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TAKE-OFF FORCES AND IMPULSES IN THE LONG JUMP

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A series of jumps by an experienced female athlete were recorded with a force platform and a high-speed video camera. We obtained a wide range of run-up velocities by using direct intervention to set the length of the athlete's run-up. In all jumps the horizontal take-off force was predominantly a backwards braking force and so the athlete's horizontal velocity was substantially reduced during the take-off. The athlete's breaking impulse increased with increasing run-up velocity, but not so much as to negate the increase in run-up velocity. The optimum long jump take-off technique is a compromise between the conflicting desires of generating vertical impulse and minimising the horizontal braking impulse. We currently have no firm recommendation as to the usefulness of a force platform in improving an athlete's take-off technique.

KEY WORDS: long jump, take-off force, take-off impulse, take-off technique.

INTRODUCTION: The distance achieved in a long jump is strongly determined by the athlete's horizontal velocity at the end of the run-up (Hay, 1993). However, to make best use of this run-up velocity the athlete must generate appropriate forces at take-off so as to launch their body at the optimum take-off velocity and take-off angle (Linthorne, Guzman & Bridgett, 2005). During the take-off the athlete wishes to generate a high vertical velocity so as to give time in the air, whilst also minimizing loss of horizontal velocity so as ensure a fast forwards travel. For elite athletes the optimum take-off technique is to lower the centre-off mass into the take-off stride and plant the foot ahead of the centre of mass, with a leg plant angle of about 60–65° to the horizontal and with the knee al most straight. The jumper's body then pivots up and over the take-off foot, during which time the take-off leg rapidly flexes and extends. This technique generates a high vertical velocity (about 3.1 m/s for women and 3.4 m/s for men), retains a high proportion of horizontal velocity from the run-up (about 8.0 m/s for women and 8.8 m/s for men), and produces a take-off angle of about 21° (Alexander, 1990; Arampatzis, Brüggemann & Walsch, 1999; Seyfarth, Blickhan, & Van Leeuwen, 2000; Linthorne, 2008).
Some coaches and sports biomechanists have suggested using a force platform to monitor the athlete's take-off forces during training. The aim is to provide diagnostic feedback to the athlete and so improve their take-off technique. For this endeavour to be fruitful we need a thorough understanding of the relationships between run-up velocity, take-off technique, and jump distance. One method of improving our understanding of these relationships is to conduct an intervention study in which the run-up velocity of the athlete is varied by setting the length of the run-up. Bridgett and Linthorne (2006) found that as the athlete's run-up velocity increases the jump distance and take-off velocity increase, the leg plant angle and vertical take-off velocity remain almost unchanged, and the take-off angle and take-off duration decrease. However, their study only used video analysis techniques and did not examine take-off forces. Here, we report results from a similar run-up intervention study that included a force platform to measure the athlete's take-off forces and impulses.

METHODS: An experienced female athlete (age 20 years, height 1.65 m, weight 57 kg, personal best 5.76 m) performed a series of long jumps using a run-up length of 2, 4, 8, 12, and 16 steps. The horizontal and vertical ground reaction forces during the take-off of the jumps were measured using a Kistler piezoelectric force platform that was sampled at 1000 Hz. Video images of the jumps were recorded using a JVC GR-DVL9800 camera operating at 100 Hz and an Ariel Performance Analysis System was used to manually digitise the motion of the athlete in the video images.

The force trace data from the force platform were used to calculate the horizontal and vertical take-off impulses and hence the changes in the horizontal and vertical velocities of the athlete during the take-off. (The impulse of a force is the 'integral of the force over time' and is given graphically as the area under the force versus time curve. An impulse that acts on a body produces a change in the velocity of the body.) The video data was used to determine other technique variables of the athlete, such as leg angles and knee angles, the vertical and horizontal positions of the athlete's centre of mass, and the vertical and horizontal velocities of the athlete's centre of mass.

RESULTS: As expected, the athlete's jump distance increased with increasing run-up velocity. The jump distance curve was roughly parallel to those of other experienced long jumpers examined by our laboratory (Figure 1).

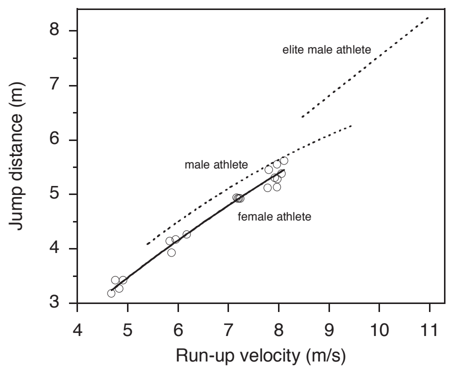

Figure 1: Effect of run-up velocity on the jump distance of a female athlete. Also shown are the relationships for two male athletes.

The force traces produced by the athlete in the present study (Figure 2) were similar to those seen in previous studies of long jumping (Koyama, Muraki & Ae, 2005). The vertical take-off force exhibited an initial large impact peak followed by an 'active' peak. The horizontal take-off force was predominantly a backwards braking force and only for a very short time at the end of the take-off did it switch over to become a forwards propulsion force. Because the braking impulse was much greater than the propulsion impulse, the athlete's horizontal velocity was substantially reduced during the take-off.

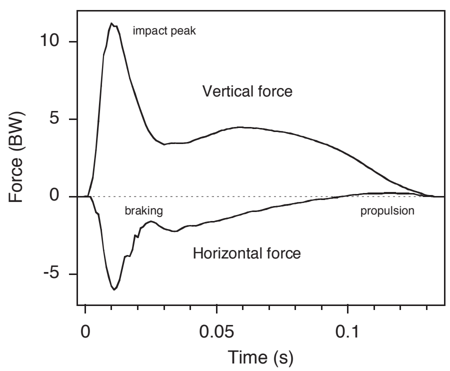

Figure 2: Time traces of the horizontal and vertical take-off forces (expressed in bodyweights) in a long jump (female athlete; 16 step run-up).

The athlete's horizontal braking impulse increased with increasing run-up velocity (Figure 3), but not so much as to negate the increase in run-up velocity. That is, the athlete's horizontal take-off velocity continued to increase with increasing run-up velocity (Figure 4). The vertical take-off impulse generated by the athlete (about 270 N·s) was almost the same across all run-up velocities and so the athlete had a constant vertical take-off velocity of about 2.6 m/s (Figure 4). The athlete's take-off angle decreased with increasing run-up velocity as result of the increase in horizontal take-off velocity. The athlete's leg plant angle decreased very slightly with increasing run-up velocity, with an average value of about 63° when using a 16-step run-up. Despite the athlete using a slightly greater angular range of motion of the take-off leg, the duration of the take-off decreased with increasing run-up velocity.

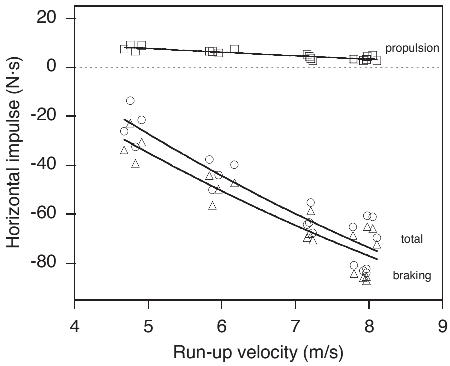

Figure 3: Effect of run-up velocity on horizontal take-off impulse (female athlete). (Total impulse = braking impulse + propulsion impulse.)

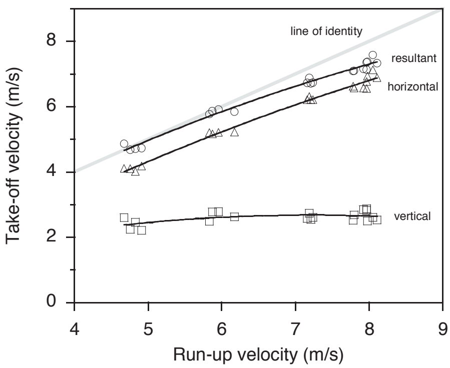

Figure 4: Effect of run-up velocity on take-off velocity (female athlete).

DISCUSSION: Long jumpers may increase their run-up velocity through technique training (where the athlete learns to use more appropriate movement patterns when sprinting and during the transition onto the take-off board) or through physical training (where the athlete increases their muscular strength, particularly in the muscles of the hips and legs that are used in sprinting). We contend that the relationships between run-up velocity, jump distance, and take-off technique seen in the present study are indicative of those that will result from an increase in run-up velocity arising from technique training. Extrapolating the athlete's curves indicates that for a 0.1 m/s increase in run-up velocity we expect the athlete's jump distance to increase by 6 cm, the horizontal braking impulse to increase by 1.2 N·s, the

vertical impulse to remain constant, the take-off velocity to increase by 0.06 m/s, and the take-off angle to decrease by 0.2°.
A force platform could be used to monitor an athlete's take-off forces during training. Diagnosing an athlete's technique is probably easiest when it is known that certain technique variables should be either maximised or minimised (e.g., run-up velocity; fall-back distance). Unfortunately, the generation of optimum take-off forces is a compromise between the conflicting desires of generating vertical impulse and minimising the horizontal braking impulse. A faster run-up produces a larger horizontal take-off velocity, but it also shortens the duration of the ground contact and hence the ability of the athlete to generate a vertical impulse. To increase the duration of the foot contact the athlete plants their foot ahead of the centre of mass. However, the resulting increase in vertical propulsive impulse is accompanied by an undesirable increase in horizontal braking impulse. Therefore, there is an optimum leg plant angle which offers the best compromise between vertical propulsive impulse and horizontal braking impulse. This optimum leg plant angle is likely to depend on the athlete's anthropometric factors (e.g. limb segment lengths) and the athlete's physical conditioning (maximum running velocity; eccentric leg strength). Other factors such as the 'vigour' of the arms and free leg during the take-off may also interact in a complex way with the optimum leg plant angle. When using her competition run-up length, the athlete in the present study used a leg plant angle of about 63°. Although this leg plant angle is similar to that used by other experienced athletes, we do not know whether it is the optimum angle for this athlete.

CONCLUSION: The present study has increased our knowledge of the relationships between run-up velocity, take-off technique, and jump distance. However, we are not yet able to provide scientifically rigorous advice to the individual athlete on how to optimise their take-off impulses and take-off technique so as to maximise their jump distance.

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