BIOMECHANICAL DIFFERENCES BETWEEN LOADED COUNTERMOVEMENT AND STATIC SQUAT JUMPS

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It was the aim of this study to assess differences between countermovement (CMJ) and static (SJ) unloaded and loaded squat jumps. Eight male national/international level athletes and badminton players performed a series of jumps on two Kistler force plates. Maximum vertical force (F_{max}) and rate of force development (RFD_{max}), net impulse (Imp_{net}) and vertical take-off velocity (V_{T-O}) were calculated and compared using a Two-Way (Jump x Load) ANOVA with two repeated factors. F_{max} increased significantly with load and displayed a significant interaction with jump type. RFD_{max} showed significant jump main and interaction effects. Imp_{net} only changed significantly with load. These results may lend credence to the spinal reflex or elastic energy theory of enhanced CMJ performance.

KEYWORDS: force, vertical jump

INTRODUCTION: Differences between countermovement (CMJ) and static squat jumps (SJ) have often been studied (Bobbert et al., 1988, Bobbert et al, 1996, Pandy et al, 1990), but there has been little research on the biomechanical effects of performing jumps with loaded weight bars. Researchers have investigated the effect of prior eccentric exercise on concentric movement performance, and there has also been research on the effect of external loading on these activities (Cronin et al, 2000). The improved performance in countermovement exercise has been attributed to a variety of sources; elastic energy storage and use, enhanced spinal reflex, pre-stretch changes in contractile elements, prior 'build-up' of force, and co-ordination (optimal control) differences (Bobbert et al, 1996).
There has been little research investigating the effects of increased external loading in these activities. However, this is an important area of research for two reasons. Firstly, the increased external loading may enhance differences between CMJ and SJ performance and thus make the underpinning mechanisms easier to detect. Secondly, loaded squat jumping exercises are common among athletes undergoing resistance training regimes to improve performance in sports such as field athletics, volleyball and badminton.
Therefore, it was the aim of this study to examine differences between CMJ and SJ performance in loaded and unloaded conditions.

METHODS: Eight male internationalists (mass = 79.6±13.8kg., age 26.4±5.8 yr., height 1.81±0.08 m.) from track and field athletics and badminton, (including one Olympic Gold Medallist and World Record Holder, and one European Championship winner) performed a series of countermovement and static jumps in unloaded and three loaded (40, 60, 80 kg.) conditions.
The loaded conditions utilized a bar and free weights (Eleiko Ltd, Sweden) and the unloaded jumps used a plastic pipe (mass < 1kg.). Subjects stood on two Kistler force plates (models 9261, 9281) and then squatted to a position with a knee joint angle of 90^o as measured by goniometry. This position was marked by using a wire at the subject's posterior mid-thigh level, so that during the jumps the subjects would be aware of the lowest position prior to upward movement. In the static jumps, subjects assumed the 90^0 knee angle position for a count of 3 s., and then were given the weight bar or pipe to place on their shoulders, after which they jumped as high as possible. In the countermovement condition, the subjects started standing upright with the bar/pipe, and then performed the lowering part of the countermovement until they felt the string, after which they again jumped as high as possible.
Data were collected for 3s. at 500Hz. using an Elonex PC computer running MIE Provec 5.0 Software, and were then smoothed at 30 Hz. using Butterworth 4th order reverse digital filter written in Microsoft Visual Basic 4.0. Data analysis was performed using Provec 5.0, a specially-

written program in Visual Basic 4.0 (to calculate impulse and rate of force development), Microsoft Excel 97 and SPSS for Windows 9.0.
The performance measure of the tests was the height jumped, measured from the time of flight ($s=½gt^2$, where t is total flight time/2). Other dependent variables were the Maximum force (F_{max}) during take-off, Maximum Rate of Force Development (RFD_{max}), and Net Impulse (Imp_{net})
Each dependent variable was statistically analysed with 2-Way ANOVA (Load x Jump) with 2 Repeated Measures, (α-level=0.05) with Greenhouse-Geiser epsilon adjustment where necessary.

RESULTS AND DISCUSSION: The CM vertical displacement (m) results are shown below.

Table 1 CM Vertical Displacements

Load	CMJ (Mean±SD)	SJ (Mean±SD)
0	0.381 ± 0.055	0.343 ± 0.040
40	0.250 ± 0.048	0.225 ± 0.035
60	0.194 ± 0.046	0.173 ± 0.036
80	0.149 ± 0.042	0.131 ± 0.031

The 2-way ANOVA showed significant main effects (Jump type, $F_{1,7}$=20.25, P=0.003, Load $F_{3,21}$=255.69, P<0.001) but no significant interaction between main effects. Table 2 shows the Maximum Vertical Force (F_{max}) results (N).

Table 2 Maximum Vertical Force

Load	CMJ (Mean ± SD)	SJ (Mean ± SD)
0	1937 ± 292	2006 ± 287
40	2295 ± 293	2318 ± 281
60	2457 ± 274	2470 ± 284
80	2638 ± 281	2590 ± 281

There was a significant Load main effect ($F_{3,21}$=270.80, P<0.001) and a significant interaction between main effects ($F_{3,21}$=8.98, P=0.004), but an insignificant Jump main effect.
The results for Maximum Rate of Force Development (RFD_{max}) are shown in Table 3. There was a significant main effect for Jump ($F_{1,7}$=29.60, P=0.001) and a significant interaction ($F_{3,21}$=6.34, P=0.02), but not for the load main effect.

Table 3 Maximum Rate of Force Development

Load	CMJ (Mean ± SD)	SJ (Mean ± SD)
0	10090 ± 4299	10014 ± 2750
40	9262 ± 2672	6528 ± 1240
60	11134 ± 4749	5201 ± 741
80	12026 ± 4236	5021 ± 1180

Finally, the Net Impulses showed a significant main effect for load ($F_{3,21}$=7.54, P=0.003), but not for the jump type or for the interaction between load and jump.

Table 4 Net Impulses

Load	CMJ (Mean ± SD)	SJ (Mean ± SD)
0	209.7 ± 38.4	209.5 ± 47.5
40	244.4 ± 32.5	247.0 ± 41.6
60	246.5 ± 42.5	225.4 ± 67.1
80	237.4 ± 56.7	230.7 ± 62.9

The results for the unloaded jump heights are in agreement with those of Bobbert et al (1996), who found an increase of approximately 9% in CMJ (0.362m. and 0.328m. for CMJ and SJ respectively). This is mirrored by an increase in the present study of 10% for the unloaded conditions, and by increases of 10%, 11% and 12% for the loaded conditions of 40, 60 and 80 kg.

It was therefore necessary to investigate changes in the other dependent variables. The F_{max} values showed an increase with load, but no differences between jump types. It may have been useful to 'normalise' the F_{max} results (for example by dividing by body and bar weight), but simple approaches to this are fraught with problems (Neville et al, 1991). Also, as the bar weights were the same for CMJ and SJ, there would still have been no significant differences between the two jumps.

The values for rate of force development were interesting. In the CMJ, RFD_{max} was maintained (and even increased slightly) as the load on the bar increased. However, in SJ this was not observed, and the RFD_{max} decreased greatly with increasing load. This result would seem to lend credence to the importance of maintaining *speed* of contraction at higher loads in CMJ, rather than the actual forces (F_{max}) themselves. This would support the elastic energy or spinal reflex theories of improved CMJ performance, rather than those concerned with the prior 'build-up of force'. (Bobbert et al, 1996)

The net impulses showed a 'plateau' effect with higher loading, even though there was a significant load main effect. This would suggest that there was a maximum force-time integral that a subject could produce, and with higher loads, this did not increase. Why this should be so is not currently clear in terms of muscle mechanics.

In conclusion, the differences in jump performance between CMJ and SJ have again been demonstrated. Impulse values showed an optimal value, above which results decreased, and this needs further investigation. Our results for RFD_{max} appeared to support theories that emphasize speed of contraction, and not simply increased force production, as the underlying cause of performance differences between the two jump types. This has important implications for the planning of resistance training.

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