BIOMECHANICAL ANALYSIS OF ACCELERATION LADDERS WITH VARYING STEP DISTANCES

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This study assessed select kinetics and kinematics of each of the first three steps of the acceleration phase of sprinting using three different acceleration ladders. Subjects (N=15) performed sprints using acceleration ladders with short, medium, and long rung spacing, over two large force platforms. Multi-factorial repeated measure ANOVAs were used to assess horizontal and vertical ground reaction force (GRF), the ratio of horizontal to vertical GRF, the duration of vertical GRF, time between steps, distance between steps, and velocity between steps and across all steps. Main effects were significant ($p \leq 0.05$) for all variables except time. Post-hoc analysis identified a variety of differences in the dependent variables in the analysis of steps, test condition and their interaction ($p \leq 0.05$). Results show that greater velocity is attained with ladders that have longer step distances.

KEYWORDS: running, sprinting**,** stride frequency, kinetics, kinematics

INTRODUCTION: A variety of devices are used by athletes and coaches to improve agility and speed. These devices include agility and acceleration ladders, which are made of two parallel nylon straps connected by plastic slats or ladder "rungs," and placed on the ground. An alternative is to use tape placed on the floor or court to replicate the ladders. For agility drills, these rungs are equidistant apart. For acceleration training, the rung spacing increases from smaller to larger from the start to the end of the ladder. This configuration presumably allows for greater ground reaction force (GRF) to overcome static inertia initially, with a progression to larger step distances as the athlete sprints across the ladder with a concomitant increase in step length, whole body inertia, and velocity. While many internet sites describe the use of these devices, no research has been conducted to evaluate acceleration ladders.

The research on the use of ladders to train athletes is limited to the evaluation of agility ladders (Afonso et al., 2020). The use of ladders for training agility has produced mixed results with respect to sprinting performance (Pardon-Cabo et al., 2020; Venturelli et al., 2008) along with other outcome variables. The use of agility ladders as part of a training intervention has been shown to improve subject stride rate (Murray et al., 2017).

The use of ladders to train acceleration, by adjusting the distance between rungs to create shorter steps in an attempt to optimize acceleration has been briefly described (White, 2007). An internet search using a common browser shows many purveyors sell ladders with incrementally spaced rungs that are purported to train acceleration and/or speed. When acceleration ladders were used along with other strategies as part of a training intervention, there was an improvement in sprinting velocity (Venturelli et al., 2008). Increasing the step length after the first two steps of sprinting may be important. Training athletes with acceleration ladders may actually impair performance if steps are too close together, since step distance was correlated with velocity during the initial steps of a sprint (Thone et al., 2020). However, no research exists on how these ladders work or how they should best be deployed. Therefore, this study was designed to assess select kinetics and kinematics of each of the first three steps of the acceleration phase of sprinting and to determine if these variables differed as a function of acceleration ladder rung spacing.

METHODS: Subjects included fifteen women (age = 19.80 ± 1.21 years, body mass = 70.65 ± 8.85 kg, and height = 1.69 ± 0.06 m). All subjects were NCAA Division III athletes and played basketball (n = 12) or softball (n = 3). All subjects filled out a Physical Activity Readiness Questionnaire which revealed no pathology. All subjects provided signed informed consent and the study was approved by the governing Institutional Review Board.

Prior to the start of the research session, subjects performed a general warm-up and a dynamic and activity specific warm-up. Following demonstration and practice, subjects were tested while sprinting in three acceleration ladder conditions: 1) ladder with short step progression (Short Ladder); 2) ladder with medium step progression (Medium Ladder); 3) ladder with long step progression (Long Ladder). The Short Ladder step length progression was 15.2 cm, 50.8 cm and 116.8 cm. The Medium Ladder step length progression was 20.3 cm, 66.0 cm, and 144.8 cm. The Long Ladder step length progression was 25.4 cm, 81.3, and 172.7 cm. The sprints for all test conditions were performed with the subject starting 2 cm behind the first of two flush mounted force platforms (Accupower, Advanced Mechanical Technology, Inc., Watertown, MA, USA) in series. The force platforms were calibrated prior to the testing session. Data were acquired at 1000 Hz and analyzed in real time with proprietary software (BP 6001200, Advanced Mechanical Technologies Incorporated, Watertown, MA, USA). All test conditions were randomized to reduce potential order effects associated with either fatigue or potentiation.

Peak horizontal/anterior GRF (H-GRF) and vertical GRF (V-GRF) were obtained, and the duration of the V-GRF development and the H-GRF to V-GRF ratio (H:V) were calculated for each of the first three steps of each sprint. Kinematic variables including subject time between steps, horizontal/anterior distance between steps, and velocity from one step to the next, and across all steps, were derived from the temporal and center of pressure data.

Data were analyzed with a statistical software program (SPSS 28.0, International Business Machines Corporation, Armonk, New York). The trial-to-trial reliability of the dependent variables were assessed using average measures intraclass correlation coefficients (ICC) and coefficients of variation (CV). The ICC were found to be > .60 and CV less than 10.0; thus, the average values were used for further analyses. A 3 x 3 (steps * acceleration ladder condition) ANOVA with repeated measures for acceleration ladder condition was used to assess H-GRF, V-GRF, duration of V-GRF, and H:V. A 2 x 3 (between steps * acceleration ladder condition) ANOVA with repeated measures for acceleration ladder condition was used to assess time, distance, and velocity. A one-way ANOVA was used to assess the mean velocity across all steps for each ladder condition. Bonferroni adjusted pairwise comparisons were used when significant main effects were found. Greenhouse-Geisser correction was used for sphericity violations. The alpha level was set at $p \leq 0.05$ for all comparisons. Statistical power (*d*) and effect size (η_p^2) are reported, with effect size with thresholds of: small = 0.1, moderate = 0.3, large = 0.5, very large = 0.7, and extremely large = 0.9 (Hopkins, et al., 2009).

RESULTS: Figures 1-4 show the results of the analysis of the kinetic variables. Figures 5-8 show the results of the analysis of time, distance, velocity from steps one to two, steps two to three, and the velocity across all steps. Average measure intraclass correlation coefficients for the dependent variables for each exercise test and load condition ranged from .73 to .99.

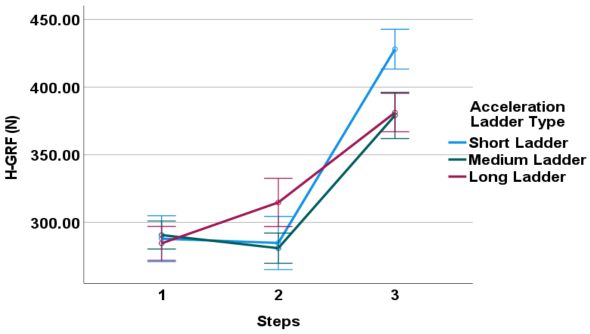

Figure 1. The analysis of H-GRF revealed significant main effects for steps (p = 0.042, d = 0.50, η_p^2 = 0.17), test condition ($p \leq 0.001$, d = 1.00, η_p^2 = 0.75), and the interaction between steps and test condition ($p \leq 0.001$, d = 0.99, η_p^2 = 0.32). Post -hoc analysis shows that step 3 is different than step 1 and 2 ($p \leq 0.001$), that the Long Ladder differs from the Short Ladder and Medium Ladder ($p \leq 0.001$).

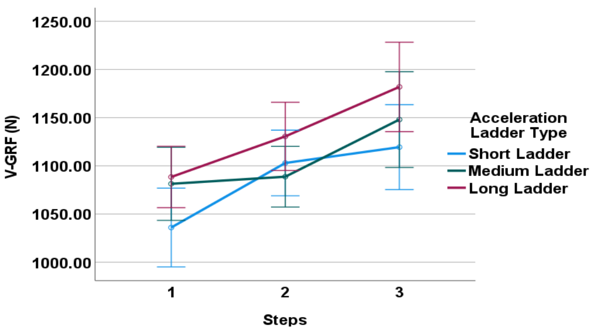

Figure 2. The analysis of V-GRF revealed significant main effects for steps (p = 0.002, d = 0.93, η_p^2 = 0.36), test condition ($p \leq 0.001$, d = 0.99, η_p^2 = 0.47), and the interaction between steps and test condition (p = 0.041, d = 0.66, η_p^2 = 0.16). Post-hoc analysis shows that steps 1 and 2 and 1 and 3 are different (p < 0.03) and that the Short Ladder is different than the Medium Ladder and Long Ladder (p < 0.05).

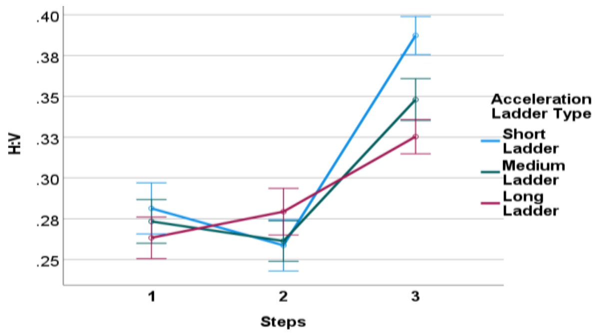

Figure 3. The analysis of H:V revealed significant main effects for steps ($p \leq 0.001$ d = 1.00, $\eta_p^2 = 0.75$), test condition ($p = 0.017$, d = 0.74, $\eta_p^2 = 0.25$) and the interaction between steps and test condition ($p \leq 0.001$, d = 1.00, $\eta_p^2 = 0.57$). Post-hoc analysis shows steps 1 and 3 are different ($p \leq 0.001$), and steps 2 and 3 are different ($p \leq 0.001$) and that the Short Ladder is different from the Long Ladder ($p = 0.004$).

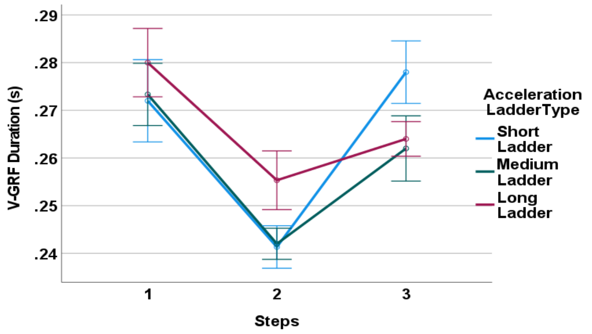

Figure 4. The analysis of V-GRF duration revealed significant main effects for steps ($p \leq 0.001$, d = 0.99, $\eta_p^2 = 0.49$), and the interaction between steps and test condition ($p = 0.013$, d = 0.83, $\eta_p^2 = 0.20$), but not for test condition ($p = 0.26$). Post-hoc analysis shows that step 1 is different than step 2 ($p \leq 0.001$) and that step 2 differed from step 3 ($p = 0.002$).

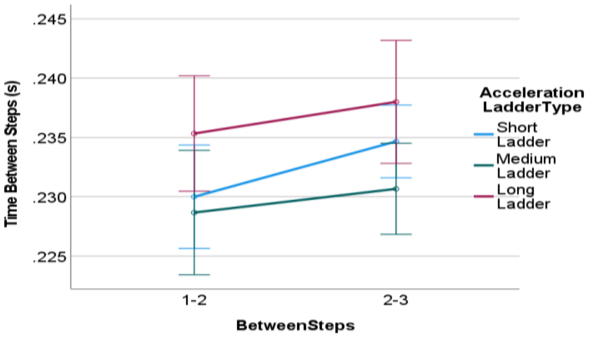

Figure 5. The analysis of time between steps revealed no significant main effects for steps ($p = 0.052$), test condition ($p = 0.38$), or the interaction between steps and test condition ($p = 0.91$).

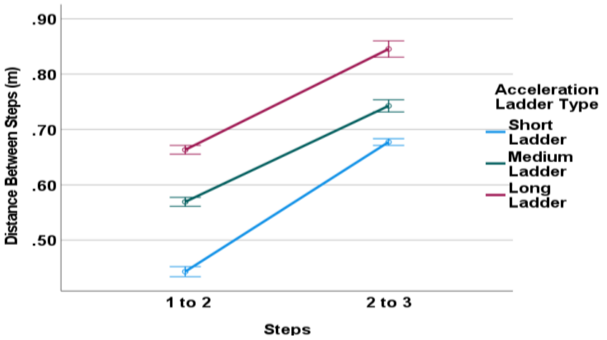

Figure 6. The analysis of distance between steps revealed significant main effects for steps ($p \leq 0.001$, d = 1.00, $\eta_p^2 = 0.96$), test condition ($p \leq 0.001$, d = 1.00, $\eta_p^2 = 0.95$), and the interaction between steps and test condition ($p = 0.004$, d = 0.88, $\eta_p^2 = 0.32$). Post-hoc analysis shows that all ladders were different ($p \leq 0.001$), and that there was a difference in the distance between steps 1 to 2 and steps 2 to 3 ($p \leq 0.001$).

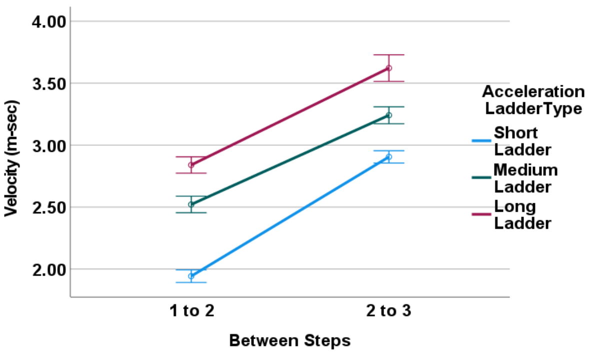

Figure 7. The analysis of velocity between steps revealed significant main effects for steps ($p \leq 0.001$, d = 1.00, $\eta_p^2 = 0.94$), test condition ($p \leq 0.001$, d = 1.00, $\eta_p^2 = 0.90$), but not the interaction between steps and test condition ($p = 0.051$). Post-hoc analysis shows that all three ladders are different ($p \leq 0.05$), and that steps 1 to 2 is different from steps 2 to 3 ($p \leq 0.001$).

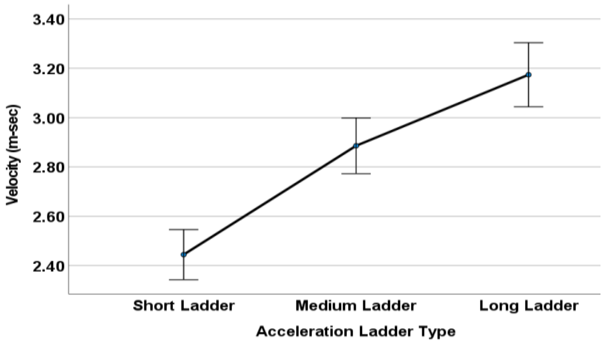

Figure 8. The analysis of velocity across all steps revealed significant main effects for test condition ($p \leq 0.001$, d = 1.00, $\eta_p^2 = 0.92$). Post-hoc analysis shows that all three ladders are different ($p = 0.001$).

DISCUSSION: This is the first study to assess acceleration ladders. Previous research focused on agility ladders, though this research is limited, the protocols were poorly described, and the results equivocal (Afonso et al., 2020). In the present study, ladders with shorter spacing

between the rungs were better for generating H-GRF. However, the Medium Ladder and Long Ladder conditions produced greater V-GRF. The V-GRF duration represented the amount of time the foot was in contact with the force platform. An interaction was present for this variable. But for all conditions, this duration decreased from first to second step and then increased again on the third step. For the third step, the duration was highest for the Short Ladder condition. While the theoretical concepts described by the force velocity curve might explain that more force could be developed if the duration of foot contact was longer, the Short Ladder condition demonstrated the longest step duration and the lowest V-GRF, making it suboptimal with respect to this variable. In sum, shorter step ladders favor the development of H-GRF while longer step ladders favor the magnitude of V-GRF produced in a shorter amount of time. These findings suggest that there is a limit to how much H-GRF is necessary for optimal acceleration. Previous reports indicated that horizontal force development was a key to maximizing acceleration during the early phase of a sprint (Kawamori, et al., 2013). Previous research which combined agility ladder training with other methods either failed to find (Padron-Cabo et al, 2020) or found (Venturelli et al., 2008) improvements in subject speed.
There was no difference in the time between steps for any of the ladder conditions. Predictably, the distance between steps was longer in the longer ladder conditions since the function of the ladders was to dictate subject step length. However, the velocity between steps, and the velocity across all the steps both increased as a function of ladder step length. Thus, within the parameters of this study, ladders with longer step progressions are better than shorter ones for training acceleration. It is possible that ladders configured with steps that are too short are a sub-optimal training stimulus as has been described (Thone et al., 2020). There likely exists an optimal magnitude of horizontal and vertical force for developing sprinting speed in the early acceleration phase. The present study suggests that horizontal force may be somewhat less important than once thought (Kawamori, et al., 2013).
The greatest H-GRF, V-GRF, and the H:V of the sprint occurred during the last step in the analysis. There were significant differences in the distance and velocity between steps, but no difference in time between steps. Thus, as subjects progressed through the acceleration ladders, their distance between steps was larger, since all of the ladders had progressively longer steps. Also, as expected, subject velocity increased as they progressed through the steps. Of greater interest was the fact that there was no significant difference in time between steps despite greater step length between the ladder conditions.

CONCLUSION: Coaches and athletes should use acceleration ladders configured with longer step progressions, such as used in this study, to train athletes at maximum velocity during acceleration ladder drills.

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