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Design optimisation of human exercises

John Rasmussen*, Natalie Lindsay, Søren Tørholm Christensen, Michael Damsgaard
Institute of Mechanical Engineering
Aalborg University
Pontoppidanstræde 101
DK-9220 Aalborg East
Denmark
Email: jr@ime.auc.dk

*Corresponding author

We perform strength training for a number of different reasons: to overcome existing injuries or prevent new ones in the musculo-skeletal system, to improve our performance in particular disciplines of sport, to enhance our general health, or simply for body building purposes, i.e., to improve the body's aesthetic appearance.

Where strength training was previously accomplished mainly through exercises working against the body's weight, it is now assisted by a wealth of different machinery. The purpose of these exercise machines is to maximise the effect of the training by imposing the movements and body loads that are believed to assist the training objectives. The purpose of this work is to determine optimal human loads and movements for strength training, i.e., to design the best possible strength equipment.

It is important to realise that the analysis of an exercise machine cannot be isolated from the body operating it. The two form one mechanism, and the body constitutes by far the more complex part. To address the complexities of human body modelling, the authors have developed the so-called AnyBody system. AnyBody performs kinematic analysis of human movements and identifies individual muscle actions, joint loads, tendon elasticity, mechanical and metabolic work, and many

other characteristics of the working human body. The system is based on so-called inverse dynamics, where the motion and external forces are used as input to the analysis, the direct result of which is muscle forces and joint reactions. The equilibrium situation solved by the system is statically indeterminate because there are more muscles spanning each joint than there are degrees of freedom. To overcome this problem, the system distributes muscle loads according to a minimum fatigue criterion leading to a min/max problem in the muscle forces with the equilibrium equations as constraints. AnyBody solves this problem by a very efficient linear programming procedure.

Due to its numerical efficiency, AnyBody is also capable of optimising input to the analysis such as the dimensions of the mechanism, the motion performed, or the exterior load variation. To our knowledge, this is a novel field of application of optimum design.

Design of exercise machines has all the characteristics of a classical engineering design problem:

- It has a finite number of variables describing the overall design of the mechanism
- Its design must meet a number of requirements such as the motion range or limitation of the load on joints or other fragile elements of the body
- Depending on the purpose of the training, a number of desirable qualities are available as candidates for objective functions.

One of the common objectives is to be able to target the effect of the exercise to a single muscle or a group of muscles with precision. This is popularly known as isolation, and is particularly important in endurance sports where growth of muscles not used in this particular physical activity constitutes undesirable weight. Isolation is also generally desirable because it maximises the training benefit obtained for a given effort and minimises the potentially damaging loads on reactive elements of the body such as joints and ligaments.

The current status of the work is that the body analysis method has been scientifically reported, and the AnyBody system is functioning and has been applied to the test cases of bicycling, cross country skiing, and sawing. In the near future, models of popular exercise situations will be developed and design optimised.