ADJUSTMENT IN THE TAKEOFF PHASE OF 1-M SPRINGBOARD FORWARD DIVES

Mohsen Sayyah, Mark A. King, Michael J. Hiley and M.R. (Fred) Yeadon

School of Sport, Exercise & Health Sciences, Loughborough University, UK

The aim of this study was to investigate whether any adjustment is made during the board contact phase of 1-m springboard forward dives. Variability of body orientation angle at landing from hurdle (touchdown) and at takeoff together with joint angle time histories of 15 forward pike dive takeoffs, performed by an international diver, were determined using video analysis. A computer simulation model of a diver and springboard was used to determine the effects of perturbations of initial conditions on takeoff variability. The variation at takeoff obtained in the simulation outcome was much greater than in the actual performance, indicating that the diver made adjustments during the board contact phase. The diver varied his body configuration during the board recoil phase to adjust his body orientation, leading to low variability at takeoff.

KEY WORDS: variability, simulation, feedforward control, feedback control

INTRODUCTION: In springboard diving board contact can be divided in board depression and board recoil phases (Figure 1). In forward dives the execution of extra joint flexion at touchdown absorbs energy and may result in a loss in dive height. Thus, the optimal flexion at touchdown greatly depends on the diver's skill and muscular strength in which extra flexion following the touchdown would be minimised to avoid energy absorption (Sanders & Wilson, 1988).

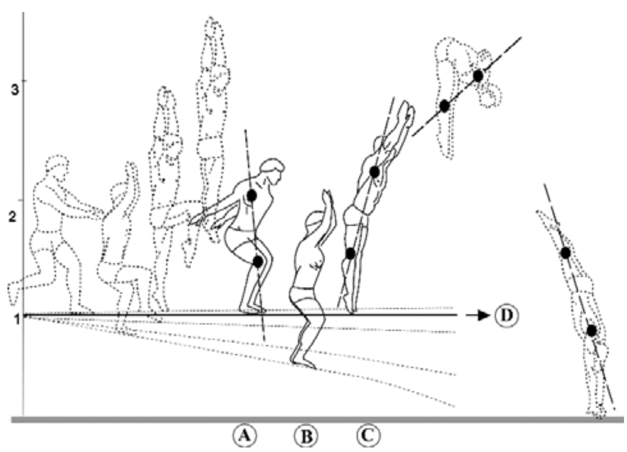

Figure 1: 1-M springboard forward pike dives. Board contact phase (A to C), Touchdown (A), Maximum board depression (B), Takeoff (C), Board depression phase (A to B), Board recoil phase (B to C), Board neutral position (D).

There are many movements that can be executed in far less time than is required for using feedback control (Keele & Posner, 1968). If there is any error in the initiation of the movement, the processes involving the generation of sensory error information, perceiving it, and initiating corrections in response to those errors requires about 0.12 s to 0.20 s to start the correction. The amount of possible feedback involvement in a movement longer than 0.20 s is dependent mainly on the movement time (Schmidt, 1975). Although it has been reported that feedforward and feedback corrections are used in sporting movements (Hiley and Yeadon, 2016), it is not clear what kind of control (feedforward or feedback) is used in the takeoff phase of springboard diving and to what extent changes in the initial touchdown conditions can affect the takeoff conditions. It is hypothesised that divers make adjustments during the contact phase to cope with variation of the initial conditions so as to obtain consistency at takeoff. A subject-specific angle-driven simulation model of springboard diving takeoff was applied to investigate the effect of variation (a) at touchdown and (b) maximum board depression on the takeoff conditions in forward pike dives.

METHOD: one Fastec TS3 high speed video camera (frame rate 250 Hz, exposure time 4 ms, resolution 1280 x 1024 pixels) was used to record 15 trials of a forward pike dive performed by a male international springboard diver (69.7 kg, 1.79 m). Before data collection, the purpose and details of the study were explained to the diver and all procedures were approved by the Loughborough University ethics committee. To calculate the diver's configuration angle and orientation as the angle of a line between the knees and trunk (body axis) relative to vertical (Figure 1), the video recordings were digitised manually (Yeadon, 1990a). A segmental inertia method (Yeadon, 1990b) was used to calculate the mass centre location. Board contact phases were expressed with respect to the board neutral position and all touchdown and takeoff variables were measured at board neutral position (Figure 1).

A simulation model of a diver and springboard developed by Kong (2005) was applied to match simulation and performance using average root mean square difference (RMS). The simulation model used initial conditions and quintic spline fits to the joint angle time histories obtained from the diver's performances to match the recorded performances. Thereby, the initial conditions at touchdown (Table 1) and the actual joint angle time histories were used to drive the model. The rotation potential of each dive was calculated as a normalised product of angular momentum (kg.m^2/s) and flight time (s), giving the equivalent number of straight somersaults (Hiley and Yeadon, 2008). An objective score was used to quantify the difference between the simulation and performance. Rotation potential variability at takeoff for perturbed simulations was compared with that of the original matching simulations (actual performances). This was done by perturbing the initial values of horizontal, vertical and angular velocities. Combinations of plus (increasing) and minus (decreasing) perturbations of one standard deviation of the actual performances were used. The analysis was performed for two different initial conditions (a) at touchdown and (b) at maximum board depression.

RESULTS: The average root mean square difference (RMS) 2.7° of the scores of matching the board contact phase demonstrated that the simulations closely matched the performances. The mean and standard deviation of the angles, velocities, toe distance and takeoff time presented in Table 1 show that the diver was consistent at touchdown and takeoff. The mean orientation angle indicates that the body was near the vertical at touchdown and takeoff (Table 1 & Figure 1). The average time of maximum board depression was 0.217 s (Figure 2). The variation in the orientation angle reached a peak at 0.176 s and decreased by the end of the takeoff. The peak variation of hip and knee angles occurred in the recoil phase at about 0.264 s and 0.256 s but the arm peak variability appeared at about 0.19 s in the board depression phase. The variation of all angles decreased by the end of takeoff (Figure 2).

Table 1. Mean and standard deviation of the angles and velocities at touchdown and takeoff along with flight time, toe distance and rotation potential at takeoff of 15 forward pike dives

Variable	Touchdown	Takeoff
Hip angle(º)	92.2 ± 4.9	168.2 ± 3.3
Knee angle (º)	98.6 ± 2.6	178.9 ± 0.8
Trunk angle (º)	59.2 ± 3.1	72.4 ± 2.0
Arm elevation (º)	-32.5 ± 5.1	178.7 ± 4.5
Orientation angle (º)	-12.2 ± 1.3	13.1 ± 1.3
CM* Horizontal Velocity (m/s)	0.25 ± 0.047	0.86 ± 0.060
CM* Vertical Velocity (m/s)	-4.8 ± 0.050	5.84 ± 0.080
Angular Velocity (rad/s)	-1.15 ± 0.641	-1.86 ± 0.177
Toe distance (m)	0.115 ± 0.060	
Takeoff time (ms)	446 ± 9.42	
Rotation potential (ss)	0.347 ± 0.018	

*CM= centre of mass

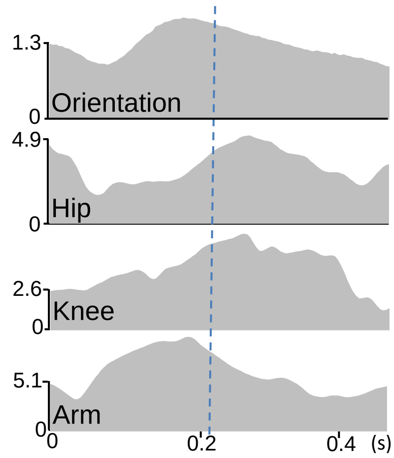

Figure 2. Standard deviation time history of angles (°) of 15 forward pike dives. Dashed-line indicates the average time of maximum board depression.

Combined perturbations: The mean and standard deviation of the rotation potential in the actual performances without perturbations, for all dives were 0.347 ± 0.018 straight somersaults (ss) (Table 1). For each individual simulation, eight combinations of plus and minus one standard deviation were used to perturb the initial conditions at touchdown, giving three perturbations at a time. The eight combinations depicted in Table 2 represent the RMS difference between the rotation potential arising from perturbing the initial touchdown conditions and the rotation potential in the actual performance. For instance, the combined effect of increasing horizontal, vertical and angular velocities at once on the rotation potential at takeoff gave an RMS difference of 0.043 ss (Table 2) which is greater than the rotation potential variability in the actual performance 0.018 ss (Table 1). The RMS difference of the eight combined perturbations obtained 0.085 ss which is 4.7 times greater than in the actual performance (Table 2). The analysis was repeated but the conditions at maximum board depression were chosen to be the initial conditions. At maximum board depression where the board is in its lowest point, the vertical velocity is zero. Therefore, for each individual simulation, four combinations of plus and minus one standard deviation of horizontal and angular velocities were used to perturb the simulations (Table 2). The RMS difference in rotation potential of the four combined perturbations was 0.076 ss (Table 2), indicating that the variability of the rotation potential at takeoff by varying the initial recoil conditions was also greater than the variability in the actual rotation potential of 0.018 ss.

Table 2. RMS difference between rotation potential obtained in each combined perturbation of initial touchdown conditions and the actual performance of 15 forward pike dives

Rmsd (Touchdown)		**+++**	**+--**	**+-+**	**++-**	**-++**	**-+-**	**--+**	**---**	**RMS**
	rmsd	0.043	0.128	0.043	0.113	0.098	0.069	0.085	0.057	**0.085**
Rmsd (Lowest point)		**++**	**+-**			**-+**			**--**	
	rmsd	0.091	0.071			0.068			0.071	**0.076**

Note: Perturbations are in order of horizontal, vertical and angular velocities in each combination. (+) indicates increasing one standard deviation and (-) refers to decreasing one standard deviation.

DISCUSSION: The aim of this study was to investigate whether the diver made any correction during the contact phase in 1-M springboard forward pike dives. A simulation analysis was carried out to examine whether movement variability during the contact phase controls the rotation potential at takeoff. In the first analysis, the effect of varying the initial touchdown conditions on the rotation potential at takeoff was investigated. In the second analysis, the effect of varying the initial recoil conditions on the rotation potential at takeoff was examined. The perturbation of horizontal, vertical and angular velocities at touchdown in analysis 1 gave an RMS difference of rotation potential 0.085 ss at takeoff and in analysis 2 the variation arising from maximum board depression (lowest point) gave an RMS difference of 0.076 ss in rotation potential at takeoff (Table 2). When compared with the variability of the rotation potential at takeoff in the actual performances of 0.018 ss (Table 1), the variation obtained in the simulation outcome was much greater than the variability in the actual performances, demonstrating that the diver must have made adjustments during the contact phase.

The amount of variation arising from perturbation of the initial touchdown conditions 0.085 ss is comparable with the variability arising from initial recoil phase 0.076 ss (Table 2). These values indicate that most of the corrections are made during the recoil phase. The peak variation in the hip and knee angles appeared in the second half of the takeoff phase (Figure 2). In this period, the variability in the orientation angle decreased. This indicates that the diver varied the hip and knee angles during the recoil phase to adjust his orientation angle, leading to low rotation potential variability at takeoff. It is to be understood that during the first half of the takeoff phase (board depression) the diver noticed some error information arising from touchdown, and during the second half of the takeoff (recoil phase) initiated correction by varying his hip and knee angles in order to minimise the rotation potential variability at takeoff. It can be interpreted that the board depression phase uses feedforward control (pre-planned), and that feedback from the initial touchdown conditions was used to make adjustment (feedback control) during the board recoil phase to compensate for the variation of the pre-planned movement. This is supported by McNitt-Gray et al. (2001) who reported that feedforward control is used to stabilise the joints and satisfy the mechanical demand imposed on the lower extremity after contact during landing tasks and by Schmidt (1975) that feedback control is involved in movements longer than 0.2 s.

In a normal jump, the arms swing upward as the legs extend to thrust the body into the air. In contrast, during all diving takeoffs the arms swing upward before the legs extend to begin the jump (O'Brien, 1992). Although the peak variability in the hip and knee in the second half of the contact phase (Figure 2) is associated with the execution of adjustments, the peak variation in the arm angle during the board depression may be due to having to maintain balance.

CONCLUSION: The variation of the rotation potential at takeoff obtained in the simulation outcome was much greater than variability in the actual performances, demonstrating that the diver made adjustments during the contact phase to reduce his takeoff variability. It was found that the diver varied his hip and knee angles during the recoil phase, leading to low variability in rotation potential at takeoff. This indicates that movement variability can have a functional role in human movement. It is concluded that coaches and divers should be aware of such adjustments.

REFERENCES:

Hiley, M.J., & Yeadon, M.R. (2008). Optimisation of high bar circling technique for consistent performance of a triple piked somersault dismount. *Journal of Biomechanics* 41,1730-1735.

Hiley, M.J. and Yeadon, M.R. (2016). Investigating optimal technique in the presence of motor system noise: application to the double layout somersault dismount on high bar. *Journal of Sports Sciences*,34 (5), pp.440-449.

Kong, P. W. (2005). Computer simulation of the takeoff in Springboard Diving. (PhD), School of Sport, Exercise and Health Science, Loughborough University, UK.

Keele, S. W, & Posner, M. T. (1968). Processing of visual feed-back in rapid movements. *Journal of Experimental Psychology*, 77, 155-168.

McNitt-Gray, J. L, Hester, D. M. E., Mathiyakom, W. and Munkasy, B. A. (2001). Mechanical demand and multijoint control during landing depend on orientation of the body segments relative to the reaction force. *Journal of Biomechanics*, 34,1471-1482.

O'Brien, R (1992). Diving for gold: Basic to advances springboard and platform skill. Champaign, Illinois: Leisure Press.

Sanders, R. H. & Wilson, B. D. (1988). Factors contributing to maximum height of dives after takeoff from the 3M springboard. *International Journal of Sport Biomechanics*,4(3),231-259.

Schmidt, R.A. (1975). A schema theory of discrete motor skill learning. *Psychological Review*, 82, 225 260.

Yeadon, M.R. (1990a). The simulation of aerial movement - I: The determination of orientation angles from film data. *Journal of Biomechanics*,23,59-66.

Yeadon, M.R. (1990b). The simulation of aerial movement - II. A mathematical inertia model of the human body. *Journal of Biomechanics*,23,67-74.