# HOW TO FIND THE OPTIMAL CUTOFF FREQUENCY FOR FILTERING KINEMATIC DATA

**Christian Fink, Rüdiger Preiß,**
**Johann-Wolfgang-Goethe Universität, Frankfurt, Germany,**
**Wolfgang I. Schöllhorn, Universität Leipzig, Germany**

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**INTRODUCTION:** For analyzing movement data recent investigations distinguish between time discrete and time continuous oriented approaches (e.g., Schöner/Kelso 1988, Schöllhorn 1995). Whereas the consequences of filtering procedures on instant intensities and cyclic movements have been investigated expansively (Angeloni et al.1994), the problem of short time course characteristics of complex movement signals is still demanding. The aim of this investigation is to look for the dependence of the filter frequencies and the time course characteristics.

**METHODS:** The data base consisted of 2D-kinematic data of 3 long jumpers at the last three strides before take off. The whole movement sequence was filmed with a high-speed camera with 150Hz and lasted about 0.9 sec (140 frames) for every trial. Twenty body landmarks were digitized with a maximum spatial error of ±1 cm. The data sequence of each body landmark was smoothed by means of a modified second-order low-pass Butterworth-Filter (critically damped filter, Winter 1990) with cutoff-frequencies from 1 to 20 Hz. A reversed mirror extrapolation was applied at both ends of the data. The length of the extrapolation at each side comprised 50 data. In order to reduce the time shift of the recursive filter, the once-filtered data were filtered again, but in the reverse direction of time. In a computer program the cutoff frequency for the filter was increased gradually from 1 to 20 Hz in steps of 0.2 Hz.
From these filtered data as well as from the raw data the first derivatives were taken by means of the finite difference method. Filter-caused changes were quantified by the Root Mean Square Error (RMSE, Winter 1990) from the first time derivatives of the raw and filtered data.

$$RMSE\ (f_c) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(X_i - Y_i)^2}$$

$X_i$ = raw data of the *i* th sample
$Y_i$ =filtered data of the *i* th sample

(This dual filtering process results in a fourth-order zero-lag filter which reduces the cutoff-frequency to 0.435 of the original. Winter 1990)

**RESULTS:** Displaying the gradient of RMSE (RMSE(f) - RMSE(f-0.2)) versus the filter frequencies we get a high intensity at lower frequencies and a minimum of

intensity at intermediate frequencies. The optimal cutoff-frequency for the examined data sequence was obtained at the first minimum of the gradient-line.
In several trials of the same athlete for the same joint equal cutoff-frequencies could be found. But frequencies for different joints deviated, (e.g. head: 5.6Hz, hand: 11 Hz). With different athletes different frequencies were found for the same joints, (e.g. knee of athlete1: 8.3 Hz, knee of athlete2: 10.1 Hz) as shown in Table 1. The frequencies of visible and partially covered landmarks were different as well.

**Table 1:** Cutoff frequencies for different vertical landmark coordinates

| Segment | subject 1 | subject 2 | subject 3. |
|---|---|---|---|
| heel | 7.5 | 9.2 | 8.8 |
| knee (tibia) | 8.3 | 10.1 | 10.2 |
| pelvis | 3.4 | 4.5 | 4.6 |
| shoulder | 5.5 | 6.9 | 6.8 |
| hand | 10.2 | 11.0 | 9.9 |
| head | 4.8 | 5.6 | 5.6. |

Similar results were found in investigations of human gait kinematics (Giakas et al. 1997, Angeloni et al.1994).
The RMSE provides information about the average error of the whole time course. For discontinuous movement analysis the error at certain instants (time discrete intensities), like take-off position in the long jump, is of interest as well. The information about time discrete deviations is limited by extreme errors. The maximum error in the analyzed data amounts up to 30%. Therefore the effect of filtering on discrete data is much more sensitive than the filtering effect on time course characteristics.

**CONCLUSION:** In order to reduce the filter-caused errors in the displacement and velocity domains, the cutoff-frequencies for the digital filter should be adapted to each athlete and each joint. Choosing the wrong filter frequency increases the risk of disregarding individual movement characteristics and manipulating the data in the direction of the investigators' expectations. The applied filtering technique must be proved with further kinematic data with different sample rates and different noise levels.
The different effects of filtering on instant (discrete) intensities and on time course characteristics can provide information about and/or a connection to biological correlates of parameters and invariant elements of movements.

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**REFERENCES:**

Angeloni, C., Riley, P. O., Krebs, D. E. (1994). Frequency Content of Whole Body Gait Kinematic Data. *IEEE Transaction on Rehabilitation Engineering* **2**, 40-46.
Giakas, G., Baltzopoulos, V. (1997). A Comparison of Automatic Filtering Techniques Applied to Biomechanical Walking Data. *Journal of Biomechanics* **30**(8), 851-855.

Schöllhorn, W. I. (1995). Comparison of Biomechanical Movement Patterns by Means of Orthogonal Reference Functions. In A. Barabás, G. Fábián (Eds.), *Biomechanics in Sports XII* (pp. 20-24). Budapest: ITC Plantin.

Schöner, G., Kelso, J. A. S. (1988). Dynamic Pattern Theory of Behavioral Change. *Journal of Theoretical Biology* **135**, 501-534.

Winter, D. A. (1990) Biomechanics and Motor Control of Human Movement. 2nd ed. New York: Wiley.