COMPARISON OF BIOMECHANICAL MOVEMENT PATTERNS BY MEANS OF ORTHOGONAL REFERENCE FUNCTIONS

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INTRODUCTION

Common biomechanical analyses (1) compare movements on the basis of variables' intensities on certain instances. The analyses of variables' time courses during a single movement are mostly qualitatively (3;6) or for singular variables (4,5). A quantitative comparison of multiple time courses can rarely be observed in movement and especially not in sport sciences. The present investigation demonstrates a method to compare singular as well as sets of time courses of biomechanical variables.

METHODS

In order to examplify, the presented method will be demonstrated at a three dimensional automated multiple joint movement: the double supported delivery phase in discus throwing. This movement was chosen, because of the duration of this phase (appr. 0.20sec) and the complexity of this gross motor movement we proceed on the assumption of no online sensory control.

Data acquisition

The subject was a member of the German Junior National team in discus 1987 participating in a research project on biomechanical feedback training (for a detailed description see (2)). One intention of this project was to increase the discus velocity of release by improving the feets' position and the twisting angle between the hip and shoulder axes at the beginning of the double supported delivery phase. Three discus throws were filmed before winter training and five were filmed in different intervalls afterward. Thereby the last three attempts were performed after one week training with biomechanical feedback. The throws were filmed 3D using two high speed 16 mm LoCam cameras with one oriented perpendicular (25m) to the throwing sector and the other positioned (25m) to the rear, Frame rates were set at 200 fps with the rate verified by internal timing lights. Kodak 7294 color film was used. Both cameras were synchronized by an external light impulse which was shown on the margins of the films. Serial film frames from 20 body land marks and L reference point were digitized using computerized motion analysis systems at the' Institute. The film data were smoothed by butterworth filter with a cut off frequency of 10Hz.

The athletes' movement is described by time courses of main joint angles and angular velocities. Therefore the joints at the ankle, knee, ellbow and head were assumed as planar and, the hip and shoulder joints were assumed as three dimensional. In addition the orientation angle of the trunk axis is considered in order to define the body position in space. The time courses of all angular variables correspond to 'angular movement patterns', all angular velocity variables to 'angular velocity movement patterns', and the time courses of both groups of variables correspond to 'kinematic movement patterns'.

DATA PROCESSING

For the comparison of the variables' time courses and movement patterns each time course was correlated with 6 orthogonal mathematical functions. The six functions come up With the condition

$$\int_{-t}^{t} f(x)g(x)dx = \begin{cases} 0 \ \forall f(x) \neq g(x) \\ 1 \ \forall f(x) = g(x) \end{cases}$$

In this case this is: **sinx,** cosx, **sin2x, cos2x, sin3x,** and **cos3x** in the interval from $-\pi$ (pi) to $+\pi$ (pi).

The variables' time course and the reference functions were normed to equal length with 50 intervals. So each time course was mapped to a vector with six correlation coefficients c_{klm} and the whole movement patterns were mapped to matrices with six columns. The similarity coefficient s_{kl} of each variables' time course is defined by the angle between the two vectors c_{klm} and c_{k+1lm} with **six** correlation coefficients.

$$s_{kl} = \frac{\sum_m c_{klm} \, c_{k+1lm}}{\sqrt{\sum_m c_{klm}^2 \sum_m c_{k+1lm}^2}}$$

Here k equals the number of attempt, 1 equals the number of variable, and m gives the number of reference function. The movement pattern similarity sp_k between two matrices C_k and C_{k+1} is defined by

$$sp_k = \frac{tr\,C_k^{\prime} C_{k+1}}{tr\,C_k^{\prime} C_k \, tr\,C_{k+1}^{\prime} C_{k+1}}$$

In accordance with these definitions, the similarity coefficient assumes values between 1.0 and -1.0. A similarity coefficient of 1.0 corresponds with two equal time course characteristics, independent from the initial and finish value. In the case of -1.0 the two variables 'show opposite time courses. All throws were compared with the throw, which had the highest discus velocity of release (reference movement pattern). The number of reference functions was defined by the influence on the similarity coefficients. More than six reference functions led to changes of the variables' similarity coefficients smaller than 0.001 (10E-3).

RESULTS AND DISCUSSION

The courses of the variables' similarity coefficient show manifold characteristics (fig.1). Some variables show parallel changes and a dependence from applied training contents. But the changes did not always correspond to the original intentions. Some variables display minimal changes in their course characteristics (e.g. left shoulder angle in fig.1) during the whole time span. Most of the changes of the variables' time courses occur after trial 3, which is demonstrated in more detail at the left hip angle (fig.2). The reference time courses (AR (eq A5)) in fig. 2 has an almost monoton ascending tendency. In comparison, the time courses of the first three (AO-A2) trials have an inverted (descending) characteristic which provide negative similaritiy coefficients. The characteristic of the time courses in trials A3 to A7 is again ascending and results in higher positiv similarity coefficients. With respect to the training contents, after the winter training more changes are obvious in the time course characteristics than after one week training with biomechanical feedback.

Comparing the movement patterns of all angles or angular velocities **(fig.3),** the acceptance of a changing movement pattern during the winter training seems very likely. Thereby the variance of the similarity coefficients within the angular movement patterns is smaller than those of the angular velocity movement patterns. The variance of the whole kinematic movement pattern is found between them.

Further studies should investigate the possible dependence of the time courses from the initial and finish values.

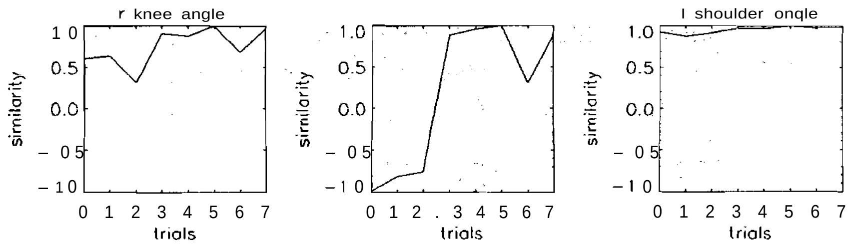

Fig. 1. Similarities of single variables

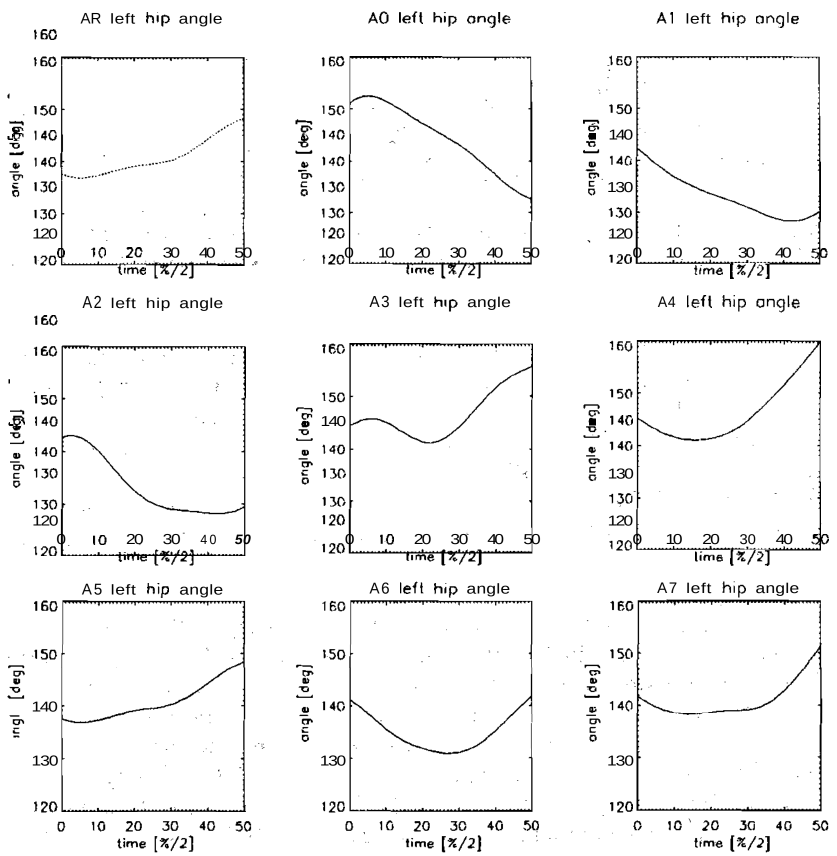

Fig. 2 Time courses of right hip angle

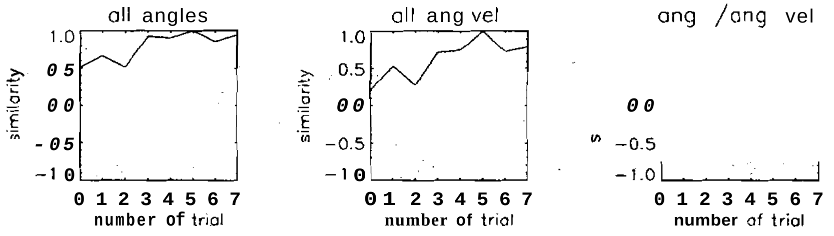

Fig.3 Similarities of angular, angular velocities', and sets of variables

CONCLUSION

With the help of six orthogonal functions the time courses of biomechanical variables are mapped to vectors and matrices. The vectors and matrices are compared with regard to similarity by their (inner) scalar product. The introduced procedure provides the **posibility** to compare the characteristics of time courses neglecting the intensity of the variable.

With this method parts of the learning process of a gross motor movement are analysed. The movement is described by main joint angles and angular velocities. During the learning process the changes of these variables' time courses are very versatile. A tendency of the similarity coefficients show changes of the kinematic movement pattern after certain training contents.

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