ANGULAR VELOCITY AND ACCELERATION AT THE ELBOW JOINT AND ACCELERATION OF THE SHOULDER JOINT DURING PUSH-UPS USING 3D VIDEO MOTION ANALYSIS

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1 Abstract

The main reason of this 3D Motion Video Analysis was the determination of parameters during push-ups like acceleration of the shoulder in a three dimensional coordinate system, angular acceleration and velocity at the elbow joint. 3D was chosen because arms and shoulders do not only move in a 2D level.

Besides that, a comparison of a performance of an endurance athlete and a recreational sports man was done.

For doing a 3D Video Analysis a lot of points had to be done: right setup, calibration of the cameras and building up a coordinate system. Further always visible markers attached to test persons, editing records and of course analyzing data including interpreting them.

As hypothesis was determined that an endurance athlete should be able to have a higher acceleration and velocity output then the other. Interestingly there was almost no difference measurable.

2 Introduction

Push-ups are probably one of the oldest and simplest muscle train methods for the upper body. A regular push-up is performed in a prone position by raising and lowering the body using the arms (Fig. 1).

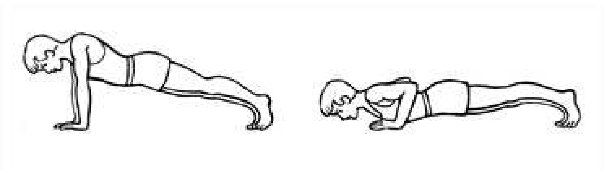


Fig. 1 push up in the highest position (left) and in the lowest position (right)

This kind of workout does not require any external weights. The athlete's own weight is enough for a serious strength endurance workout (except high trained elite athletes).

Another point is that push-ups are an indicator for intramuscular synchronization. (Güllich & Schmidtbleicher, 2000)

While this exercise primarily targets anterior and medial deltoids, triceps brachii, pectoralis major and pectoralis minor (Fig. 2), support from other muscles is required and results in a wider range of integrated muscles. Those secondary integrated muscles are mainly rhomboid major and rhomboid minor, posterior deltoids, serratus anterior, rectus abdominus, gluteus maximus, and quadriceps femoris.

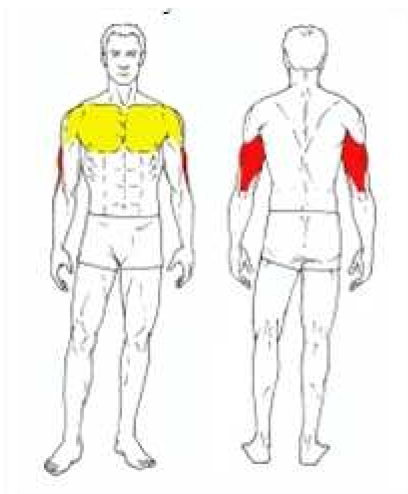


Fig. 2 primary target muscles (source: www.gain-weight-muscle-fast.com)

The aim of the laboratory exercise of November 22nd 2011 was a 3D Video Motion Analysis of a series of three push-ups with measurement of the angular velocity and acceleration at the elbow joint. Further the acceleration of the shoulder joint should be determined. The grade of intensity was the test person's personal maximum.

Main focus was on the comparison of two test persons (22 and 26 years old). The first one (test person A) exercises regularly in endurance sports (swimming, cycling and running) and the other (test person B) does not.

The hypothesis was, although the test person A does almost only endurance training and no specific strength training, he is able to reach a significant higher angular velocity and acceleration in the elbow joint. Because of this circumstance the acceleration of his shoulder joint should be disproportionately higher as well. (Häkkinen, et al., 2003)

3 Methods

Applied Methods

To proof the hypothesis a 3D video motion analysis was used. Two video cameras in an angle filmed the test person during the selected movement. The chosen angle of the cameras to each other was about 90°. Because of a mandatory calibration of the cameras there was no need to determinate an angle exactly. Further the tested person had to wear markers on specific points to set references for the followed analysis of the movement. These markers had to be visible all the time for every camera.

Test Setup

Two cameras (door-camera and window-camera) were located like shown on Fig. Hence two spotlights were placed parallel to every camera. Both cameras were connected directly to a computer via Firewire to save data immediately (Fig. 3).

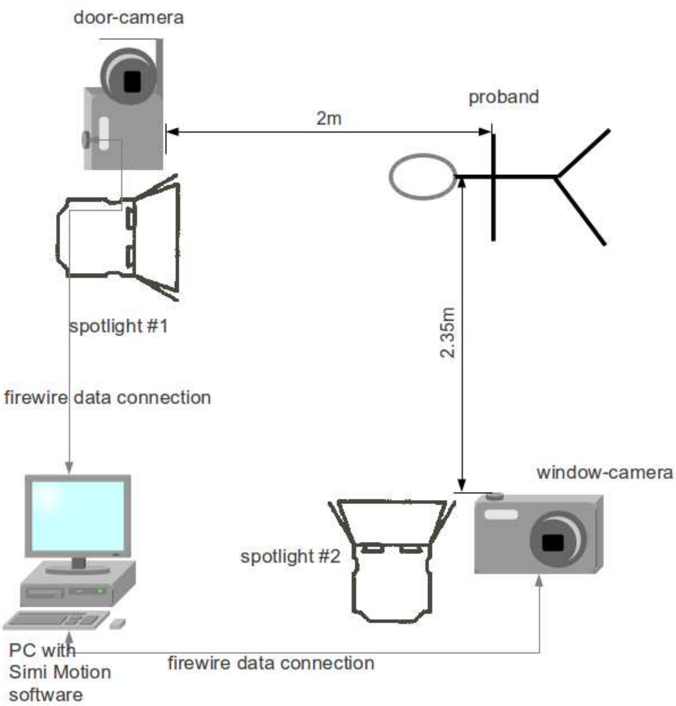


Fig. 3 measurement setup (schematic)

Markers were attached on test person's lateral wrist joint, lateral elbow joint (articulatio cubiti) and on the lateral shoulder joint (greater tubercle of Humers).

Equipment

- Cameras:
  Sony DCR-TRV80E (Sony, Tokyo, Japan)
- Tripods for Cameras:
  Cullmann Alpha 2000 (Cullmann, Langenzenn, Germany)
- Calibration Object:
  3D Vicon (Vicon, Los Angeles, CA, USA) mounted on a Manfrotto 3021BN (Manfrotto, Cassola, Italy) Tripod.
- 3D Video Motion Analysis Software:
  Simi Motion 3D Version 7.5.304 (Simi Reality Motion Systems GmbH, Unterschleissheim, Germany)
- Calculation Software:
  Matlab 7.1 (Mathworks, Inc., Natick, MA, USA)
- Spotlights:
  not defined
- Markers:
  self-made, reflective

Test Persons

Test person A: 22 years old, 68kg competes on an international level in triathlons.

Test person B: 26 years old, 70kg does various recreational sports, but not competitive.

Both test persons were not handicapped during testing und both felt average.

Measurement

1. Positioning of cameras and spotlights that all markers on the test person's joints were visible during the whole push-up.

2. Calibrations of the cameras: References were eight defined points on the 3D calibration object (Fig. 4). This object defines the coordinate system with its three axes (x,y,z). All points had to be clearly visible in both cameras.

Fig. 4 3D calibration object

3. Recording of a calibration video (actually one frame per camera is enough). Saved as .avi-file and defined in Simi Motion as calibration.

4. Input of coordinates from the used points of the calibration object.

5. Checked the calibration with Simi Motion (accuracy should be lower than 1%)

6. Recorded three videos of test person A doing 5 push-ups. Only push-up two to four were used for further analysis.
   The cameras recorded with 2x25 half images. However Simi Motion interpolates those half images to 50 single images. That meant we got a sampling rate of 50Hz.

7. Same procedure for test person B.

8. Tape editing of all video takes, to get the defined three push-ups. After editing, every video started at the highest position during a push-up and last exactly for three repeats.

9. Automatic marker tracking by differences of brightness (reflective markers) with Simi Motion.

10. Data export (x, y, z coordinates of every marker) to .txt file.

11. To determine an angle for further calculations two vectors had to be specified.
    One vector represented the forearm the other the upper arm. The origin of both vectors was the elbow joint.
    To calculate the angle between two vectors following formula had been used: (1)

$$\varphi = cos^{-1}\left(\frac{\vec{a} * \vec{b}}{|\vec{a}| * |\vec{b}|}\right) \quad (1)$$

12. To get an angular velocity or acceleration time intervals were needed. Because of the known sampling rate of 50Hz, time between every indicated value was 0.02s. For angular acceleration (2) and for angular velocity (3) these formulas had been used:

$$\alpha(t) = \frac{\mathrm{d}\omega}{\mathrm{d}t} \quad (2)$$

$$\omega = \frac{d\varphi}{dt} \quad (3)$$

13. Acceleration of the shoulder joint was not just in one single direction. All three coordinates had to be considered to get real movement directions. (4)

$$|\vec{v}| = \sqrt{v_1{}^2 + v_2{}^2 + v_3{}^2} \quad (4)$$

For comparing diagrams of both test persons, time had to be normalized. Due to a varying length of time for doing three push-ups it would not be possible to do a meaningful interpretation and comparison. Although, if specific – in this case, maximum values - are needed you must use real time intervals. That means time normalized diagrams can only be taken for comparison characteristics and not for determine values.

All calculations und figures were made with Matlab calculation Software.

Graphs and maximum values are based on mean values of all three measurements for each person to avoid significant influences of measuring errors.

4 Results

Up and down positioning characteristics of the shoulder joint between testing person A and testing person B is very similar (Fig. 5). That means the range of motion of both is nearly the same.

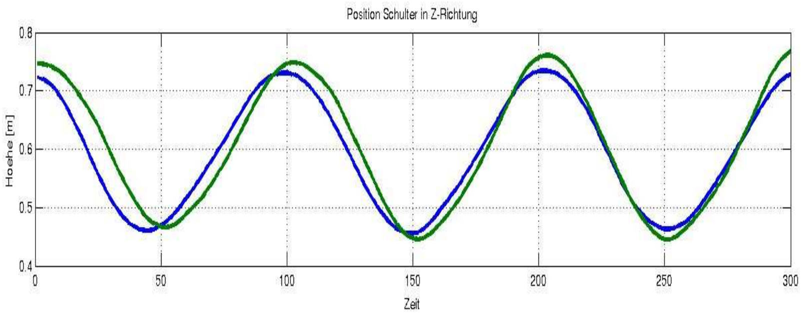


Fig. 5 up- and down movement of the shoulder joint (green test person A, blue test person B)

Comparing the graphs of angular velocity at the elbow joint brings not a significant either. Only during the first push-up going-down phase test person B has got a 10% higher angular velocity the A. (Fig. 6)

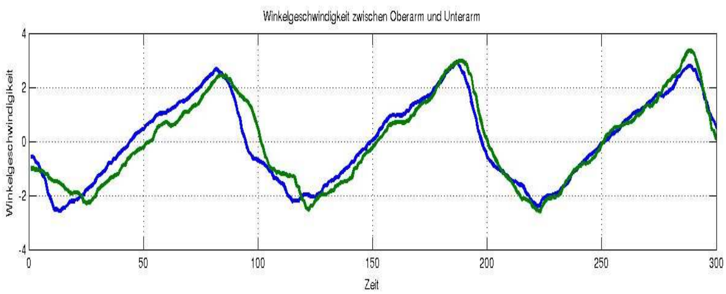


Fig. 6 angular velocity at the elbow joint (green test person A, blue test person B)

The graphs of angular acceleration of A and B got during the whole measurement almost same values. Noticeable is that both test persons increase their up- and down acceleration by 5% during each push-up. (Fig. 7)

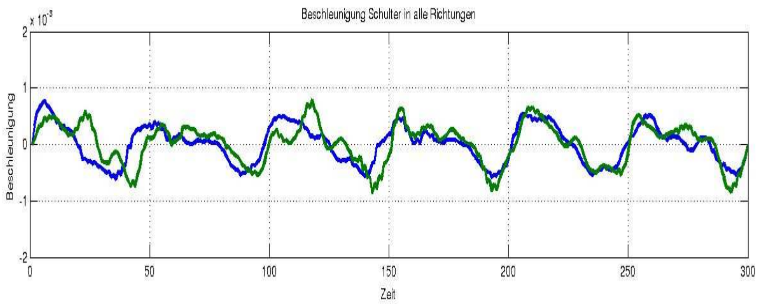
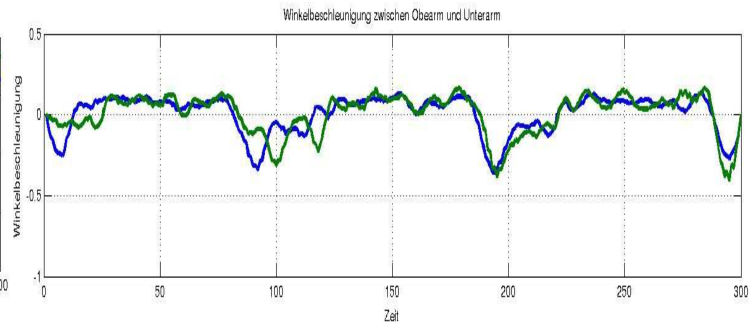


Fig. 7 angular acceleration at the elbow joint (green test person A, blue test person B)

The acceleration of the shoulder joint – measured in all three directions – indicates no clear difference between test persons. However it is again noticeable that both increase their acceleration by about 3% each push up. (Fig. 8)



Test person A got slightly better peak values of angular acceleration and velocity compared to test person B. But the maximum acceleration of test person B's shoulder is 19% higher. (Chart 1)

	test person A	test person B
angular acceleration (elbow) [°/s2]	801.3	798.3
angular velocity (elbow) [°/s]	181.5	167.6
acceleration shoulder	2.904	3.455

Chart 1 comparison of maximum values of specific parameters from the test persons

5 Discussion

The Hypothesis that a well-trained endurance athlete is able to reach higher angular acceleration and velocity at the elbow and a significant higher acceleration in the shoulder joint compared to a not trained person could not be proofed.

In fact, both test persons performed actually on the same level.

However it is possible to find some interesting facts und to review the quality of the measurements.

Both test persons seem to increase their accelerations (angular and translational) with every push-up. That could be possible that the muscles get more activated after the first one, or the bounce of the whole body helps to accelerate better. The graphs of the up- and down movement and velocity are quite smooth. On the other hand die acceleration graphs got a bit of a high frequency in the. That could be because of a low sampling rate of 50Hz, which is already based on interpolated images and the fact that you need three points to define acceleration. This of course multiplies the chance of an odd value.

6 References

Güllich, A., & Schmidtbleicher, D. (2000). Struktur der Kraftfähigkeiten und ihrer Trainingsmethoden. In M. Siewers, *Muskelkrafttraining* (S. 17-71). Kiel.

Häkkinen, K., Alen, M., Kraemer, W. J., Gorostiaga, E., Izquierdo, M., Rusko, H., Paavolainen, L. (2003). Neuromuscular adaptations during concurrent strength and endurance training versus strength training. *Eur J Appl Physiol*, 89, S. 42-52.