KINEMATICS CHANGE IN COUNTERMOVEMENT JUMPS WITH ADDITIONAL LOADS

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The aim of this study was to investigate the effect of sex and additional load during countermovement jumps on hip, knee, and ankle joint kinematics. For this purpose, a total of 25 female and male participants performed barbell-loaded countermovement jumps with an additional load of up to 80 % body mass. No significant main effect of sex on any of the kinematic parameters was found. The additional load resulted in a significant decrease in hip, knee, and ankle joint angles in the sagittal plane and an increase of the absolute performance time with increasing additional. The changes in kinematics of all three anatomical planes could increase the risk of injury and should therefore be closely monitored, especially in less experienced individuals performing countermovement jumps.

KEYWORDS: vertical jumps, barbell load, sex differences, joint kinematics

INTRODUCTION: Countermovement jumps (CMJs) are often used as performance tests or for strength training because they are easy to perform and can be used in various sports (Vaverka et al., 2013). In addition, CMJs with additional loads are useful training exercises to improve various performance measures such as explosive strength (Vaverka et al., 2013) or sprint start (Sleivert & Taingahue, 2004), thus also influencing joint power and hip, knee, and ankle work (Fessl et al., 2022; Harry et al., 2019). A comparison between males and females found that males perform loaded jump squats at a greater concentric velocity due to a greater displacement of the center of mass in the same amount of time. Therefore, males are able to generate greater concentric force and momentum, which leads them to greater jump height amongst other factors (McMahon et al., 2017). In addition, males perform loaded CMJs with greater positive hip work during the eccentric phase compared to females whereas females exhibit greater positive ankle work during the unloading phase (Harry et al., 2019). Furthermore, the relative contribution of joint work remains stable in females and males with additional loads; however, females show a greater contribution of the knee and ankle joints, while males have a greater contribution of the hip joint to the total work (Fessl et al., 2022). The effect of loaded CMJs on performance (e.g. explosive strength (Vaverka et al., 2013)) and joint power (Fessl et al., 2022) has been frequently studied so far. In contrast, the effects of additional loads during CMJs on the kinematic parameters of the lower extremities have not yet been studied intensively, and especially not for a complete movement cycle (from start to take-off). Plyometric training is generally considered a safe strength training program for healthy younger and older participants and under supervision (Behm et al., 2008; Vetrovsky et al., 2019). However, in participants after anterior cruciate ligament (ACL) reconstruction and especially in females, who are more likely to perform loaded CMJs in a knee-dominant manner compared to males (Fessl et al., 2022), changes in kinematic strategy with increasing additional load should be evaluated in terms of potential injury risk. Furthermore, it has been shown that women perform CMJs with a more upright trunk with increasing additional load, which also affects lower extremity kinematics and kinetics (Vanrenterghem et al., 2008). Therefore, the purpose of this study was to compare hip, knee, and ankle joint angles between five different loaded CMJs (0 %, 20 %, 40 %, 60 % and 80 % of body mass (BM)) and between a cohort of female and male participants. We hypothesized that kinematic movement strategy changes with additional load and that females and males change their kinematic movement pattern differently.

METHODS: Twelve female (age: 24.9 ± 2.4 years, body mass: 60.6 ± 8.2 kg; body height: 1.66 ± 0.05 m) and 13 male (age: 25.2 ± 3.9 years, body mass: 74.9 ± 6.0 kg; body height: 1.79 ± 0.08 m) sport students who performed strength training regularly and at least two hours per week, were recruited to participate. They completed two CMJ sessions (first: familiarization, second: testing) and performed CMJ tasks with five different additional loads

(0 %, 20 %, 40 %, 60 % and 80 % BM). Ground reaction forces and marker trajectories were captured. An inverse kinematics and dynamics algorithm approach was used to calculate joint angles, moments and powers (V3D; C-Motion, Rockville, MD, USA). The trial with the maximum jump height out of the four jumps for each loading condition was used for further analysis. Only the data from the right limb was included due to assumed leg symmetry (Fessl et al., 2022). We investigated the hip, knee and ankle joint angles for the three anatomical planes and for the five loading conditions. Statistical parametric mapping was used to compare the normalized movement cycle from start to take-off rather than discrete values (Pataky et al., 2013). A two-way ANOVA (sex and load) with repeated measures on one parameter (load) was performed and pairwise paired *t*-tests were used as post hoc test with Bonferroni corrected *p*-values if the ANOVA detected significant effects ($\alpha = 0.05$). Significant results were reported if they were consisted for at least 4 % of the movement time (Wesseling et al., 2018).

RESULTS: No significant effect was found for sex on any of the kinematic parameters. Significant effects of the loading condition were found for all kinematic parameters except for the knee ad-/abduction angle. No significant interaction effect between sex and load on any of the kinematic parameters was revealed. Pairwise post hoc tests were performed for the complete data set of female and male participants between all loading conditions. Mainly, the sagittal plane kinematics of all three joints were significantly affected by additional load and post hoc tests revealed significant differences between almost all loading conditions. Results are displayed in figure 1 and significant effects or differences are highlighted in grey and black, respectively.

DISCUSSION: In this study we compared the kinematics of the hip, knee and ankle joint during loaded CMJs against five different loading conditions up to + 80 % BM between female and male participants. A significant main effect was only found for the loading condition. Therefore, the hypothesis was rejected for the sex effect and confirmed for the loading condition. In the sagittal plane in all three joints the maximal flexion at the lowest point of the countermovement and therefore also the total range of motion decreased with additional load. Moreover, the absolute performance time of the countermovement increased with the load (0 % BM: 0.82 s ± 0.08; 80 % BM: 1.14 s ± 0.19), whereas participants reached the lowest point earlier relatively to the total time (0 % BM: 65.2 % ± 3.4; 80 % BM: 58.8 % ± 1.2) between loading conditions. All these parameters lead to the conclusion that the kinematic execution of the CMJ changed with different additional load. Therefore, we assumed that not only the kinematic strategy, but also generating joint power, muscle activation and joint loading differ between loading conditions. These aspects need to be further analyzed in future studies. In the frontal plane changes were only small between the loading conditions and not statistically significant. The hip and ankle joint tended to have a more abducted angle with increasing additional load, while the knee joint had a tendency to have a more adducted knee joint angle especially between 40-80 % movement time. A higher knee adduction could slightly stress the ACL more, which could increase the injury risk for the ACL (Schweizer et al., 2022). When looking at the comparison between females and males independently, females in general tended to a knee adduction angle, whereas males to a knee abduction angle throughout all loading conditions with a difference of approximately 6° between 20-80 % of movement time. This difference in knee abduction angle between males and females has also been demonstrated in vertical drop jumps, thus confirming our results (Beaulieu & McLean, 2012). Besides an increased knee adduction angle, an increased internally rotated knee angle was found (0 vs. 80 % BM additional load) and was also associated with an increased ACL injury risk (Meyer & Haut, 2008). These two parameters in combination lead to the assumption that especially for females a special focus should be put on controlling the frontal and transversal alignment of the lower extremity when performing CMJs with additional load. This study needs to be interpreted with respect to its limitations. In this study we focused on the kinematics of the hip, knee and ankle joint, but others found differences of trunk inclination between males and females when performing loaded CMJs (Harry et al., 2019; Vanrenterghem et al., 2008). Moreover, the large

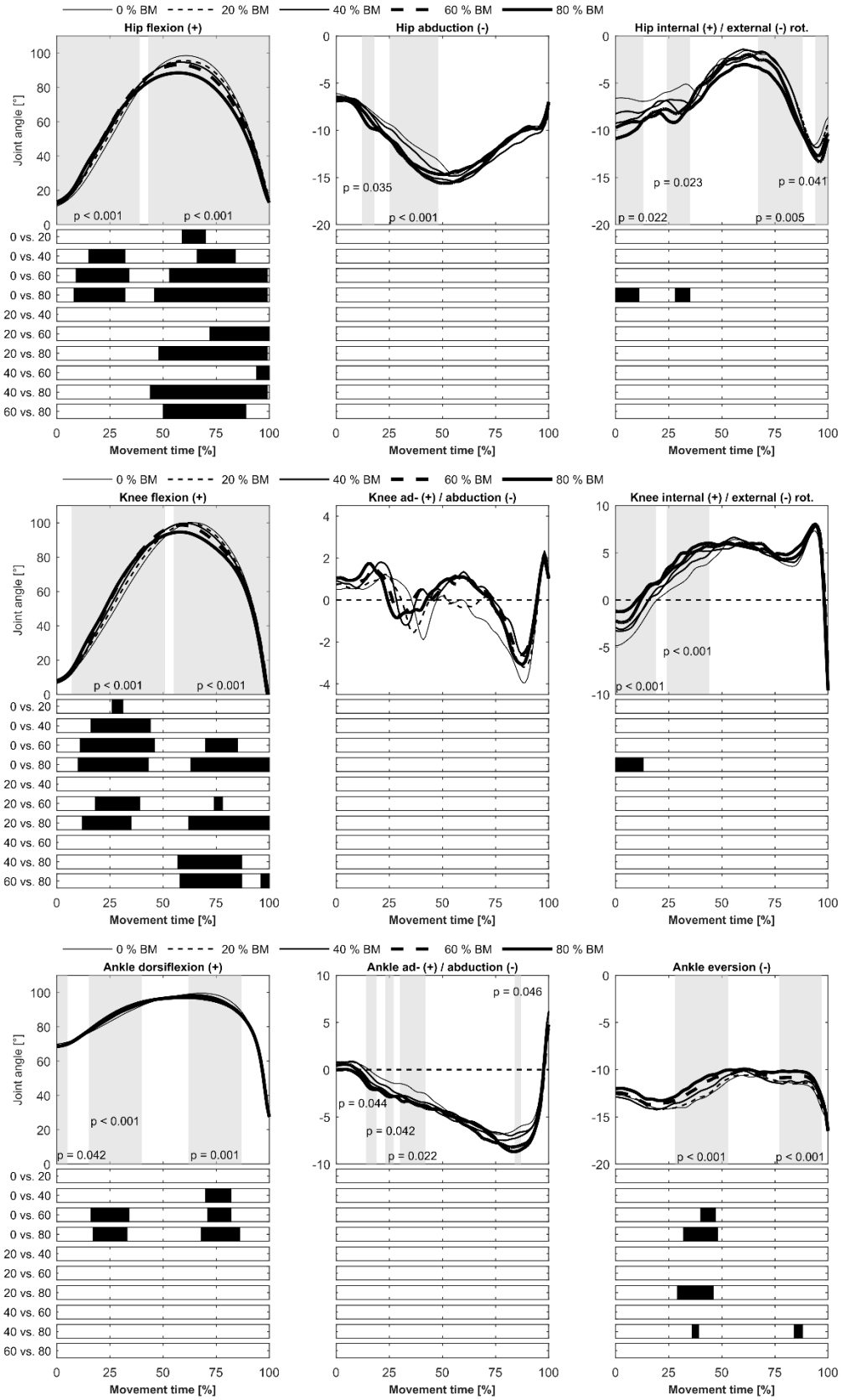

Figure 1: Results for the main effect "loading condition" of the two-way ANOVA and the post hoc paired *t*-tests: Time normalized mean curves per loading condition are displayed for the hip, knee and ankle joint angles. Significant effects are highlighted with the grey shaded areas in the same graphs as the mean curve. Significant differences from the post hoc tests are highlighted as black areas in the bars below the corresponding mean curve graphs.

standard deviations in some parameters might lead to the conclusion that the kinematic strategy between participants differs quite substantially. Therefore, investigating the changes within each participant might be helpful in regards of injury risk assessment as well as performance enhancement.

CONCLUSION: Participants performed loaded CMJs with mainly altered kinematics in the sagittal plane of the hip, knee, and ankle joints with increased additional loads. These changes affect performance in terms of jump height, but also the timing of maximal hip, knee, and ankle joint flexion. Furthermore, the changes in kinematics of all three anatomical planes could increase the risk of injury and should therefore be closely monitored, especially in less experienced individuals performing CMJs. Future studies should investigate the effects of additional loading on joint loading parameters and muscle activation.

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