INFLUENCE OF JUMPING STRATEGY ON KINETIC AND KINEMATIC VARIABLES

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Abstract

Aim: Different jumping strategies can be used during plyometric training. Understanding how manipulating variables such as the counter-movement, flexion amplitude, the drop and the load could influence neuromuscular adaptation would be beneficial for coaches and athletes. The purpose of this study was to analyze how these variations in the vertical jump influenced kinematic and kinetic parameters as measured by a force platform.

Methods: Ten male subjects performed, eight kinds of vertical jumps on a force platform : (1) squat jump (SJ); (2) shallow counter-movement jump (S-CMJ); (3) natural counter-movement jump (N-CMJ); (4) deep counter-movement jump (D-CMJ); (5) loaded (20kg) counter-movement jump (20-CMJ); (6) shallow drop jump (S-DJ); (7) deep drop jump (D-DJ); (8) six consecutive jump test (6CJ). Customised Labview software was used to calculate time, displacement, velocity, acceleration, force, power, impulse and stiffness. After statistical analysis, jumping variables were grouped to achieve spécific training objectives.

Results: The mechanical parameters were largely influenced by the jump strategy, all the deep jumps produced superior jump heights and concentric velocities as compared to the shallow jumps. The exercises associated with greater power outputs were the S-DJ (5386±1095w) and 6CJ (5795±1365w) that involved short impulse durations and very high accelerations. The greatest values of muscle stiffness were not recorded during the highest vertical jumps, meaning that stiffness is not critical for jumping high.

Conclusion: This study gives an overview of what is changing when we manipulate jumping variables and instructions given to the athletes. Plyometric exercises should be carefully selected according to the sport and specific individual needs.

Key words : vertical jump, biomechanics, plyometrics, instruction, training

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Introduction

It is widely accepted that plyometric type training is beneficial for developing explosive power. As a consequence, over the last few decades, plyometrics has become a particularly common and accepted form of training utilized by athletes seeking to improve their muscular power and jumping ability (1-3). While vertical jump exercises are the most widely used, there is a large variety of exercises available to the strength and conditioning practitioner. Given that the choice of exercise and the strategy used during the vertical jump can result in very different neuromuscular patterns and outputs, it would seem prudent to understand how different variables influence the kinematic and kinetic outputs of respective exercises. Such information would assist in the streamlining of assessment and programming in relation to the individual needs of an athlete, activity and/or sporting event.

Researchers have compared concentric squat jumps (SJ) to counter-movement jumps (CMJ) and observed that the use of a muscular pre-stretch improved subsequent concentric performance and consequently jumping height by 10-20% (4-8). This eccentric-concentric coupling is known as the "stretch-shorten cycle", is implicated in plyometric training and the stretch augmentation can be explained by the product of different physiological mechanisms such as recoil of elastic energy, spinal reflex activity, muscle pre-activation and favorable muscle- tendon configuration (9-12).

Drop jumps (DJ) are among the more widely used exercises selected for plyometric training. Early Soviet research (Verhoshanski, cited by (3)) concluded that drop jumps, by emphasizing the stretch-shorten cycle and eccentric loading which could have a positive influence on concentric work, were an effective method for improving strength power capabilities. During the seventies, several researches have clearly highlighted that different heights for drop jump training resulted in different performance enhancement (4, 7, 8). Since these seminal studies, several studies have investigated the biomechanics associated with drop jumps from different drop heights (13-15) and from different jumping strategies (16, 17). For example, Moran and Wallace (17) have demonstrated that for a given drop jump height, a change in knee flexion had significant consequences on both kinetic and kinematic variables. In fact, knee flexion amplitude was a critical variable that influenced jump height in all vertical jumps (SJ, CMJ and DJ) (18). Bobbert et al. (18) have simulated biomechanical models for squat jumps and confirmed that knee flexion amplitude influences subject acceleration and take-off velocity. The level of knee flexion during plyometric exercise also appears to influence the rate of force development (19). As reported by various researches (13, 16, 20), the instruction during plyometric training is also critical. For example, Young et al. (20) have shown that when instruction was to achieve absolute height regardless of ground contact time, DJ and CMJ performance were similar. By contrast, when contact time had to be reduced as much as possible, DJ performance was different when compared with the CMJ.

Using additional weight during plyometric training is a wide utilised method that aims to improve the work performed by the muscle. Researchers have profiled the load-power relationship for squat jumping and contradictory to most coach's thoughts, maximal power output was observe at very low loads (21-23). Whilst a great deal of research has investigated the power-load relationship (21-23) the mechanical profile and hence mechanical advantage of loaded jumps has not been compared to other plyometric activities.

From this brief treatise of the literature, it is obvious that there are many jump types and variables that can be used for the training of athletes. That is, jump training can occur with or without counter movement, dropping from height, with additional loads, with short or ample knee angle flexion, and so on. Each kind of jump will offer unique and different mechanical stimuli, which with repeated application will lead to specific neuromuscular adaptation. With this in mind careful selection of exercises and instruction is fundamental to optimize sport specific and individual needs. For example, drop jump exercises may optimize performance in sports that require rebounds and high eccentric muscle contractions as in athletic jumps, gymnastics and basketball. CMJ exercises on the other hand may be best suited for sports involving high vertical jumps and change of direction as in soccer, volley-ball, basket ball, ski jumping or diving. It is therefore important to understand how each of these jumps differ in terms of the mechanical output they offer and how jump training can be conducted in order to accentuate certain training objectives e.g. eccentric, braking phase, stiffness, high concentric power outputs, and so on.

A review of the literature has shown that most investigations have focused on one or two jumping variables within their research paradigm. Consequently, comparisons between descriptive data of the jump variables between studies is problematic given the differences in protocols, subject gender and training status, technology and data analysis procedures, etc. Comparing the mechanical characteristics of a number of jump types in one study would address these limitations and provide valuable information to the strength and conditioning coach. Consequently, the aim of this study was to compare the mechanical characteristics of different vertical jump variables (e.g. influence of the counter-movement, the influence of flexion amplitude, the influence of the drop and the influence of load). This study should lead to a better understanding of differential adaptation when certain variables are manipulated via jump type and instructions given to the athletes. With such understanding, coaches should be better able to prescribe exercise in accordance with the specific training objectives/needs of the individual and/or sport.

Material and methods

Subjects

Ten male subjects, participated in this study (age: 26±4 years; height: 1.80±0.05 m; mass: 77±9 kg). All had a recreational sports background, and were free from injury. The subjects were informed about the potential risks involved with participating in the study and gave their written consent. The experimental procedures were approved by the Ethical Committee of the University of Liege.

Equipment

A force platform (Kistler, type 928A11, Switzerland) was used to measure the vertical component of the ground reaction force during each jump. The signal was collected at 500Hz via an acquisition card (type ATMIO16, National Instrument) driven by specific software (Daqware, National Instrument).

Procedures

Subjects had to refrain from strenuous physical activity for 24 h prior to the testing session. They were instructed to wear their usual training shoes. After a standardized warm-up, all subjects performed, in a randomized order, eight kinds of vertical jumps on the force platform: (1) squat jump (SJ); (2) short counter-movement jump (S-CMJ); (3) natural counter-movement jump (N-CMJ); (4) deep counter-movement jump (D-CMJ); (5) loaded (20kg) counter-movement jump (20-CMJ); (6) short drop jump (S-DJ); (7) deep drop jump (D-DJ); and, (8) six consecutive jumps (6CJ). Jump order was randomized to prevent any order and fatigue effects with the exception of the six consecutive jump test (6CJ), which was the last test to be performed. All jumps were repeated for three trials with one-minute inter-trial rest periods, except for the 6CJ where two minutes rest was taken. Three minutes rest was allocated between the different jumps. Before each jump, the subjects were issued standardized and specific instructions according to the details listed in Table 1.

Table 1. Standardized and specific instructions addressed to the subjects for each jumping modality.

Jump	Instruction
Squat Jump (SJ)	"Start with a 90° knee flexion and jump as high as possible without any counter-movement"
Short counter-movement jump (S-CMJ)	"Jump as high as possible with a shallow and quick counter-movement"
Natural counter-movement jump (N-CMJ)	"Jump as high as possible with a natural (self-selected) counter-movement"
Deep counter-movement jump (D-CMJ)	"Jump as high as possible with a deep and fast counter-movement"
Loaded (20kg) counter-movement jump (20-CMJ)	"Jump as high as possible with a natural (self-selected) counter-movement"
Short drop jump (S-DJ)	"Start on the box, step off, when you touch the ground jump as high as possible with minimal ground contact time, and very little knee flexion"
Deep drop jump (D-DJ)	"Start on the box, step off, when you touch the ground jump as high as possible with a long ground contact time a deep knee flexion"
Six consecutive jump test (6CJ)	"Execute 6 consecutive maximal jumps with minimal ground contact time"

Data Analysis

The vertical component of the force signal was thereafter analyzed using customized softwares (Labview 8.5, National Instrument, USA) specifically developed for the jump analysis, the software calculating the variables of interest. Center of mass vertical acceleration was directly measured from the force signal by using the following formula:

Acceleration = (force/mass)-9.81

A single integral of the acceleration signal was used to obtain vertical velocity (V) and a double integral was used to determine vertical displacement (D). The vertical power output was determined from the product of the force and velocity signals. As recommended by other authors (24), subjects were instructed not to move just before and just after each jump for one second in order to record with the force plate a flat signal at the beginning and at the end of each test. Such instructions were very important in order to adjust for possible signal drift that can be observed after a single and double integration. Signal drift was automatically corrected by the Labview software.

An example of a record obtained from the platform during a CMJ can be observed in Figure 1. Four different phases can be identified (eccentric-flexion, concentric-extension, flight and landing). The eccentric flexion phase (all jumps except SJ) included a lightening sub-phase where agonist muscles relax during initial flexion (except for D-DJ, S-DJ and 6CJ) and a braking sub-phase where agonist muscles start the braking contraction. The ground contact time (GCtime) can be split into three parts: lightening time (Ltime); braking time (Btime) and concentric time (Ctime). Ltime corresponds to the initial part of knee flexion during which the ground reaction force (GRF) is below the body mass force. Btime corresponds to the

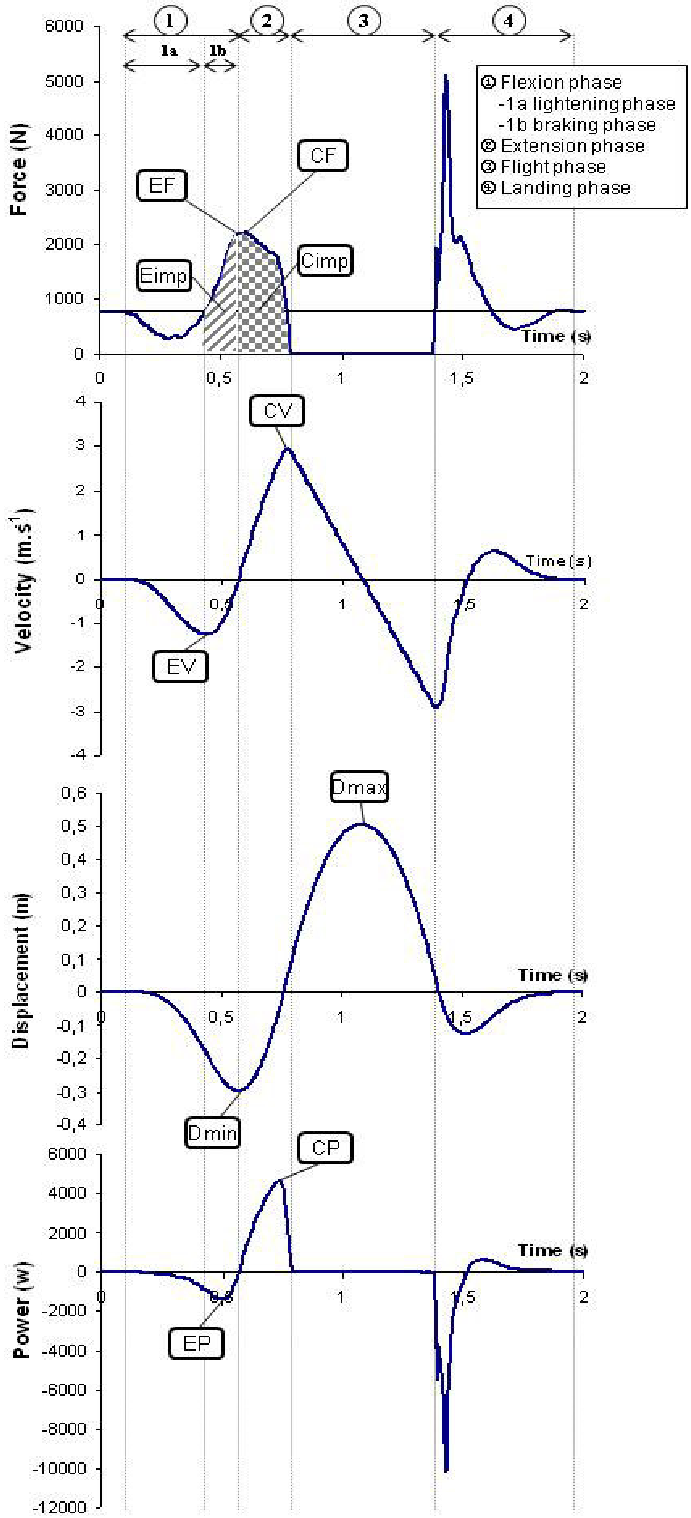

Figure 1. Force-time (a), velocity-time (b), displacement-time (c) and power-time (d) curves for a counter-movement jump with phase identifications and selected parameters.

part of eccentric flexion during which GRF is over the body mass force (24). Because of movement characteristics, Btime is not present in the SJ and Ltime is not present in SJ, S-DJ, D-DJ and 6-CJ.

Center of mass at lowest position (Dmin), eccentric peak force (EF), eccentric peak velocity (EV), and eccentric peak power (EP) were determined during the flexion phase of the jump. In this phase, eccentric impulse (Eimp) was established as the area under force curve during the braking sub-phase. Concentric peak force (CF), concentric peak velocity (CV), and concentric peak power (CP) were determined during the extension phase of the jump. The concentric impulse (Cimp) corresponded to the area under the force curve during the extension phase. Total impulse (Timp) is the sum of Cimp and Eimp. Jump height (Dmax) corresponds to the center of mass peak position during the flight phase, and was calculated from the flight time. The leg stiffness (Stif) of the jump was also measured. Leg stiffness distinguishes the ratio between peak ground reaction force and peak center of mass displacement (25). In the present study stiffness was measured at maximal center of mass lowering using the following equation: Stif = F/Dmin, where F represents the force at Dmin.

Statistical Analysis

Means and standard deviations were employed throughout as measures of centrality and spread of data. Shapiro-Wilk test was used to test for normality. Ten out of 136 comparisons (17 parameters x 8 modalities), concerning 7 different parameters, were not normally distributed. . For these comparisons, Friedman repeated measures were used to determine significant differences. Wilcoxon test was then used to determine significant differences between the jumps. For the other comparisons, a repeated measures analysis of variance

(ANOVA) and Tukey post hoc comparisons were used to determine differences between jumping strategies. The statistical significance was set at an alpha level of p≤0.05.

Results

The influence of jumping strategy was found to significantly (p≤0.05) influence many of the variables of interest in this study. As similarities were less frequent than differences and in order to avoid data/analysis overload, the same letter has been used to denote when different jumping modalities are identical for a given parameter. As a consequence all variables with the same letter were not statistically different and due to the large number of comparisons and differences only the more important findings are discussed herewith.

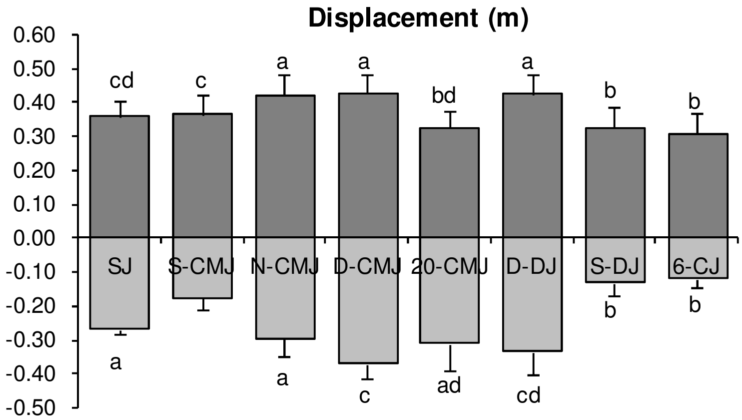

Figure 2. Mean (±SD) maximal displacement (Dmax) and minimal displacement (Dmin) of the centered mass(CM) in different jump conditions. Mean±SD.

It can be observed from Figure 2 that jump height was statistically greater in three jump conditions: N-CMJ (0.42±0.06 m), D-CMJ (0.43±0.05 m) and D-DJ (0.42±0.06 m), although these three jumps were not significantly different from each other. The lowest jump heights were observed in 20-CMJ (0.32±0.05 m), S-DJ (0.32±0.06m) and 6CJ (0.31±0.06 m). Dmin was influenced by the jumping strategy with deepest flexion observed in D-CMJ and D-DJ and the shallowest flexion observed for S-DJ and 6CJ.

The greatest concentric velocity (see Figure 3) was observed in the N-CMJ (2.79±0.19 m.s^{-1}), D-CMJ (2.80±0.17 m.s^{-1}) and D-DJ (2.78±0.17 m.s^{-1}) while the lowest velocity (<2.5m.s^{-1}) was noted for the 20-CMJ, S-DJ and 6CJ. EV was independent from CV. The hierarchy was as follow: 6CJ (-2.39±0.19 m.s^{-1}). < D-DJ (-1.90±0.35m.s^{-1}) and S-DJ (-1.85±0.23m.s^{-1}) < N-CMJ and D-CMJ < S-CMJ and 20-CMJ ($p<0.05$).

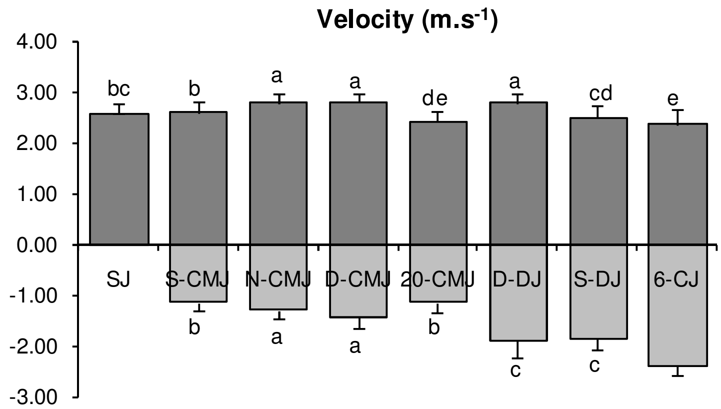

Figure 3. Mean (±SD) peak concentric velocity (CV) and peak eccentric velocity (EV) for the different jump conditions.

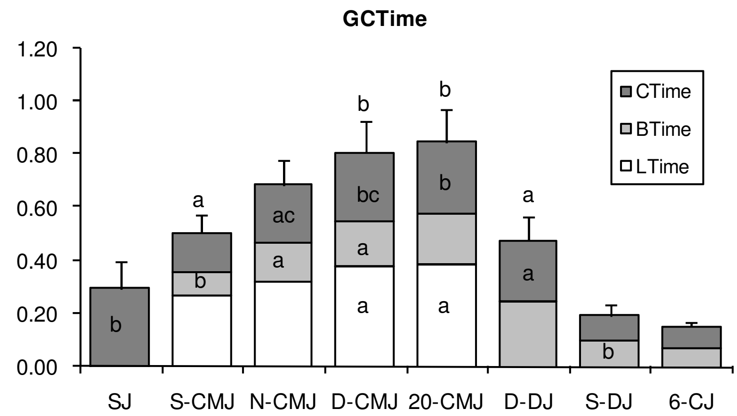

Figure 4. Mean (±SD) lightening (Ltime), braking (Btime) and concentric (Ctime) phase time in different jump conditions.

Ground contact time (Ltime+Btime+Ctime) for the D-CMJ (0.81±0.12 s) and 20-CMJ (0.84±0.12 s) was more than four times greater than the S-DJ (0.19±0.05 s) and 6CJ (0.15±0.02 s) – see Figure 4. Btime was shorter in 6CJ (0.07±0.01 s), S-DJ (0.10±0.03 s) and

S-CMJ (0.09±0.01 s) and longer for the D-DJ (0.25±0.06 s) and 20-CMJ (0.27±0.05 s). Ctime was the shortest in the 6CJ (0.08±0.01 s), followed by the S-DJ (0.1±0.02 s) and the S-CMJ (0.15±0.02 s). The longest Ctime ($p<0.05$) were recorded in SJ (0.30±0.10 s), D-CMJ (0.26±0.02 s) and 20-CMJ (0.27±0.05 s).

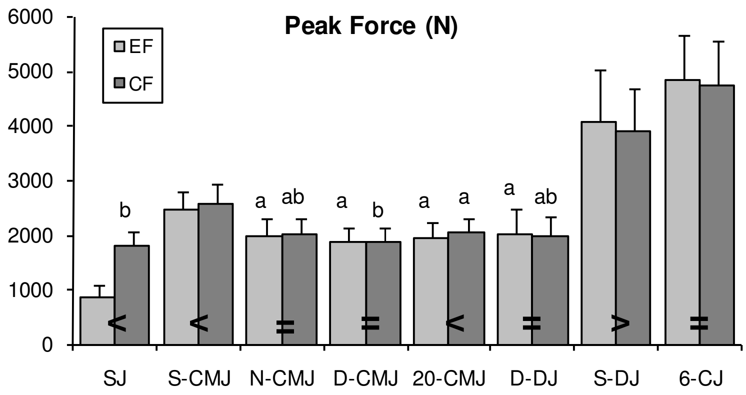

Figure 5. Mean (±SD) peak eccentric (EF) and concentric force (CF) for the different jump conditions. (< is indicated when CF is greater (p<0.05) than EF ; > is indicated when EF is greater (p<0.05) than CF ; and = is indicated when there is no significant difference between EF and CF).

Highest force development (>4000 N) can be observed in the 6CJ and S-DJ conditions (see Figure 5). By contrast, SJ, N-CMJ, D-CMJ, 20 CMJ and D-DJ were typified by substantially lower peak forces (<2100 N)($p<0.001$). S-CMJ (2579±349 N) resulted in the best PF of all the CMJs. Comparison between EF and CF revealed that CF was greater than EF in S-CMJ (+5%, $p<0.05$) and 20-CMJ (+4%, $p<0.05$), whereas in the S-DJ, the converse applied (-4%, $p<0.05$). For all other modalities, there were no significant differences between EF and CF.

Total impulse, which included Eimp and Cimp were greater (see Figure 6) in the loaded (20-CMJ; 782±130 N.s) and deep flexion exercises such as D-DJ (716± 99 N.s), D-CMJ (645±77 N.s) and N-CMJ (589±96 N.s). Eimp was the greatest for the D-DJ (329±49 N.s) while Cimp was the highest in the 20-CMJ (490±77N.s).

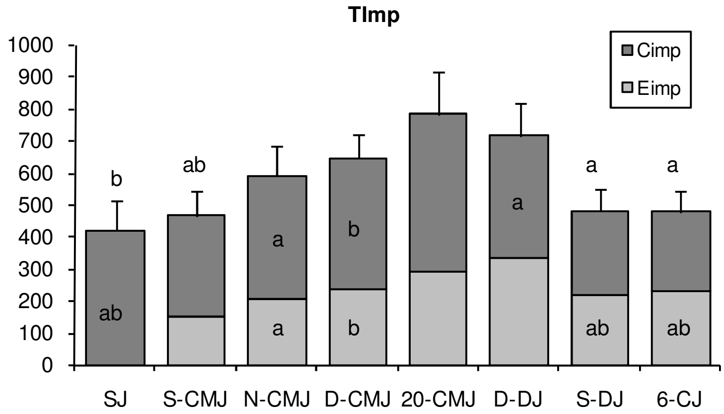

Figure 6. Mean (±SD) total impulse (Timp), represented as eccentric impulse (Eimp) and concentric impulse (Cimp) for the different jump conditions.

Eccentric power was similar ($p > 0.05$) for all CMJ modalities. Drop jump exercises and repeated jumps resulted in the greatest eccentric power: -3073±631 W for D-DJ; -4954±1416 W for S-DJ and -6354± 1126 W for 6CJ (Figure 7). Peak concentric power was the greatest in the S-DJ (5386±1095 W) and in 6CJ (5795±1365 W) conditions. Amongst the CMJ conditions, S-CMJ (4291±876 W) and N-CMJ (4121±640 W) resulted in superior concentric.

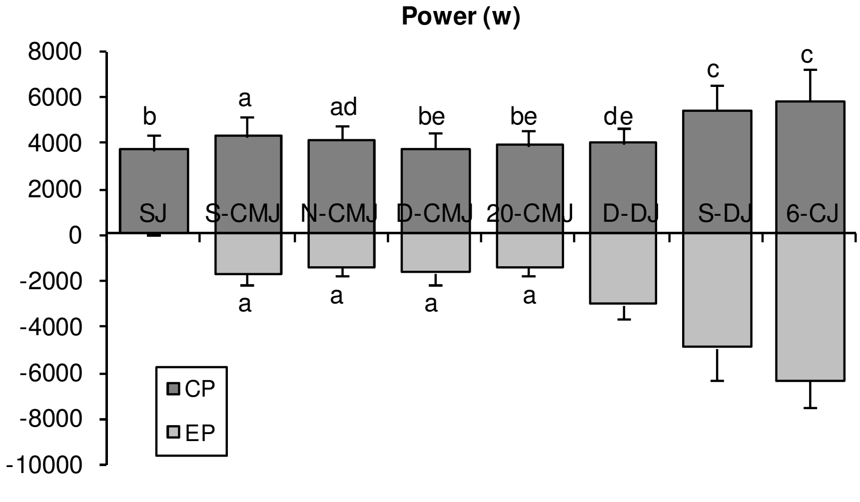

Figure 7. Mean (±SD) peak concentric power (CP) and peak eccentric power (EP) for the different jump conditions.

Stiffness (Figure 8) at Dmin was greatest in S-DJ (29343±12200 $N.m^{-1}$) and the 6CJ (38712±1378 $N.m^{-1}$). S-CMJ (13794±3624 $N.m^{-1}$) produced the greatest stiffness among all

CMJ conditions (<7000 N.m^{-1}). The comparison of the two DJ modalities revealed that stiffness was more than four time superior in S-DJ in comparison with D-DJ.

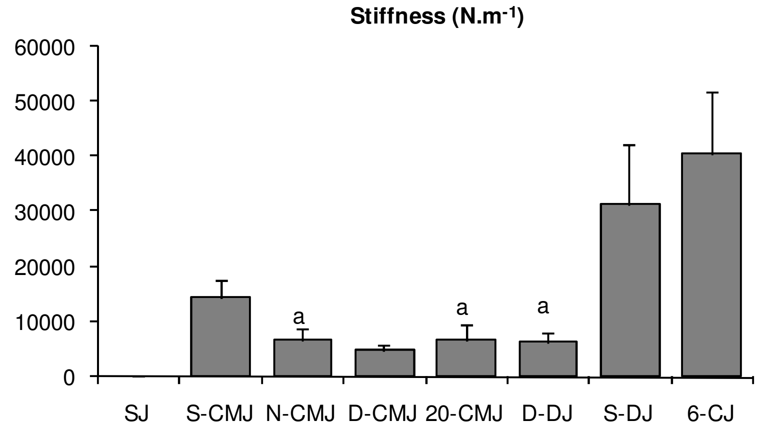

Figure 8. Mean (±SD) stiffness (Stif) for the different jump conditions.

Discussion

Many studies have investigated the various forms of vertical jumps (1, 15, 16, 18-20, 24, 26-30) highlighting how one or another variable may affect biomechanics and jumping performance. However, to the knowledge of the authors, this study is the first that has reported the kinetics and kinematics of a broad range of vertical jumps. It is well accepted that a counter-movement induces a muscular stretch improving subsequent concentric performance and consequently increasing jumping height, velocity, power and force (4-8). In the present study, the differences of ~16% between SJ and N-CMJ appeared quite high in comparison to previous research (8, 29-31) although some researchers have reported similar results (4, 17). While the use of counter-movement improved Dmax, CV and CP surprisingly it was not the case for either CF or Cimp. Such findings are in disagreement with Bobbert and Cassius who simulated the force-time curve for both CMJ and SJ, and reported that peak force was greater during the CMJ (32). However, recent literature has provided no evidence that peak concentric force is superior in the CMJ in comparison with the SJ (33-35). The greater jump height is attributed to the fact that the counter-movement allows the subject to attain greater force levels at the initiation of the concentric contraction (26), which does not necessarily coincide with the occurrence of peak force. It is interesting to note that Cimp was not significantly different between SJ and CMJ-N. These results may be surprising as impulse has been considered as an important determinant of take-off velocity given the impulse momentum relationship. However, Linthorne (36) and Reiser et al (37) reported that take-off velocity was not directly related to the Cimp but rather to the impulse due to subject center of mass acceleration ($Cimp_{cm}$ = m.a.Ctime) which corresponds to the difference between Cimp and the impulse due to the jumper's body weight ($Cimp_{bw}$ =m.g.Ctime) : $Cimp_{cm}$=Cimp - $Cimp_{bw}$. During a squat jump, $Cimp_{bw}$ is improved by the longer Ctime while $Cimp_{cm}$ is reduced by the lower acceleration level.

All the deep jumps (N-CMJ, D-CMJ and D-DJ) produced superior Dmax and CV as compared to the shallow jumps (S-CMJ, S-DJ and 6CJ). Our results support previous research findings that report an insufficient center of mass lowering (a combination of ankle, knee and hip flexion) leads to decreased jumping performance (17, 18). In fact, the jumps with shorter range of movement produced very short Ctime reducing concentric impulse and consequently velocity development which is necessary to jump high (37). Interestingly, an unnatural jumping strategy (D-CMJ) produced equal jump height to the N-CMJ. These findings are in agreement with recent studies (18, 19) demonstrating that the use of a deeper knee flexion than naturally selected did not reduce jump height in comparison with self-selected depth jumps. Consequently, it was not surprising to observe in our study that 5 out of 10 subjects jumped higher during the D-CMJ condition. Indeed, it has been demonstrated that when an appropriate coordination is adopted, using a deeper position may result in increased jump height than from the preferred position (18, 19). Coaches should be aware that in some athletes, using additional squat depth could lead to better jumping performance. While using deep squats is not recommended in some activities, such a strategy may be pertinent for some tasks and lead to improved performances. However, an excessive knee flexion in the squat may reduce performance because muscles may be taken beyond their optimal length (37).

Loading a counter-movement jump with 20 kg (20-CMJ) as expected reduced Dmax and CV, and increased ground contact time but interestingly, didn't produce greater peak forces than the unloaded jumps. Force is dependent on mass and acceleration and in the present countermovement context, the 20 kg increase in mass was countered by a corresponding decrease in acceleration. It was interesting to observe that in the 20-CMJ, CF was greater than EF ($p<0.05$). This phenomenon may be attributed to the lower velocity and acceleration observed during the eccentric phase in the 20-CMJ. It is possible that in order to preserve their muscles from any extreme eccentric loading and potential risk for injuries, subjects naturally adopted a jump strategy incorporating less velocity and acceleration during flexion.

Loading a CMJ with 20 kg induced longer movement (GCtime) which influenced the force-time curve and resulted in the highest Timp. Despite such high Timp, maximal velocity and jump height was reduced in the 20-CMJ in comparison with N-CMJ. As discussed previously, jumping performance does not depend on Timp but the difference between Timp and the impulse due to the subject's weight, that is 20 kg greater in the 20-CMJ jump condition. Despite the decreased eccentric and concentric velocities, loaded jumps appear to be an excellent exercise to solicit high force level in specific durations, and such the longer impulses associated with this jump may be important to improve activities such as the initial acceleration phase in the sprint and initiating a throw such as a shot put.

In the present study, CP was higher in the unloaded jump (N-CMJ) than the loaded jump (20-CMJ). These findings are in agreement with several reports on the load that maximizes power output (Pmax) in squat jumps (17-19, 21-23, 38, 39). For example, Cormie et al. (23) observed that Pmax was significantly superior at 0% than 12% of 1RM. We included body-mass in the equation for power (so-called 'system-mass'). Not doing so causes a substantial shift in Pmax toward the heavier end of the load spectrum and causes a proportionally larger error in calculation of power at lighter loads (38). It was also demonstrated that the more powerful exercises were the S-DJ and 6CJ that involved short and very high acceleration levels. In contrast, a large range of motion seemed to decrease power development, as demonstrated by the lower force and power production during D-DJ and D-CMJ in comparison with S-DJ and D-CMJ respectively. The results are in agreement with the research of Bobbert at al.(1) that has found that the subjects making a drop jump of small amplitude presented higher force and power output in comparison with those who were making a drop jump with a large amplitude. Such finding indicates that vertical jump performance and peak power output are not necessarily linked. According to previous research, power output is largely influenced by the jumping strategy and could not be accurately predicted from a single assessment of vertical jump height (40). Obviously, in a given jumping modality, the power output is related with jump height and improvement in power should lead to an improvement in jumping performance (28).

With regards to the eccentric phase it appears that eccentric loading (EF) is emphasized by short impulse time jumps (S-CMJ, S-DJ and 6CJ). In these modalities, the high landing negative velocity (corresponding to EV) and the short flexion level involved an enhanced braking action leading to a very high rate of eccentric force development. These findings are in agreement with other studies (14, 17, 31, 41) and underlines the importance of such exercises for loading the eccentric phase and improving eccentric braking action. However, as demonstrated by the works of Moran and Wallace (17), Lin et al (41) and Walsh et al. (16), the knee flexion amplitude appears to be the critical determinant for eccentric loading intensity. In comparison with large amplitude stretch drop jumps, short-range stretch drop jumps lead to greater peak force and acceleration during both concentric and eccentric phases. By contrast, as discussed above, the more intense S-DJ lead to lower jumping performance, reinforcing the theory that absolute force and power development are not directly linked to jump height. As reported by other researchers, drop jumps enhance eccentric loading and peak force levels, but do not necessarily produce greater jump heights than CMJ when range of knee flexion is comparable (1, 8, 17, 31, 33).

Stiffness has been reported to be a key determinant of sport performance, especially in high power tasks like jumping and sprinting (42-44). Our results showed that this parameter is highly dependent on the jumping strategy. Interestingly, greatest stiffness values were not recorded during the highest vertical jumps.. These findings are not surprising as the highest jumps are the deepest ones. A study of Arampatzis et al. (13) has demonstrated that the same jumping performance can be achieved with different level of leg stiffness. A decrease in stiffness is counterbalanced by a proportional increase in the GCT. These results are in accordance with those of Hobara et al. (45) who have demonstrated that leg stiffness increased with hopping frequency. Stiffness appears to be critical to the rate of eccentric force development (46) and in maintaining a positive energy balance (33), which are key points for short duration and high impulse activities encountered in several sporting contexts like sprinting, athletics jumping, bounding or changing direction.

This study demonstrated that kinematic and kinetic outputs are largely influenced by the style of jump. However, in most cases, coaches use a wide range of plyometric jumping exercises in order to improve lower limb function without making any distinction between the distinctive neuromuscular stresses and subsequent benefits that particular exercises provide. Different training objectives can be defined: (1) jumping high is important for all sport that required to jump as high as possible like in basket ball, volley ball or athletics jumps; (2) muscle stiffness has to be emphasized in all the sports where limb deformation at ground impact has to be reduced like in sprinting or athletic jumps; (3) impulse is a training objective for all sport activities that require the development of a high level of force during a long lasting impulse like in weightlifting or in rowing; (4) the development of maximum power output remains an important training objective for many sports and it is important to know the jumping exercises that maximize power output; (5) eccentric loading appears to be important in all sports that required high level of eccentric force, either to avoid limb deformation at impact (rebounding, athletic jumps), or to ensure safe braking action (basket ball, ski jumping). A classification of the vertical jump exercises in accordance with these five specific training objectives (jumping high, muscle stiffness, impulse, eccentric loading, and maximal power) is represented in the Table 2. This table can be used to inform the practitioner how jumping variables may be manipulated in order to achieve a training objective.

Table 2. Classification of jumping exercise according to a specific training objective.

	Jumping performance	**Stiffness**	**Impulse**	**Eccentric loading**	**Power**
Categories	**Depth jumps**	**Short impulse jumps**	**Depth and loaded jumps**	**Drop and continuous jumps**	**Short impulse and natural jumps**
SJ	**V**		**V**		
S-CMJ		**V**			**V**
N-CMJ	**V**		**V**		**V**
D-CMJ	**V**		**V**		
20-CMJ			**V**		
D-DJ	**V**		**V**	**V**	
S-DJ		**V**		**V**	**V**
6CJ		**V**		**V**	**V**

Conclusions

The present study has offered an original and complete comparison of the main vertical jump exercises used by coaches in the field. Different training objective may be achieved by manipulating variables like counter-movement, movement amplitude, drop jumping, and load. While knee flexion appears indispensable for jumping high, it has to be limited for stiffness development. Drop and repeated jumps have to be used for eccentric force development. Interestingly exercises that maximize power output were not necessarily loaded nor exercises that enabled superior jumping performance. Such understanding should improve programming and therefore adaptation and performance.

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