

Artifacts Due to Filtering Mismatch in Drop Landing Moment Data

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ABSTRACT

In human movement analysis, joint moments have been reported as a risk factor for anterior cruciate ligament injury in landing. Using the inverse dynamics approach to measure joint moments during high-impact activities, inconsistencies in data occur when digitally filtering the marker and analog (force) data at different cut-off frequencies. In order to quantify this, data were collected using 9 cameras sampling at 240 Hz and a force platform sampling at 2400 Hz. Thirty females performed single leg drop jumps from 40 cm. The hip and knee flexion/extension and abduction/adduction moments were calculated using various cut-off frequencies of marker and force data, respectively: 10-10 Hz, 15-15 Hz, 10-50 Hz, and 15-50 Hz. Peak moments were obtained during the first 40 ms of the landing phase, where the artifacts were typically largest. A statistical approach was used to determine the size of the artifacts under the various filtering schemes. A high cut-off frequency for force data and low cut-off for marker data shows the largest artifacts. Filtering both marker and force data at the same low cut-off frequency eliminates artifacts in joint moments during landing, but unavoidably limits the frequency resolution of the data to the marker cut-off frequency.

INTRODUCTION

Analysis of joint moments and forces are important for understanding injury prevention during high-impact activities. Inverse dynamics is used to determine joint forces and moments from kinetic (force platform) and kinematic (marker) data. Since force plate data has less noise than marker data, it is common practice to filter the kinetic data with a higher cut-off frequency than the kinematic data. [1] However, inconsistencies may occur when marker and force plate data are filtered at different cut-off frequencies, leading to high-frequency artifacts in the joint moment calculations. The joint moments M_J are calculated from equations of the form

$$\sum_J M_J + \sum_J r_J F_J = I_{cm} \alpha \quad \text{Eq.1}$$

where r_J is the moment arm of the joint reaction force F_J from the center of mass, I_{cm} is the moment of inertia about the center of mass, and α is the angular acceleration, and the sum is over the joints attached to the limb. If the angular acceleration is filtered at one level, say 10 Hz, and the forces are filtered at another level, say 50Hz, then high frequency artifacts result in the calculated M_J in order to compensate for the mismatch.

The hypothesis tested in this investigation is that a larger mismatch in filtering frequencies results in large artifacts in the calculated moments. These artifacts are observed as high frequency oscillations in the moment data in the initial phase of the landing.

METHODS

Measurements

Measurement trials consisted of single-leg drop landings and a subsequent single-leg jump. Nine digital cameras recorded marker positions at 240 Hz as subjects [30 females (ages 18-24)] dropped onto a 2400 Hz force platform (See Fig.1) Thirty healthy female (ages 18-24) subjects dropped for 5 performance trials.

Processing

Knee flexion/extension and ankle plantar flexion/ dorsiflexion moments were calculated using various frequencies of marker and force data respectively:

Table 1. Low-pass filtering schemes

Marker Data	Force Plate
10 Hz	10 Hz
15 Hz	15 Hz
10 Hz	50 Hz
15 Hz	50 Hz

Analysis

A statistical approach was used to determine the size of the artifacts under the various filtering schemes. [2] The differences between peak maximum and minimum landing moments for different filtering schemes were compared in scatter plots (see Figs.4-7). The scatter plots were compared for equal filtering levels (10-10 vs. 15-15) and different filtering levels (10-50 vs. 15-50). Lines were fitted to the data in order to compare to the $y=x$ line corresponding to no change.

RESULTS

The slopes of the scatter plots of the peak moments was always smaller than one when going from 15-15 Hz to 10-10 Hz filtering schemes, as one would expect. The slope for the ankle moment 10-50 vs. 15-50 comparison was larger than the 10-10 vs. 15-15 slope, but still less than 1. The slope for the knee moment 10-50 vs. 15-50 comparison was larger than 1, indicating that the knee moments were actually larger for lower filtering frequency.

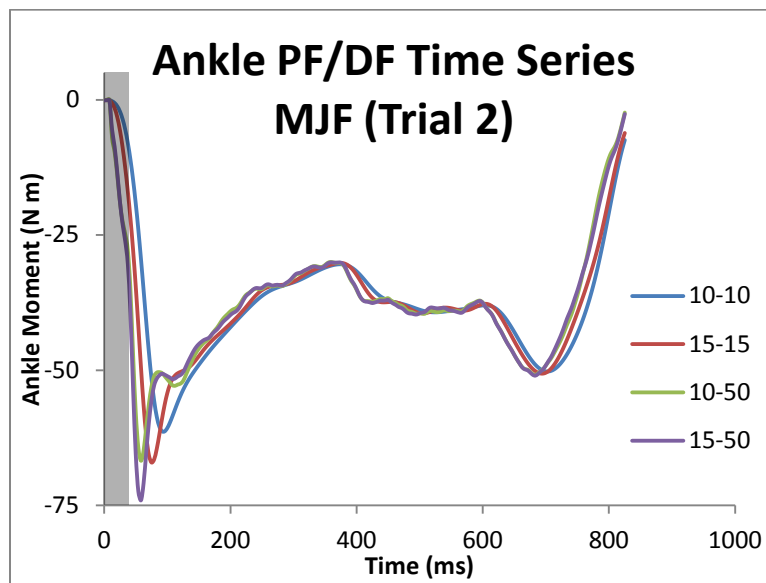


Figure 1. Time series of ankle plantar flexion moment data during drop landing processed with different filtering schemes. The gray region indicates the time interval over which the variation in the moment data was sampled.

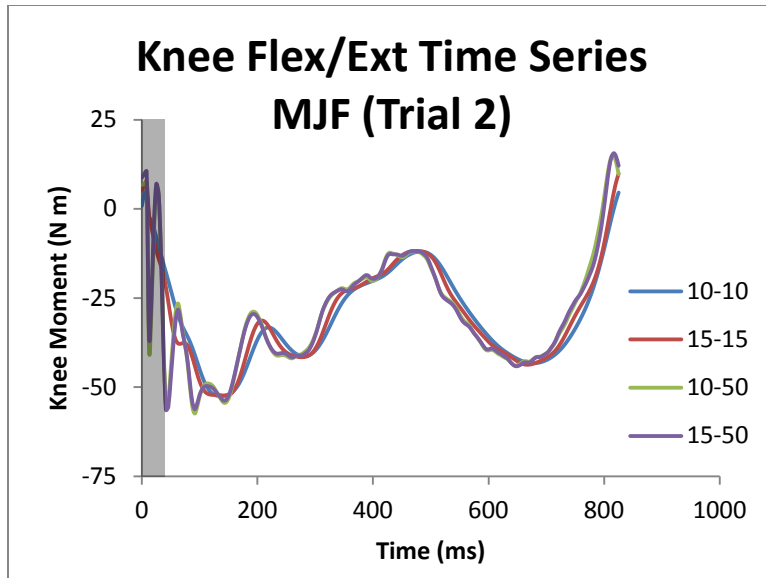


Figure 2. Time series of knee flexion moment data during drop landing processed with different filtering schemes.

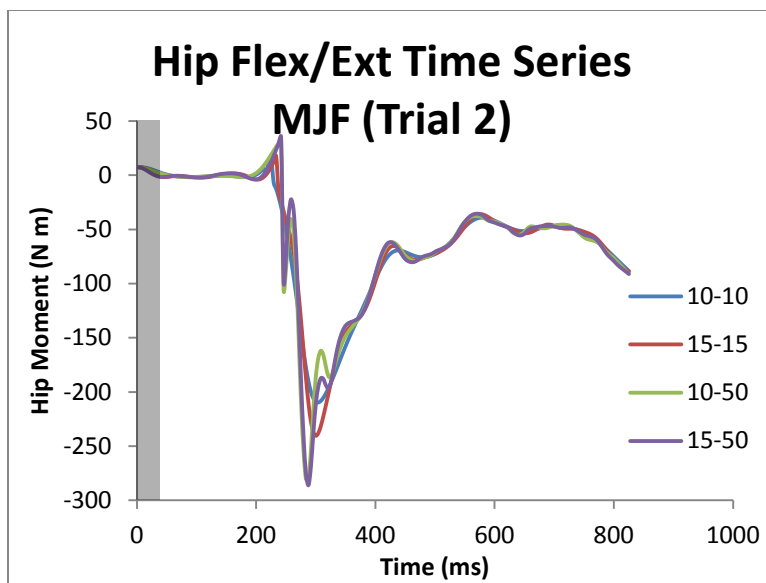


Figure 3. Time series of knee flexion moment data during drop landing processed with different filtering schemes.

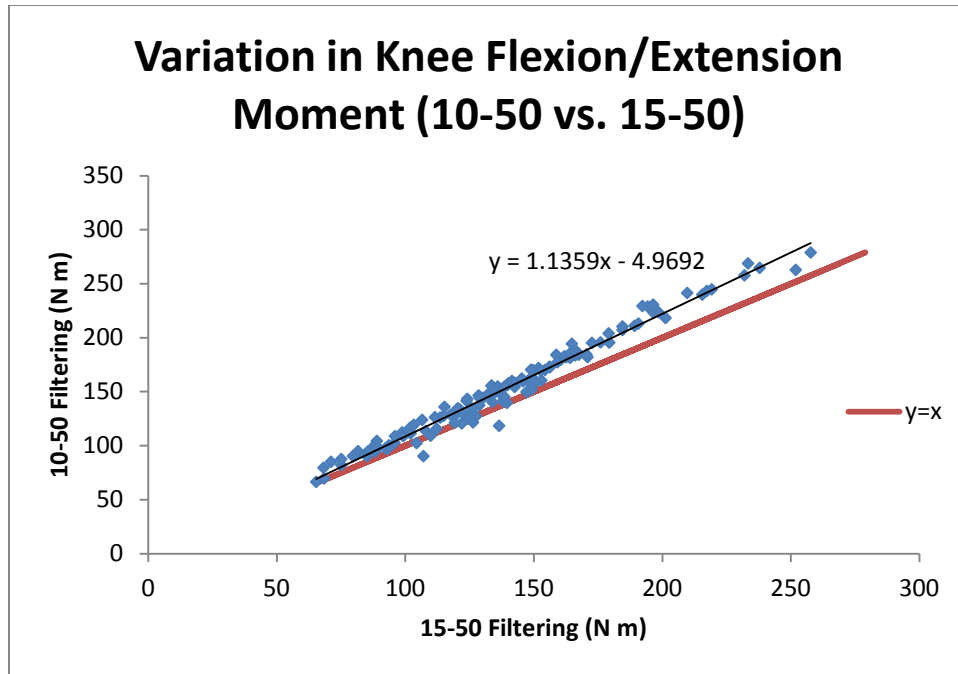


Figure 4. Scatter plot of the difference between the maximum and the minimum knee moments for each trial. The y-axis values result from a 10 Hz – 50 Hz filtering scheme. The x-axis values result from a 15 Hz – 50 Hz filtering scheme.

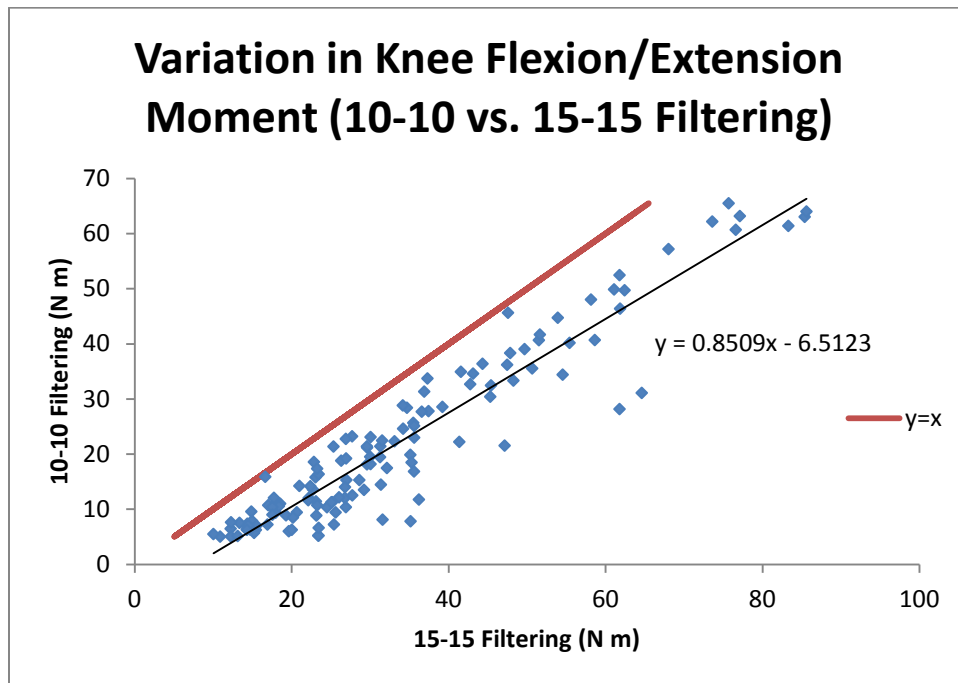


Figure 5. Scatter plot of the difference between the maximum and the minimum knee moments for each trial. The y-axis values result from a 10 Hz – 10 Hz filtering scheme. The x-axis values result from a 15 Hz – 15 Hz filtering scheme.

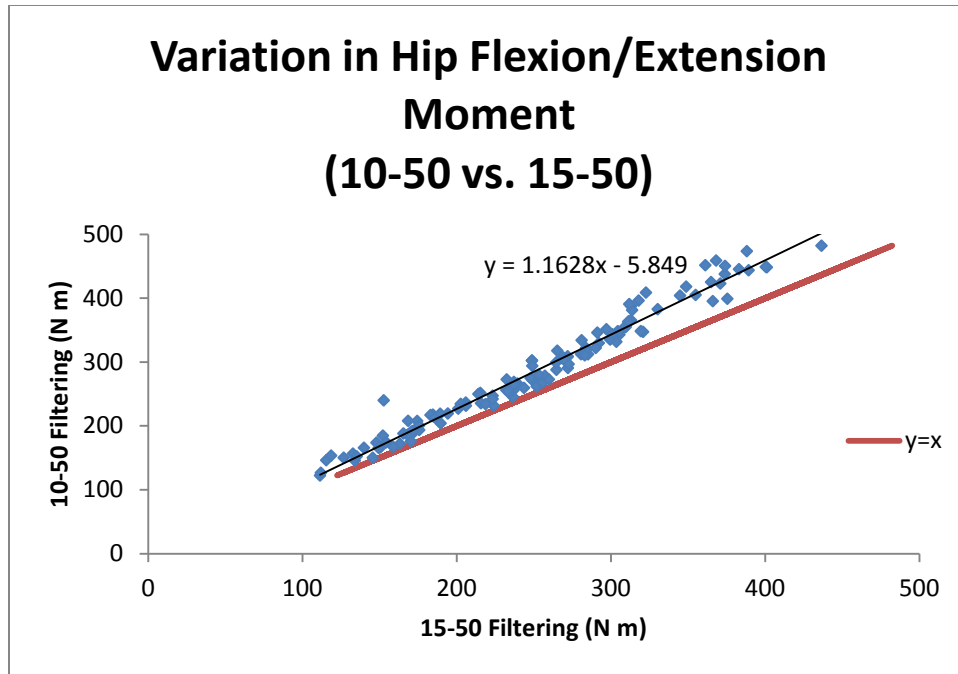


Figure 6. Scatter plot of the difference between the maximum and the minimum knee moments for each trial. The y-axis values result from a 10 Hz – 50 Hz filtering scheme. The x-axis values result from a 15 Hz – 50 Hz filtering scheme.

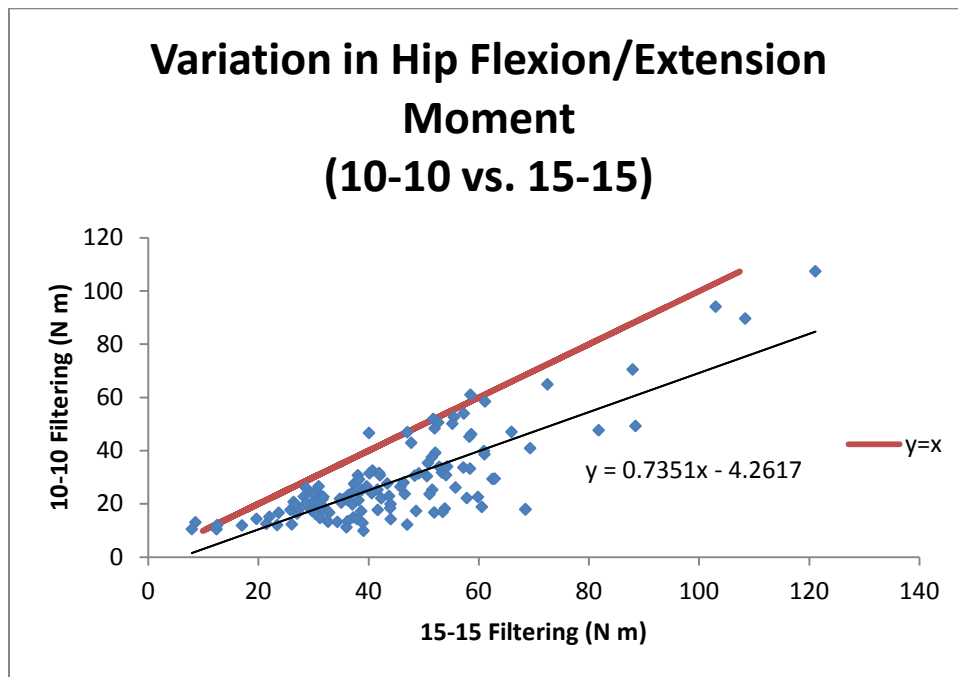


Figure 7. Scatter plot of the difference between the maximum and the minimum knee moments for each trial. The y-axis values result from a 10 Hz – 10 Hz filtering scheme. The x-axis values result from a 15 Hz – 15 Hz filtering scheme.

DISCUSSION

The fact that the variations of the moments were larger for the 10-50 than the 15-50 (i.e. above the $y=x$ line) is indicative of the artifact that is present when different filtering levels are used. This artifact is due to the fact that the high frequency components of the ground reaction force are inconsistent with the highly filtered kinematic data, and so high frequency joint moments result in the inverse dynamics calculations. [3] The effect gets more severe as one moves ankle to knee to hip, due to error propagation. [4]

CONCLUSIONS AND IMPLICATIONS

Although we used a somewhat different analysis, our results agree with previous investigations [2-3] that concluded that different filtering levels for kinetic and kinematic data should not be used in inverse dynamics calculations. This is true even though force plate data can be extremely noise-free. Thus the noise in the kinematic data ultimately limits the quality of the inverse dynamics calculations.

REFERENCES

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