BIOMECHANICAL ANALYSIS OF LOADED PLYOMETRIC EXERCISES

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Plyometric intensity and specificity are determined by the exercises performed. This study assessed ground reaction forces (GRF) in the frontal (F), horizontal-anterior (H), and vertical (V) planes, and the ratio of H to V GRF (H:V) of plyometric exercises and load conditions. Subjects (N=15) performed five plyometric variations with five handheld loads on two force platforms. A two-way RM ANOVA was used. Analysis of F GRF revealed main effects for plyometric exercise (p = 0.004). Analysis of H GRF revealed main effects for plyometric load (p = .042) and plyometric exercise (p ≤ 0.001). Analysis of V GRF revealed main effects for plyometric load (p ≤ 0.001) and plyometric exercise (p ≤ 0.001). Analysis of H:V revealed main effects for plyometric exercise (p ≤ 0.001). Practitioners should use the plyometric exercises and loads that optimize the kinetics and transfer of training.

KEYWORDS: kinetics, halters, sprinting, stretch-shortening cycle, specificity

INTRODUCTION: Plyometric exercises improve a variety of skills, including agility, jumping, and sprint performance (deVillarreal et al., 2009, deVillarreal et al., 2012). Results of a meta-analysis demonstrated that plyometric training is effective, although there is considerable variation in program design (deVillarreal et al., 2009). To further understand elements of plyometric program design such as intensity and optimal exercise selection, kinetic variables of plyometrics were assessed (Ebben et al., 2011, Kossow & Ebben, 2018).

Analysis of kinetic variables allows for the comparison of plyometric exercises and understanding their potential transfer of training to sports movements. Commonly assessed kinetic variables include ground reaction forces (GRF) and rate of force development (RFD) (Ebben at al., 2011; Kossow & Ebben, 2018). Research also shows that some plyometric exercises more than others approximate the development of the horizontal and vertical ground reaction forces and their ratio (H:V) that are present during sprint starts (Duffin et al., 2019).

The kinetics of plyometric exercises, as an assessment of intensity, has also been studied in loaded and unloaded conditions. This research includes the assessment of exercises such as the loaded countermovement jump with dumbbells equal to 30% of the subject's back squat load (Ebben et al., 2011), the standing long jump with 1.5 kg or 3.0 kg dumbbells (Papadopoulos et al., 2011), training with plyometrics with added loads that ranged from 2 kg to 12 kg (Rosas et al., 2016), 8% of body mass (Kobal et al., 2017) or with weighted vests using approximately 10-11% of body mass (Khlifa et al., 2010). In some cases, loaded compared to unloaded plyometrics have been shown to have a higher intensity (Ebben et al., 2011) and enhanced performance (Khlifa et al., 2010; Papadopoulos et al., 2011; Rosas et al., 2016). Exercises that were studied include right leg horizontal countermovement jumps, left leg horizontal countermovement jumps, horizontal countermovement jumps, and countermovement jumps (Khlifa et al., 2010; Papadopoulos et al., 2011; Rosas et al., 2016). Only one study examined the acute effects of loaded plyometric exercise (Papadopoulos et al., 2011). However, this study was limited to only the standing long jump and two loading conditions.

No studies sought to compare the external loads that optimize the kinetics of a variety of plyometric exercises, or to compare these variables and their potential specificity to sprinting. Therefore, the purpose of this study was to assess several plyometric exercises and loading conditions, and the resultant multi-planar kinetic performance variables.

METHODS: Subjects included fifteen women (mean ± SD, age = 19.00 ± 0.93 yr; body mass = 62.09 ± 7.60 kg; height = 169.33 ± 6.5 cm) who participated in at least six weeks of plyometric training prior to the study. Subjects performed plyometric training 2.40 ± 1.64 days per week.

All subjects provided written informed consent and the study was approved by the institution's internal review board.

Subjects participated in one testing session. Prior to testing, a general, dynamic, and activity specific warmup was performed. Subjects then received demonstration and practiced in each plyometric exercise and load condition. Subjects rested for five minutes prior to testing. Test exercises included the standing long jump (SLJ), 18-inch hurdle hop (HH), power skip (SKP), double leg hop (DLH), and countermovement jump (CMJ). Each plyometric exercise was performed in a body weight condition, as well as with handheld dumbbells weighing a total of 0.57, 1.13, 1.70, and 2.26 kilograms. All plyometric exercises and load conditions were randomized for each subject and performed for two trials.

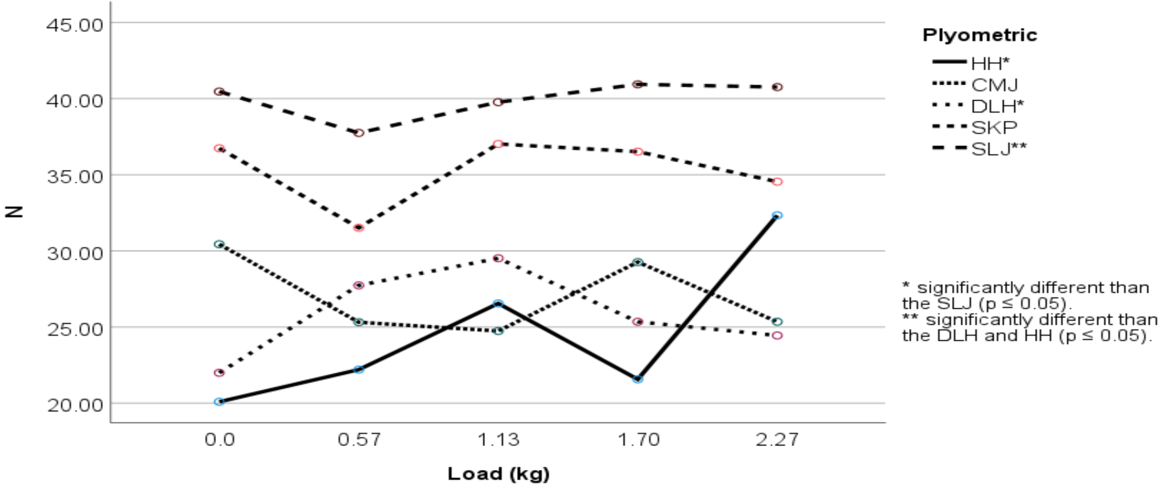
Data were obtained from two flush to the floor-mounted force platforms deployed in series (Accupower, Advanced Mechanical Technology, Inc., Watertown, MA, USA). The force platforms were calibrated prior to the testing session and data were sampled at 1000Hz. Peak GRF for the frontal (F), horizontal-anterior (H), and vertical (V) planes were obtained, and the H:V were calculated for each plyometric exercises and load condition.

Data were analyzed with a statistical software program (SPSS 27.0, International Business Machines Corporation, Armonk, New York) using a two-way ANOVA with repeated measures for plyometric exercise and load. Bonferroni adjusted pairwise comparison were conducted when main effects were present. The reliability of the trials was assessed using intraclass correlation coefficients for each of the dependent variables. Assumptions for linearity of statistics were tested and met. Statistical power (*d*) and effect size (η_p^2) are reported and all data are expressed as means ± SD. The η_p^2 values of .0099, .0588, and .1379 represent small, medium, and large effect sizes. The *a priori* alpha level was set at $p \leq 0.05$.

RESULTS: The analysis of F GRF revealed significant main effects for plyometric exercise ($p = 0.004$, $d = 0.99$, $\eta_p^2 = 0.27$) but not for plyometric load ($p = 0.66$), or the interaction of plyometric load and exercise ($p = 0.84$). The analysis of H GRF revealed significant main effects for plyometric load ($p = .042$, $d = 0.71$, $\eta_p^2 = 0.16$) and plyometric exercise ($p \leq 0.001$, $d = 0.99$, $\eta_p^2 = 0.59$), but not the interaction of plyometric load and exercise ($p = .18$). The analysis of V GRF revealed significant main effects for plyometric load ($p \leq 0.001$, $d = 0.96$, $\eta_p^2 = 0.27$) and plyometric exercise ($p \leq 0.001$, $d = 0.99$, $\eta_p^2 = 0.37$), but not the interaction of plyometric load and exercise ($p > 0.16$). The analysis of H:V revealed significant main effects for plyometric exercise ($p \leq 0.001$, $d = 0.99$, $\eta_p^2 = 0.59$), but not for plyometric load ($p = 0.39$), or the interaction of plyometric load and exercise ($p = 0.24$). Figures 1-4 show the results of the post-hoc analysis of the F GRF, H GRF, V GRF, and H:V.

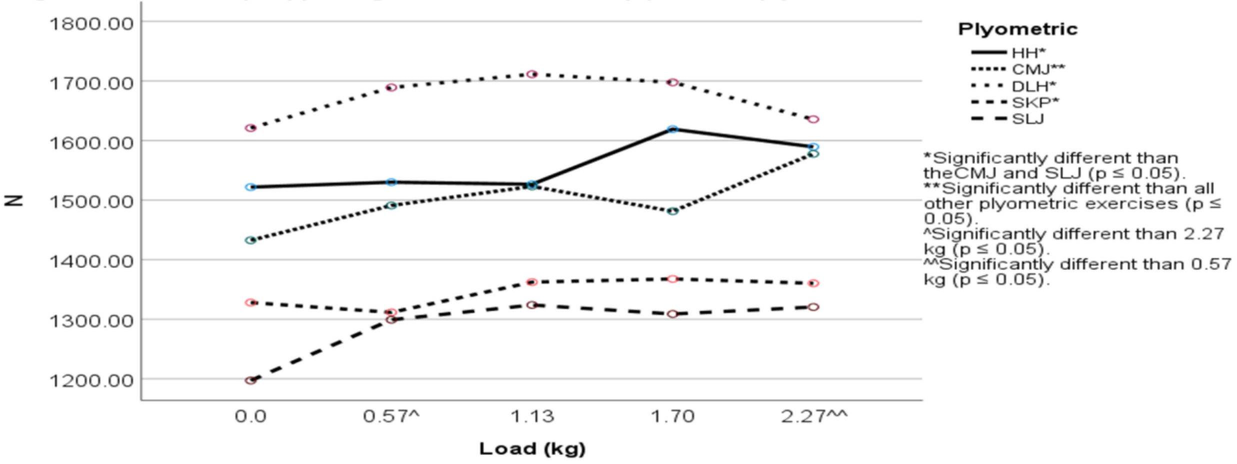
Average measure intraclass correlation coefficients for the dependent variables for each exercise test and load condition ranged from .70 to .99.

Figure 1. Frontal plane ground reaction forces (N) for each plyometric exercise and load condition.



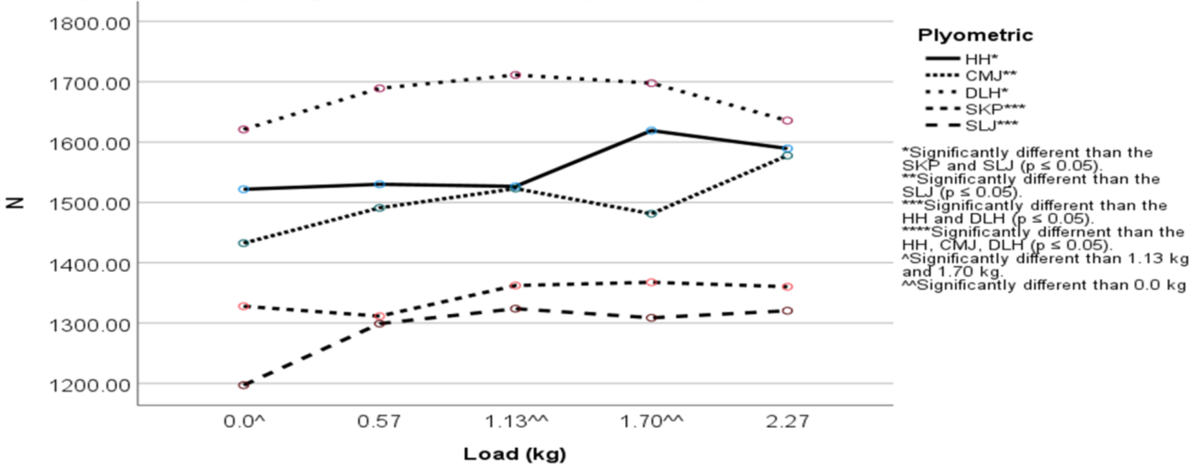
* significantly different than the SLJ ($p \leq 0.05$).
** significantly different than the DLH and HH ($p \leq 0.05$).

Figure 2. Horizontal (A-P) plane ground reaction force (N) for each plyometric exercise and load condition.



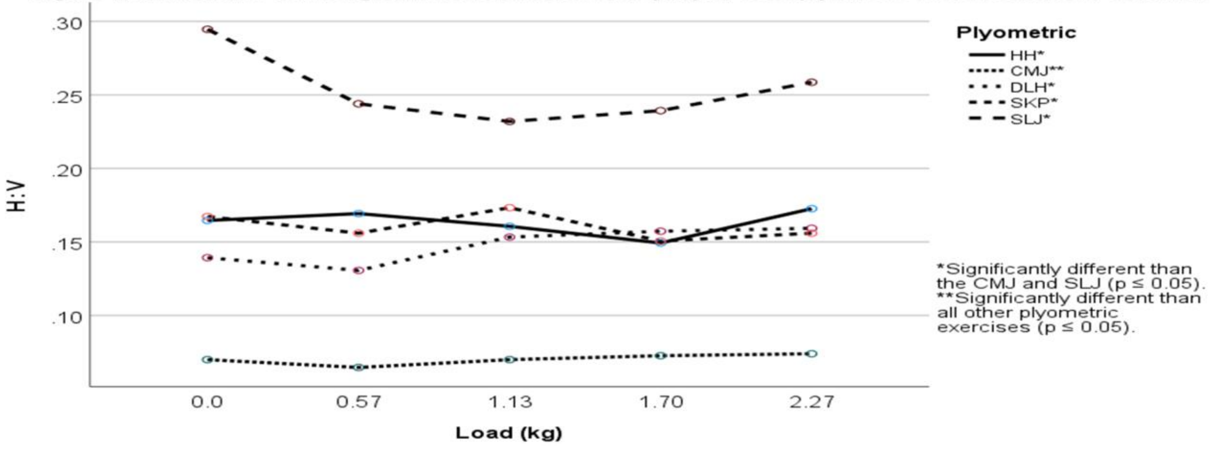
*Significantly different than theCMJ and SLJ (p ≤ 0.05).
**Significantly different than all other plyometric exercises (p ≤ 0.05).
^Significantly different than 2.27 kg (p ≤ 0.05).
^^Significantly different than 0.57 kg (p ≤ 0.05).

Figure 3. Vertical plane ground reaction forces (N) for each plyometric exericse and load condition.



*Significantly different than the SKP and SLJ (p ≤ 0.05).
**Significantly different than the SLJ (p ≤ 0.05).
***Significantly different than the HH and DLH (p ≤ 0.05).
****Significantly differnent than the HH, CMJ, DLH (p ≤ 0.05).
^Significantly different than 1.13 kg and 1.70 kg.
^^Significantly different than 0.0 kg

Figure 4. Horizontal to vertical ground reaction force ratio (H:V) for each plyometric exercise and load condition.



*Significantly different than the CMJ and SLJ (p ≤ 0.05).
**Significantly different than all other plyometric exercises (p ≤ 0.05).

DISCUSSION: This is the first study to assess the kinetic features of several plyometric exercises performed in several load conditions, to determine which exercises and loads optimized multiplanar kinetics. This is also one of the first studies to assess plyometrics in three planes of motion. Results show that there are differences in GRF and H:V among these exercises for some of the variables assessed, and in some cases the magnitude of added load effected the kinetics. Previous research assessing plyometrics using added loads examined only one exercise or one or two different loads. For example, research showed that the countermovement jump performed with dumbbells representing 30% of the subject's one repetition maximum squat load yielded larger GRF than a number of other plyometric exercises without added loads (Ebben et al., 2011). Additionally, standing long jump horizontal velocity and displacement of the center of mass and GRF were more optimal when performing plyometrics with loads of 1.5 kg to 3.0 kg in each hand compared to this exercise with no load (Papadopoulos et al., 2011).

Additionally, training studies assessed a variety of plyometric exercises performed with weighted vests, showing that the loaded condition was superior to the unloaded condition for a number of variables (Khlifa et al., 2010). Plyometric training performed with loads from 2.0 to 12.0 kg resulted in superior training adaptations than unloaded plyometrics (Rosas et al., 2016). These results confirm that plyometric training is effective as described (de Villarreal et al., 2009, de Villarreal et al., 2012) and that training with added loads may be optimal.

Previous research did not attempt to determine if there are optimal loads to use and some research found no difference in the outcome variables for subjects training with plyometrics using handheld loads compared to unloaded plyometrics (Kobal et al., 2017). The present study shows that the loads in the higher end of the range used were superior for some of the variables assessed, while the SLJ was optimal for the variables assessed, in the no load condition. Thus, training interventions should use the plyometrics and loads that optimize the exercise kinetics.

The H:V of the exercises in the present study were in an approximate range of .04 to .30. This ratio of horizontal to vertical force was predictably lowest for the countermovement jump. At the high end of the range was the SLJ. The SLJ best approximates the H:V of standing sprint starts and sprinter position sprint starts which have a H:V ratio of .36 and .40 respectively (Duffin et al., 2019).

CONCLUSION: Plyometrics exercises performed in higher load conditions showed a tendency toward producing higher H GRF and V GRF. The SLJ performed in the no load condition yielded a superior H:V. The SLJ produced the greatest F-GRF and H-GRF and H:V ratio. The DLH produced the greatest V-GRF, even more than the vertically oriented CMJ. The H:V ratio of plyometric exercise was not influenced by added load. The H:V of some plyometric exercises such as the SLJ more closely approximates the H:V previously shown during sprint starts. Practitioners should prescribe plyometric exercises that progress in intensity and evolve to include those that are most specific to athletic activities such as sprinting.

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