Artefacts in measuring joint moments may lead to incorrect clinical conclusions: the nexus between science (biomechanics) and sports injury prevention!

Eirik Kristianslund,1 Tron Krosshaug,1 Antonie J van den Bogert2

Measuring joint moments at high speed is integral for sports-related research, but substantial artefacts can arise with certain computational methods. This is relevant for BJSM readers as measurement errors can lead to flawed conclusions. Potential settings where errors have the potential to creep in include anterior cruciate ligament (ACL) risk factor studies, running biomechanics analysis and other fields where biomechanists study fast movements. Our recent paper in *Journal of Biomechanics* demonstrated the effect of different filtering of force and marker data in joint moment calculations.1 This paper explains those findings for the clinical readership of BJSM and highlights the areas where it may be wise to ‘proceed with caution’ when interpreting previous studies that aim to identify key risk factors for injury.

WHAT IS A JOINT MOMENT AND WHY SHOULD I CARE?

Estimates of joint moments are fundamental in the study of sporting motion. Joint moments calculated in standard motion analysis are net joint moments, the total effect of all structures that produce forces that work across the joint. Joint moments stem from muscle forces, articular contact and ligaments. We are interested in joint moments because, unlike these separate forces, they can be measured. A correct interpretation of joint moments may help us understand which muscles and ligaments are at risk of injury in certain settings.

WHAT IS ALL THIS NOISE ABOUT?

If biomechanics is not your thing, feel free to skip down to ‘Implications’ below. Joint moments are normally calculated through the process of inverse dynamics, where ground reaction forces (force plate data) and segment accelerations (marker data—the reflective markers attached to the participant) are combined.

In all high-impact movements, such as running and sidestep cutting, it is normal to see an impact peak in ground reaction force that will result in high acceleration of body segments. Unfortunately, due to random noise in the measurement of marker positions, current motion analysis systems cannot reliably measure the impact peak in segment accelerations.2 Marker data are low-pass filtered to avoid large errors in the calculation of segment accelerations. Unfortunately, as a consequence, also the impact acceleration peak is removed. Thus, it is the need to filter marker data that prevents us from reliably measuring the peak in segment accelerations.

The smoothing of the segment acceleration curve that results from the necessary filtering of marker positions lead to an overestimation and underestimation of the segment acceleration during the stance phase, similar to the overestimation and underestimation that is seen with filtering of force data in figure 2. This overestimation and underestimation is an inherent property of the filtering methods and can unfortunately not be avoided with current methods to estimate segment acceleration.

Unfortunately, the combination of force data with impact peaks and filtered marker position data lacking impact peaks lead to inconsistencies in joint moment calculations. To illustrate this, consider the calculation of joint forces at a segment where impact forces are measured with high accuracy at the distal end (figure 1). According to Newton’s second law, the sum of forces equals mass times acceleration. At the time of the impact peak, the relative underestimation of segment acceleration will mathematically result in an overestimation of proximal joint forces (equation (1)).

\[
F_p = F_d - G - m\ddot{a}
\]

\(F_p\), proximal force; \(F_d\), distal force; \(G\), gravity; \(m\), mass and \(a\), segment acceleration.

The effect of this inconsistency in the equations of motion can be seen as unphysiological impact artefacts in joint moment curves (figures 2 and 3). Sagittal plane joint moments depend on muscle force generation, and muscle force does not vary as seen in these curves, with rapidly alternating positive and negative joint moments.3 Furthermore, studies of electromyogram activity of the hip muscles show consistent extensor activation in the first phase of the stance, indicating that the rapid changes in hip joint moments seen in figure 3 are likely incorrect.4–6

A simulation study of sprint running displayed artefacts in knee and hip flexion moments similar to those in figure 3 when different cut-off frequencies was applied for force and movement data, while matched cut-off frequencies gave joint moments that closely estimated the real joint moments (figure 2).

To avoid artefacts in the calculation of joint moments, the ground reaction force should be filtered with the same procedure as the marker data, even if it leads to a smoothing of the impact peak. In our opinion, possibly losing some information about the impact peak is better than introducing the unpredictable artefacts that arise with unmatched filters.

WHAT IS THE EFFECT OF THE ARTEFACTS?

In our 2012 study in *Journal of Biomechanics*, maximum joint moments first 100 ms of the stance phase of side-step cutting were compared across four conditions with different combinations of cut-off frequencies: markers filtered at 10 Hz cut-off, force at 10 Hz cut-off (10–10); markers 10, force 50 (10–50); markers 15, force 15; markers 15 and force 50.1 The differences are illustrated in a plot of a typical player (figure 3).

The greatest differences were seen between conditions with different cut-off frequencies for force data and marker data. Hip joint moments were most affected by the artefacts, with mean (SD) peak hip flexion moment of 3.64 (0.75) under the 10–10 and 5.92 (1.80) under 10–50 filter conditions. Substantial differences were also found for knee abduction moments, with mean peak (SD) values of 1.27 (0.53) and 1.64 (0.68) Nm/kg for the 10–10 and 10–50 filter condition, respectively. Although statistically significant, the differences in maximum knee

---

1Oslo Sports Trauma Research Center, Norwegian School of Sport Sciences, Oslo, Norway; 2Orchard Kinetics, Cleveland, Ohio, USA

Correspondence to Eirik Kristianslund, Oslo Sports Trauma Research Center, Norwegian School of Sport Sciences, PB 4014 Ullevaal Stadion, Oslo 0806, Norway; eirik.kristianslund@nh.no, eirik.kristianslund@gmail.com

Flexion moments were minor. However, large differences between the curves were seen prior to the peak.

To further investigate the implication of these filtering artefacts for the conclusions of motion analysis research, the rank correlation of players based on knee abduction moment was calculated across conditions. The rank correlation describes whether the ordering of players based on a measure is similar. This correlation was greater between knee abduction moments calculated with matched cut-off frequencies, compared to the correlations between calculations with matched and different cut-off frequencies (10–10 vs 15–15: 0.969, 10–10 vs 10–50: 0.857, 15–15 vs 15–50: 0.931). These correlations show that the magnitude of joint moment measures is affected by different or matched cut-off frequencies and the ranking of players based on these measures are affected as well.

**Figure 1** A free-body diagram of a segment and the forces and moments acting on the segment.
studies if the same cut-off frequency is used for force and marker data in both studies.

Even when the shape of the joint moment curves is less affected by the artefacts, as is the case for knee abduction moments, artefacts can affect results. We showed that there is a difference between methods in ranking of players based on knee abduction moment during sidestep cutting. This can potentially change conclusions on for example, injury risk.

WHAT DOES THIS MEAN FOR CLINICIANS?

Joint moments calculated with the inverse dynamics approach should have matched filters for force and marker data. Previous research may have been affected by artefacts, and conclusions from studies with different filters for force and marker data may have to be reconsidered in light of the findings of our paper in Journal of Biomechanics.1

Artefacts due to different filtering of force data and marker data in inverse dynamics are one of many potential sources of errors in motion analysis.11–14 This should be kept in mind when drawing conclusions based on motion analysis studies.

Four practical tips for clinicians interested in biomechanics:

1. Check the filtering of markers and force data in articles you read—are the cut-off frequencies matched? The combination of high cut-off frequency or no filtering for force data and a lower cut-off frequency for marker data can potentially yield artefacts.

2. Consider if the movement studied can be considered of high impact. The impact peak present in force and segment acceleration data in high-impact movements is the basis for the described artefacts.

3. Consider if the variable of interest can be affected by artefacts. Hip joint moments are most susceptible to these artefacts, but also knee joint moments can be affected.

4. When comparing results between motion analysis studies—check if filtering methods are compatible. Do not compare magnitudes of joint moments between studies with matched and unmatched cut-off frequencies.

If these impact artefacts are not considered, the data may yield ‘relationships’ that are not biologically founded. To avoid faulty conclusions researchers and clinicians must be aware of settings that can generate substantial artefacts when analysing sporting movements.

Acknowledgements The Oslo Sports Trauma Research Center has been established at the Norwegian School of Sport Sciences through generous grants from the Royal Norwegian Ministry of Culture, the South-Eastern Norway Regional Health Authority, the International Olympic Committee, the Norwegian Olympic Committee & Confederation of Sport, and Norsk Tipping AS. The research of Eirik Kristianslund has been partly funded by the Medical Student Research Program at the University of Oslo.

Contributors This paper is based on a previously published paper in Journal of Biomechanics. For that article, EK and TK contributed to project planning, data acquisition, data processing, data analysis and writing of the manuscript. TV contributed to project planning, data analysis and writing of the manuscript.

Competing interests None.

Provenance and peer review Not commissioned; externally peer reviewed.


REFERENCES


3. Aagaard P, Simonsen EB, Andersen JL, et al. Increased rate of force development and neural drive of human skeletal muscle following...


Artefacts in measuring joint moments may lead to incorrect clinical conclusions: the nexus between science (biomechanics) and sports injury prevention!

Eirik Kristianslund, Tron Krosshaug and Antonie J van den Bogert

doi: 10.1136/bjsports-2012-091199

Updated information and services can be found at:
http://bjsm.bmj.com/content/47/8/470.full.html

These include:

References

This article cites 13 articles, 2 of which can be accessed free at:
http://bjsm.bmj.com/content/47/8/470.full.html#ref-list-1

Email alerting service

Receive free email alerts when new articles cite this article. Sign up in the box at the top right corner of the online article.

Notes

To request permissions go to:
http://group.bmj.com/group/rights-licensing/permissions

To order reprints go to:
http://journals.bmj.com/cgi/reprintform

To subscribe to BMJ go to:
http://group.bmj.com/subscribe/