EAN 2017
55th conference on experimental stress analysis

Motion Analyses of Human Body on a New Exercise Trainer: Pilot Study

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Introduction

The history of exercise equipment goes back to early man´s need physical strength and speed. During the centuries, human being became more sedentary and beside mentioned need the rehabilitation role became also important. If we focus only to cardiovascular equipment, there are three basic equipment: bicycle trainer, treadmill and elliptical trainer. The choice of above mentioned training devices is influenced by the therapeutic goals and by the functional abilities of the patient. A lot of effort was put into a biomechanical evaluation of these trainers.

Cycling can augment rehabilitation effect and can control lower extremities stress [1]. The load of lower extremities muscles depends on various parameters including seat height, pedal locations and others. By omitting these factors several injuries can occurs. This include knee pain, patellar quadriceps tendinitis, iliotibial band syndrome, hip pain, medial tibial stress syndrome, stress fracture, compartment syndrome, numbness of the foot, and metatarsalgia [2]. Injury is usually caused by a combination of inadequate preparation, inappropriate equipment, poor technique, and overuse. Another dark side of cycling is loading of spine column. Patients with back problems should not cycle shortly after surgery as a precaution [3]. It means that this type of trainer cannot be used for these patients. Elliptical training appears to be a safe and feasible training alternative. Jackson et al. demonstrated that patient's rehabilitation at elliptical trainer resulted in no improvements in walking speed; however, participants did demonstrate variable improvements in endurance, balance, and functional mobility [4]. Wu-Lu et al pointed out, when using elliptical trainer, that users` joint function and muscle strength, especially at the knee must be monitored, to avoid injuries [5].

It seems, from the literature, that none of the training machine has a capability for complex and save training after rehabilitation. The aim of this article is to introduce a new exercise machine that would be more complex for various exercises.

Design of the trainer

The principles of today's machines for aerobic-cardio exercise are derived from those of the bicycle. This new exercise machine uses a rocking platform whose range of rotary motion is ±10°. The rocking platform is V-shaped with an angle of 160°, where each of its halves has a size of 600×500 mm. The center of the rocking machine is pivotably attached to a fixed frame of the machine. The exercise machine includes a mechanism which provides defined resistance to the practitioner's movement, and thus determines the levels of load during the exercise. In the version of the machine presented here, this mechanism comprises a crank mechanism with a flywheel. The machine provides resistance through an electromagnetic brake which is installed on the flywheel and controlled by a transformer. Thanks to the design of the training machine, the practitioner can perform various kinds of exercise engaging large groups of muscles of the entire body or only selected parts in a highly comprehensive manner.

The design study of the training machine (fig.1) comprises all structural parts and user settings of the current version of the machine. Besides various kinds of stance (with feet together, legs astride sideways or forward, etc.) on the machine, the practitioner may also use fixed or movable grips which have a major effect on exercise control. Both grips are vertically adjustable and are provided with a training computer which displays and records the speed, time, the practitioner's performance, and other data. The surface of the rocking platform has anti-slip finish.

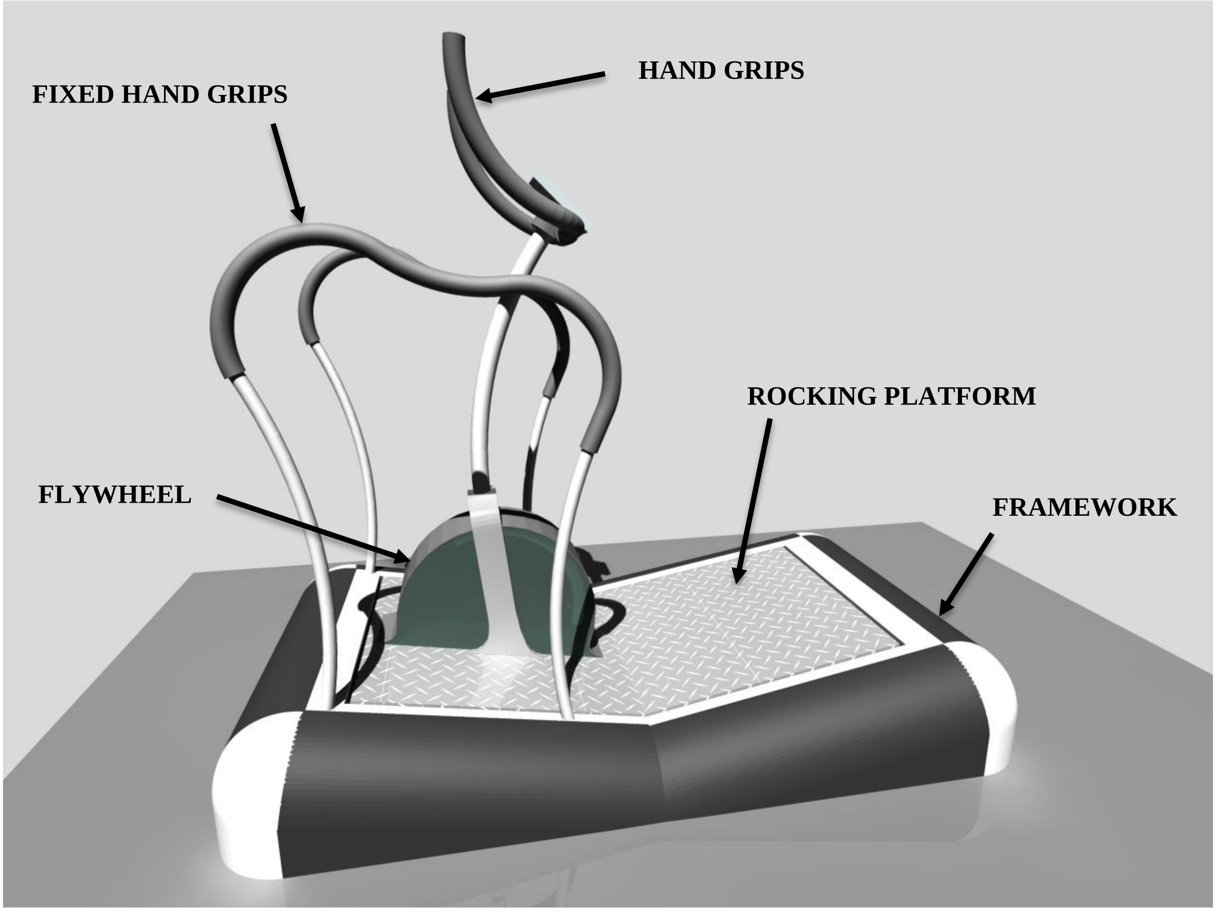

Fig. 1 Design study of the training machine

This machine is of simplified construction, comprising only load-bearing and functional parts, which means that the prototype lacks safety and design covers and specially-shaped grips. By contrast, a great emphasis was laid on verifying its function and on the crank mechanism (fig. 2b) with a flywheel (4), the parts which, together with the electromagnetic brake (5), make up the machine's source of resistance to be overcome by the practitioner.

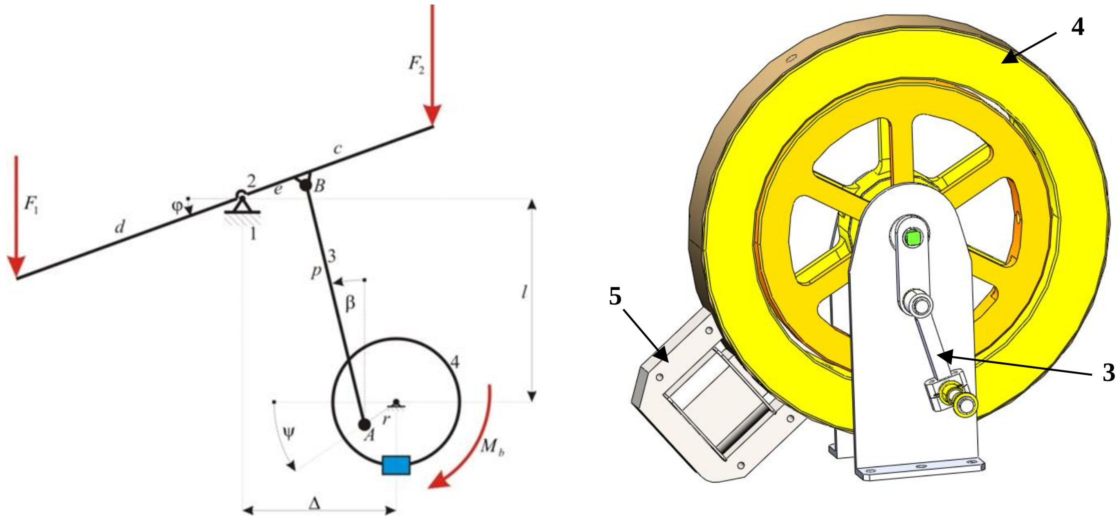

Fig. 2 Four-bar linkage a) calculation diagram b) design solution

The use of the Newton's method for finding kinematic dependences (fig. 2a) helped solve the movement of the platform (2) and crank (3) on the flywheel (4). Then, equations of motion for the four-bar linkage were constructed using Lagrange equations of the second kind. The generalized force on the right side of the equation can be obtained by comparing its virtual work with the virtual works of all generalized forces that act on the system as it is given a virtual motion. The equation which is constructed in this manner is a non-linear differential equation of the second order to which the analytical method cannot be applied, and therefore a procedure for obtaining the numerical solution is outlined here. It is based on a transformation of this second-order differential equation to two first-order differential equations. The problem can then be solved using one of standard numerical methods, such as the Runge-Kutta one. In MATLAB environment, this method can be implemented using instructions such as ode23 or ode45.

$$\dot{x}_1 = \frac{cos\varphi(x_2)\{F_1 dh(p_1 x_1)p_1 + F_2 c[h(p_1 x_1)-1]p_1\} - M_b - I^* p_1 p_1' x_1^2 - I_{kor} p_2 p_2' x_1^2 - bs^2 p_1^2 x_1}{I^* p_1^2 + I_4 + m_B r^2 + I_{kor} p_2^2}.$$

$$\dot{x}_2 = x_1. \tag{1}$$

To obtain the numerical solution, mass and geometric parameters of the mechanism shown in Fig. 1.1 were substituted into the equation. Based on the calculation, some dimensions or mass parameters can be adjusted. An example of the time course of the displacement, angular speed and acceleration of the flywheel in dependence on the rocking platform is shown in Fig. 3.

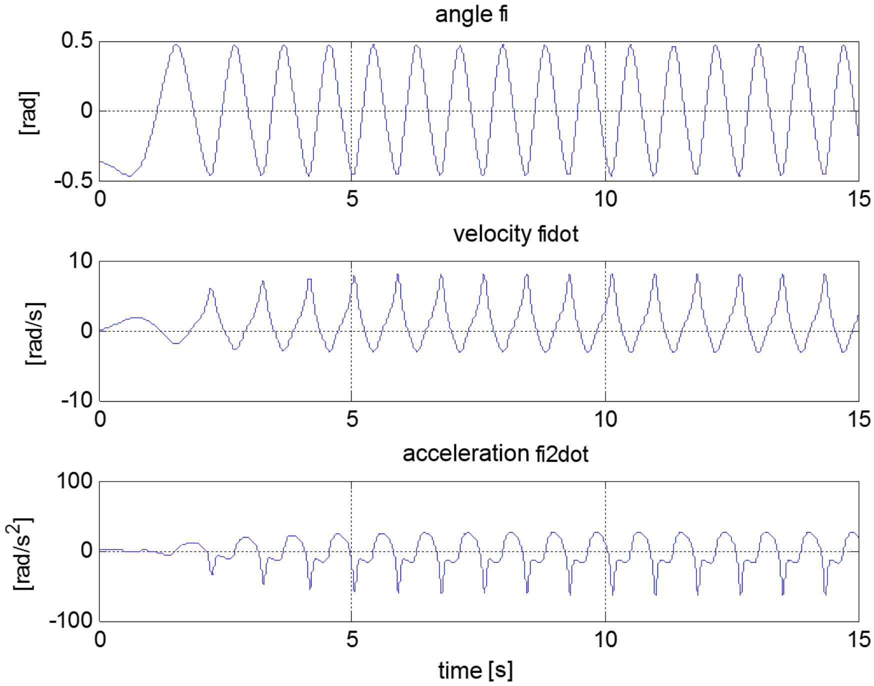

Fig. 3 Time course of flywheel parameters

Motion analyses

The aim of the second step of this study was to analyze motion of human on this trainer. Physically healthy male subject (37 years, 82 kg) volunteered for this investigation. The resistant load was set to 110 W for all cases. 3D motion capture was provided by the optical system Pontos M4, 15 Hz speed cameras (GOM GmbH, Germany). The exercises were done in two ways:

a) Legs are positioned at the opposite side of V shaped plane and the movement is dominantly done by arm movement on handlebars.
b) Left leg is positioned at one side of the V shaped plane and the right leg on the opposite one. The arms are holding the handlebars.

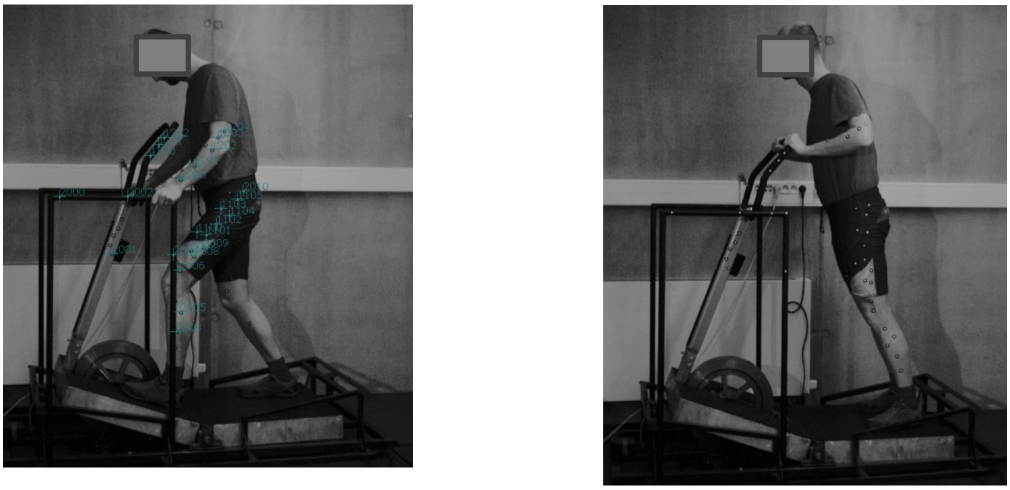

Fig. 4 Possible type of exercising a) (left), b) (right)

The region of arm, leg and handlebars were covered by markers.

Results

Displacement, velocity and acceleration of selected region were treated for every type of exercising. The typical gained functions are on fig. 5.

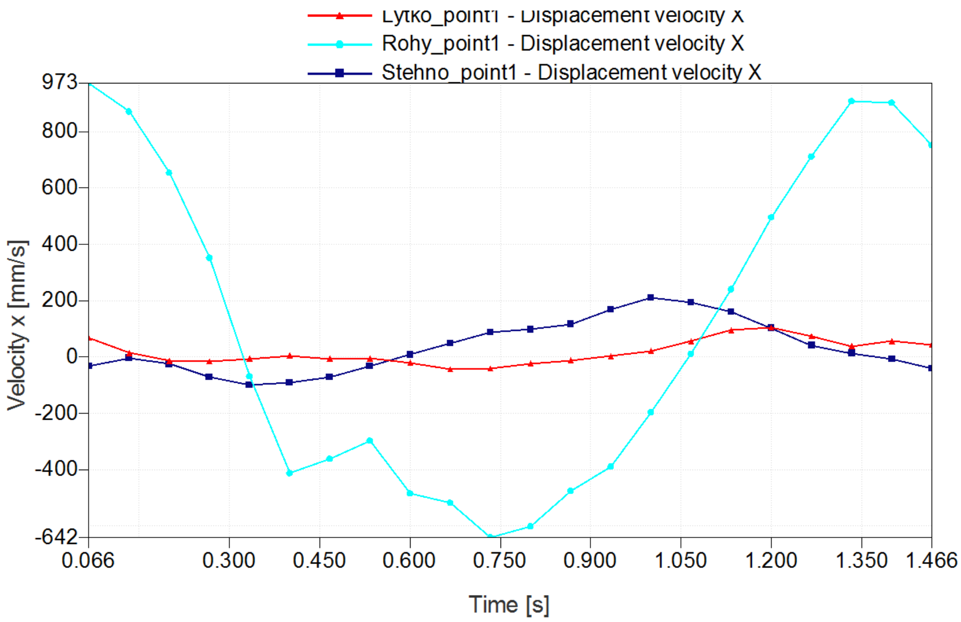

Fig. 5 Velocity in axis X for case b. Calf (triangle), handlebars (circle), thigh (rectangular)

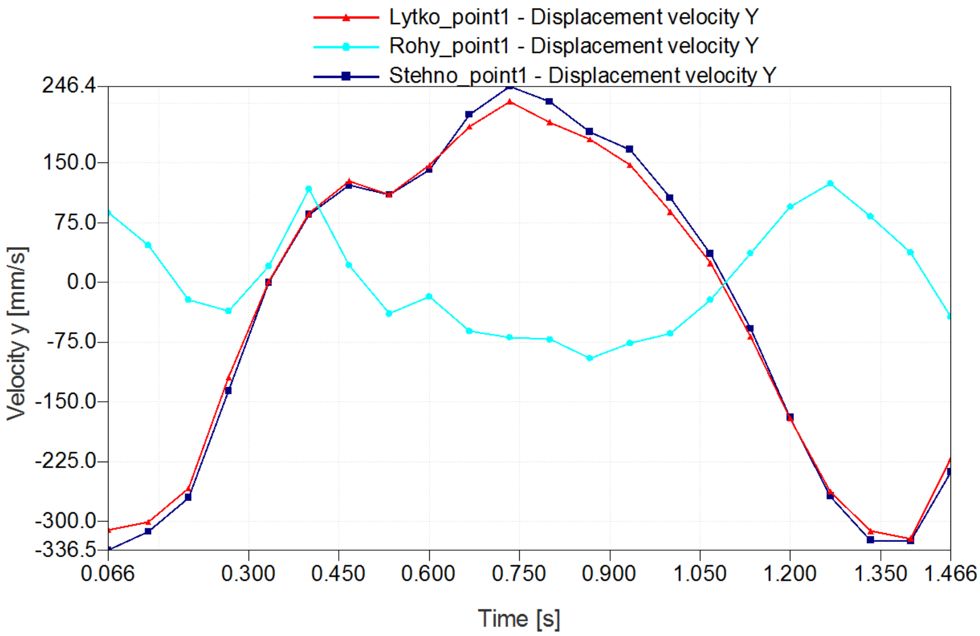

Fig. 6 Velocity in axis Y for case b. Calf (triangle), handlebars (circle), thigh (rectangular)

The maximal velocity in X direction reaches 904 mm/s in case a) and 1472 mm/s in case b).

Velocity x [mm/s]	Exercise a	Exercise b
Handlebar	904	1472
Thigh	201	283
Acceleration x [mm/s2]		
Handlebar	3842	12019
Thigh	811	2851

Tab.1: Maximal measured velocity and acceleration in x directions

Conclusions

There are many articles aimed on comparison of different type of trainer. Usually following conclusion is made: treadmill walking most closely resembled overground walking. Cycling showed the largest difference from overground walking, with elliptical closer but still a significant distance from all three. Cycling showed greater hip reciprocation. Cycling and elliptical training showed stronger intralimb synergism at the hip and knee than the other two. Based on kinematics, results suggest that elliptical training may have greater transfer to overground walking than cycling and cycling may be more useful for enhancing reciprocal coordination [6]. In this study a new type of trainer based on a completely new philosophy was introduced. Based on pilot experiments it is assumed that it would have more complex use in the field of rehabilitation.

Acknowledgment

This study was created by project Development of West-Bohemian Centre of Materials and Metallurgy No.: LO1412, financed by the MEYS of the Czech Republic.

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