ADJUSTMENT IN THE FLIGHT PHASE OF 1M SPRINGBOARD FORWARD PIKE DIVES

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The aim of this study was to investigate the variability in 1m springboard forward pike dives (101B). Variability of body orientation angle at takeoff and water entry together with joint angle time histories of 15 forward pike dives, performed by an international diver, were determined using video analysis. A computer simulation model was used to investigate the effects of initial conditions variability and flight phase configuration variability on outcome (orientation at entry) variability. It was found that the variation in the simulated orientation at entry arising from variability in the initial conditions was greater than the actual variation. This indicates that the diver used feedback correction to make adjustments during flight to reduce the variability of his entry angle.

KEY WORDS: variability, computer simulation, feedback control, adjustment

INTRODUCTION: The aerial phases in some sports are complex and form the basis of sports such as springboard diving, tumbling, trampolining, gymnastics and the aerials event in freestyle skiing (Yeadon, 2013). In springboard diving, the interaction between the diver and springboard highlights one aspect of the complexity of the event since divers need to know how to make best use of the springboard and how to cope with any perturbations. A competitive diver uses the approach steps and hurdle to make the board oscillate and then jumps from the end of the board into the air, performs the somersault rotation and finally enters the water (Figure 1). The variability in the diver's joint angle changes may be viewed as an unwanted source of error which needs to be minimised or eliminated to improve accuracy. On the other hand, a diver's adjustment of body configuration during flight may be a deliberate compensation for variations in takeoff, leading to increased joint angle variability and decreased entry angle variability. The study of movement correction in aerial sports has been limited to a few studies (Hiley and Yeadon, 2008, 2012; Yeadon and Hiley, 2014).

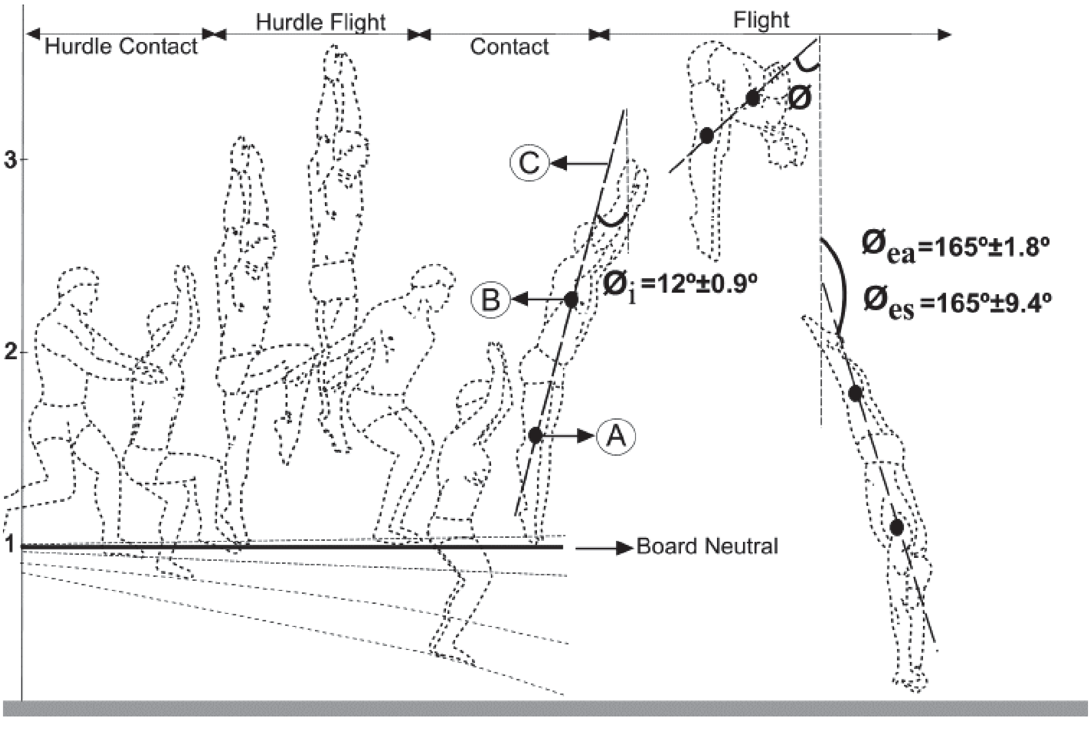

Figure 1: 1M springboard forward pike dive. $Ø_i$ = initial body orientation angle at takeoff, $Ø_{ea}$ = entry orientation angle in recorded performance, $Ø_{es}$= entry orientation angle in simulation, A = centre of knees, B = a fixed point on trunk, C = body axis.

The study of human information processing has been recognised as one of the most popular ways to understand human behaviour (Schmidt & Lee, 1999). As the springboard recoils, the takeoff conditions could be seen as sensory input for the neuro-skeletal system. During the flight and entry phases the diver may use feedback to compensate for the initial conditions. Since the flight phase is over a 1 s there is sufficient time for feedback control (Schmidt & Lee, 1999). Both feedforward and feedback control may be used in acrobatic aerial movements whereby takeoff and the early part of the flight phase are preplanned and feedback control is used in the later stages to adjust body configuration to minimise the entry angle (outcome) variability (Yeadon and Hiley, 2014). Although, this suggests that feedback control could be used in flight, there is currently no evidence for what kind of control (feedforward or feedback) is used. The purpose of this study is to investigate the extent to which configuration changes during the flight phase control the outcome in 1m springboard forward pike dives.

METHOD: A 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 (mass = 69.7 kg, height = 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. Each dive was divided into four phases (Figure 1) and the video was digitised manually in order that orientation and configuration angles could be calculated (Yeadon, 1990a). For each digitised image the mass centre location was calculated using a segmental inertia method (Yeadon, 1990b) along with the whole body orientation and the joint configuration angles. Body orientation was calculated as the angle between the body axis and the vertical (Figure 1). Dive flight phases were expressed with respect to the board neutral position and all takeoff variables were measured at board neutral position (Figure 1).

An 11-segment computer simulation model (Yeadon et al., 1990) was used to investigate the effect of variability in the initial conditions at takeoff and in the joint angle time histories during flight on entry angle variability. The angular momentum of each dive was calculated using the segmental inertia values and the time histories of the configuration and orientation angles in the aerial phase (Yeadon, 1990c). The model output comprised the joint angle and orientation angle time histories during the simulation of the 15 forward pike dives. The accuracy of the simulation output was evaluated by comparing the time histories of the orientation angles with those from the recorded performance. Two analyses were carried out to investigate variability and control in forward pike dives. In the first case, the variability in the entry angle arising from the variability of initial conditions was determined. The initial velocity (flight time) and angular momentum of all 15 dives were used as input to simulations while maintaining a set of joint angle time histories of an individual dive. In the second case, the variability in entry angle arising from the joint angle changes during the flight phase was investigated. Each simulation was run such that the joint angle time histories of all 15 dives were used while maintaining the initial velocity and angular momentum of an individual dive.

RESULTS: The average root mean squared difference (RMS) in orientation angle time history between simulation and performance was 3.1°. This demonstrated that the simulation closely matched the performance. The standard deviations of orientation angles, flight times and angular momenta were all small showing that the diver was consistent from trial to trial (Table 1). The mean orientation angles at takeoff and entry were 12° (SD=0.9°) and 166° (SD=1.8°) respectively, indicating that the body orientation was near the vertical and consistent at the start and end of the flight phase. The hip angle showed large variation in the last half of the flight between 0.6 s and 1.2 s (Figure 2). In this period the diver comes out of the pike and is descending. The arm angle also showed large variation between 0.1 s and 1.2 s (Figure 2). This highlights that the arm position has low variability at the start and the end of the flight. The peak variation in orientation angle appeared in the middle of the flight phase, at around 0.6 s. This suggests that adjustments are made in flight from dive to dive by changing hip and arm movements.

Table 1 Mean and standard deviation of the angles, flight time and angular momentum at takeoff and entry of 15 forward pike dives

Variable	Takeoff	entry
Hip (°)	163 (2.7)	180 (3.6)
Knee (°)	177 (1.1)	180 (0.6)
Arm (°)	179 (4.5)	165 (2.5)
Orientation (°)	12 (0.9)	166 (1.8)
Flight Time (ms)	1349 (13.8)	
Angular Momentum (kg.m^2/s)	16.9 (1.0)	

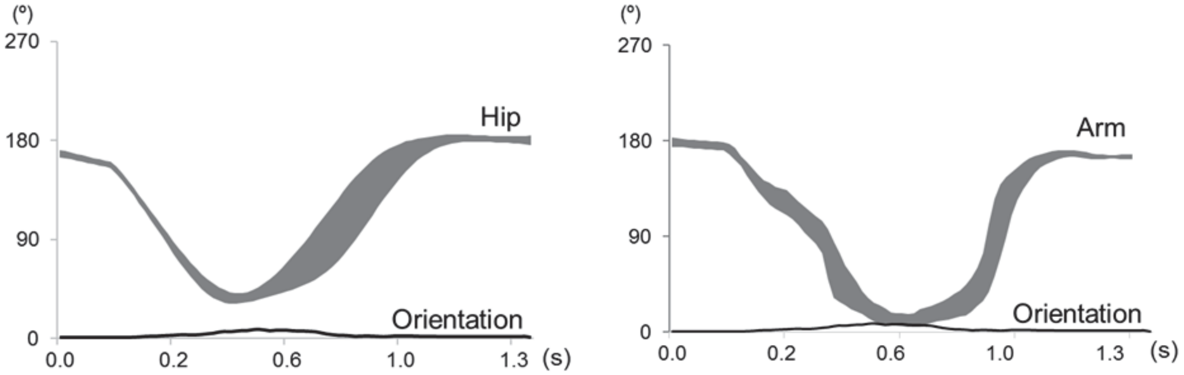

Figure 2 Angle variability within joint angle time history (grey curve shape) and standard deviation of orientation angle during the flight phase (black line) of 15 forward pike dives

The variation in the simulated orientation angle at entry arising from variation in the flight time and angular momentum was 9.4° compared to a variation of 1.8° in the recorded performances (Table 2). The variation in the simulated orientation angle at entry arising from variation in the joint angle time histories was 8.0° compared to a variation of 1.8° in the recorded performances. This indicates that the diver used feedback control because the recorded variability is much smaller than the average variation obtained from the simulation outcomes.

Table 2 Mean and standard deviation of orientation angle at takeoff and entry in recorded performance and simulation of 15 forward pike dives

Orientation angle	Actual performance (°)	Simulation (°)	
		Case 1	Case 2
Takeoff	12 ± 0.9	12 ± 0.9	12 ± 0.9
Entry	165.6 ± 1.8	165.4 ± 9.4	165.3 ± 8.0

DISCUSSION: In the first case, the variability arising from initial conditions led to variation in the final output of the simulations, giving a standard deviation of 9.4° in the entry orientation angle. In the second case the variability arising from configuration changes during the aerial phase also led to variation in the final output of the simulations, giving a standard deviation of 8.0° in the entry angle (Table 2). This indicates that the diver varied his body configuration to compensate for the variability arising from the initial conditions. According to Fitts' (1954) model of human movement, the whole aerial phase might be considered as a combination of short and long duration movements, such that the early part of the phase is preprogramed and feedback from previous stages could be used to make the final correction. According to the theory of time to collision (Lee, 1976), the diver might have used information about time to entry for controlling the outcome variable rather than information about distance, velocity or acceleration. Angular momentum is constant during the flight phase and so divers change their angular velocity by tightening or loosening their body so as to change the moment of inertia and thereby control the movement. The peak variation in hip and arm angles in the second half of the flight phase (Figure 2) occurs when the diver is extending from the pike. Thus the timing of this extension is made so as to have the correct orientation angle at entry. This might be supported by the finding of Rèzette and Amblard (1985) and Yeadon and Hiley (2014) that visual orientation information is used for making a final correction. Although it has been found that the diver has made adjustments during the flight phase to compensate for variability arising from initial conditions, it is likely that these corrections are performed using long loop / triggered and planned responses (Latash, 1998). Elite performance is characterised by both low variability and high variability (Hiley et al., 2013). While there is low variability in performance outcome (entry angle) in this study, there is high variability in body configuration during the flight phase due to making adjustments. Although elite divers can make very precise and reproducible movements, the need for adjustment can explain the existence of variation from trial to trial as supported by the finding of Yeadon and Hiley (2014). The initiation of adjustment found in this study suggests that it may be beneficial for coaches to be aware of the correction and this is supported by Yeadon and Hiley (2014). Although vision is used to assist divers to determine body position and this contributes to the consistency of the dives, further study into what information is used in order to be able to make the corrections would be useful for coaching.

CONCLUSION: The outcome variability (entry angle) in the performances was much smaller than the variation in the simulation outcome. This demonstrates that the diver must have used feedback control during the flight phase to correct the somersault rotation. It is therefore concluded that the diver made adjustments, primarily by modifying the hip angle, to reduce the variability of the entry angle. The adjustments found in the present study demonstrate that variability can have a functional role in human movement. This indicates that it would be beneficial for coaches to be aware of such adjustments.

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