Human Movement Science 59 (2018) 234–243

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Full Length Article

Functional variability in the flight phase of one metre springboard forward dives

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A B S T R A C T

In springboard diving, low variability in takeoff conditions and in the somersault orientation angle at water entry is to be expected since consistency and accuracy are necessary for a good dive. A diver's adjustment of body configuration during flight may be a deliberate compensation for variations in takeoff conditions, leading to increased joint angle variability and decreased entry angle variability. The aim of this research was to investigate the extent to which a diver pre-plans the aerial phase and then makes adjustments in flight to control the entry angle in one metre springboard forward dives. Performances of 15 forward pike dives and 15 forward 2½ somersault pike dives, performed by an international diver were video recorded at 250 Hz. Joint centres during flight were digitized and their spatial coordinates were subsequently reconstructed using the Direct Linear Transformation in order to determine orientation and configuration angles. A computer simulation model was used to investigate the effects of variability in takeoff conditions and configuration variability in flight on the variability of the orientation angle at water entry. The amount of variation in the somersault orientation angle at entry as determined using simulations based on the variability in the takeoff conditions was four times greater than the variation in the recorded performances. It was concluded that the diver used open loop control for the first half of the flight phase and subsequently used feedforward and feedback control to make timing adjustments of hip and arm angles to reduce the variability of his entry orientation angle.

1. Introduction

Many competitive sports incorporate an aerial phase within which acrobatic movements are performed as in gymnastics, trampolining and springboard diving. For competitive springboard diving the main mechanical objectives are: generating sufficient angular momentum, obtaining maximum dive height and therefore flight time, travelling safely away from the board, and having the correct orientation angle on entry into the water (Miller & Munro, 1985). The latter is often considered one of the primary performance outcomes of the dive, since it is the last part of the movement the judges see, with incorrect orientation at entry accompanied by greater splash of the water. Success in competitive diving requires consistency in achieving appropriate somersault orientation at water entry. This paper seeks to understand how such consistency is achieved.

A springboard dive can be divided into (a) the hurdle phase, (b) the contact phase, and (c) the aerial phase (Fig. 1). The hurdle and contact phases are used to generate the linear and angular momentum for the subsequent aerial phase and to ensure the diver travels safely away from the board. The aerial phase is used to complete the required number of rotations and achieve the correct orientation at entry.

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https://doi.org/10.1016/j.humov.2018.04.014
Received 17 January 2018; Received in revised form 26 April 2018; Accepted 27 April 2018
0167-9457/

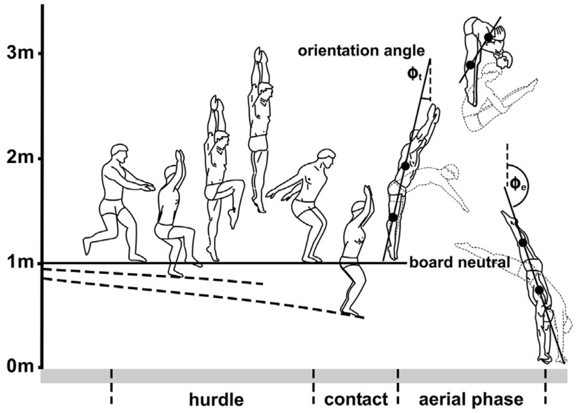

Fig. 1. One metre springboard forward pike dive (solid line) and forward 2½ somersault pike (dotted line) dive. Phases comprise: hurdle (contact and flight), contact, flight. ϕ_t = orientation angle at takeoff at board neutral position, ϕ_e = entry orientation angle.

When an expert diver aims to perform a given dive in exactly the same manner on each attempt (open loop control), it is inevitable that there will be some variation from trial to trial (Newell & Corcos, 1993; Bartlett, Wheat, & Robins, 2007; Preatoni et al., 2013). If the performance variability in one stage is incorporated into the planning of the next stage (feedforward control) the propagated variation may be reduced. For example if the diver senses that the horizontal velocity in the hurdle flight is greater than usual he may modify the plan for the takeoff muscle activations in order to be nearer the ideal horizontal velocity at the moment of takeoff. In rapid movements of short duration carried out with feedforward control, such as the contact phase in tumbling of around 0.1 s (King & Yeadon, 2004), kinematic movement variability may arise due to errors in the localisation (estimation of initial conditions) and planning stages of the movement, and also due to noise within in the execution stage of the movement (van Beers, Haggard, & Wolpert, 2004). If the movement is longer in duration, such as the contact and aerial phases of one-metre springboard diving with times of around 0.5 s and 1.3 s (Miller, Zecevice, & Taylor, 2002), there is sufficient time for the diver to make corrections for such errors. That is, the diver may use feedback control (Jagacinski & Flach, 2003, chap. 2) to adjust body configuration in flight to ensure an accurate entry to the water. Such feedback corrections, using changes in arm and hip angles, would add to the kinematic movement variability (Hiley, Zuevsky, & Yeadon, 2013).

Traditionally movement variability has been viewed as noise that needs to be minimised or eliminated (Newell & Corcos, 1993). More recently, researchers have been interested in the potentially functional role that variability may play in human movement (Preatoni et al., 2013; Bartlett et al., 2007; Hiley & Yeadon, 2016). For example, an increase in movement variability associated with a diver making feedback corrections in flight would fall under the definition of functional variability, since the adjustments could have the function of controlling the somersault rotation in order to ensure appropriate orientation on entry into the water. In other words the adjustments produce increased movement variability in flight leading to a reduction in outcome variability on entry to the water.

Feedback control has been demonstrated in a number of acrobatic activities such as handstand balance (Yeadon & Trewartha, 2003), swinging on bars (Hiley & Yeadon, 2016) and twisting somersaults (Yeadon & Mikulcik, 1996; Yeadon & Hiley, 2014). In each case the control strategy was found to use a combination of open loop control or feedforward control together with feedback (closed loop) control to achieve the task goals. The feedback control was based on detecting an error in the desired state and providing a correction, after an inherent time delay (Latash, 1998, chap. 12; Jagacinski & Flach, 2003). For example, Hiley and Yeadon (2016) demonstrated that gymnasts made adjustments (feedback control) to their pre-planned movements to regulate the pace of consecutive backward longswings on the horizontal bar. In springboard diving it might be expected that the diver pre-plans the aerial phase (either open loop control or feedforward control) and then makes adjustments during flight (feedback control) to correct for errors generated during the contact phase. The aim of the present study is to determine to what extent divers pre-plan the aerial phase and make adjustments in flight in order to minimise the variability in somersault orientation on entry into the water. Specific questions to be answered comprise: (a) are in-flight adjustments made using arm or hip angle changes in response to variation in rotation potential at takeoff? (b) is a single adjustment made or are sequential adjustments employed? (c) are there differences in the adjustments made in pike dives and in 2½ somersault pike dives?

2. Methods

In order to answer the above questions repeated performances of the same dive by the same diver were conducted in order to obtain variability measures of the same dive/diver activity. The performances were video-recorded and time histories of somersault orientation and joint angles were calculated from projections of digitised body landmarks on a vertical plane. A simulation study was used to establish whether in flight corrections must have been made to obtain low variability in the somersault entry angle. Subsequently linear regression was used to identify whether adjustments of arm angle or hip angle were related to variation in rotation potential and somersault orientation angle.