phase, gravity works in the same direction as the movement. Because gravity applies a flexor torque on the elbow and a horizontal abductor torque on the shoulder, the muscle torques must be applied in the opposite directions. This means that the elbow extensors and shoulder horizontal adductors must contract in order to produce a controlled lowering of the body during the descent phase (1), (2).

Performing a push-up requires the use of various chest, back, shoulder, and upper arm muscles-including the elbow extensors and the shoulder horizontal adductors, working concentrically and eccentrically. Varying the hand placement when doing push-ups produces distinct differences in joint and muscle loads. The subject is a 27 year old male. He is 1.8 meters tall, and weights 813.4 Newton. For this analysis, the subject wore jeans with no shirt, to make the identification of the segments and joints simpler. Shoes were worn, but this did not affect the analysis. The subject had extensive experience in performing push-ups (4, 5).

The theorem of this study is based on Newton's second law of motion. Figure 1 shows the free body diagram of each segment. Based on Figure 1, substitute the distal force and distal moment of segment have known into the functions of Newton's second law of motion, we can get the proximal force and proximal moment of segments.

Fhd and *Mhd* are the distal force and distal moment of the hand, which can be measured by force plate. The proximal force and proximal moment of hand can then be calculated.

In Figure 1 the arm segments and their action forces and moments are described. Where: F is force, M is moment, m is mass, I is moment inertia, a is acceleration, α is angular acceleration, ω is angular velocity, g is gravity. In suffix: h is hand, f is forearm, u is upper arm, d is distal, p is proximal.

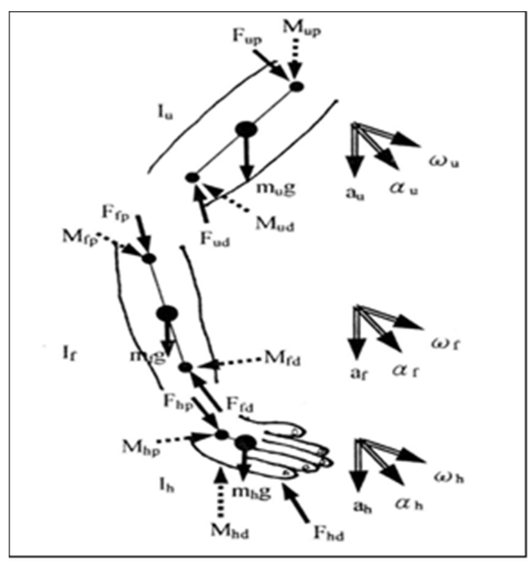

Figure 1. Hand biomechanics by segments (3)

Stabilometry analysis using digitalized biometry

The push-ups are performed in a prone position, using only the hands and toes to support the body weight. While in this position, the individual pushes off the floor with the hands to lift their body (ascent phase), maintaining a straight line between the shoulders, hips, and feet. Once full elbow extension is reached, the individual then slowly lowers themselves to the floor (descent phase). A breakdown of specific components in the movement consists of flexion and extension of elbow and horizontal abduction and horizontal adduction of the shoulder (2).

When performing a push-up, the horizontal adductors and the elbow extensors will be active throughout both the ascent and decent of the push-up. During the ascent phase, these muscles must work against gravity in order to produce elbow extension and horizontal adduction of the shoulder (2, 3).

The analysis tests were made using the FLIR B 200 Thermograph and the Digitalized Biometry Pedana Equipment with the Milletrix software. Figure 2 shows the stabilometry analysis with the palm of the hands touching the pressure pad of the ascent phase. The areas with a higher amount of pressure applied on the analysis pad can be observed, as described by the color code.

From this analysis the conclusion is that the subject is leaning mostly on his left hand while performing the push-up. Figure 3 shows the correction made after the first stabilometry test when the subject tries to apply a more ergonomically correct posture while looking at the stabilometry map from the first test.

As it can be observed, the pressure is more equally distributed on both hands.

The second analysis comes to aid by using the radar balance system (Figure 4).

The radar balance shows in enhancement mode how the pressure is unequally distributed on the hands.

Using a third Digitalized Biometry analysis of both the phases, the center of gravity has been determined while performing the push-ups. Figure 5 describes an ellipse composed by the placement of the center of gravity while performing the push-ups in the ascent phase.

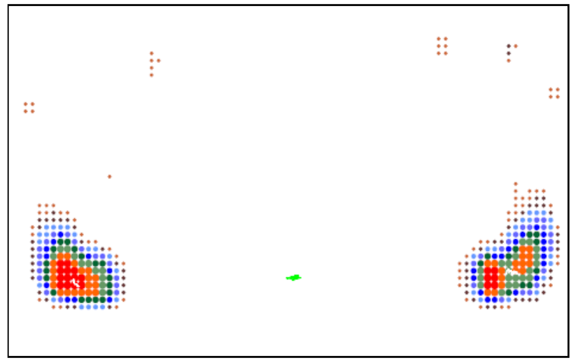

Figure 2. Stabilometry test performing a push-up

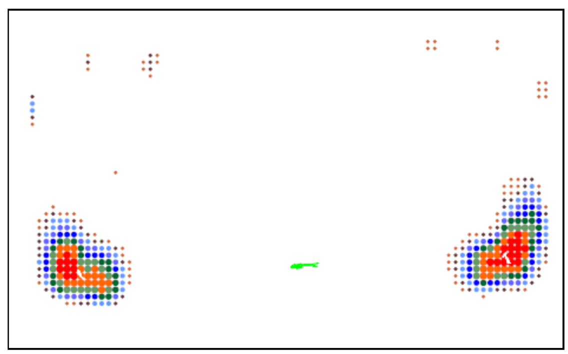

Figure 3. Ascent phase stabilometry test performing a corrected push-up

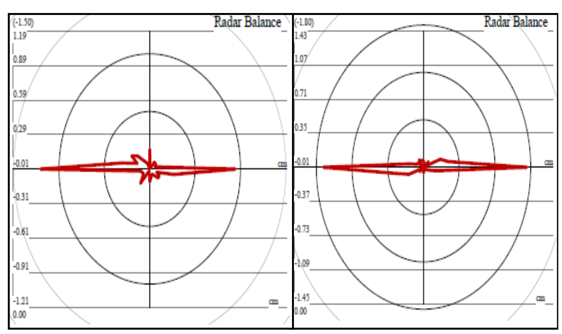

Figure 4. Ascent (left) and descent (right) phase stabilometry radar balance test performing push-ups

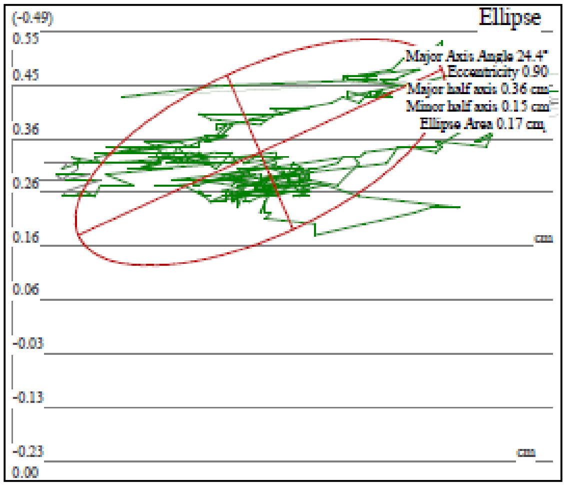

Figure 5. Stabilometry test performing a corrected push-up

Thermographic methods of push-ups analysis

The thermographic analysis includes thermographic pictures taken using the Flir B 200 Thermograph to determine the muscular activity while performing the push-ups. Using thermography, this method emphasizes the muscular activity, the intensity of this muscle activity and its distribution throughout the upper body during the whole process. As it can be easily determined, the temperature rise involves an accentuated muscle activity which is highlighted by the color code of thermography.

Pictures were taken at the beginning of the exercises, during the exercises and after.

The analysis also includes the exact time at the moment of the exercise and also during the whole period of exercises. It can easily be observed that as the subject continues the exercises the areas where the muscle activity is more predominant get highlighted, thus deducing the increase of muscle activity proportional with the time factor.

Using this method it can be determined that from the ergonomically point of view, the subject's posture has a leaning tendency towards his left hand, fact shown by the intensity of his muscular activity at his left elbow (Figure 7). It is also very well highlighted the entire muscular activity and its intensity during the whole analysis. The muscular activity rise on the upper body section is also posted throughout the figures 6 to 10.

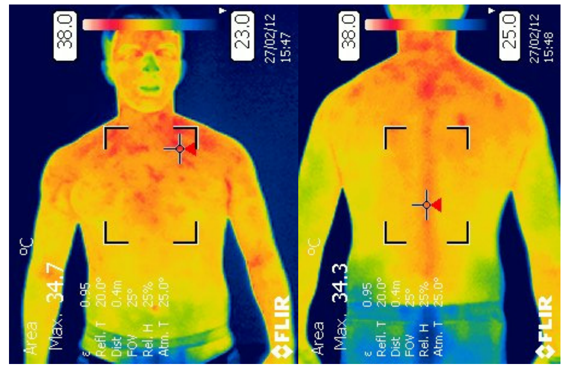

Figure 6. Thermographic analysis at the beginning of the exercises

Figure 7. Thermographic view of the back muscles in action

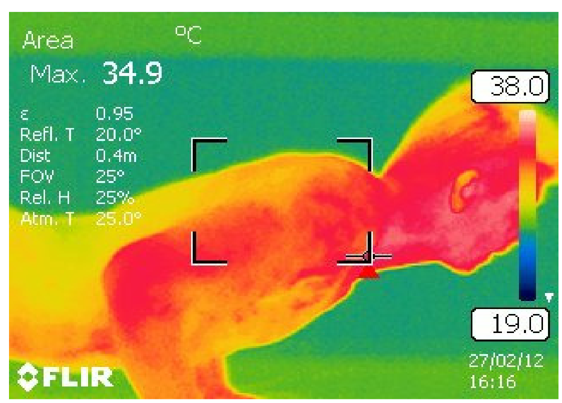

Figure 8. Side view of the muscle activity during the push-ups

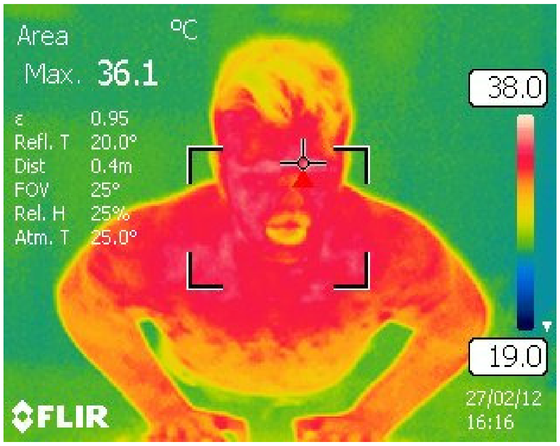

Figure 9. Front thermographic view during exercises

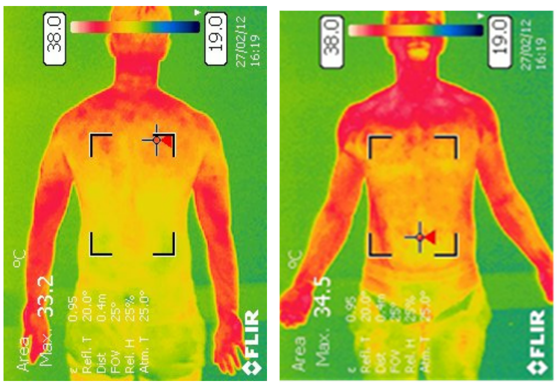

Figure 10. Thermographic analysis at the end of the exercises

Anybody simulation

In the late nineties, a group at the Institute of Mechanical Engineering at Aalborg University was studying the design of bicycle frames for optimum performance. It transpired over a period of time that the problem is ill posed unless the model includes the rider. In other words, the bicycle and the rider form one machine, and one part cannot be optimized in the absence of the other. In this respect, the bicycle is representative of a large class of products of which the interface to the human body is a primary feature. In view of this fact, it is striking that there has not been a CAE technology available to reliably simulate the interaction between the human body and its environment. Inspired by the bicycle design problem, a group comprising experts within multibody dynamics, biomechanics, physiology, design optimization, mathematics, and software engineering was established. The group developed three major versions of a software system for modeling the human musculoskeletal system:

1. A hard-coded, procedure-oriented prototype distinctly developed for optimization of bicycles. This prototype demonstrated the feasibility of the basic numerical methods.
2. An object-oriented prototype capable of handling different models by means of object definitions, albeit still hard-coded into the software. This version was used for optimization of a handsaw and a tricycle for paraplegics.
3. A version capable of handling object-oriented models in a specially developed model description language. Figure 1 shows a model of the full human body comprising more than 300 muscles.

The system was named AnyBody to reflect its ability to model “any body” the user desires. The AnyBody Modeling System is designed for constructing complex models of the human body and for determining the environment’s influence on the body, and it must consequently exhibit a computational efficiency that can only be obtained by inverse dynamics.

Using this technology the push-ups simulation was made in different phases. Notice that in Figure 11 the exact ergonomic posture was achieved by simulation and also the group of muscles that are applied during the push-ups are emphasized.

During the simulation, snapshots were captured to show the posture and muscle activity during the ascent phases and the descent phases of the push-ups (figures 12 and 13).

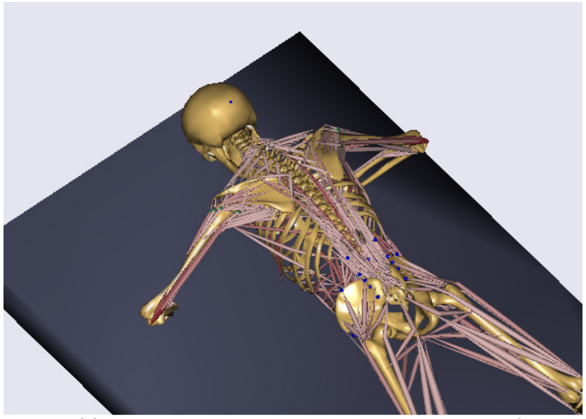

Figure 11. AnyBody simulation at the beginning of the exercises

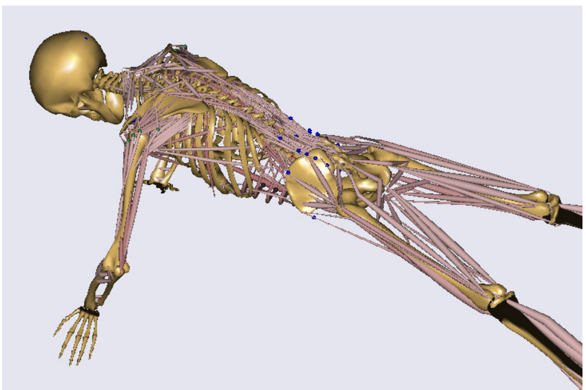

Figure 12. AnyBody simulation of the ascent phase of a push-up

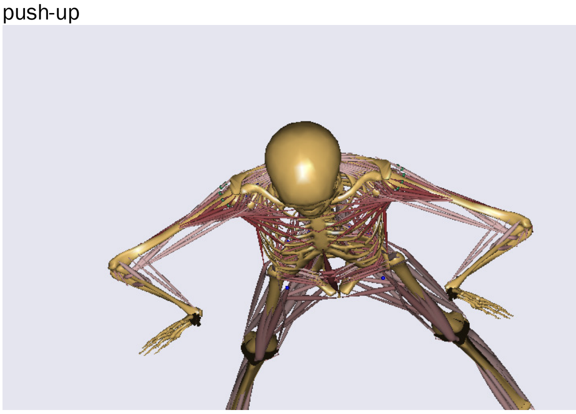

Figure 13. AnyBody simulation of the descent phase of a push-up

Using the AnyBody simulation software data, values of the whole muscle activities during the push-ups were imported in MathLab and calculus were made to have the mean values of the muscle energy during the time steps of the simulation. In the following graphs there were highlighted only the spine muscles activity (figure 14) and the total muscle activity mean value (figure 15). The muscle energy in each graph is given in (kcal) at the ordinate and the time scale at the abscissa.

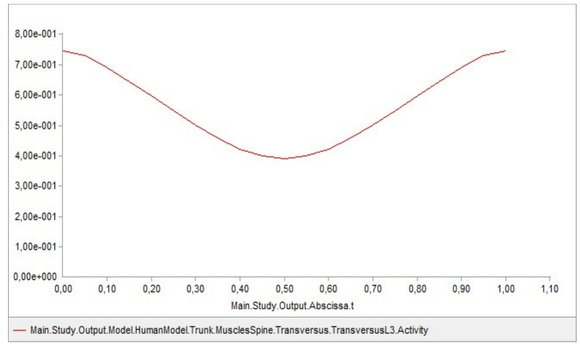

Figure 14. Spine muscle activity during exercises

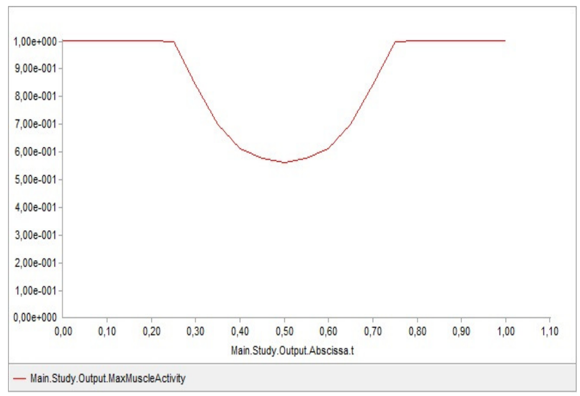

Figure 15. Total muscle activity during exercises

Conclusions

Thermography analysis emphasizes the muscular activity, the intensity of this muscle activity and its distribution throughout the upper body during the whole process. As it can be easily determined, the temperature rise involves an accentuated muscle activity which is highlighted by the color code of thermography. And with the AnyBody Modeling System the designed for the complex models of the human body was made while executing the activity, and highlighting the muscular activity in the specific areas of muscle training facts that can only be obtained in general by simulating the whole process with the methods of inverse dynamics. Thus the whole analysis shows the high muscle activity during the push-ups process, the visual simulation of the exercise and the calculus of the muscle energy involved in the process expressed in kcal.

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