KNEE JOINT LOADING IN JUMP LANDINGS IN DIVERSE CONDITIONS

Hermann Schwameder [1]

[1] Department of Sport and Exercise Science, University of Salzburg

The purpose of this single case study is to provide an overview on knee joint loading in counter movement jumps using different landing strategies and additional loads. One athlete experienced in jump training performed counter movement jumps and jump landings with additional barbell loads of 0 kg, 20 kg, 40 kg, 60 kg, 80 kg and with variations in landing conditions: “regular”,“soft”, “elevated” and “spotted”. GRF and kinematics were measured, and peak forces, peak knee moments and peak knee powers were determined using inverse dynamics. Different loading conditions and landing conditions lead – as expected – to different knee joint loadings and can therefore be used to specifically control the amount of loading during jump or jump strength training. The most effective in terms of high training loads and low landing joint loading are elevated and spotted landing conditions.

KEYWORDS: jump training, loading conditions, joint loading control

INTRODUCTION: Jumps are fundamental movements in several sports and can be seen both as a genuine discipline (e.g. high jump, long jump) or as a motor skill in sports with complex and differing motor elements (e.g. gymnastics, ball sports, ski jumping). However, they are also used in exercises to enhance force, power and coordination of the leg extension in diverse variations and settings in the entire spectrum between elite and rehabilitation sport. In this context the three “classical” jump exercises are used: squat jumps, counter movement jumps and drop jumps.

Depending on the goals, the jumps can be performed in diverse variations (with/without arm swing, one-leg/two-leg, additional load, type of landing etc.). These variations lead to diverse training effects, but are also associated with differing joint loading extensities, which have to be considered for jump technique selection. In addition, not only the jumping, but also the landing condition, should be considered in this context.

The positive effects of jumping strength training are documented by several studies (de Villarreal, Requena, & Cronin, 2012; Herrero, Izquierdo, Maffiuletti, & Garcia-Lopez, 2006; Slimani, Chamari, Miarka, Del Vecchio, & Chéour, 2016). Using these training methods high risk for lower extremity joint overloading may occur due to the high number of jumps and landings with and without additional load (leading to high joint forces). This is specifically true for the patellar tendinitis (Bahr & Bahr, 2014; Van der Worp, de Poel, Diercks, Van Den Akker-Scheek, & Zwerver, 2014; Zwerver, Bredeweg, & van den Akker-Scheek, 2011). In particular, these overloading situations have to be avoided during the rehabilitation phase following lower extremity injuries as the recovery phase might be extended in these cases.

For avoiding overloading situations, diverse strategies might be considered; for example, training with less additional loads, lower number of jumps, changes of the landing conditions or less training sessions in general. This reduces the loads on active and passive structures of the lower extremities and therefore also decreases the risk of overloading injuries. In this case, however, the training stimuli are also reduced with possible negative effects on a successful rehab process (Haas & Kurz, 2020). An alternative option would be to specifically shift the acting forces or their time-courses, which can be achieved by diverse interventions.

One option is to alter the landing stiffness. Stiff landings are characterized by small flexions in the hip and the knee joints, short eccentric phases and high peaks of the ground reaction force. In contrast, soft landings show a more pronounced flexion in hip and knee, longer eccentric phases and lower and delayed GRF peaks (Devita & Skelly, 1992; Myers et al., 2011; Silva, Ferreira, Nakagawa, Santos, & Serrão, 2015).

Another variation can be achieved by adding additional loads (Janssen, Sheppard, Dingley, Chapman, & Spratford, 2012; Suchomel, Taber, & Wright, 2016; Vaverka et al., 2013) with spotted landings where the load is picked up by a specific retaining device similar to a safety belt. The latter allows for high loading of jumps with the avoidance of additional loads during landing (Fritz, Stallegger, Fessl, Schwameder, & Kröll, 2021; Humphries, Newton, & Wilson, 1995). Another similar option for reducing landing forces can be provided by landings on elevated platforms (Fatouros et al., 2000).
The purpose of this single case study is to provide an overview on knee joint loading in counter movement jumps using different landing strategies and additional loads.

METHODS: One jumping and jump training experienced athlete (23 yrs, 1.85 m, 86 kg) performed counter movement jumps and jump landings in diverse conditions on a force plate (AMTI, 1000 Hz). The full body kinematics were measured with a motion capture system (Qualisys, 200 Hz).
Variations in additional load (barbell) were applied with weights of 0 kg, 20 kg, 40 kg, 60 kg, 80 kg. Four variations in landing conditions were instructed, including “regular” (i.e. no specific instruction), “soft” (i.e. yielding in the hip-, knee- and ankle joint), “elevated“ (i.e. landing on a box 30 cm high), and “spotted” (where the barbell is picked up by a safety apparatus at the apex of the jump). Due to the specifics of the loading/landing conditions, not all combinations were measured.
The measured data were analysed using an inverse-dynamics approach and the following variables were calculated: jump height (calculated from the impulse), peak ground reaction force during landing (F_{peak}), peak knee moment during landing (M_{knee}), and peak negative knee power during landing (P_{knee}).

RESULTS and DISCUSSION: The results of this single-case study are presented in Table 1. It displays the jump height, peak ground reaction force, peak knee moment and peak negative knee power during landing for the four loading and the four landing conditions. (Table 1).

			soft	regular	elevated	spotted
h	m	0	0.285	0.316	0.293	
		20	0.221	0.202	0.224	0.229
		40	0.174	0.169	0.161	0.183
		60		0.127	0.136	0.167
		80		0.089		0.080
F_{peak}	N/BW	0	2.79	3.68	2.27	
		20	3.01	3.68	2.24	2.33
		40	2.77	3.75	2.52	2.65
		60		3.72	2.85	2.32
		80		3.22		1.98
M_{knee}	Nm/kg	0	2.21	2.56	2.16	
		20	2.34	2.66	2.15	2.09
		40	2.56	2.79	2.12	2.33
		60		2.77	2.29	1.79
		80		2.57		0.77
P_{knee}	W/kg	0	-16.2	-22.7	-4.8	
		20	-13.1	-21.4	-5.5	-10.4
		40	-14.3	-20.1	-6.5	-10.6
		60		-16.5	-5.7	-6.7
		80		-10.0		-3.1

Jump height (h): The jump heights hardly differ within each loading condition, indicating that the jumps were executed in a similar way for the different landing conditions when the same load was applied. As expected, the jump height decreased substantially with increasing additional load.

Peak ground reaction forces (F_{peak}): Peak ground reaction forces during landing substantially differ between the landing conditions and show a similar relationship for each loading condition. F_{peak} was highest in the regular landing, followed by the soft landing conditions. They were lowest for elevated and spotted landings with similar load amounts. F_{peak} presented similar magnitudes in regular and soft landings for all landing conditions. When including additional loads, a higher F_{peak} might be expected, however, the lower jump heights compensate for that. In the elevated landing condition, F_{peak} is highest with the 60 kg condition because the athlete barely reached the platform and could not dampen the impact. In the spotted condition, F_{peak} decreased with the increasing additional load, which is caused by the decreases in jump height.
Peak knee moments (M_{knee}): In all loading conditions, the knee moments differed substantially between the landing conditions. As expected, they were lower in the soft compared to the regular landings. In the elevated landing conditions they are substantially lower, which is mainly caused by the lower F_{peak}, although the lever arm for the knee joint is increased. Due to the absence of the additional loads during landing, M_{knee} was substantially reduced in the spotted landing conditions. In soft and regular landings, M_{knee} increased only slightly as both F_{peak} and the kinematics are similar. In elevated landings, the M_{knee} was very similar in all loading conditions, while in spotted landings M_{knee} decreased substantially with additional load due to the landings from lower height.
Peak knee powers (P_{knee}): In all levels of additional loading, the highest peak power values were present during regular landings. They were substantially reduced in the soft landing conditions due to both the reduced knee moments and the lower knee angular velocity during landing. In the elevated landing, P_{knee} was lower compared to all other landing conditions. This is caused by lower M_{knee} and the fact that knee bending proceeds much slower in the elevated conditions. As expected, P_{knee} is much lower in the spotted landings compared to the regular and soft landing conditions. In soft landings, P_{knee} showed similar amounts in all loading conditions. However, in regular landings, P_{knee} decreased systematically and substantially with the increasing additional load. As M_{knee} stays more or less stable, the reduction of P_{knee} is caused by lower knee angular velocity due to decreasing jump heights. In the elevated landings, the differences between the loading conditions was very small and low in general. As expected, P_{knee} was low in all spotted landing conditions.

CONCLUSIONS and SUMMARY:

- For the assessment of the loading of the knee joint or the knee joint structures, the ground reactions force is not a sufficient indicator. The results differ substantially from the more relevant variables, such as knee joint moments or knee joint power.
- Different loading conditions and landing conditions lead – as expected – to different knee joint loadings and can therefore be used to specifically control the amount of loading during jump or jump strength training.
- Soft landings lead in all additional loading conditions to substantial reductions of F_{peak}, M_{knee} and P_{knee}.
- Elevated landings show – compared to regular and soft landings – a substantial reduction of P_{knee}, a considerable reduction of M_{knee} and a remarkable reduction of F_{peak}. Therefore, this landing technique can be used to provide similar loading conditions during the jump phase with a substantial reduction of joint loading in the landing phase.
- Spotted landings exhibit similar joint loading conditions as elevated landings. Thus, spotted landings reduce joint loadings substantially, specifically at higher additional loads, however it requires an apparatus for catching the barbell during the flight phase.

REFERENCES

Bahr, M. A., & Bahr, R. (2014). Jump frequency may contribute to risk of jumper's knee: a study of interindividual and sex differences in a total of 11 943 jumps video recorded during training and matches in young elite volleyball players. British journal of sports medicine, 48(17), 1322-1326.
de Villarreal, E. S., Requena, B., & Cronin, J. B. (2012). The effects of plyometric training on sprint performance: a meta-analysis. The Journal of Strength & Conditioning Research, 26(2), 575-584.

Devita, P., & Skelly, W. A. (1992). Effect of landing stiffness on joint kinetics and energetics in the lower extremity. Med Sci Sports Exerc, 24(1), 108-115.
Fatouros, I. G., Jamurtas, A. Z., Leontsini, D., Taxildaris, K., Aggelousis, N., Kostopoulos, N., & Buckenmeyer, P. (2000). Evaluation of plyometric exercise training, weight training, and their combination on vertical jumping performance and leg strength. The Journal of Strength & Conditioning Research, 14(4), 470-476.
Fritz, J., Stallegger, J., Fessl, I., Schwameder, H., & Kröll, J. (2021). Jumping with barbell load: Assessment of lower limb joint kinematics and kinetics during landing. Journal of Biomechanics, 120, 110354.
Haas, H.-J., & Kurz, E. (2020). Progression: von „Low Load" zu „High Load". Sportphysio, 8(01), 1-1.
Herrero, J., Izquierdo, M., Maffiuletti, N., & Garcia-Lopez, J. (2006). Electromyostimulation and plyometric training effects on jumping and sprint time. International journal of sports medicine, 27(07), 533-539.
Humphries, B., Newton, R., & Wilson, G. (1995). The effect of a braking device in reducing the ground impact forces inherent in plyometric training. International journal of sports medicine, 16(02), 129-133.
Janssen, I., Sheppard, J. M., Dingley, A. A., Chapman, D. W., & Spratford, W. (2012). Lower extremity kinematics and kinetics when landing from unloaded and loaded jumps. Journal of applied biomechanics, 28(6), 687-693.
Myers, C. A., Torry, M. R., Peterson, D. S., Shelburne, K. B., Giphart, J. E., Krong, J. P., Steadman, J. R. (2011). Measurements of tibiofemoral kinematics during soft and stiff drop landings using biplane fluoroscopy. The American journal of sports medicine, 39(8), 1714-1722. doi:10.1177/0363546511404922
Silva, R. S., Ferreira, A. L. G., Nakagawa, T. H., Santos, J. E., & Serrão, F. V. (2015). Rehabilitation of patellar tendinopathy using hip extensor strengthening and landing-strategy modification: case report with 6-month follow-up. Journal of Orthopaedic & Sports Physical Therapy, 45(11), 899-909.
Slimani, M., Chamari, K., Miarka, B., Del Vecchio, F. B., & Chéour, F. (2016). Effects of plyometric training on physical fitness in team sport athletes: a systematic review. Journal of human kinetics, 53, 231.
Suchomel, T. J., Taber, C. B., & Wright, G. A. (2016). Jump shrug height and landing forces across various loads. International journal of sports physiology and performance, 11(1), 61-65.
Van der Worp, H., de Poel, H. J., Diercks, R. L., Van Den Akker-Scheek, I., & Zwerver, J. (2014). Jumper's knee or lander's knee? A systematic review of the relation between jump biomechanics and patellar tendinopathy. Int J Sports Med, 35(8), 714-722.
Vaverka, F., Jakubsova, Z., Jandacka, D., Zahradnik, D., Farana, R., Uchytil, J., Vodicar, J. (2013). The influence of an additional load on time and force changes in the ground reaction force during the countermovement vertical jump. Journal of human kinetics, 38, 191.
Zwerver, J., Bredeweg, S. W., & van den Akker-Scheek, I. (2011). Prevalence of Jumper's knee among nonelite athletes from different sports: a cross-sectional survey. The American journal of sports medicine, 39(9), 1984-1988.