COORDINATION IN DYNAMIC JUMPING

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This study investigated coordination in dynamic jumping using a forward dynamics computer simulation model. A planar eight-segment torque-driven model was used to match the takeoff phase in a recorded running jump for height and recorded jump for distance by varying the torque generator activation timings. Two optimisations were then carried out to maximise height reached and distance travelled for each set of initial conditions used in the matching simulations. Although for each set of initial conditions, the order of activation onset timing was different for the two optimisations, the timing of activation onset in the optimisations for height and distance using the same initial conditions was very similar. This study has shown that the optimal activations are more a function of the initial conditions than the selection of maximal height or maximal distance.

KEY WORDS: coordination, activation, torque.

INTRODUCTION: The successful execution of a dynamic jump, such as a long jump or a high jump, requires the complex coordination of many muscles due to the multi-joint nature of the skill. Because multi-joint movement is complex, data must be interpreted using forward dynamical models complex enough to study coordination (Zajac, 1993). Previous research on the coordination of joint torque or muscle activations has focused on squat jumping (Pandy and Zajac, 1991) and vertical jumping (Selbie and Caldwell, 1996). Differences in coordination were found when optimal jumps were performed from varying starting positions (Selbie and Caldwell, 1996). The high jump and the long jump involve a series of similar movements between touchdown and takeoff but due to the specific requirements of the skills there are differences in initial conditions. The aim of this study was to investigate the differences in coordination between jumps for height and jumps for distance using a torque-driven forward dynamics model.

METHOD: A computer simulation model of the contact phase in high jumping and long jumping was developed and customised to an elite high jumper through the determination of subject-specific inertia, strength and visco-elastic parameters. The model was evaluated by matching a simulation with a recorded performance of a running jump for height and a running jump for distance. Each jump was recorded in a laboratory using two 50 Hz cameras and a 200 Hz camera to collect the kinematic data and a force platform to collect ground reaction force data. Fifteen body landmarks (wrist, elbow, shoulder, hip, knee, ankle and toe on each side of the body plus the centre of the head) were digitised in each field of the movement sequence from each of the three camera views. The 11 Direct Linear Transform (DLT) parameters and a central lens distortion parameter were calculated for each camera, and these parameters along with the synchronised digitised co-ordinates of the movement data were used to reconstruct the 3D locations of each digitised point using the method of Karara (1980). The coordinate data were then used to calculate the athlete's orientation and configuration angles throughout each movement, along with the mass centre velocity and whole-body angular momentum about the mass centre (Yeadon, 1990a; Yeadon, 1990b). The time histories of the orientation and configuration angles were fitted using quintic splines (Wood and Jennings, 1979) in order to obtain angle and angular velocity estimates throughout the movement.
A planar eight-segment torque-driven computer simulation model was developed for the foot contact phase in running jumps. The model comprised foot, calf, and thigh of the takeoff leg; shank and thigh of the free leg; trunk + head; upper arm and lower arm with torque generators situated at five of the joints (ankle, knee and hip of the takeoff leg; hip of the free leg and shoulder). Wobbling masses, within the shank and thigh segments of the takeoff leg

and the trunk segment, and a foot-ground interface were represented as non-linear spring-damper systems. Ten torque generators acting around the five joints were used to represent the extensor and flexor contractile elements with a rotational elastic element in series with each rotational contractile element. The maximum voluntary torque capable of being produced by each torque generator was modelled using a nine parameter surface fit. The actual torque produced was then calculated by multiplying this maximum torque value by an activation level between 0 and 1. Two different profiles were used to represent the activation time histories of the agonist and antagonist muscle groups. Six parameters were used to define the activation time histories of the agonists and five parameters were used to define the activation time histories of the antagonists. The six parameters for each of the agonists defined two quintic functions representing the ramp up to the upper activation limit and the ramp back down to zero. The five parameters for the antagonists also defined two quintic functions representing the ramp down from maximum to minimum activation and then back up. Each quintic function was defined by start time, end time, start value and end value (Yeadon and Hiley, 2000). The additional two parameters for the agonist torque generators were the initial activation level and the upper activation limit. For the antagonist torque generators the upper activation limit was assumed to be 1.0 resulting in only one additional parameter, the initial activation level. Initial conditions used as input to the model were taken from the actual performances.

The Simulated Annealing algorithm (Corana et al., 1987) varied the 55 torque generator activation parameters (5 joints and 11 parameters per joint) in order to minimise a cost function which consisted of six components to assess how well the simulated and recorded performances matched. Component (1) was the absolute difference in the trunk orientation at takeoff (measured in degrees); component (2) was the RMS difference in the joint angles at takeoff (measured in degrees); component (3) as the percentage absolute difference in the time of contact; component (4) was the percentage RMS difference in the horizontal and vertical linear momentum at takeoff; component (5) was the percentage absolute difference in the angular momentum at takeoff; component (6) was the overall RMS difference in the time histories of the horizontal and vertical ground reaction forces during the takeoff phase as a percentage of peak force. The overall RMS difference expressed as a percentage was then calculated from the six components with all components equally weighted since differences in degrees and percentages were considered to give comparable measures (Yeadon and King, 2002).

Following evaluation of the model two optimisations were carried out to maximise (a) jump height and (b) jump distance using the initial conditions from both the matching simulation of the jump for height and the matching simulation of the jump for distance, resulting in a total of four optimisations.

RESULTS AND DISCUSSION: Close agreement was obtained between simulation and performance with differences of 6.6% and 13.8% for the matching simulations of the jumps for height and distance respectively, providing confidence in the model's ability to simulate running jumps. The heights reached by the mass centre in the matching simulations of the jumps for height and distance were 1.82 m and 1.53 m respectively with maximum knee flexions of 134˚ and 115˚ respectively. The corresponding values in the optimised jumps for height and distance were 1.91 m and 1.69 m and 138˚ and 120˚ respectively using the initial conditions from the matching jump for height, and 1.56 m and 1.57 m and 118˚ and 118˚ respectively using the initial conditions from the matching jump for distance. In the matching simulations of jumps for height and distance, the distance travelled when the mass centre had fallen to 0.6 m from the ground was 1.61 m and 3.95 m respectively. The corresponding distances travelled in the optimised jumps for height and distance were 1.68 m and 2.32 m respectively using the initial conditions from the matching jump for height and 4.04 m and 4.11 m respectively using the initial conditions from the matching jump for distance. The initial conditions for the matching simulations of the jumps for height and distance are shown in Table 1.

Table 1. Initial conditions used in the matching simulation of the jumps for distance

	Jump for height	**Jump for distance**
CMx velocity	4.4 ms-1	6.9 ms-1
CMy velocity	-0.9 ms-1	-0.4 ms-1
Plant angle	59°	60°
Ankle angle	135°	132°
Knee angle	157°	151°
Hip angle	150°	134°
Shoulder angle	-56°	-20°
Free hip angle	187°	197°

One of the six parameters defining the activation profile for the extensors of the ankle, knee and hip joints was the activation onset time. Although for each set of initial conditions, the order of activation onset timing was different for the two optimisations (Table 2), the timing of activation onset, and level of activation reached in the optimisations for height and distance using the same initial conditions were very similar (Figures 1 and 2). Using the initial conditions from the matching jump for height the time differences between the activation onset of the three lower limb joints in the optimised jumps for height and distance were 0.061s and 0.076s respectively. The corresponding time differences using the initial conditions from the matching jump for distance were 0.002s and 0.001s.

Table 2. Order of activation onset timing for the optimised simulations

	optimised jump for height	**optimised jump for distance**
initial conditions – matching jump for height	hip-knee-ankle	knee-hip-ankle
initial conditions – matching jump for distance	hip-ankle-knee	knee-hip-ankle

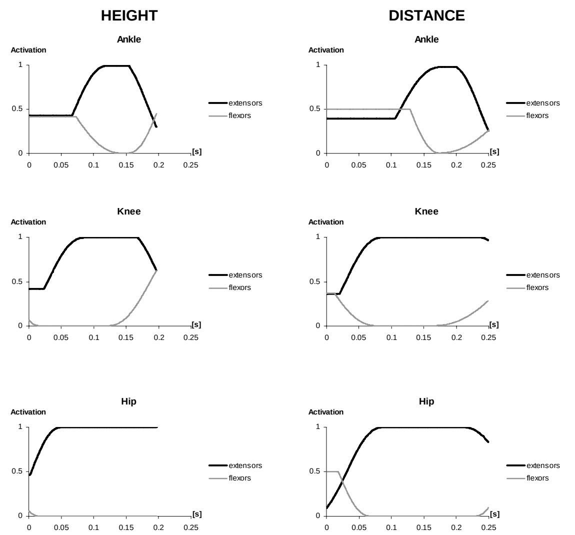

Figure 1. Torque activation time histories for optimisations of jumps for height and distance are similar when using the initial conditions from the matching simulation of the jump for height.

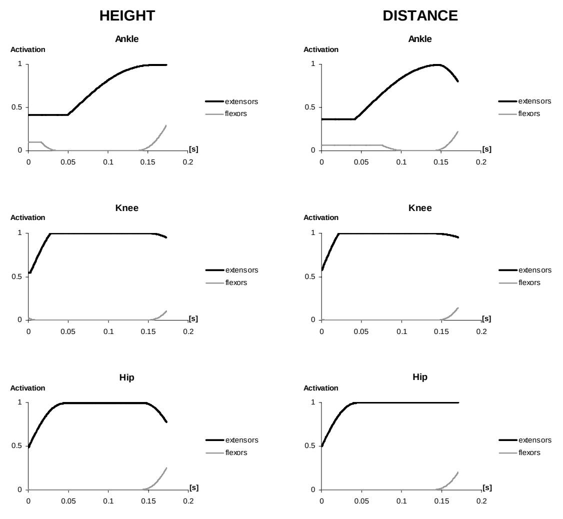

Figure 2. Torque activation time histories for optimisations of jumps for height and distance are similar when using the initial conditions from the matching simulation of the jump for distance.

CONCLUSION: This study has shown that coordination patterns are different in jumps for height and distance and that this is mainly due to differences in initial conditions rather than differences in the required outcome of the two skills.

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