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Original Research Article

Differences in Vertical Performance Caused by Drop Jumping on Surfaces with Different Stiffness

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Abstract

It is well established that muscle activation regulates leg stiffness to optimize stretch shortening cycle (SSC) performance. There is a significant interaction between the surface properties, muscle activation and leg stiffness. The aim of this study was to examine the potentiating adjustments after drop jumps (DJs) executed on two surfaces with different elasticity. Twenty-two adults randomly performed 3 protocols: Protocols with three pre-conditioning DJs performed on a springboard (PSB), Protocol (PG) with three pre-conditioning DJs performed on a stiff ground surface and Protocol without any type of pre-conditioning (C). Vertical jump performance was evaluated at four time points: before (COND0), immediately after pre-conditioning (COND10), and after 1 (COND60) and 2 min (COND120) of rest. Dynamics, kinematics and electromyographic parameters of the ankle were evaluated. ANOVA with repeated measures revealed statistically significant increase in H_{peak}, P_{peak} and K_{leg} was observed ($p<0.05$), over split-intervals and rest periods for Protocol (PSB) while no differences were recorded in jump kinematics. Both protocols (PSB and PG) significantly decreased CI during the pre-activation and eccentric phase, whereas the CI was increased during the concentric phase. The positive effect observed in jump performance could not be attributed to co-activity of the ankle joint, indicating that jumping on an elastic surface, may be beneficial in cases where increased leg stiffness is a determining factor for final performance.

Keywords: Stretch shortening cycle, drop jumps, muscle activation, leg stiffness, springboard.

INTRODUCTION

The increased performance during SSC, relies on the use of the recoiled energy in the muscle tendon unit due the optimal stiffness and activation levels (Nicol C *et al.*, 2006). Pre programmed muscular activation, prior contact time, is responsible for the regulation of optimal stiffness to lead to an increased performance (Taube W *et al.*, 2012). Previous study (Arampatzis A *et al.*, 2004a) showed that leg stiffness is related with the pre-activation levels. Interestingly, pre-activation level was also shown to depend on the surfaces properties and the intensity of the movement. Taube *et al.*, (2012) suggested that muscle activation is highly adaptive to provide the balance between maximization of the performance and the protection of the injury. However, it is not clear whether jumping on a sprung surface as a pre-conditioning stimulus, could result in different muscle activation on subsequent fast SSC.

It has been previously shown that significant interaction between the surfaces properties and the jumping performance (Farley CT *et al.*, 1998), results in different muscle activation levels or patterns. Arampatzis *et al.*, (2001) showed that drop jumping on a sprung surface led to a greater jumping height due a greater positive to negative work ratio while Prieske *et al.*, (2013b) demonstrated that jumping on a foam pad resulted in lower jumping performance which accompanied by lower muscle activity of the legs. In contrast, there were no differences in muscle activation during counter movement jump on a stable and foam pad surfaces (Howard, J *et al.*, 2015). Previous study (Marquez G. *et al.*, 2014) supported these findings by reporting similar leg muscle activation during submaximal hopping on a spring floor. Moreover, it has been shown that the activity of Soleus increases during hopping on an inclined wooden surface, possibly because of the increased orientation demands (Kannas

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T *et al.*, 2011). Although muscle activation during drop jumps is highly dependent on the feedforward and feedback control (Taube W *et al.*, 2012), central nervous system adjust neural activation taking into consideration surface properties (Marquez G. *et al.*, 2014) and the task demands (Leukel C *et al.*, 2008a).

Leg stiffness is considered a crucial factor for the final performance of the SSC (Butler RJ *et al.*, 2003). The optimal level of stiffness could be achieved by the adjustment of the neural activation during the phases of SSC (Leukel C *et al.*, 2008b; Leukel C *et al.*, 2012). It was found that the duration of the pre-activation controls the leg and the joints stiffness as well as the ground reaction forces and the angular displacement (Arampatzis A *et al.*, 2001). Previous studies showed that by increasing dropping height, during the eccentric phase of the drop jump, both H-reflex and leg stiffness decrease as well (Taube W *et al.*, 2012; Marquez G *et al.*, 2014). Previously, Hobara *et al.*, (2007) has shown that leg stiffness was related to the preactivation and the braking phase during hopping. In contrast, they concluded that antagonist muscle's activity is not a crucial factor for the leg stiffness regulation. Although, leg stiffness adjustments during jumping on different surfaces have been previously described, it is not clear whether there is any difference in its regulation during drop jumping immediately after jumping on a sprung surface.

Therefore, the purpose of this study was to compare the adjustments caused by drop jumps on surface with different characteristics, such as ground and springboard surfaces, on the subsequent vertical performance. It was hypothesized that a pre-conditioning stimulus on a surface with different properties could induce different effects on biomechanical and dynamics of the drop jumps. The second hypothesis was that DJs on an elastic surface may cause specific neural adjustments, leading to a different activation pattern compared with DJs on ground.

MATERIAL AND METHODS

Participants

Twenty-two young adults (age = 18.4 ± 0.6 years, height = 183 ± 7.6 cm, mass = 76.7 ± 8.8 kg) volunteered to participate in the current study (table 1). All the subjects were physically active and had regular plyometric training experience in various sport activities, while been injury free (both musculoskeletal and neurological). The participants were requested to abstain from caffeine and alcohol consumption for 24 hours and to avoid any physical activity preceding the measurements by 48 hours. The Aristotle University Ethics Committee approved the study (ERC-008/2020) which adhered to the Declaration of Helsinki. All the subjects were informed of potential risks and signed a university-approved human subject's informed consent form, prior to the study.

Experimental Procedure

A randomized, crossover study design was used to compare the effects of two plyometric protocols on different surfaces on a spring board vault surface (Protocol SB), and on stable ground surface (Protocol G), relative to a control (Protocol C) (Figure 1). All subjects initially visited the laboratory 3 days prior to testing, as to familiarize themselves with the spring board vault, the DJ technique and to have theirheight and body mass catalogued (SECA 220, Hamburg, Germany).Following the familiarization session, each, participant completed three experimental trials involving a standardized warm-up followed by either a control protocol or a pre-conditioning protocol, with three days difference. Upon each visit, the participants performed an 8-min standardized warm-up (4 min of jogging and 3 min of dynamic stretching and 1 min plyometric drills).Afterwards, they rested for 15 min. Each subject randomly performed a pre-conditioning (COND) or a control protocol (C)on three separate occasions. The pre-conditioning stimulus consists of 10 consecutive DJs from a 40 cm high box onto a spring board vault (Protocol SB), or 10 consecutive DJs from 40 cm on a stiff ground surface (Protocol G). The participants executed 3 vertical jumps on a stiff surfaceat 5 s interval, before the pre-conditioning (COND$_{0}$), and immediately at 10sec (COND$_{10}$), 60 sec (COND$_{60}$) and at 120 sec (COND$_{120}$) after the conditioning stimulus to determine potentiating effects (Figure 1).

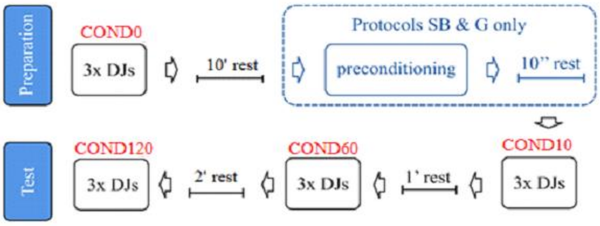


Figure 1. The diagram of experimental procedure. Preconditioning refers to DJs on spring board vault (Protocol SB- PSB), or DJs on a stiff ground surface (Protocol G-PG).

The duration of the DJ test, including the rest intervals and duration of the jumps, did not exceed 15s. The total duration of the conditioning trial was 3 min and 20 seconds (200s). In the control session, the exact same procedure was followed, and the performance of DJs was evaluated at the same time points (CONT0, CONT10, CONT60 and CONT120), with the exception that the subjects rested passively for 15s during the "conditioning period". Vertical ground reaction force (vGRF), EMG and kinematic data were measured during the execution of each DJ.

Measurements

The vGRF was recorded with a Kistler piezoelectric force platform (Type 9281C, Kistler Instruments, Winterthur, Switzerland). The force platform was interfaced through Kistler amplifying units (Type 233A) to a BIOWARE software Kistler System (Moritz & Farley, 2003), and vGRFs were A/D converted at a sampling rate of 1.000 Hz. The technique used for the DJs was the bounce DJ where a small amplitude movement is typical. The subjects performed DJs from 40 cm with the command jump as high as possible, while keeping their hands on their hips. For all measurements, the highest DJ(H_{peak}) was recorded from each trial to reduce variability (Moir G *et al.*, 2018).

Electromyography

Bipolar surface electrodes (Motion Control, IOMED Inc. voltage range: 64–612 V) interfaced to a 16-channel analog amplifier (sampling frequency 1,000 Hz, CMRR 100 db at 50/60 Hz, bandwidth 8,500 Hz, gain 400), were used to record the EMG activity of Tibialis Anterior (TA) and Medial Gastrocnemius (MGAS) muscles. For the electrode placement SENIAM guidelines were followed (Hermens HJ *et al.*, 1999). Electrode locations were prepared by shaving the skin of each site and cleaning it with alcohol wipes. The electrode placement was marked with permanent ink to ensure a fixed electrode placement between measurements. All signals were synchronized and converted to digital using the Biopac MP150 unit (Biopac Systems Inc. CA, USA) with 1 kHz sampling frequency at 16 bit.

Kinematics

For motion analysis, 2 video cameras (JVC-GR-DVL 9800, frame rate 250 Hz). The cameras were placed at a 90°angle at a focal distance of 8 m. Skin markers were placed at 5 locations on the body: shoulder(midaxillar line at umbilicus height), hip (superior part or greater trochanter), knee (lateral epicondyle), ankle (lateral malleolus), and foot (head of the fifth metatarsal). The video image of a calibration frame was recorded before each measurement, and 8 calibration points were digitized to determine the 3-dimensional position of any point in space. The coordinates for these markers were digitized using the Ariel Performance Analysis System. For synchronization of the force and video data, the computer triggered a stroboscopic light, which was visible on the camera's field of view. Three-dimensional marker position data were generated from the two-dimensional co-ordinates of the cameras using the direct linear transformation method. The resulting displacement-time data of each marker were filtered using a second-order Butterworth digital filter with a zero-order phase lag (Young WB *et al.*, 1999). Optimal cut-off frequencies were chosen by comparing the residuals of the difference between filtered and unfiltered signals at several cut-off frequencies ("Biomechanics and Motor Control of Human Movement, 4th Edition Wiley," n.d.). From the smoothed angular displacement data, the hip and knee extension-flexion position data were further analyzed.

Equipment

A gymnastic Springboard (Stratum Vault Board, 120 x 60 x 22cm, FIG approved) with six oxide springs was used during Protocol SB.

Variables analysis

As outcome variables, the maximal vertical displacement (H_{max}), peak power (P_{peak}), and peak vertical force (F_{peak}) were measured on a Kistler force platform. Vertical stiffness (K_{leg}) was calculated by dividing the change inF_{peak} by the change in displacement of center mass (ΔL) during the eccentric phase in the jump{Formatting Citation}:

$F_{peak}/\Delta L$

The eccentric phase was defined from the instant at which the vertical GRF began to decrease and the deepest excursion of the knee joint.

Root mean square (RMS_{GAS}, RMS_{TA}) (mV) for the jumps (DJs) was calculated by full-wave rectification and averaged overpreactivation, eccentric and concentric phases. The EMG raw data were full-wave rectified and low-pass filtered at 6 Hz yielding the linear envelopes of each muscle EMG. The EMG of each muscle was then expressed as a percentage of the EMG value during the maximum voluntary contraction (MVC).

The Co-contraction Index (CI) was calculated using the following equation:

CI= I_{ant} / I_{ang} X100%;

Where, I_{agn}= RMS_{GAS}andI$_{ant}$= RMS_{TA} .

In addition from the kinematic analysis, ankle, knee and hip joint-displacement and velocities values (d_{ankle}, $V_{ankle}d_{knee}$, V_{knee}, d_{hip},V_{hip} respectively) were extracted for each jump.Maximal angles were analyzed because they provide an indication of the maximum joint range of motion achieved during each task.

Statistical Analysis

Mean and SD were calculated from individual measurements for the 3interventions. A two-way ANOVA test (3 × Protocol × 4 X Time) with repeated measures on "protocol" and "time" were used to determine the main and the interaction effects on each dependent variable. A Post hoc Tukey test was used to further examine changes in measures where statistical significance was reached. The level of significance was set at $p < 0.05$.The effect sizes were calculated using partial eta squared (η^2_p)for ANOVAs The small, medium, and large effects would be reflected for η^2_pin values greater than 0.0099, 0.0588, and 0.1379, respectively.

RESULTS

ANOVA indicated a significant Protocol X Time interaction on H_{peak} ($F_{6.126}$= 73.680,η^2_p=0,658, p = 0.000), as illustrated in Figure 2. The H_{peak} increased at 10 sec, 1 and 2 min, following the PSB, compared with baseline value ($F_{3.63}$=17.661, p=0.001), and was significantly higher compared to the respective values of the PG and C groups (p=0.001).

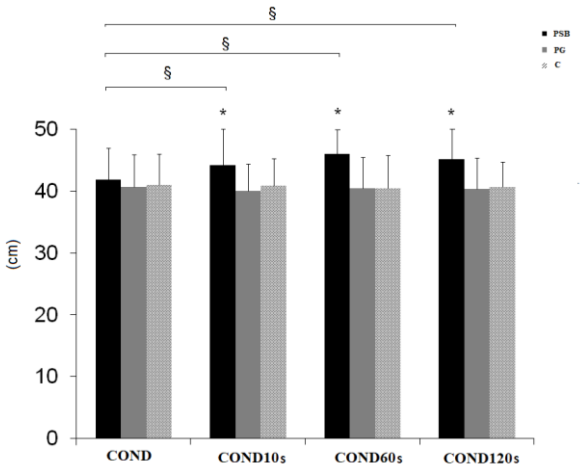


Figure 1: Hpeak Pre-conditioning (COND0) at COND10s, COND60s and COND120s, following each condition (PSB, PG, C, *= main effect, ‡ = interaction effect, p <0.05)

ANOVA also revealed a significant Protocol X Time interaction effect on the P_{peak}in the DJ ($F_{(6.126)}$= 17.158, η^2_p= 0,262,p =0.000). Post hoc analysis showed thatonly the PSBincreasedP_{peak}, compared to the baseline value but remained unchanged in the PG and C protocol(p =0.000). The P_{peak} was higher in PSB vs. PG_P and C at $COND_{10s}$, $COND_{60s}$ and $COND_{120s}$ time points ($F_{(3.63)}$ = 7.468,p = 0.001), as demonstrated in Figure 3.

K_{leg}: ANOVA also showed a significant Protocol × Time interaction on K_{leg}in DJ ($F_{(6.126)}$= 6.602, η^2_p =0,660, p =0.001). PSB significantly increasedK_{leg}in DJ at $COND_{10s,}$ $COND_{60s}$ and $COND_{120s}$.$K_{leg}$was higher in PSB vs PG at $COND_{10s}$, $COND_{60s}$and $COND_{120}$time points($F_{(3.63)}$ = 3.395, p =0.011), as shown in Figure 4.

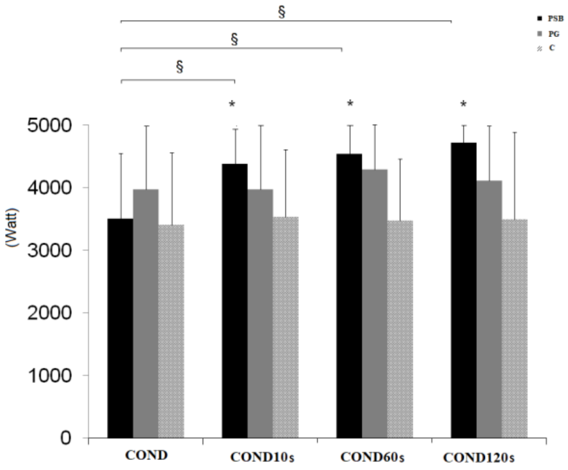


Figure 2: Mean and SD from Ppeak in Pre-conditioning (COND0) at COND10s, COND60s and COND120s, following each condition (PSB, PG, C, *= main effect, ‡ = interaction effect, p <0.05)

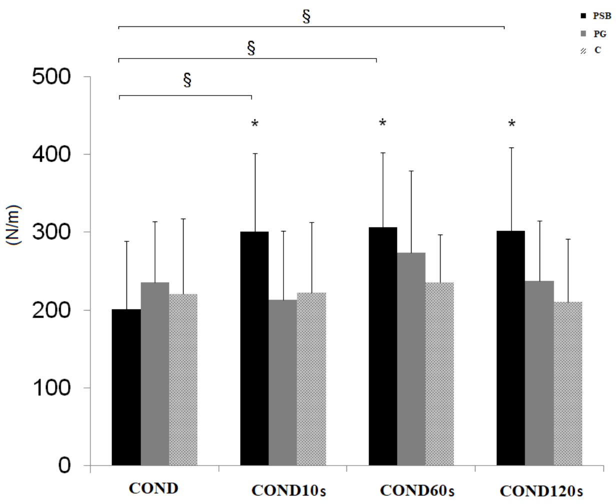
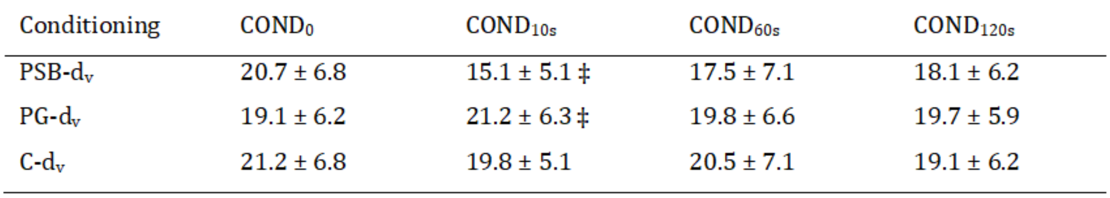


Figure 3: Mean and SD from Kleg in Pre-conditioning (COND0) at COND10s, COND60s and COND120s, following each condition (PSB, PG, C, *= main effect, ‡ = interaction effect, p <0.05)

ANOVA showed no main effect of Protocol on most kinematics variables during DJ (d_{ankle},V_{ankle},d_{knee}, V_{knee}, $d_{hip)}$) (p > 0.05). However, ANOVA showed significant Protocol × Time interaction ($F_{6.126}$ = 6.936,η^2_p= 0,272 p = 0.015) on the vertical displacement of the center of gravity (d_v) during the eccentric phase in DJ. Post hoc analysis showed that the PG increased the downward displacement at $COND_{10s}$while the PSB decreased significantly the downward displacement at $COND_{10s}$, compared to baseline values.



Conditioning	$COND_0$	$COND_{10s}$	$COND_{60s}$	$COND_{120s}$
PSB-d_v	20.7 ± 6.8	15.1 ± 5.1 ‡	17.5 ± 7.1	18.1 ± 6.2
PG-d_v	19.1 ± 6.2	21.2 ± 6.3 ‡	19.8 ± 6.6	19.7 ± 5.9
C-d_v	21.2 ± 6.8	19.8 ± 5.1	20.5 ± 7.1	19.1 ± 6.2

Table 1: Mean and SD of vertical displacement of the center of gravity (d_v) for all testing protocols (SB, G and C, ‡ = interaction effect, p <0.05)

ANOVA also showed significant Protocol X Time interaction effect only onV_{hip} in DJ ($F_{3.63}$ = 2.726, p =0.05). The interaction suggests that the effect of COND on V_{hip} is similar across the different conditioning protocols, whereas the effect of time onV_{hip} is dependent on protocol (Figure 3). Post hoc demonstrated that PGsignificantly increased the hip angular velocity (V_{hip}) at $COND_{10s}$ andat $COND_{60s}$, while the PSB decreased it only at $COND_{10s}$, compared to the baseline but was unchanged for Protocol C.

EMG results are presented in Figure 5. There was a significant Protocol × Time interaction on CI in the pre-activation phase during DJ ($F_{6.126}$=40.190, η^2_p= 0,098 p=0.000). Post hoc analysis showed that CI decreased after both protocols, compared with baseline value, within all-time points but remained unchanged in C condition. ANOVA also showed that there was not "Protocol × Time" interaction effect on CI, during the eccentric phase of the DJ. Both conditions, PSB, PG decreased significantly the CI within all-time points ($F_{3.63}$ =10.069 p=0.001). There was also no Protocol × Time interaction on CI during the DJ concentric phase, but in both conditions the CI increased significantly and the effect of time on CI was depended on protocol($F_{3.63}$ =4.701, p=0.005). CI values remained unchanged in the C session independent of the time and the jumping phase (p >0.05). More specifically, CI indexes increased at $COND_{10s}$, $COND_{60s}$and $COND_{120s}$ following PG whereas after PSBCI increased at $COND_{10s}$only compared with baseline value (p<0.05), as shown in Figure 5.

Conditioning	COND$_0$	COND$_{10s}$	COND$_{60s}$	COND$_{120s}$
PSB-$d_{knee(°)}$	75.7 ± 8.1	76.5 ± 8.7	76.3 ± 11.1	78.8±12.9
$V_{knee(°/sec)}$	568.8 ± 104.8	562.8 ± 137.3	545.7 ±128.9	563.3 ± 133.5
PG-$d_{knee(°)}$	73.7 ± 8.7	74.4 ±7.3	75.3 ±10.1	74.3 ±10.5
$V_{knee(°/sec)}$	525.8 ± 109.5	587.5 ± 128.4	553.9 ± 131.6	575.3 ± 163.3
C-$d_{knee(°)}$	76.1 ±16.1	75.8 ±14.9	77.1 ±18.1	76.2 ±14.7
$V_{knee(°/sec)}$	545.8 ± 119.5	567.9 ± 108.4	558.2 ± 99.6	549.3 ± 146.3
PSB-$d_{hip(°)}$	81.8 ±16.1	87.9 ±12.5	91.1 ± 15.9	82.1 ± 15.9
$V_{hip(°/sec)}$	389.8 ± 144.8	346.5 ± 117.3*	366.6 ± 148.9	384.3 ± 143.5
PG-$d_{hip(°)}$	88.1 ±11.1	90.5 ± 12.7	87.5 ±16.6	86.9 ±1.4
$V_{hip(°/sec)}$	350.8 ± 139.3	387.2 ± 123.4*	365.9 ± 141.1*	389.3 ± 145.3*
C-$d_{hip(°)}$	85.9 ± 19.1	86.2 ±15.2	85.3 ±19.9	84.1 ±16.5
$V_{hip(°/sec)}$	369.8 ± 113.3	393.2 ± 132.4	377.9 ± 91.1	379.8 ± 95.8

Table 2: Mean and SD of angle displacement and velocity of the knee and hip (dknee, dhip, Vknee,and Vhip respectively) for all testing protocols (SB, G and C, ?= main effect, $p < 0.05$)

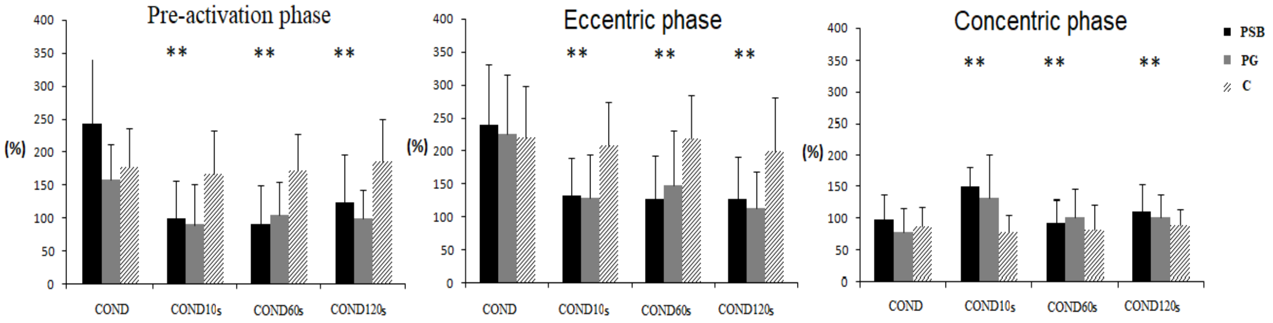


Figure 4: CI during the pre-activation, eccentric and concentric phase, following each condition (PSB, PG, C,)

DISCUSSION

The present study investigated the COND effects of the same stimulus on different surfaces. The main findings of this study were: (a) PSB significantly improved drop jumping height and the produced power during the concentric phase of the drop jump, (b) PSB significantly increased leg stiffness, (c) both COND stimulus showed similar alteration in muscle activation during the pre-activation, the eccentric and the concentric phase with different duration of the effect. Thus, the differences found in jumping height between the drop jumps on the ground and the springboard might attribute to mechanical rather to neural adaptation.

As previously reported, the drop jumping performance is related to the mechanical properties of the surface on which it is conducted. This study showed that performance might be reinforced by the addition of the elastic surface. Our results are in agreement with previous report that demonstrated that jumping on a sprung surface led to an increase at the final height (by 7%), which is attributed to a higher ratio of positive to negative mechanical work during ground contact phase (Arampatzis A *et al.*, 2004a). Furthermore, the increased drop jump height, by the use of a springboard, is accompanied by an increased power production during the concentric phase and a smaller maximal excursion during the eccentric phase (Table 1) leading to greater leg stiffness. On the contrary, DJ on a stiff surface failed to show any acute improvements on vertical jumping performance. Similarly, Marquez *et al.*, (2014) reported no significant difference between hopping on a stiff and soft surface despite the increases in vertical reaction forces and leg stiffness. These differences might reflect the effects of the springboard's rebound characteristics resulting in an acute transfer of the adjustments to the consequent drop jump height.

Despite the fact that the leg stiffness was increased after springboard jump stimulus, the kinematics hardly showed significant changes in joint angles. These small changes could not explain the differences into the two tasks since there are no significant changes on ankle and knee velocities. Earlier studies, supporting the above, reported changes in leg stiffness as well as in the displacement of the center of mass during hopping and running on surfaces with different properties, without any change in ankle- knee kinematics (Ferris DP *et al.*, 1998; Prieske O *et al.*, 2013c). In contrast, hip joint angle and velocity were decreased after drop jumping on springboard leading to a more extended position during landing. Similarly, previous study showed increases in leg stiffness by altering the body orientation at the touchdown (Ferris DP *et al.*, 1998). Prieske *et al.*, (2013c), also confirmed the above by showing that a more extended body is accompanied by increased leg stiffness during DJs on unstable in healthy young adults. In addition, Moritz *et al.*, (2004) showed that the subjects adapt a spring-like behavior of the leg-surface interaction and the center-of-mass dynamics as on elastic surfaces. Our finding adds to the existing literature by showing the acute transfer of the drop jump on a springboard to the consequent drop jumping performance. That could be explained by the mechanical properties of the body due the greater effect on enhancing direct the SSC mechanism compared to jumps performed on the ground. That means that jumping either on elastic or a hard surface is consistent with the principle of training specificity adopting the same technique of jumping execution.

According to our initial hypothesis, it was expected that springboard conditioning could present different COND effect on jumping performance than traditional jumping as a result of different neural adjustments in ankle joint. However, there were no clear differential responses in CI of ankle joint which decreased during the in pre-activation and eccentric phase, while increased during the concentric after both protocols (Figure 5). Moreover, PSB showed increased and greater CI only after the intervention while PG showed increases at all time points after the stimulus. The similar behavior of co-activation activity seems to correlate differently to DJ performance after the two preceding protocols. Our results demonstrated that the increased of CI during the concentric phase of the drop jump right after the intervention was a combination of a reduced MGAS activation with an increase of the activation of TA at 10’’. In contrast, the TA activity almost remained the same while the MGAS activity increased during the 60’’ and the 120’’ time points. The increased CI activity could be a result of two different factors. Firstly the uncertainty which is involved with the task, such as DJs on unstable device (Sparkes R *et al.*, 2010). Secondly, the preconditioning stimulus was executed on an inclined elastic surface where MGAS working in bigger length and TA was activated more because of the dorsi flexion position of ankle. These results indicated the existence of a safe protective strategy of the ankle joint against an uncertain degree of anticipated perturbation by the unstable surface (Hauglustaine S *et al.*, 2001). Furthermore, it is possible that Soleus’ (Sol) activity was increased, right after PSB, which might counterbalance any negative effects of the TA activity on the final net forces. Indeed, previous study showed that hopping on an incline wooden surface, such as springboard, both increased TA and Sol activity to protect joint stability (Kannas T *et al.*, 2011). Further increases in MGAS activation lead to an improved jumping performance. Thus, the task’s external requirements may result in joint-specific adjustments which in turn may cause specific responses of the knee and ankle muscles during the braking phase of drop jumps shortly after ground. It might be possible that the central nervous system counterbalances power production and ankle joint stability to ensure joint integrity, increasing the stiffness via elevated antagonist co-activation in unstable movement conditions during the concentric phase (Arai A *et al.*, 2013). The novel finding of the present study is that the adjustment was found after PSB, transferred directly to the DJ performance and indicated greater COND effects compared to the traditional jumps. This suggests that DJ performance gains, after DJs performed on an elastic surface, can be attributed to both adjustments of the mechanical properties of muscle-tendon complex and muscle co-activation.

As far as the DJ on stiff ground surface is concerned, muscle co-activation in DJ exhibited comparable responses to those of the springboard protocol, without any mechanical result on performance. The fact that the performance was no different could be attributed to the fact that surface jumping does not provide sufficient stimulus to provoke COND effect. The increased muscle co-activation in DJ during the concentric phase, after DJs on the ground, mostly occurred due greater activation of the TA muscle. TA activation might may assist in maintaining the required muscle output, counteracting the effect of fatigue, during the breaking phase but it may have no effect on the propulsion and the reuse of elastic energy (Helm N *et al.*, 2019). In addition a higher CI without an increase of vertical stiffness during the propulsion phase, could not result in sufficiently high recruitment of muscle fibers to elevate the postsynaptic potentials (Arabatzi F *et al.*, 2018). However, plyometric exercises on the ground are thought to be beneficial for the functional capacity of the activated muscles and the resistance of increased impact loads (Ross AL *et al.*, 1997) but not for the jumping performance.

In conclusion, the present study revealed COND effects on drop jump performance after a preceding stimulus on unstable compared to stable surface conditions. The two protocols induced different responses and COND effects on jump performance. For plyometrics on the stiff ground surface, vertical stiffness and jump performance were unchanged in contrast to jumping on the springboard, whereas the jump performance improved mainly via an increase in leg stiffness. In addition, the behavior of CI around the ankle was similar, independent on the type of surface. The co-activation increase in the concentric phase may be an attempt for dynamic restrain and functional ankle stability due to postural perturbations after unstable situations after the drop jumps. We would therefore stipulate that the basic plyometric conditioning exercises did not result in sufficient COND effects on DJ performance compared to plyometric on springboard surface. Unfortunately, in the present study the EMG data of muscles around the knee were unavailable, rendering the contribution of such protocols on enhancement and maintenance of jump performance unclear. Moreover, future studies should use additional data from ultrasound to evaluate morphological characteristics of muscles to assist in the explanation of the mechanisms by which plyometric exercises enhance subsequent strength and power performance, especially in activities that involve the stretch-shortening cycle.

CONCLUSION

Jumping on a springboard surface combines the stiff ground due the wooden part during touchdown and the elastic properties due the springs under the stiff one. This means that provides a more complex stimulus than other soft surfaces. Moreover, DJ on a springboard should be considered a more demanding task compared to the DJ on ground surface due the inclination of the springboard. Our results showed that DJ on a springboard could be used as a sufficient stimulus to improve jumping performance without any changes in the jumping technique. Such stimulus could be used, by the coaches, during the preparation, the basic and/or the specific phases of the yearly periodization planning.

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