Contribution of the lower limb joints in difference of power output from rebound jump

Shingo hondo[1], Ikuhiro Miyauchi [1],Itsuo Kawaguchi[2], Kiyohide Aoyama[1]

Nihon university[1]
Graduate School of Literature and Social Science, Nihon University[2]

This study aimed to perform kinetic analyses of joint movements during rebound jumps and reveal the individual power-output contributions of lower-limb joints. The subjects included 21 male students who were members of a track and field club. Initially, each attempt was considering to comprise five consecutive rebound jumps at six subjective levels of maximum effort: 100%, 90%, 80%, 60%, 45%, and 30%. The subjects performed each attempt twice, and the sequence of attempts was randomized. However, because the subjective effort levels were inconsistent among subjects in the initial analysis, we asked the subjects to attempt rebound jumps to reach at 90%, 80%, and 70% of their maximum jumping heights (100%). Our results demonstrated that the degree of contribution was the greatest at the ankle joint for any level of output within the ranges used in this study.

KEY WORDS: plyometric–training, mechanical work, joint torque power

INTRODUCTION: Under various sports-related circumstances, athletes are often required to bring their full power output into play for a very short period. Because such ability is considered different from that of exerting power over long periods, specialized training is required to demonstrate full power for short periods. Plyometric training is a method used to achieve this effect. Many studies have analyzed drop jumps—a common in plyometric training exercise—from several standpoints (Bobbert et al., 1987a,b).

In addition, many other studies have reported on rebound jumps—which are exercises similar to drop jumps—from several standpoints (Endo et al., 2007; Kariyama et al., 2013). Although rebound jumps are easier to perform than other exercises in plyometric training, no study has discussed the dynamics of the difference in the power-output levels for rebound jumps performed by the same subject. In addition, efficient ways of demonstrating power use of a human body have not been studied in detail. The differences in power-output levels could be used as an index to conduct more efficient jump trainings. Considering this background, this study aimed to perform kinetic analyses of difference in power-output levels during rebound jumps so as to reveal the individual contributions of the various lower-limb joints.

METHODS: The subjects included 21 male students (age, 20.66 ± 0.85 years; height, 179.59 ± 6.39 cm; body weight, 81.71 ± 15.15 kg) who were members of a track and field club. Nine subjects specialized in jumping and 12 specialized in throwing. Before the experiment, the subjects were provided written and verbal explanations regarding the study aims and methods, along with written explanations concerning the safety and dangers accompanying the experiment. Subjects then provided written informed consent for study participation. An attempt consisted of five consecutive rebound jumps above the ground at six subjective effort levels (i.e., subjects themselves controlled the power output): 100%, 90%, 80%, 60%, 45%, and 30%. The subjects performed each attempt twice, and the sequence of attempts was randomized. During an attempt, they were required to wear shoes and place their hands on their waists so as to avoid using the leverage of arm swing. In addition, subjects were requested to rest sufficiently between attempts or before restarting attempts because of an invalid start. As reported previously, we filmed the subjects performing rebound jumps on the force platform (Kistler product) from a spot that was 5-m away from their right side. We used a high-speed camera GC-P100 (JVCKENWOOD; 300 fps) for the same. In addition, we installed calibration markers at a distance of 1 m toward the right, left, front, and back, and filmed to later covert the true length.

In addition to these videos, we obtained images using a motion-analysis system (Frame-DIASV; DKH) at a 100-Hz sampling frequency. We obtained the position coordinates of the bilateral toes, thenar eminencess, heels, malleoli, knee joints, greater trochanters, and acromions; four calibration markers were obtained in the images for all valid attempts. The converted true lengths were based on the position coordinates of these calibration markers. The calculated two-dimensional coordinates determined the optimum cutoff frequency for each analysis point by using the Wells and Winter (1980) method; the coordinate data was smoothed with a Butterworth low-pass digital filter. The optimum cutoff frequency was 2–9Hz. On the basis of the smoothed coordinate data, we made a rigid whole-body link-segment model consisting of four segments: trunk, thighs, lower thighs, and feet. We also calculated the moment of the hip, knee, and ankle joints. The mass-centered position coordinates, the mass, and the inertia moment of each segment were computed using the body-part coefficient of inertia by Ae et al. (1992). With regard to mechanical work and contribution, we used the calculation method by Ae et al. (1994) for reference, and computed the mechanical work from the joint moment, by subtracting the negative work from positive work. We considered the sum of absolute values of both as absolute work, and calculated the relative contribution by dividing each joint's work by the absolute work.

RESULTS: The relative values of jumping height in the attempt of each subject's effort towards the maximum jumping height were as follows: 57.80% ± 14.19% for attempts with 30% subjective effort, 66.18% ± 10.87% for attempts with 45% subjective effort, 72.84% ± 10.95% for attempts with 60% subjective effort, and 82.61% ± 9.73% for attempts with 80% subjective effort. Thus, a tendency of excessive output over the established effort up to the subjective effort of 80% was observed. However, for 90% subjective effort, a relative value below the maximum subjective effort was established as 85.93% ± 10.71%. Therefore, instead of focusing on the subjective effort, we focused on relative values of jumping height. Thus, for examining the effect on contribution of each part of the lower limb according to the variance of jumping height, we selected the attempt in which the maximum jumping height was achieved (attempt of 100%(support time(s):0.20±0.04)), along with the attempts that obtained relative values nearly 90%, 80%, and 70%. The average value of the relative values of jumping height on each attempt were 89.52% ± 2.74%(support time(s):0.19 ± 0.03) for attempts of 90% maximum height, 79.66% ± 2.18% (support time(s):0.20±0.03) for attempts of 80% maximum height, and 70.08% ± 2.37%(support time(s):0.21±0.03) for attempts of 70% maximum height. Figure 1 shows the changes in torque and torque power at each lower-limb joint after standardizing the time from the takeoff point to the landing point in each attempt as 100%. An analysis of variance (ANOVA) and multiple comparison tests were performed. The results demonstrated that at the ankle (ankle) joint, significant differences were observed between attempts in torques at 1%–7% (100% > 70%) and 11%–23% (11%–20%: 90%, 100% > 70%, 21%–23%: 100% > 70%). Significant differences were also observed in torque power between attempts at 3%–5% (100% > 70%), 11%–17% (100% > 70%), and 73%–82% (100% > 70%). For the hip joint, a significant difference was observed in torque power between attempts at 52%–64% (100% > 70%). For the knee joint, however, no significant difference was observed in both torque and torque power. Table 1 presents the mean values of the mechanical work of each lower-limb joint at takeoff in each attempt. A two-way ANOVA ($p < 0.05$) was performed for the amount of work at each lower-limb joint; the results demonstrated that no significant interaction was observed between two factors at any amount of work. Therefore, the main effect tests were performed for each factor; in positive work, significant main effects were observed at each lower-limb joint for each attempt. Multiple comparisons were performed afterward. In all attempts at 70%–100%, the effect was greater in the ankle joint than at the knee, hip, and lower-limb joint; in the ankle joint, the effect was greater at 100% height than at 70% height. In negative and absolute work, a significant difference was observed at each lower-limb joint.

The results of the multiple comparisons test showed that the effect was greater at the ankle and knee joints than at the hip joint during negative work. During absolute work, it was greater at the ankle joint than the knee joint, followed by that at the hip joint.

Table 2 presents the mean values of the degree of contribution for each lower-limb joint. A two-way ANOVA ($p < 0.05$) was performed to the degree of contribution of each lower-limb joint, and the results revealed that there was no significant interaction between these two factors. The main effect tests were therefore performed, and a significant difference was observed at each lower-limb joint. Then, multiple comparisons were performed; the degree of contribution in the attempts at 70% and 100% was greater at the ankle joint than at the knee joint, followed that at the hip joint. The degree of contribution in the attempts at 80% and 90% was greater at the ankle joint than at the knee and hip joints.

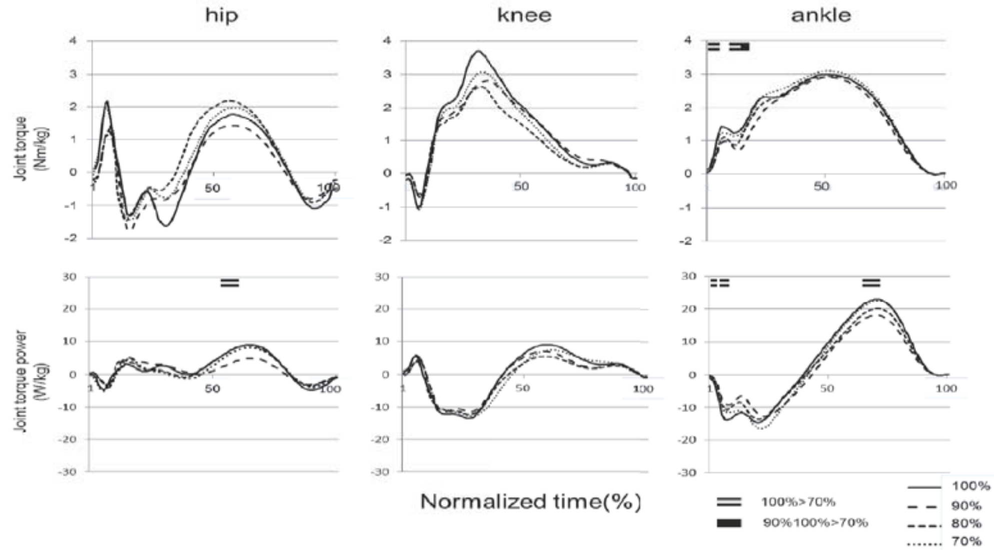

Figure 1 Averaged patterns of joint torque and joint torque power about the lower limb joint during takeoff phase .

Table 1 : The mean values of mechanical work(mean±SD) and two way-ANOVA results

postive work	lower limb joint									
relative values(%)	hip			knee			ankle			difference
70%	0.52	±	0.33	0.58	±	0.34	1.15	±	0.26	ankle>knee,hip
80%	0.65	±	0.38	0.43	±	0.20	1.24	±	0.29	
90%	0.62	±	0.44	0.55	±	0.38	1.36	±	0.37	
100%	0.72	±	0.51	0.69	±	0.27	1.42	±	0.30	
difference	ns			ns			100%>70%			ns:non significant
negative work	lower limb joint									
relative values(%)	hip			knee			ankle			difference
70%	-0.22	±	0.13	-0.75	±	0.42	-0.70	±	0.25	ankle,knee>hip
80%	-0.23	±	0.15	-0.67	±	0.32	-0.67	±	0.25	
90%	-0.30	±	0.16	-0.65	±	0.34	-0.81	±	0.32	
100%	-0.31	±	0.18	-0.73	±	0.43	-0.75	±	0.26	
difference	ns			ns			ns			ns:non significant
abusolute work	lower limb joint									
relative values(%)	hip			knee			ankle			difference
70%	0.74	±	0.42	1.34	±	0.64	1.85	±	0.43	ankle>knee>hip
80%	0.88	±	0.47	1.10	±	0.43	1.92	±	0.48	
90%	0.92	±	0.49	1.20	±	0.49	2.17	±	0.63	
100%	1.03	±	0.64	1.42	±	0.55	2.17	±	0.48	
difference	ns			ns			ns			ns:non significant

Table2 : The mean vales of the degree of contribution of each lower limb joint(mean±SD) and two way-ANOVA results

	lower limb joint									
relative values(%)	hip			knee			ankle			difference
70%	18.15	±	7.68	32.56	±	8.34	49.29	±	13.55	ankle>knee>hip
80%	21.57	±	9.73	27.86	±	6.95	50.57	±	12.42	ankle>knee,hip
90%	20.96	±	9.31	27.71	±	7.39	51.33	±	11.80	ankle>knee,hip
100%	21.55	±	9.87	29.87	±	6.60	48.58	±	11.55	ankle>knee>hip
difference	ns			ns			ns			ns:non significant

DISCUSSION: No significant difference was observed for any of the attempts, with regard to patterns of torque and torque power at each lower-limb joint. This suggested that the output of rebound jumps within the range of the relative value established in this study had a similar control mechanism.

Furthermore, the difference between the attempts was primarily observed during the first half of the takeoff phase. It was previously reported (Bobbert et al., 1987a,b) that negative power is produced by the eccentric muscle contraction at the ankle joint during the first half of the takeoff phase, absorbing the impact of the fall. Therefore, the difference between attempts in torque and torque power at the ankle joint during the first half of the takeoff phase was reflected precisely in the difference in the power produced at the ankle joint against the magnitude of impact, which appeared to depend on the jump height. In general, the amount of work imposed on the ankle joint at takeoff is greater than that on the other joints. Similar results have been obtained in a study (Zushi and Takamatu, 1995) of rebound drop jumps, which presents a similar pattern of performance.

Moreover, in this study, these tendencies did not seem to vary greatly according to the subjective efforts. In a study of various jump movements, Fukasiro, S. (1990) reported that the degree of contribution of the ankle joint is greater as jumps become more flexible. Similar results were obtained for rebound jumps in this study, and it was also found that the variation in outputs established was not large enough to affect the flexible movement patterns during rebound jumps. In conclusion, our findings indicate that the ankle joint plays a crucial role in the general takeoff, regardless of the magnitude of the outputs, during rebound jumps; this finding is similar to that observed in previous studies on flexible jumps.

CONCLUSION: It was demonstrated that the degree of contribution was the greatest at the ankle joint at any level of output within the range of the outputs established in this study. This indicates that the flexible movement of rebound jumps is not affected by a variation in the outputs within the range established in this study.

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