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Expressing the joint moments of drop jumps and sidestep cutting in different reference frames – does it matter?

Eirik Kristianslund [a,*], Tron Krosshaug [a], Kam-Ming Mok [a], Scott McLean [b], Antonie J. van den Bogert [c]

[a] Oslo Sports Trauma Research Center, Norwegian School of Sport Sciences, PB 4014 Ulleval Stadion, 0806 Oslo, Norway
[b] School of Kinesiology, University of Michigan, US
[c] Department of Mechanical Engineering, Cleveland State University, US

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ABSTRACT

Joint moments help us understand joint loading and muscle function during movement. However, the interpretation depends on the choice of reference frame, but the different reference frames have not been compared in dynamic, high-impact sporting movements. We have compared the magnitude and the resulting ranking of hip and knee joint moments expressed in the laboratory coordinate system, the local system of the distal segment and projected or decomposed to the Joint Coordinate System (JCS) axes. Hip and knee joint moments of drop jumps and sidestep cutting in 70 elite female handball players were calculated based on recordings from an eight-camera 240 Hz system and two force platforms and expressed with the four methods. The greatest variations in magnitude between conditions were seen for drop jump hip internal rotation (range: 0.31–0.71 Nm/kg) and sidestep cutting knee flexion (2.87–3.39 Nm/kg) and hip internal rotation (0.87–2.36 Nm/kg) and knee internal rotation (0.10–0.40 Nm/kg) moments. The rank correlations were highest between conditions for flexion moments (0.88–1.00) and sidestep cutting abduction moments (0.71–0.98). The rank correlations ranged from 0.64 to 0.73 for drop jump knee abduction moments and between −0.17 and 0.67 for hip and knee internal rotation moments. Expression of joint moments in different reference systems affects the magnitude and ranking of athletes. This lack of consistency may complicate the comparison and combination of results. Projection to the JCS is the only method where joint moments correspond to muscle and ligament loading. More widespread adoption of this convention could facilitate comparison of studies and ease the interpretation of results.

1. Introduction

Analyses of joint moments are at the core of mechanical analysis of human movement, and help us understand joint loading and muscle function. In standard three-dimensional (3D) motion analysis, net joint moments are calculated via an inverse dynamics approach (Bresler and Frankel, 1950). They can be expressed in different reference frames, e.g. the laboratory frame or the coordinate systems of the local segments adjacent to the joint (Andrews, 1984). The choice of reference frame depends primarily on the research questions and preferences, which may affect the interpretation of results (Winter and Ishac, 1994; Andrews, 1984; Schache and Baker, 2007). Joint moments expressed relative to a laboratory axis, for example, will represent this joint's contribution to movement in the plane perpendicular to that axis. On the other hand, joint moments expressed relative to the local joint axes will represent the loading of the joint structures, and may be interpreted to correspond to muscle force production or ligament loading.

Lower extremity joint angles are usually calculated using the non-orthogonal axis system of the Joint Coordinate System (JCS), as recommended by the International Society of Biomechanics (Grood and Suntay, 1983; Wu and Cavanagh, 1995; Wu et al., 2002, 2005). Joint moments can be expressed relative to these axes to achieve correspondence between the joint angles and the joint moments, i.e. to ensure that a net flexion moment will result in a pure flexion (Andrews, 1984; Schache and Baker, 2007; Desroches et al., 2010). However, most commercial software systems have expressed joint moments in the orthogonal coordinate system of the distal segment of the joint and this has been commonly used in previous research (Dempsey et al., 2007; Chappell et al., 2002; Davis et al., 1991). The reasons for this choice are not clear, but it may be related to the use of local segment coordinate systems in the calculation of joint moments and the fact that a joint moment

* Corresponding author. Tel.: +47 400 42 792; fax: +47 23 26 23 07.
E-mail addresses: eirik.kristianslund@nih.no, eirik.kristianslund@gmail.com (E. Kristianslund).

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is a vector (unlike joint angle) and it is desirable to express it in an orthogonal axis system (Schache and Baker, 2007). In addition, the reflective markers over the tibia experience less soft-tissue artifacts than the femur markers, and Miranda et al. (2013) suggested that knee joint moments should be expressed in the tibia system to reduce the effects of soft-tissue artifacts.

Previous studies of standard gait have reported significant differences between joint moments expressed in different reference frames (Liu and Lockhart, 2006; Schache and Baker, 2007; Schache et al., 2007; Brandon and Deluzio, 2011). When comparing respective joint moments expressed in the global coordinate system, the local coordinate systems of the proximal and distal segment and the JCS, Schache et al. (2007) concluded that the frontal and transverse plane joint moments were more sensitive to a change of reference frame. This may affect conclusions from gait analysis, as Schache et al. (2008) found the effect of gait modification on knee adduction moments to be dependent on reference frame. However, Brandon and Deluzio (2011) reported results from gait analysis that were independent of reference frame. Subjects with osteoarthritis had reduced hip abduction moment and increased knee abduction moments during gait regardless if the joint moments were expressed in the global, distal or proximal frame, or the JCS.

Joint moments are important outcome variables in studies of drop jumps and sidestep cutting, tasks that involve a high range of motion and changes of direction (Besier et al., 2001; McLean et al., 2004; Hewett et al., 2005; Kristianslund and Krosshaug, 2013). These tasks are investigated particularly in studies of sport injury causation. An anterior cruciate ligament injury is one of the most serious sports injuries, based on its frequency and the serious consequences such as a long rehabilitation time and a high risk of early osteoarthritis (Renstrom et al., 2008). Knee abduction moments have been in focus as a risk factor for anterior cruciate ligament injury, and numerous studies on the knee abduction moment in drop jumps and sidestep cutting have been published (Besier et al., 2001; Hewett et al., 2005; McLean et al., 2005; Sigward and Powers, 2007; Carson and Ford, 2011; Benjaminse et al., 2011). With the direction changes and greater range of motion seen with drop jumps and sidestep cutting, the choice of reference frame may be even more important. However, the choice of reference frame is commonly not reported (Besier et al., 2001; Hewett et al., 2005; Sigward and Powers, 2007), and different methods are in use (Kristianslund and Krosshaug, 2013; McLean et al., 2005; Dempsey et al., 2007; Chappell et al., 2002). Standardization of joint moment reporting, similar to the ISB standard of joint angle reporting (Wu and Cavanagh, 1995), may improve the quality of reporting of results and facilitate comparison of studies, but this requires information on the differences between methods. Robinson and Vanrenterghem (2012) reported that the choice of knee axes may affect the kinetics of sidestep cutting, but the differences among different joint moment reference frames have only been investigated in gait.

Three reference frames are typically used in 3D motion analysis: the global laboratory frame (global), the local coordinate system of the distal segment (distal) and the JCS axes (Liu and Lockhart, 2006; Schache and Baker, 2007; Brandon and Deluzio, 2011). Two different methods can be used to express joint moments relative to the JCS axes: projection (JCSp) and decomposition (JCSd) (Desroches et al., 2010). The differences among methods stem from the difference in axis definitions and different methods to express joint moments relative to the axes. All methods but the JCSd use representations that equate projection of the joint moment vector to the relevant axes. The differences in orientation of the axes depend on their definitions and the orientation of body segments relative to the lab and to each other.

The aim of this investigation is examine the sensitivities of hip and knee joint moments for a drop jump and sidestep cutting task to four different calculation methods: global, distal, JCSp and JCSd. Respective calculation methods will be compared based on the difference between maximum values and the correlation of the ranking of trials based on maximum joint moments between methods.

2. Methods

Recordings from the baseline testing for a prospective risk factor study in elite Norwegian handball were used for this methodological study. The study was approved by the Regional Ethics Committee and all subjects signed informed consent forms.

2.1. Testing and calculations

Seventy female elite handball players (age 21.7 ± 2.6 years, weight 70.1 ± 8.0 kg, height 172 ± 6 cm) performed drop jumps and sidestep cuts in a motion analysis lab with eight 240 Hz infrared cameras (ProReflex, Qualisys, Gothenburg, Sweden) and two 960 Hz force platforms (AMTI, Watertown, Massachusetts, USA). Thirty-five reflective markers were attached as described previously (Kristianslund and Krosshaug, 2013). We performed a recording of the static anatomical position for each player prior to testing to define the anatomical coordinate systems.

Drop jumps were performed from a 30-cm box. The athletes were instructed to drop off the box onto two force platforms and immediately perform a maximal jump. For sidestep cutting the players performed their usual sidestep cutting technique to pass a static human defender, cutting to the left (Fig. 1). They arrived at an angle of approximately 30° to the long axis of the lab. Due to technique differences, the cutting angle ranged from 31° to 110° (mean ± SD 67° ± 17°) and the approach speed from 2.3 to 4.2 m/s (3.4 ± 0.4 m/s). The defender adjusted her position to make sure the athlete hit the force platform using her self-selected sidestep cutting technique. Only trials where the athlete hit the force platform with all markers firmly attached to the skin and where the athlete displayed a match-like effort, as assessed by an investigator and team mates, were used for analysis. The test procedures and calculations are described in detail previously (Kristianslund and Krosshaug, 2013).

Force and marker trajectories were processed with a smoothing spline with a 15 Hz cut-off frequency (Woltring, 1986; Kristianslund et al., 2012). Calculations were performed in custom Matlab scripts (MathWorks Inc, Natick, Massachusetts, USA), with kinematics calculated according to the JCS convention (Grood and Suntay, 1983) and external joint moments calculated with iterative Newton–Euler inverse dynamics (Davis et al., 1991).

2.2. Expression of joint moments

Joint moments were expressed in four different reference frames (Fig. 2): the global laboratory frame ('global'), the local frame of the distal segment ('distal'), projected on to the JCS axes ('JCSp') and decomposed to JCS axes ('JCSd'). The expression of joint moments in different reference frames is defined in Eqs. (1)–(4).

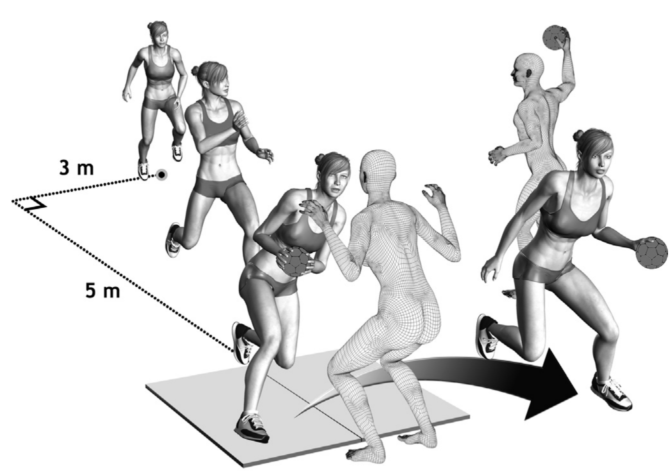

Fig. 1. Sidestep cutting situation. The players were instructed to try to fake the static defender into going to one side while cutting to the other. Prior to the cut, the player received the ball from a team mate in order to make the situation realistic. Reproduced from Kristianslund et al. (2012).