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KINEMATIC RESPONSES TO PLYOMETRIC EXERCISES CONDUCTED ON COMPLIANT AND NONCOMPLIANT SURFACES

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ABSTRACT. Crowther, R.G., W.L. Spinks, A.S. Leicht, and C.D. Spinks. Kinematic responses to plyometric exercises conducted on compliant and noncompliant surfaces. *J. Strength Cond. Res. 21(2):460–465. 2007.*—Jumping is an important performance component of many sporting activities. A number of training modalities have been used to enhance jumping performance including plyometrics. The positive effects of plyometric training on jumping performance are a function of the stretch-shortening cycle phenomenon. However, there has been little research on the effects of the surface on jumping performance. This study examined the effects of performing 2 different plyometric exercises, depth jump (DJ) and counter movement jump (CMJ), on noncompliant (ground) and compliant (mini-trampoline) surfaces. Male participants ($N = 20$; age = 21.8 ± 3.8 years; height = 184.6 ± 7.6 cm; mass = 83.6 ± 8.2 kg) randomly performed 10 CMJ and 10 DJ on compliant and noncompliant surfaces. Kinematic data were determined via 2-dimensional high-speed video. There were significant ($p < 0.05$) differences in DJ and CMJ joint and segment range of movement for ankle, knee, hip and trunk, indicating less crouch when the participants performed plyometric exercises on the compliant surface.

KEY WORDS. jumping, stretch-shortening cycle, mini-trampoline

INTRODUCTION

The high level of performance and professionalism required of athletes, coaches, and trainers in modern sport demands that athletes complete training methods that are matched, as close as possible, to the demands of the sport. Plyometric exercises involve the training of the stretch-shortening cycle (SSC) phenomenon and have been shown to be an effective way to achieve higher velocities than those using traditional weight training. This increased velocity enhances the specificity of this training modality to competitive performance, improving the transfer of training gains to the competitive situation (12).

Despite these advantages, the dynamic nature of plyometrics exercise may lead to injury. High impact forces in the order of 3 to 4 times body mass can occur when landing from activities such as the depth jump (DJ), the counter movement jump (CMJ) or bounding (5). These high transient forces impact on the musculoskeletal system and can result in injuries such as anterior compartment pressure syndrome and tibial stress syndrome or even stress fractures (3, 7). The potential for injury is reduced if the athlete develops a relatively high level of strength prior to performing plyometric exercises (5, 7). Furthermore, landing on a compliant surface, such as rubber matting, and using shock absorbing shoes will also reduce impact forces (7, 13).

Research on the effect of different surfaces on plyometric training has shown that the type of surface such as a typical gym mat can significantly influence joint kinematics which could influence the SSC mechanism (13, 14). In addition, it has been suggested that changing the nature of the surface could also minimize the trauma of landing and thus reduce the risk of injury (7). The use of a compliant surface such as a mini-trampoline in rehabilitation procedures appears to emphasize the role of the proprioceptors and has been shown to improve balance problems (9, 14). Mini-trampolines have been shown to lessen the need for a jumper to crouch, therefore reducing loss of elastic energy and facilitating speed of movement resulting in maximum leg power during the jumping action (14). This research by Ross and Hudson (14) examined the influence of the mini-trampoline on the knee kinematic movements; however, other joints such as the hip and ankle were neglected. The process of jumping involves a 2-link system; therefore, an examination of just the knee angle does not give a whole body result (4).

The primary purpose of this study was to determine if 2 different (compliant and noncompliant) landing surfaces influence the kinematics of jumping performance and how the type of surface relates to SSC training and the potential for injury. It was hypothesized that there are significant differences in the kinematic characteristics of DJ and CMJ when performed on a compliant surface compared to a noncompliant surface.

METHODS

Experimental Approach to the Problem

A repeated measures study was used to examine the effects of 2 different surfaces, compliant and noncompliant, on the whole body kinematics of 2 plyometric activities, DJ and CMJ. Participants completed in random order, a block of 10 CMJ and 10 DJ on a randomly selected surface, and 7 days later completed further blocks of 10 CMJ and 10 DJ on the other surface. Previous research has shown significant differences in knee kinematics when jumping on a mini-trampoline (14). However, the influence of a compliant surface on whole body joint movement during plyometric jumping activities is unknown (4).

Subjects

Twenty healthy male university students (age = 21.8 ± 3.8 years; height = 184.6 ± 7.6 cm; mass = 83.6 ± 8.2 kg) volunteered to participate in this study. Written informed consent was obtained prior to the commencement of the study. The methodology and procedures used in

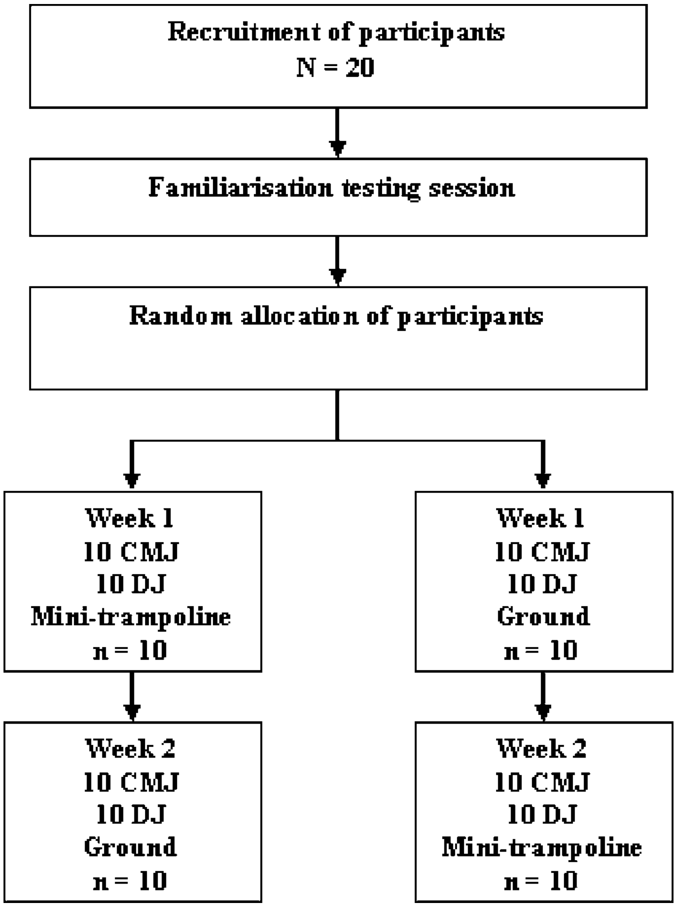

FIGURE 1. Experimental setup. CMJ = counter movement jump; DJ = depth jump.

this study were approved by the James Cook University Human Research Ethics Sub-Committee.

Procedures

All participants undertook a test familiarization and health prescreening session 7 days before testing began. On reporting to the laboratory for the first test session, the participants undertook a warm-up routine which involved a 10-minute dynamic warm up of the lower limb muscles (hamstring, gluteal, quadriceps) involving the athletic drills known as "high knees," "heel pick-ups," and "quick cycle leg" (5). To reduce the possibility of delayed onset muscle soreness, a similar cool down routine was conducted after the testing procedures were completed. The participants then completed in random order a block of 10 CMJ or 10 DJ on a randomly selected surface (compliant or noncompliant). The compliant surface consisted of a mini-trampoline (Reebok RE10038 Rebounder, Reebok Ltd., Lancaster, UK) and the noncompliant was ground concrete (Young's Modulus 30 GPa). A further block of 10 CMJ and 10 DJ was conducted on the other surface 7 days later following the same warm-up routine (Figure 1). Participants were required to wear the same appropriate athletic footwear for each testing session.

A standardized starting position was used for both the CMJ and DJ. For the CMJ the participants were positioned so that they were side on (right side) to the camera with hands on hips and feet shoulder width apart. For the DJ the participants were positioned with the hands placed on the hips and the right foot out in front of the body in mid air. A demonstration of each starting position was given prior to each testing session (Figures 2–5).

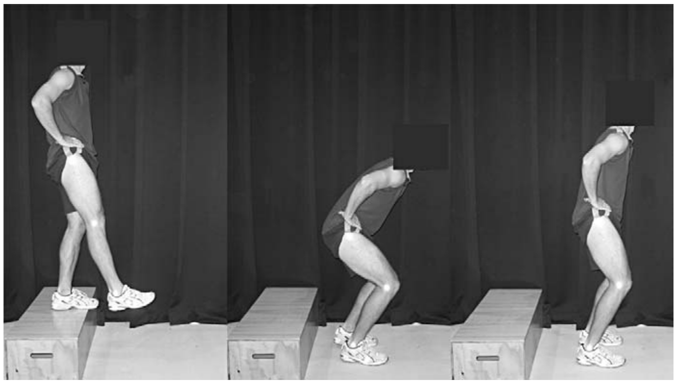

FIGURE 2. Depth jump performed on the ground.

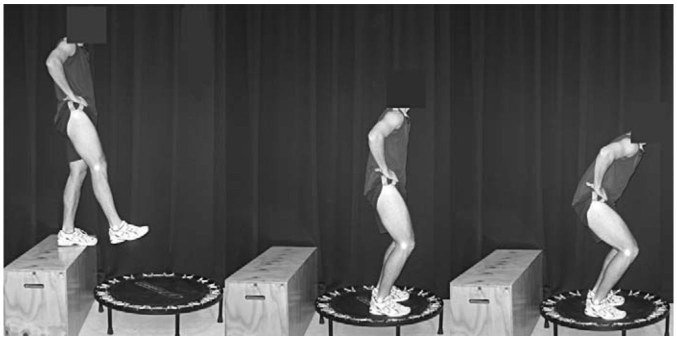

FIGURE 3. Depth jump performed on the mini-trampoline.

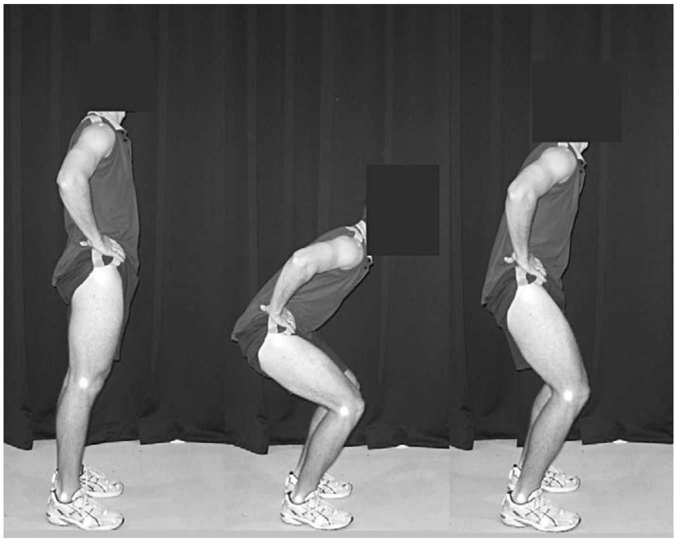

FIGURE 4. Counter movement jump performed on the ground.

The elasticity of the mini-trampoline bed was measured with known masses prior to the testing procedures. The known masses were placed in the center of the mini-trampoline bed, and the distance from the lowest point of the bed under the known masses to the floor was recorded. The degree of deflexion of the elastic bed was graphed and a polynomial calculated from the curve ($0.0036x^2 - 1.1198x + 219.0437$). When the material comprising the bed had stretched by more than 10%, a new mini-trampoline was used. The stretch was set at 10% to ensure

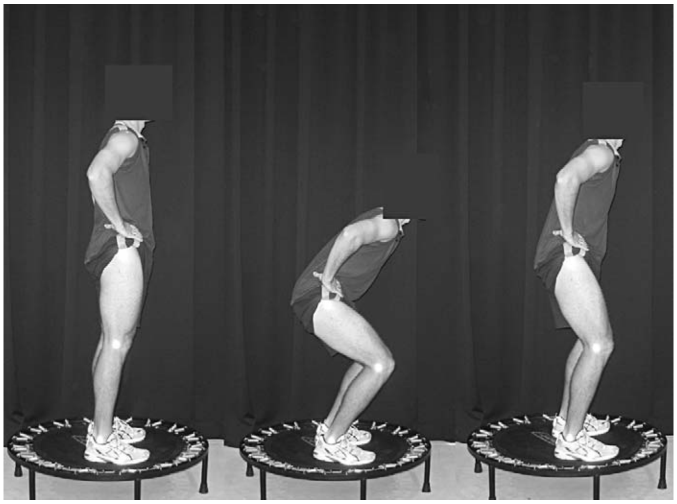

Figure 5. Counter movement jump performed on the mini-trampoline.

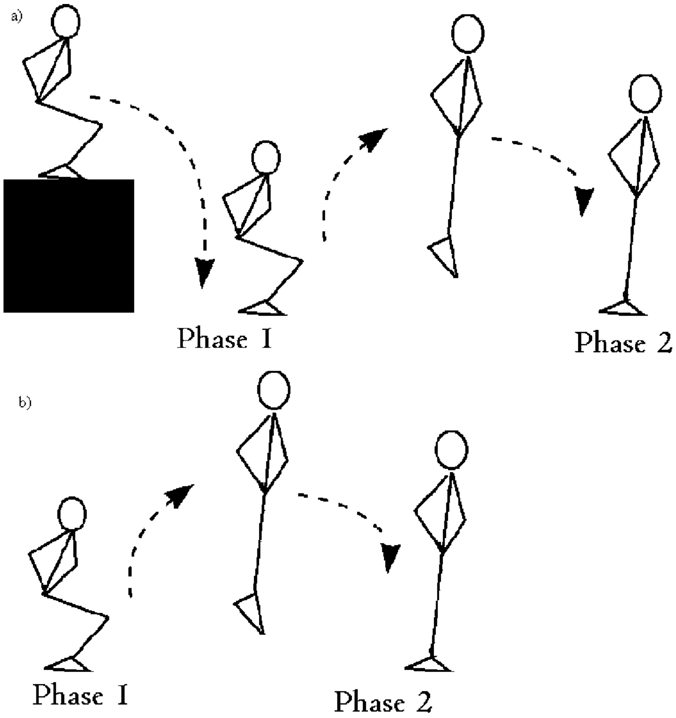

Figure 6. Depth jump phases (a) and counter movement jump phases (b).

that the elastic surface of the mini-trampoline did not influence the performance of the plyometric exercise in different ways for other participants. A total of 2 mini-trampolines were used.

Prior to testing, anatomical markers were placed on each participant in order to identify joint segments. The markers were placed on 5 landmarks on the right side of the body namely, shoulder (acromion), hip (greater trochanter of femur), knee (lateral epicondyle of femur), ankle (lateral malleolus of fibula), and head of the fifth metatarsal.

A high-speed digital video recorder (Canon MV550i, Canon Australia, New South Wales, Australia) recorded all jumps with a video capture card (Adaptec FireConnect for Notebooks, Adaptec, Inc., Milpitas, CA) transmitting the captured signal to a notebook computer (Toshiba PIV; Toshiba International, New South Wales, Australia) for analysis purposes. The high-speed digital camera format provided an uninterrupted video field and was set at a sampling rate of 50 Hz. Two markers were placed 1 meter apart in the field of view in order to calibrate the motion analysis system. Following recording of the digital images appropriate joints were identified with digitizing software (SiliconCoach, Dunedin, New Zealand).

The first author performed all digitizing of the digital video images in order to reduce intertester variability. Three of each of the plyometric exercises were randomly selected for analysis. The jump phases of interest were identified as the first (phase 1) and second landing (phase 2) in the DJ and the time just before the jump (phase 1) and after the landing (phase 2) of the CMJ (Figure 6). These phases were defined as the point where vertical velocity of the total body center of mass (TBCOM) reached zero when landing on a surface. The TBCOM was calculated using Winter (15) anthropometric data for the whole body. Nine frames, before and after TBCOM reached minimum vertical position (total of 19 positions), were also digitized to ensure that the data points within the landing phase were not inappropriately influenced by the filter and differentiation algorithms (13). Data points were determined for jump movement parameters including displacements, velocities, and acceleration for joints and segments, which were then averaged over the 3 jumps. Total time (time history) to perform the CMJ and DJ exercises was recorded and each jumping style time history was also averaged over 3 jumps. Time history was used to examine the total time spent performing the plyometric exercises on the 2 surfaces.

Statistical Analyses

Data were analyzed using the Statistical Package for the Social Sciences (version 11; SPSS, Inc., Chicago, IL). All statistics were expressed as mean ± *SD*. Data were analyzed via a 2-way (2 jumps × 2 surfaces) repeated measures analysis of variance and Tukey's HSD post hoc test. An alpha level of 0.05 was set for this study. Intraclass correlation (ICC) reliability for all kinematic variables ranged from 0.75 to 0.92.

RESULTS

Range of Movement

There were significant main effects for surface on ankle, knee, hip, and trunk range of movement (ROM) in phase 1 ($p < 0.001$) for DJ. Post hoc analysis of the interaction effect indicated that ankle, knee, hip, and trunk ROM were significantly less when a DJ was performed on a compliant compared to a noncompliant surface (Figures 7 and 8). There were no significant main or interaction effects for phase 2 of the DJ performed on the 2 surfaces for ankle, knee, hip, and trunk ROM (Figure 9a).

There were significant main and interaction effects for ankle, knee, and trunk ROM in the takeoff movement of phase 1 for the CMJ (Figure 10 and 11). The hip ROM was the only joint to show significant difference between the surfaces, during the preparation (crouching) before takeoff in phase 1 (Figure 11a). There were no significant effects for phase 2 of the CMJ performed on the 2 surfaces for the ankle, knee, hip, and trunk kinematics (Figure 9b).

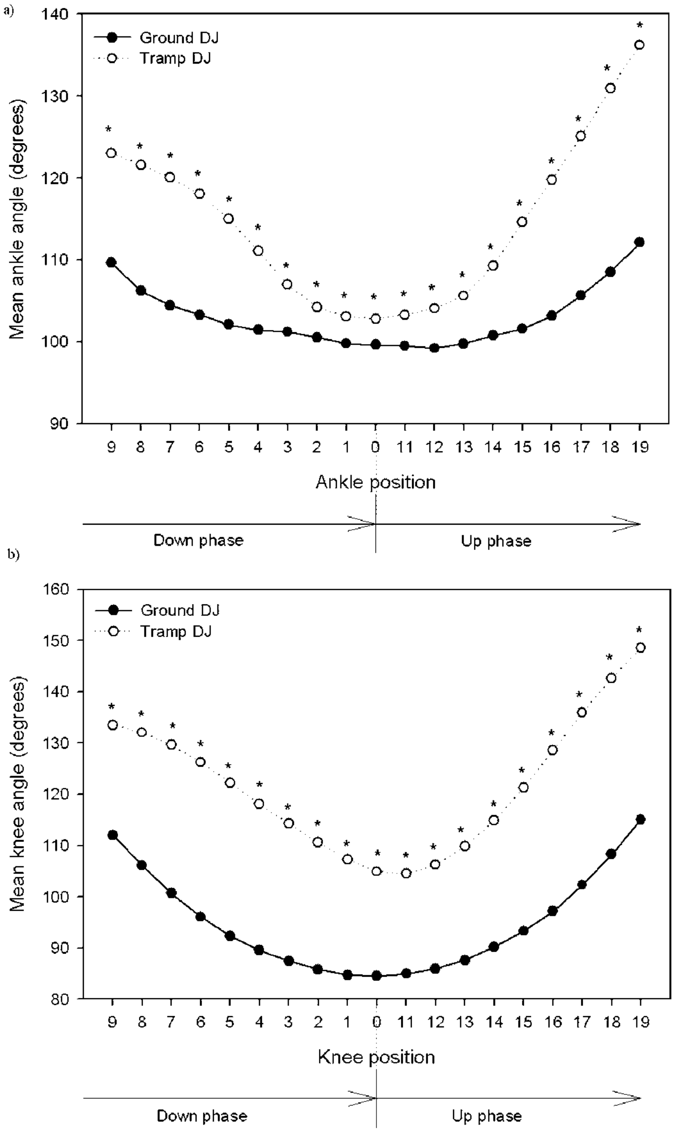

FIGURE 7. Mean range of motion for depth jump (DJ) phase 1. * $p < 0.05$ ground vs. trampoline for ankle (a) and knee (b).

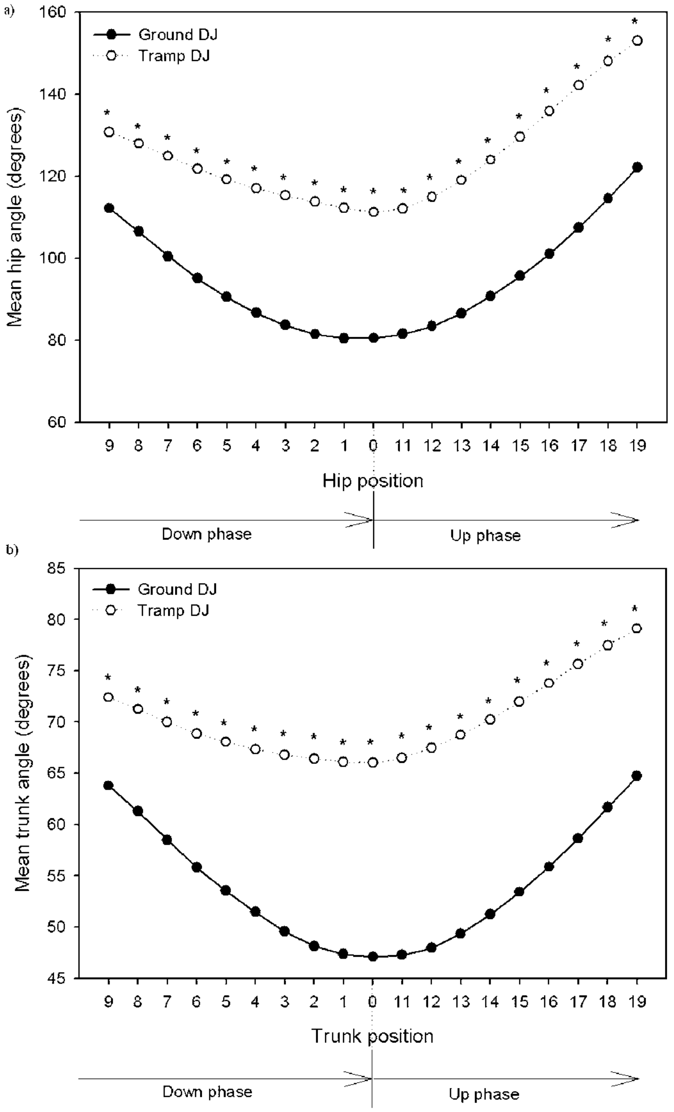

FIGURE 8. Mean range of motion for depth jump (DJ) phase 1. * $p < 0.05$ ground vs. trampoline for hip (a) and trunk (b).

Velocity and Acceleration

There were no significant effects for any of the joint velocities and accelerations for CMJ and DJ conducted on the 2 surfaces.

Time History

There were no significant effects for time history for DJ and CMJ between the 2 surfaces. However, there was a significant main effect ($p < 0.05$) for the DJ and CMJ time histories on the ground (Table 1).

DISCUSSION

Jumping capacity is integral to successful performance in a variety of sports (e.g., basketball, Australian Rules football, volleyball and high, long and triple jumping). To jump in any direction involves the coordination of upper and lower limbs (14, 15). Other factors including force and angle development of the ankle, knee, and hip joints and the rate of force development (muscular power) produced by lower limb muscles also influence jumping performance (15). The current study was conducted to investigate the influence of a compliant surface on kinematic parameters while performing 2 different plyometric exercises. While there has been much research on training methods designed to improve vertical jumping ability including plyometrics (1, 2, 6, 8), there has been little research on the injury potential of the stress of plyometrics training on the musculoskeletal components of the lower limbs (7). It is important to consider ways of reducing the negative impact effects of plyometric training, thereby reducing the likelihood of injury while retaining the performance enhancing effects on the SSC.

Significant differences were found across all joint and segment ROMs (ankle, knee, hip, and trunk) in phase 1 for DJ (Figures 2 and 3). The knee ROM significantly varied (~20°) between the 2 surfaces in phase 1 indicating that the knee did not bend to the same extent when performing a DJ on the mini-trampoline compared to the ground (Figure 2b). This is in agreement with Ross and Hudson (14) who reported that when the jumping surface was more compliant, the knee angle remained significantly larger throughout the movement. The significant variation in the knee ROM between the mini-trampoline

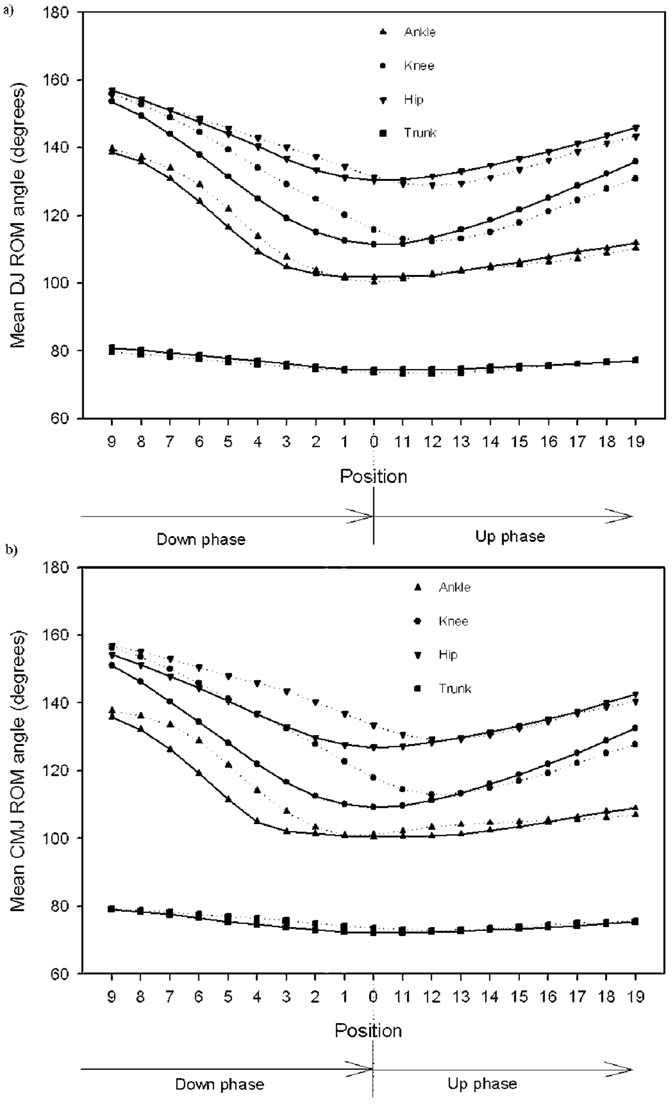

Figure 9. Mean range of motion (ROM) for phase 2 (a) depth jump (DJ) for ground (solid line), tramp (dotted line) and (b) counter movement jump (CMJ) for ground (solid line), tramp (dotted line).

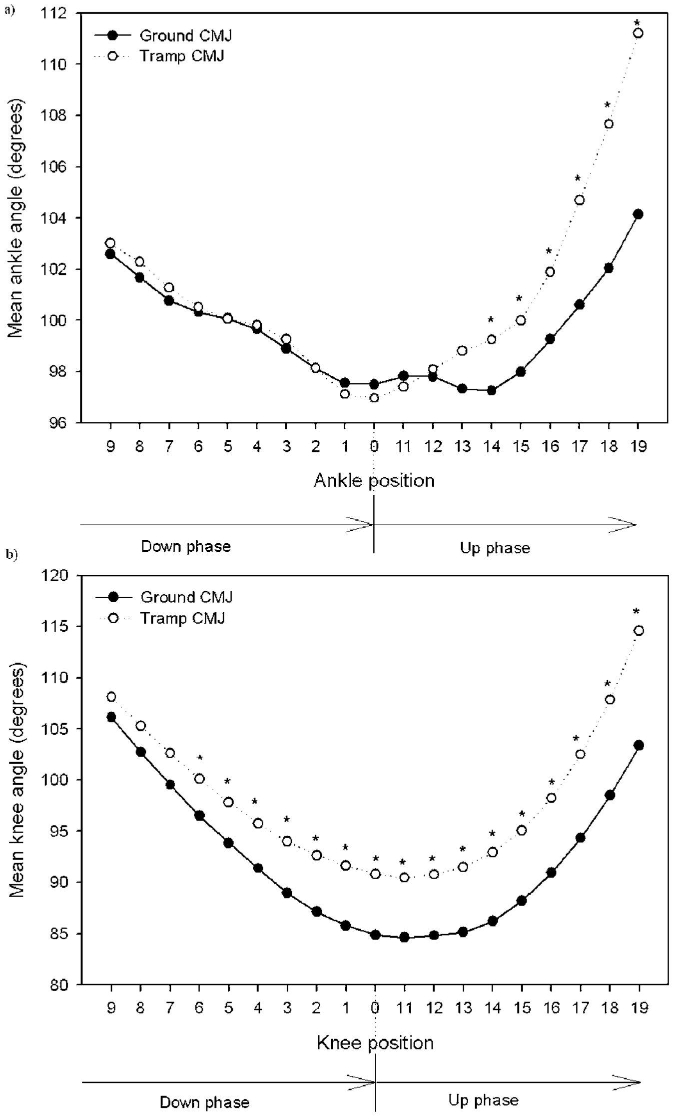

Figure 10. Mean range of motion for counter movement jump (CMJ) phase 1.* $p < 0.05$ ground vs. trampoline for ankle (a) and knee (b).

and the ground was also reflected in the hip and trunk ROM resulting in a smaller crouch position during a DJ. Research has shown that skilled jumpers crouch to a lesser extent than less skilled jumpers (1, 2, 5, 7, 10, 11). Ross and Hudson (14) also found that with a smaller knee ROM, the training effect of performing plyometric exercises on a mini-trampoline is such that the SSC mechanism generates greater maximum leg power during jumping.

The CMJ results also indicated significant differences between the joint ROMs in phase 1 (Figures 5 and 6). These results indicate that the compliant surface of the mini-trampoline causes the jumper to reduce all joint ROMs before undertaking the CMJ. As in the case of the DJ, joint ROMs in phase 2 of the CMJ were not influenced by the nature of the jumping surface (Figure 4b).

There were a number of (nonsystematic) significant differences in the data for CMJ joint velocities and acceleration but no significant differences for DJ. This result indicates that CMJ and DJ joint velocities and acceleration are similar for compliant and noncompliant surfaces, which is in agreement with Ross and Hudson (14). However, this is in contrast with McNitt-Gray et al., (13) who found that there were significant differences in joint velocities when performing a DJ on a mat. However, it should be noted that while the authors utilized mats of varying thicknesses, the mats did not have the rebound characteristics of a mini-trampoline.

As there was no significant effect for landing surface on joint velocity and acceleration, it could be suggested that the impact forces on the body are the same for both jumps on both surfaces. However, the impact forces experienced by the body when landing on the mini-trampoline surface would be different from those experienced when landing on the ground due to the energy absorbing nature of the elastic surface of the mini-trampoline. If this is the case, risk of injury may be reduced as impact forces are reduced. This notion should be addressed using force plate and force transducer technology to determine the relative impacts of landing on the 2 surfaces.

Despite the significant differences in joint and segment ROMs indicating faster jump times, the average

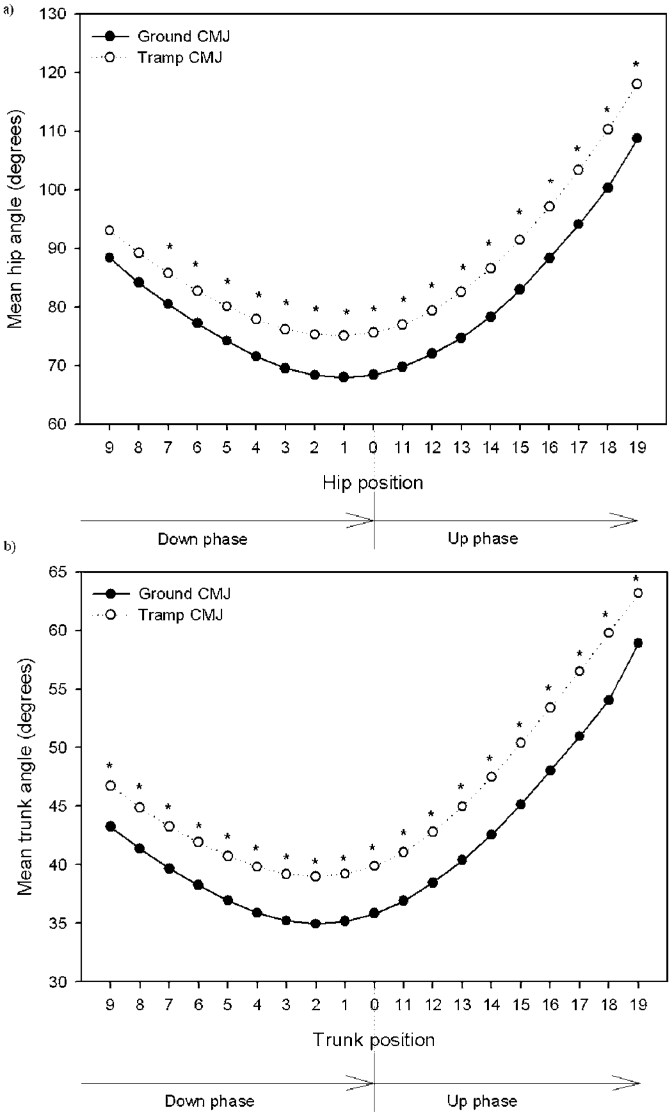

FIGURE 11. Mean range of motion for counter movement jump (CMJ) phase 1. * $p < 0.05$ ground vs. trampoline for hip (a) and trunk (b).

TABLE 1. Total time taken to perform a counter movement (CMJ) and depth jump (DJ) (mean ± *SD*).

	Mini-trampoline	Ground
CMJ (s)	2.5 ± 0.4	2.4 ± 0.3
DJ (s)	2.6 ± 0.3	2.7 ± 0.3*

* $p < 0.05$ between DJ and CMJ on the ground.

time history of each jump was not influenced by the respective surfaces. This was most likely due to the elastic surface of the mini-trampoline resulting in longer surface contact time.

This study has shown that the compliant surface of a mini-trampoline can influence the joint and segment kinematics of a jumper, resulting in an optimal movement pattern that is limited degree of crouch. With a smaller ROM the mini-trampoline allows the SSC mechanism to produce greater maximum leg power during jumping (14). While there were significant changes in joint kinematics there was no influence on joint velocities and acceleration and, therefore, the effect of the impact forces on the body can only be inferred from kinematic changes.

PRACTICAL APPLICATIONS

Plyometric training in the form of DJ and CMJ performed on a mini-trampoline may have a greater effect on enhancing the SSC mechanism compared to jumps performed on the ground. Significant changes in lower-body kinematics during jumping on a mini-trampoline indicate a reduced crouch action. This reduced crouch has been shown to be a feature of effective plyometric training. With a smaller crouch action the mini-trampoline allows the SSC mechanism to produce greater maximum leg power during plyometric training and acts to reduce the impact forces on the body during jump training. Improvement in jumping technique when performing plyometric training on the mini-trampoline could be transferred to performing ground plyometrics with improvement in jumping ability.

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