A KINEMATIC ANALYSIS OF THE BACKWARD 2.5 SOMERSAULTS WITH 1.5 TWISTS DIVE (5253B) FROM THE 3M SPRINGBOARD

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The aim of this case study was to determine the practical application of 3D inertial measurement units and compare angular velocity profiles, key position angles and event timings for the backward 2½ somersaults with 1½ twists (5253B). One male diver performed 11 trials of the 5253B while 3D inertial measurement units (IMU) and high speed video were used to measure kinematic variables. Peak angular velocity about the somersault and twist axes were 900±11deg/s and -1435±28.deg/s, with highly consistent patterns displayed for total flight time (<1%) and peak angular velocity (≤2%). A comparison between the 5253B and the backward 2½ somersaults dive (205B) indicated significant kinematic differences at take-off, flight and entry. IMU provide a quick and practical analysis tool for coaches wanting to monitor their athlete's daily performance.

KEYWORDS: variability, angular velocity, inertial measurement unit, 205B

INTRODUCTION: A straight somersaulting dive only requires rotational control about one axis of movement. A twisting dive increases the complexity of the aerial movement as it requires rotational control about multiple axes (Yeadon, 2001). During the twist portion of a somersault, a straight body alignment must be attained to minimise the moment of inertia about the longitudinal axis. This will allow the twist to be completed quickly, and subsequently slowing the somersault rotations about the transverse axis (Sanders & Burnett, 2007). The backward 2.5 somersaults with 1.5 twists (5253B) is a high demanding dive which requires the generation of a large angular momentum during a standing takeoff from the 3m springboard. Due to its high demand and complexity, FINA increased the degree of difficulty rating from 3.3 to 3.4 in 2014, increasing the incentive for divers to perform this dive. In performing dives, divers must both acquire the specific and complex movement patterns and demonstrate high levels of coordination. Thus, the ability to functionally adapt movement and coordinate during execution is proposed as enabling the skilled diver to produce consistently highly coordinated movement within what is regarded as a potentially highly variable and dynamic task (Bradshaw, Maulder, & Keogh, 2007; Davids & Button, 2004). Divers have previously shown that they have the ability to regulate the duration and velocity of somersaults to within 1% of variability, producing a high degree of consistency in angular velocity during non-twisting multiple somersault dives (Sinclair, Walker, & Cobley, 2014).
The majority of research for the sport of springboard diving has been conducted on non-twisting somersault dives. This may be due to the complexity of the methodology that is required when analysing twisting somersault dives (Yeadon, 1990a), with the most common techniques requiring time consuming digitisation from multiple camera angles. The current case study aimed to examine the angular velocity profiles, key positional angles, and key event timings for a single athlete during the backward 2.5 somersaults with 1.5 twists (5352B). Furthermore the current study endeavoured to determine the 3D application of using inertial measurement units (IMU) during twisting dives.

METHOD: One internationally ranked male diver (height = 1.70m, mass = 67kg), was recruited for the study. Informed consent approved by the University of Sydney human ethics committee was obtained. Following a normal dry land warm-up, and as part of normal training, the diver completed 11 trials of the 5253B dives across four training sessions. In addition to the 5253B, 8 trials of a backward 2½ piked dive (205B) were collected in order to compare the twisting and non-twisting kinematics of the backward takeoff dives.
An inertial measurement unit, IMU, (IMeasureU, Ltd; Auckland, New Zealand) (dimensions 22 mm x 34 mm x 10 mm, mass = 12g) strapped to the divers' lower back (L4/L5) with a

transparent film dressing (Opsite Flexigrid), was used to measure angular velocity profiles during the four training sessions. The IMU sample frequency was 100Hz. A comparison between IMU and 3D motion analysis (Cortex, 3.3) revealed <1% difference between the two motion capture systems, therefore the raw IMU output was used with no filtering. A custom Matlab script (The MathWorks, Inc., Natick, MA, USA) was used to export the individual dive data into Microsoft Excel (Microsoft Corp, Redmond, Washington, USA) to calculate peak angular velocities about the somersault and twist axes. Average angular velocity plateau and duration were also calculated for the twist portion of the dive. The angular velocity plateau was determined by an iterative procedure that identified the portion of the graph where the angular velocity was >90% of the plateau mean.

A high-speed Casio Exilim EX-FH100 camera was placed level with and perpendicular to the 3m springboard; with a frame rate of 120fps and a shutter speed of 1/250s. The field of view was limited to the diver's takeoff from the springboard, dive, and entry into the water. Video was digitised using Tracker software (Brown, 2008). A calibration frame, 7m x 3m, (Sinclair, Walker & Rickards, 2012) was used to transform digitised coordinates into real world coordinates. Takeoff and entry angles were calculated from digitised coordinates. Takeoff angle was defined as the line between the ankle and iliac crest with respect to the right hand horizontal. Entry angle was defined as the line between the iliac crest and the shoulder with respect to the right hand horizontal. Relative hip angles were calculated at takeoff, somersault, and entry and were defined as the angle between the thigh and trunk segments. Total flight time was calculated and measured from the final frame of foot contact with the springboard to the first frame where hands broke the water on entry (Sanders & Gibson 2000). Time durations between key events were also calculated from takeoff to somersault initiation, from the somersault to the initiation of somersault opening and from the somersault opening to water entry.

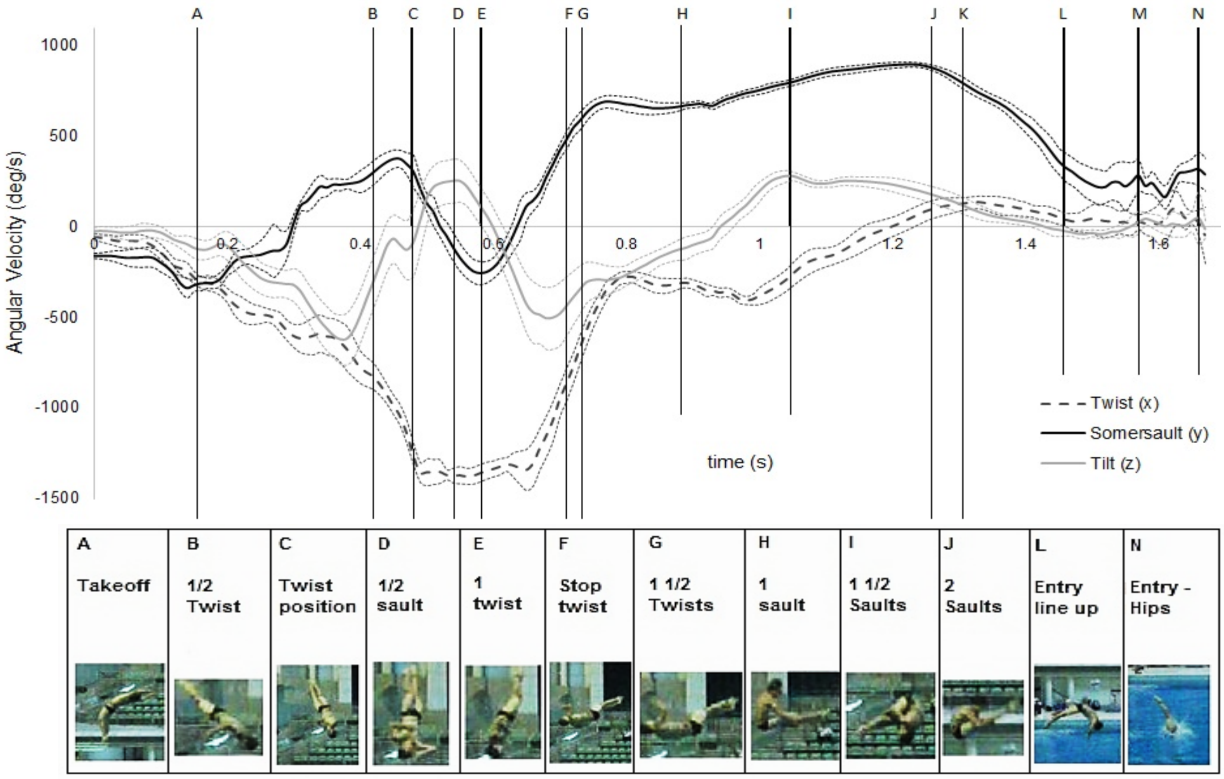
Coefficient of variation calculated the level of intra-variability and an independent T-test determined whether there were any significance differences ($p \leq 0.05$) between the 205B and 5253B.

RESULTS AND DISCUSSION: The gyroscopes in the IMU provided tri-axial angular velocity data for a twisting somersault dive (Figure 1.) They provided a clear distinction between the somersault rotations about the transverse axis, the twisting rotations about the longitudinal axis and the body's tilt.

To produce a twist about the longitudinal axis two techniques can be used; contact and aerial. Divers performing backward twists have been shown to use a combination of both techniques (Yeadon, 2001). The diver in this case study set the twisting motion prior to flight by turning their arms and torso in the direction of the twist (A, Figure 1). Once in the air the diver performed asymmetrical arm movements that were followed by arm adduction at the ¼ twist position to increase the tilt angle and therefore the rate of twist (B-C, Figure 1). During the twisting motion the somersault rotation fluctuated between negative and positive angular velocity (A-F Figure 1). This is due to the orientation of the body with respect to the fixed transverse axis. At each ½ twist increment the orientation changes, resulting in the fluctuation. The peak twisting angular velocity was -1435±28 deg/s, with 2% movement variability. The angular velocity plateau was highly consistent, 0.9%, with an average of -1347±12 deg/s, and a duration of 0.18±0.02s.

Once the 1½ twist rotations are complete the diver performs hip flexion to slow the rate of twist by increasing the moment of inertia about the longitudinal plane. Therefore, reducing the moment of inertia about the transverse axis and increasing the somersault angular velocity (F-H, Figure 1). Hip flexion in conjunction with anteroposterior rotation of the arms also helps to realign the rotation about the transverse axis in preparation for a straight entry (Sanders & Wilson, 1987). The odd number of twists results in the diver's somersault being performed in the forward direction. In accordance with the conservation of angular momentum, the direction of somersault rotation remained unchanged with respect to the external frame (Sanders 1999). The somersault angular velocity profile showed two obvious peaks. The first peak coincides with the initiation of the hip flexion (near G, Figure 1) and the second peak coincides with the second somersault rotation (J, Figure 1). The average angular velocity was 697±33 deg/s at peak one and 900±11 deg/s at peak two, with a variability measure of 4.8% and 1.3% respectively. When comparing the rational speeds of the twisting and non-twisting dive, the 5253B had 62 deg/s greater angular velocity at peak two, p=0.000. Angular momentum has been found to be greater for twisting dives when compared to non-twisting dives (Sanders and Wilson 1987). Thus, once the twist has stopped, the angular momentum is transferred purely to the somersault axis, which may result in the increased angular velocity when compared to the non-twisting dive.

Figure 1: IMU Angular velocity profile of the 5253B dive. Solid line represents the mean from 11 trails and the dotted line represents the standard deviation. A – takeoff, B – ½ twist, C – twist position (arms in), D - ½ somersault rotation, E - 1 twist, F - stopping twist and starting to form pike position, G - 1½ twists, H - 1 somersault, I - 1 ½ somersaults, J - 2 somersaults, K - Open from somersault, L - extension; entry line up, M - Hands entry, N - Hip entry.



The 2D video analysis of the somersault axis revealed 13° greater extension about the hip at takeoff when performing the 5253B dive (Table 1). The somersault position showed no significant difference (p=0.34), illustrating the diver performs a comparable tight pike position during both dives. The diver was in a straighter body alignment at hand contact with the water when performing the 5253B. This may be due to the dive finishing in the forward direction allowing them to “spot” the water in preparation for entry. There was a reduction in total time of flight, dive height and dive distance for the 5253B dive. This may be due to the increased angular momentum required to perform the additional 1½ twists during the backward 2½ somersaults (Sanders and Wilson 1987). The increased hip angle at takeoff for the 5253B corresponds to this theory. The ratio of linear to angular momentum may be reduced in order to develop the increased rotational demands resulting in greater elastic strain energy from the springboard being transferred to the rotational aspect of the dive rather than translation. The key event timings during the dive flight were different due to the requirements of the movement patterns for each dive type.
The total time of flight variability measured at <1% for both dives, however the variability ranged between 2-12% for the timings of the key events. It appears that the diver was able to

adapt to variations during these key events to allow for a consistent dive duration in order to successfully complete the required movement patterns.

Table 1
Mean, standard deviation and coefficient of variation (parentheses) for 2D kinematic measures taken from video footage.

Dive	205B	5253B - Somersault axis (y)
N	8	11
Takeoff angle (deg) *	74.4 ± 1.5 (2.1%)	76.1 ± 1.6 (2.1%)
Takeoff – hip angle (deg) **	138.6 ± 2.6 (1.9%)	125.3 ± 3.2 (2.6%)
Somersault hip angle (deg)	38.6 ± 2.2 (5.7%)	39.31 ± 2.51 (6.4%)
Entry angle (deg) **	102.5 ± 3.8 (3.7%)	121.5 ± 4.3 (3.5%)
Entry - hip angle (deg) **	132.9 ± 4.1 (3.1%)	158.1 ± 8.2 (5.2%)
Time of flight (s) **	1.40 ± 0.01 (0.7%)	1.37 ± 0.01 (0.6%)
Takeoff to sault position (s) **	0.31 ± 0.01 (3.2%)	0.71 ± 0.01 (2.0%)
Sault position to open (s) **	0.56 ± 0.04 (7.1%)	0.37 ± 0.05 (12.3%)
Open to entry (s) **	0.53 ± 0.04 (7.5%)	0.29 ± 0.03 (10.5%)
Dive height (m) **	1.30 ± 0.10 (7.7%)	0.96 ± 0.06 (6.1%)
Dive distance (m) **	2.29 ± 0.22 (9.5%)	2.06 ± 0.12 (6.0%)

Statistical difference between the means; *$p<0.05$, **$p<0.01$

CONCLUSION: Inertial measurement units provide a quick and practical analysis tool for coaches wanting to monitor their athlete's daily performance for both twisting and non-twisting dives. The 5253B dive is a highly complex dive that requires increased mechanical and physical abilities to develop the necessary momentum to successfully perform this dive. Our athlete was able to successfully complete this complex dive to an international standard at a high level of consistency with less than 2% variability at peak angular velocity about both the twist and somersault axis, and less than1% variability shown in dive flight time.

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