VARIABILITY IN VERTICAL JUMP HEIGHT AND LOWER LIMB KINEMATICS BETWEEN DAYS

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The purpose of this study was to determine the variability of lower limb range of motion (ROM) during vertical jumps using inertial-based systems. Ten participants attended three laboratory session to familiarise with the countermovement jump (session 1) and to perform three maximum countermovement jumps (session 2 and 3). Motion from the lower limbs and pelvis were tracked using an inertial-based system and sagittal plane ROM computed for the hip, knee and ankle joints. ROM was compared between sessions using t-test, typical error and effect sizes. Moderate effect sizes were observed with differences in angular data varying from <1 to 12° for similar heights of the jump ($p = 0.27$ and $d = 0.21$). Moderate differences in sagittal plane ROM for the lower limbs were observed for vertical countermovement jumps which limits the use of joint ROM between sessions from inertial-based system.

KEYWORDS: Inertial-based system, motion analysis, range of motion, reproducibility.

INTRODUCTION: The vertical jump is a common movement in many sports and more recently has been used as a screening method to assess lower limb power in a wider population (Argaud, Pairot de Fontenay, Blache, & Monteil, 2017). If the position of the trunk and hands is sustained (e.g. keeping the hands in the waist) and the countermovement is allowed, the range of motion (ROM) for the lower limb joints will depend on the depth of the squatting portion of the counter movement. Kirby et al. (2011) observed that, during a countermovement jump, participants tend to self-select the depth of the jump in order to optimise the height of the jump. However, given the vertical jump involves the motion of various body segments and the recruitment of many muscles, it is possible that various optimal strategies could be intuitively sought to maximise the height of the jump.
Joint kinematics can allow an indirect assessment of muscle excursion and help determining the coordination during various tasks, including the vertical jump (Harrison, Ryan, & Hayes, 2007). However, the reliable measurement of joint kinematics depends on the appropriate position of markers on bony landmarks, camera set up and calibration. For three-dimensional analyses, errors in position of anatomical markers and model scaling are critical to the reliability of joint angles (Della Croce, Leardini, Chiari, & Cappozzo, 2005). At the moment, there are no known studies assessing the variability of joint kinematics during a vertical jump.
Motion analysis systems traditionally use cameras to track markers and reconstruct the movement in the three-dimensional space. More recently, inertial-based systems have been employed to assess movements without the need of markers or cameras. These systems involve the use of inertial sensors that allow the real time tracking and analysis of joint kinematics. Inertial-based systems have been shown to be valid for the assessment of joint kinematics during handling tasks (Robert-Lachaine, Mecheri, Larue, & Plamondon, 2017) and functional activities [i.e. walking and climbing stairs (Zhang, Novak, Brouwer, & Li, 2013)]. They also provide benefit for the researcher by reducing the time involved in placing anatomical markers, assigning markers to the model, and correcting missing markers during digitisation. Therefore, the use of inertial-based systems is beneficial, but lack an assessment of variability, particularly for the vertical jump. In addition, the variability between sessions for joint kinematics during vertical jumps has not been assessed.
In this scenario, the aim of the present study is to determine the variability of lower limb ROM during vertical jumps using inertial-based systems.

METHODS: Ten apparently healthy participants (age 22 ± 2 years, mass 79 ± 9.7 kg and height 183 ± 7.9 cm) volunteered to take part in this study. During the time of the data

collection, they were free from neuromuscular or skeletal injuries that could restrain maximal vertical jump performance. After receiving full information on the study, they signed an informed consent form, approved by the university ethics committee (HEC 16-126).

In the first session, body mass and height were collected, along with arm span, shoulder and pelvis width, hip, knee and ankle heights from the floor, standing height and foot length required to scale the biomechanical model in the motion analysis software (MVN Studio 4.4, Xsens, Netherlands). After that, participants were familiarised with the countermovement jump and were required to perform at least three familiarisation jumps. This involved jumping as high as possible, with hands placed on their waist during the whole jump, and landing onto the force plate. Participants returned to the laboratory in two additional sessions (Session 2 and 3) to perform maximum jump height trials.

During Sessions 2 and 3, seven wireless inertial-based sensors were placed on pre-defined body segments (i.e. pelvis, upper and lower legs, and on the dorsal aspect of the feet) as per instructions provided by the manufacturer (Xsens, Netherlands). These sensors were detected by a wireless receptor and synchronized using the manufacturer software. A biomechanical model was scaled using anthropometric measures taken in the first session. The model was defined to track the pelvis and bilateral lower limb movements to calculate hip, knee and ankle angles. Three trials per session were used for capturing kinematic data during the vertical jumps with 1-min of rest between jumps.

After data collection, files were visually inspected and models with abnormal motion, such as non-physiological hyperextension for the knee joint were removed. Data were then exported for further analysis in MATLAB (R2016b, MathWorks, Natick, USA) allowing the phases of the jump to be identified. Take-off and landing ROM (º) was calculated using the predicted vertical coordinate for the centre of mass exported from Xsens. Specifically, take-off ROM was considered the time interval between the lowest position of the centre of mass (i.e. squat before jumping) and the highest height for the centre of mass during the jump. Landing ROM was the time interval between the end of take-off and the lowest position of the centre of mass after the participant has contacted the floor (Figure 1A).

Angles for the hip, knee and angle joints were defined as shown in Figure 1B and were assessed in the sagittal plane, bilaterally. The mean ROM for both legs was computed for each joint, in the sagittal plane, for take-off and landing for each jump to allow the comparison between sessions. The maximum vertical displacement of the predicted centre of mass, from standing height, was computed to assess the height of the jump.

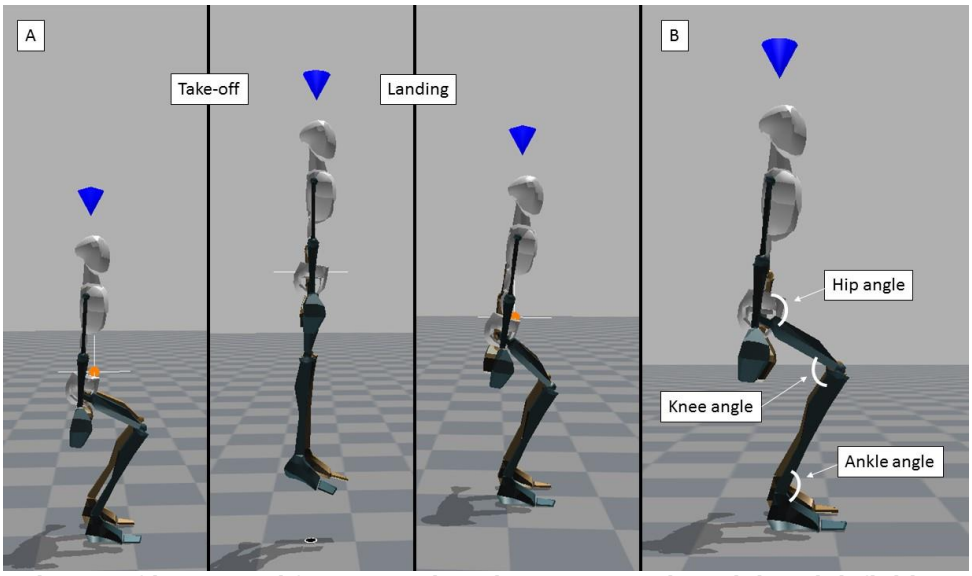

Figure 1: Phases of jump used for comparison between sessions (A) and definition of angles used in this study (B).

For the comparison of lower limb joints ROMs during take-off and landing, and for the comparison of the height of the jump, paired samples t-tests were used along with Cohen's d effect sizes. Whenever p <0.05 and Cohen's d >0.50, substantial differences were considered for discussion. Confidence intervals for the differences between sessions were computed for each variable and are provided as a practical measure of variability. Intraclass correlation coefficients were calculated and ranked as poor (ICC<0.5), moderate (ICC = 0.5-0.75), good (ICC = 0.75-0.9) and excellent (ICC>0.9) as suggested by Koo and Li (2016).

RESULTS: No significant differences were observed in jump height (p =0.27; Table 1). Significant differences were observed for the hip and knee joint ROM during take-off (p <0.01) and landing (p <0.01) with both displaying small to moderate effect sizes (d range = 0.47 – 0.78). For the ankle joint ROM, significant differences were only observed during landing (p =0.01) with moderate effect sizes. The 95% confidence interval for the differences indicated that the hip joint varied 5.1-5.7°, the knee varied 3.3-4.5°, and the ankle varied 3.3-4.5° between sessions.

Table 1: Jump height and lower limb ROM between sessions (n=30).

Outcomes	Session 2	Session 3	Mean difference ±95%CI	d	ICC
Jump height (cm)	30±6	31±6	1±6 (2)	0.21	0.51
ROM during Take Off (°):					
Hip Flexion/Extension	70±15	83±17*	12±16 (5.7)	0.78	0.51
Knee Flexion/Extension	86±12	93±12*	7±9 (3.3)	0.58	0.73
Ankle Dorsi/Plantarflexion	65±7	65±9	<1±9 (3.3)	0.01	0.31
ROM during Landing (°):					
Hip Flexion/Extension	35±20	45±22*	10±14 (5.1)	0.47	0.78
Knee Flexion/Extension	57±15	64±16*	7±12 (4.5)	0.48	0.67
Ankle Dorsi/Plantarflexion	48±10	54±13*	6±12 (4.5)	0.56	0.44

All values are mean ±SD. * Session 3 was significantly different from Session 2 (p < 0.05 and d >0.50). ICC = intraclass correlation coefficient; ROM = range of motion; 95% CI = 95% confidence interval.

DISCUSSION: The aim of this study was to determine the variability in lower limb ROM during vertical jumps using inertial-based systems. Our main finding was that, although jump height performance was similar, ROM were mostly significantly different between sessions with small to moderate effect sizes. Differences in angular data varied from <1 to 12°, which are considered practically important (Leigh, Pohl, & Ferber, 2014).

During a vertical jump, participants were allowed to self-select their jump style which could be expected to optimise their jumping performance (Kirby et al., 2011). This may have led to large variations in joint coordination, leading to different strategies being adopted in each session. The lower limbs have a large number of muscles that could be recruited in various sequences (Park & Durand, 2008), therefore, we could infer that a different sequence in motor control was opted for in each session. One reason for this assumption is that, the ROM was typically larger in the second session compared to the first. Although participants were familiarised with the task in a primary session, learning effects cannot be discarded as affecting their joint angles. Further studies are needed to assess if guided joint angles and squat depths could diminish the variability between sessions and lead to similar performance.

Sensors were removed and re-attached between sessions, which could have led to increases in errors in angular measurements. The manufacturer provides instructions for sensor placement that, in our view, are not sufficiently detailed to ascertain that segments would be tracked similarly if sensors are to be removed. Calibrations were performed for each session, after repositioning the sensors which should have led to reductions in errors in calculating joint angles. In addition, the static pose calibration assumes that the participant

stands in a similar upright position between sessions. However, differences in static pose could have led to differences in segmental positions between sessions. Further studies are required in order to determine the magnitude of variability in the static pose between sessions or assessing benefits from a dynamic calibration. More studies are also needed in order to assess if, in constrained movements (e.g. single joint), the errors are reduced, which could signal for a large variability emerging from the participant. The potential influence from soft tissue vibration on the angular data is also yet to be determined.
This study was limited to some extent. We did not have full information on the anthropometric model used by the manufacturer to compute the centre of mass, which limits the agreement between sessions for our jump height calculations. The limited information on the influence of changes in placement of sensors also constrains the assessment of the main source of errors. We expect that variability in movement by the participants could be a large source of variation if further instructions are not provided (e.g. depth of the squat). However, we cannot eliminate errors in aligning the model with the motion by the software, which suggests the need for further studies.

CONCLUSION: Moderate differences in sagittal plane range of motion for the hip, knee and ankle were observed for vertical countermovement jumps for a similar jump height measured in two sessions. We can then conclude that lower limbs range of motion measured in two sessions are not reproducible using an inertial based motion tracking system when participants jump using self-selected squat depth aiming for maximum jump height.

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