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Biomechanical Comparison of the Track Start and the Modified One-Handed Track Start in Competitive Swimming: An Intervention Study

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This study compared the conventional track and a new one-handed track start in elite age group swimmers to determine if the new technique had biomechanical implications on dive performance. Five male and seven female GB national qualifiers participated (mean ± *SD*: age 16.7 ± 1.9 years, stretched stature 1.76 ± 0.8 m, body mass 67.4 ± 7.9 kg) and were assigned to a control group ($n = 6$) or an intervention group ($n = 6$) that learned the new one-handed dive technique. All swimmers underwent a 4-week intervention comprising 12 ± 3 thirty-minute training sessions. Video cameras synchronized with an audible signal and timing suite captured temporal and kinematic data. A portable force plate and load cell handrail mounted to a swim starting block collected force data over 3 trials of each technique. A MANCOVA identified Block Time (BT), Flight Time (FT), Peak Horizontal Force of the lower limbs (PHF) and Horizontal Velocity at Take-off (Vx) as covariates. During the 10-m swim trial, significant differences were found in Time to 10 m (TT10m), Total Time (TT), Peak Vertical Force (PVF), Flight Distance (FD), and Horizontal Velocity at Take-off (Vx) ($p < .05$). Results indicated that the conventional track start method was faster over 10 m, and therefore may be seen as a superior start after a short intervention. During training, swimmers and coaches should focus on the most statistically significant dive performance variables: peak horizontal force and velocity at take-off, block and flight time.

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In competitive swimming, the fundamental goal is to cover a set distance in the least amount of time. When evaluating a swimmer's performance, several measures are considered including final time, strategy, and technical components. The latter includes speed, stroke mechanics, starting, turning, and finishing (Smith et al., 2002). Emphasis during training is often placed on high mileage, speed work, and stroke drills, leaving very little time for perfecting the starting technique (Maglischo, 2003). The start is an area where small yet significant gains can be made. Researchers have found that through consistent dive practice an elite swimmer can reduce their total race time by a minimum of 0.10 s (Blanksby et al., 2002; Maglischo, 2003). At the elite level, this improvement could represent the time difference between a first and third place in a sprint event (Thayer & Hay, 1984; Cossor et al., 1999; Breed & McElroy, 2000; Breed & Young, 2003; Lyttle & Benjanuvatra, 2005).

As cited by Lyttle & Benjanuvatra (2005), the three main starting techniques currently used by elite swimmers include the track start (both rear and front weighted), the grab start, and the swing start (mainly used during relays). It has been suggested that neither preference nor experience is a good indicator of the best dive style for a swimmer and guided experimentation may be most beneficial (Welcher et al., 1999). The findings to date have shown that regardless of swim start choice, the swimmer's goal is to react quickly to the starting signal, leave the blocks rapidly generating as much horizontal velocity as possible, gain maximal flight distance while using an optimal projection angle on entry, and maintain a streamline position that will minimize the loss of horizontal velocity associated with drag on water entry (Pearson et al., 1998).

Over the last 40 years, the swim start technique has evolved. The original arm swing diving technique was

used consistently up to the late 1960s, but was later replaced by the grab start (Carlile, 1963; Colwin, 1969; Counsilman, 1985). Introduced by Hanauer in 1967, the grab start rapidly gained popularity and by the 1972 Olympics, most swimmers were using a variation of the technique (Nelson & Pike, 1978; Counsilman et al., 1988) and it remains a widely used technique today (Pearson et al., 1998). When compared with the conventional swing start, most researchers have found the grab start superior in terms of timed distances and time spent on the block (Bowers & Cavanagh, 1975; Zatsiorsky et al., 1979).

The track start debuted in the late 1970s; both the rear- and front-weighted track starts have gained popularity and proven successful on the international competition scene (Lyttle & Benjanuvatra, 2005). The track start is reported as equivalent to the grab start due to trade-offs in increased take-off velocity and reduced block time (grab; Costill et al.,1992; Allen et al., 1999), yet others have found the track start superior to the grab start when solely comparing performance times (Ayalon et al., 1975; Zatsiorsky et al., 1979; Counsilman et al., 1988; Kruger et al., 2002). Due to changes in the swimmer's foot placement, the track start employs a wider base of support than the grab start resulting in greater stability for the swimmer (Breed & McElroy, 2000).

Recent anecdotal evidence of a one-handed track method used by swimmers in the UK and Japan suggested that modifications made to the traditional track start could be beneficial for biomechanical reasons due to the incorporation of both a grab and a counter-movement swing.

The effectiveness of dive starts has been measured by the time to a set distance, ranging from 1.52 m (5 ft) to 25 m (Ayalon et al., 1975; Bowers & Cavanagh, 1975; Stevenson & Moorehouse, 1979; Guimaraes & Hay, 1985; Counsilman et al., 1988; Blanksby et al., 2002). However, recent findings using elite subjects have demonstrated that the best criterion measure of swim start performance is time to 10 m (Blitvich et al., 2000; McLean et al., 2000; Blanksby et al., 2002). Havriluk (1983) found that subjects attain a constant velocity during the 8.7- to 11.7-m interval. Block time, flight time, and glide time are included in this 10 m, but the effects of other swim variables on performance are eliminated.

Force characteristics of dive techniques have been assessed in several comparison studies including the swing, grab, track, and handle starts (Shierman, 1979; Pearson et al., 1998; Allen et al., 1999; Breed & McElroy, 2000; Breed & Young, 2003). Breed & McElroy (2000) found a significant difference between the horizontal impulse of the track and grab start ($p < .05$) but not between the swing or grab, nor the track and swing starts. When separating the force contribution from the hands and feet, Breed & McElroy (2000) also discovered that the arms in the grab start acted as a brace for the legs to push against (mean 6.4 ± 10.9 N·s) and that almost all of the drive came from the lower limbs (mean 174 ± 19.0 N·s). Conversely, the contribution of the arms in the track start was much more significant (mean 70.2 ± 27.4 N·s) and represented one-third of the total horizontal impulse. In addition, Breed and McElroy (2000) found that the rear-weighted dive produced a greater take-off velocity and flight distance than the grab and front weighted track technique and attributed this to the increased force contribution of the upper limbs in the track start.

A major limitation in the research to date is the use of nonswimmers, who lack the required skill and coordination to perform the complex racing start movements and have very little dive experience (Guimaraes & Hay, 1985; Ayalon et al., 1975; Breed & McElroy, 2000; Breed & Young, 2003). For the results to apply convincingly to the elite population, there is a need to use proficient swimmers who can perform consistently (Pearson et al., 1998; Hopkins et al., 1999).

The purpose of this study was to compare the track start and one-handed track techniques and to assess dive performance in age group elites. A one-handed track start was developed, where the lower limb stance remained identical to the conventional technique but the upper body was rotated and a one-arm countermovement swing was used: No previous research used this technique. This study hypothesized that, following an intervention, the modified start would significantly affect the kinematics and kinetics of a dive start when compared with the track start in elite swimmers and, further, swimmers would elicit faster times over 10 m when using the conventional track method.

Methods

Subjects

Seven female and five male age group Great Britain National qualifiers of a mean ± *SD* age of 16.7 ± 1.9 years, stretched stature 1.76 ± 0.8 m, and body mass 67.4 ± 7.9 kg, participated in the study. No significant changes in mass or stature occurred during the study ($p > .05$). Participants had been involved in competitive swimming for 8.5 ± 2.0 years and their career-best 50-m freestyle (long course) was 27.41 ± 3.0 s. The preferred starting method of all swimmers was the track start technique. The institutional ethics committee approved all procedures and informed consent and assent was gained from both parents and children, respectively, before data collection.

Initial Testing Procedure

All swimmers performed 8 trials of their preferred competitive dive to assess how many dives would produce repeatable results. Normal competition procedures were followed using a standard starting block (0.72 m). Time to 10 m was recorded at the point where the vertex of the

head crossed the 10-m line, using above water video cameras (50 Hz, Sony TRV-900-E, shutter speed 800 Hz, and exposure 18dB) synchronized with a video timer box (Omega, British Swimming, 2002) and DV recorder (Sony, GVD-1000 E DV) with a time code display and an audible starting signal (Lakomy, British Swimming, 2002). Within-athlete reliability was achieved, as the coefficient of variance was less than 5% (2.2%) using time to 10 m over the first 3 dive trials.

Using rank order over 2 variables (career-best 50-m freestyle time and initial testing track start time), groups of equal performance ability were assigned to respective cohorts (control group or intervention group). The one-handed technique was explained to the intervention group and they performed an additional 8 trials of the new technique: A coefficient of variance of less than 5% (3.2%) was obtained over the first 3 dive trials.

Training Procedure

A 4-week intervention period of 12 ± 3 practice sessions of 30 min in duration was carried out in a 33-m indoor pool. The intervention group learned the new one-handed track start technique (Figure 1). For control purposes, swimmers were instructed to adopt their track start stance (feet 0.40 m apart) with the toes of one foot curled over the front of the starting block and the other foot placed at the rear of the block. Weight was positioned over the front foot, and the T-bar handrail was grasped as close to the center as possible with their dominant arm while extending their nondominant arm to the rear, past their hip (as per a swing start). The control group did not receive the intervention training but were permitted to practice the track start during the dive training sessions.

The controls were instructed to adopt their track start stance (Figure 2), position their weight over their front foot and grasp the T-bar handrail with both hands. Both groups received verbal and video feedback on their respective diving techniques during Weeks 2 and 3. All dive practice sessions were led by the same coach to ensure consistency in coaching techniques, training, and programming.

Final Testing Procedure

Following the intervention period, all subjects were tested in a randomized set of 3 dive trials using both start techniques. Testing was conducted after a coach-led dry-land warm-up and 10 min pool warm-up. The control group was provided with general instruction in the one-handed track start and 3 practice trials encompassing both techniques were permitted before testing. The rest interval between each dive was 3 min.

A portable multicomponent Kistler force plate with built-in charge amplifier (9286AA, Amherst, New York) sampling 500 Hz (600 mm × 400 mm × 35 mm) measured the ground reaction forces. The force plate was

Figure 1 — The one-handed track start.

Figure 2 — The track start.

mounted to a 10-mm-thick aluminum plate that was bolted to the starting block frame, and the force plate feet were affixed to the aluminum plate. An aluminum T-bar handrail instrumented with a load cell (Biometrics, UK) was affixed to the front of the starting block to measure the force application of the upper limbs (Cavanagh et al., 1975). The load cell was mounted inferiorly to the center of the T-bar handrail to minimize force measurement error during the one-handed track start (Figure 3). The modifications made to starting block did not significantly alter its height, width, or

Figure 3 — The modified starting block.

angle. However, due to the dimensions of the force plate, the depth of the starting block was reduced by 7 cm. Force data were analyzed using Bioware version 3.24 (Amherst, New York) and upper limb data were analyzed using Biometrics Datalogger (Biometrics, UK) software.

Two Sony TRV-900-E digital cameras (50 Hz, shutter speed 800 Hz, and exposure 18dB) were positioned perpendicular to the plane of motion and the starting block. Camera 1 was placed in line with the starting block; Camera 2 was placed on the pool deck 4.5 m from the starting block wall. Cameras were calibrated vertically and horizontally using a 1-m-long rigid pole with visible markings at 0.1-m increments. Kinematic data were digitized and analyzed using SIMI motion analysis software (SIMI, Germany).

Data Analysis

Four temporal and two kinematic variables were identified: Block Time (BT)—the time from starting signal until the first field in which the feet had left the blocks; Flight Time (FT)—the time from when the last foot left the block to the first field in which the fingertips broke the water surface; Total Time (TT)—the sum of BT and FT; Time to 10 m (TT10m); Flight distance (FD)—the horizontal distance from the edge of the pool to fingertip entry; and Take-off angle (TOA)—the angle between a line from the hip to the toes and between the toes and horizontal plane at take-off.

Six variables were measured using the force platform: peak horizontal and vertical force (PHF and PVF respectively) adjusted for body mass, horizontal and vertical velocity at take-off (Vx and Vy respectively), vertical force of the upper limbs (VFH) and horizontal impulse (HI). The vertical and horizontal velocity calculations were derived using the mass of the swimmer and the impulse-momentum relationship, ($F_t = M_{v\ (final)} - M_{v\ (initial)}$), where impulse equals area under the graph and initial velocity at take-off equals zero. Resulting force data represented the force application through the center of mass.

Force and impulse data were adjusted for body mass. As cited by Breed and McElroy (2000), horizontal impulse (HI) was calculated by adding the hand and feet readings together and the equations ($F_y = F_y\cos\theta + F_z\sin\theta$) and ($F_z = -F_y\sin\theta + F_z\cos\theta$), where F_y represents horizontal force and F_z represents vertical force, were used to adjust the results to give true horizontal and vertical force components due to the 9° downward slope of the block.

Statistical comparisons were made between the two techniques (3 trials of each) and the two groups. The Kolmogorov–Smirnov test of normality revealed that all data were normally distributed. Assumptions underpinning a MANCOVA were met as linear relationships among the kinetic and kinematic variables were identified; a MANCOVA is particularly useful when one dependent variable impacts on another despite the independent variables being mutually exclusive (SPSS Version 13.0 program for Windows, SPSS, Chicago, IL). An a priori alpha level of 0.05 was set for all data analysis, whereby the statistical significance level was 5%, and alpha represented the probability of rejecting the hypothesis when the hypothesis was true.

Results

The MANCOVA revealed four covariates: block time, flight time, peak horizontal force of the lower limbs, and vertical velocity at take-off. When controlling for covariance, the MANCOVA ascertained overall significant differences in total time, time to 10 m, peak vertical force (lower limbs), horizontal velocity at take-off, and flight distance between the two diving techniques (Figure 4). The total time and total time to 10 m were significantly improved when swimmers used the conventional track start: respectively, $F = (359.33, 7)$, $p = .01$ and $F = (6.06, 7)$, $p = .001$. Generation of peak vertical force off the blocks, $F = (28.70, 7)$, $p = .01$, and peak horizontal velocity, $F = (29.17, 7)$, $p = .01$, were also significantly greater when the swimmers used the track start. However, the swimmers achieved significantly better flight distance when they used the one-handed method, which had been previously highlighted as a key

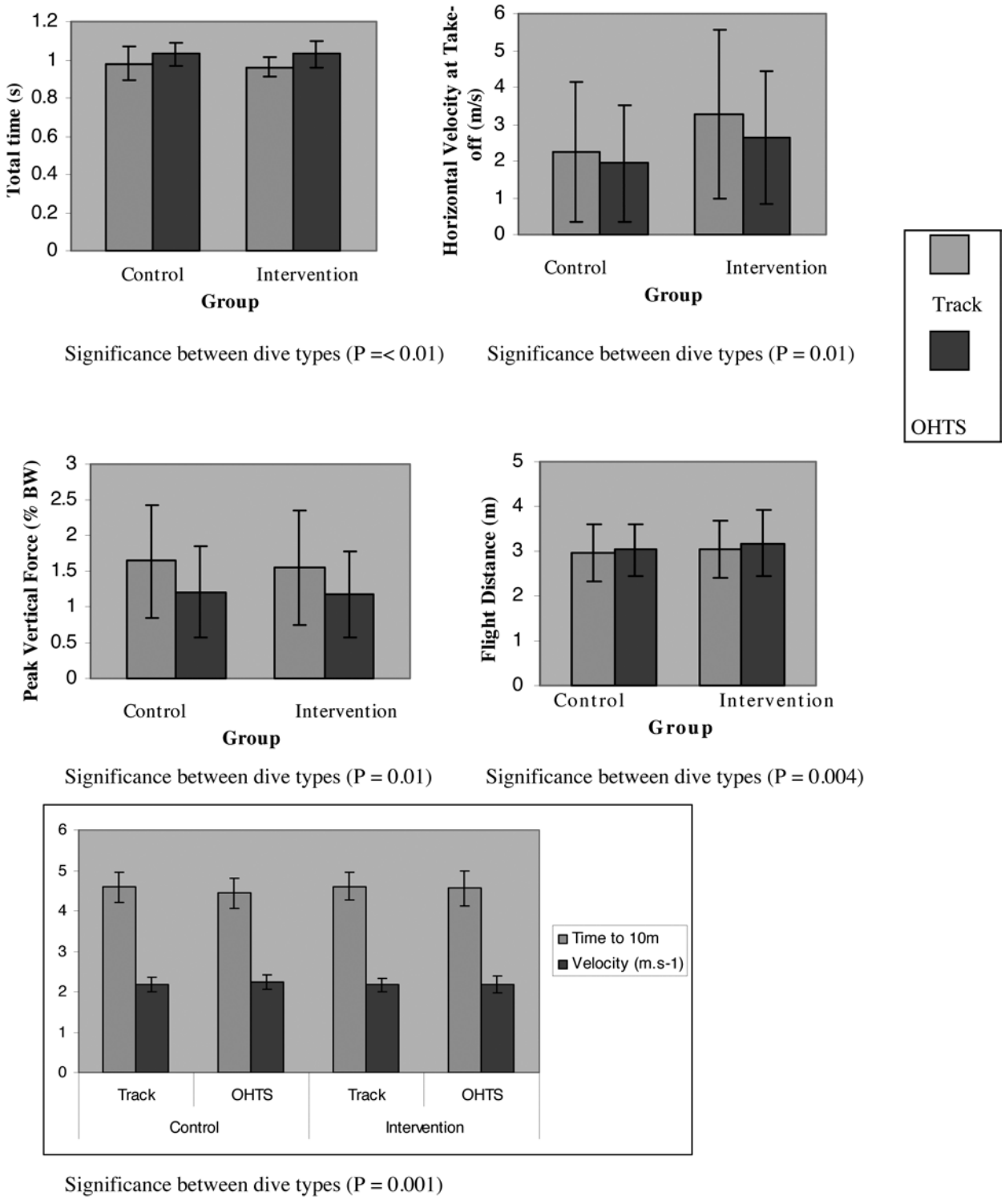

Figure 4 — Means and standard deviations in Total Time, Time to 10m/Velocity, Peak Vertical Force, Flight Distance, and Horizontal Velocity at Take-Off across dive groups and dive types.

factor in successful dive performance $F = (5.07, 7)$, $p = .003$; this occurred despite generating less force as a percentage of their body weight and less horizontal velocity off the blocks.

Despite differences in upper-body technique, the MANCOVA revealed similar block time, flight time, take-off angle, peak horizontal force of the lower limbs, vertical velocity at take-off, horizontal impulse, and

vertical force of the upper limbs when comparing both dive techniques as outlined in Table 1.

In addition, the MANCOVA identified four covariates (block time, flight time, flight time, peak horizontal force of the lower limb, and vertical velocity) that significantly influenced other variables measured as outlined in Table 2. The swimmers' block time and flight time influenced their respective time to 10 m, whereas their peak horizontal force of the lower limbs affected both their time to 10 m and flight distance. Lastly, the swimmers' vertical velocity at take-off was found to significantly influence their flight distance.

Significant differences in time to 10 m were established across the groups ($p = .05$), and significant differences in peak vertical force of the lower limbs and take-off angle ($p = .022$ and $p = .015$, respectively) were found across dive type, but the group and type of dive together did not influence the remaining variables (Table 3).

Table 1 Descriptive Statistics for Tested Variables (Mean ± *SD*)

	Control Group		Intervention Group	
Variable	Track start	One-handed track start	Track start	One-handed track start
Block Time (s)	0.66 ± 0.05	0.70 ± 0.06	0.67 ± 0.07	0.69 ± 0.08
Flight Time (s)	0.32 ± 0.09	0.33 ± 0.06	0.30 ± 0.08	0.34 ± 0.06
Angle at Take-off (°)	4.9 ± 1.9	2.0 ± 1.9	4.0 ± 2.3	2.7 ± 2.2
Peak Horiz. Force (Lower Limbs; % BW)	0.38 ± 0.06	0.39 ± 0.60	0.36 ± 0.08	0.35 ± 0.08
Horizontal Impulse (N·s)	113.5 ± 38.2	101.3 ± 26.7	124.8 ± 22.6	114.4 ± 25.0
Vertical Velocity at Take- off, V(y) (m/s)	23.1 ± 19.31	24.6 ± 20.55	27.3 ± 22.54	25.7 ± 23.88
Peak Vertical Force (Upper Limbs; N)	41.6 ± 15.0	32.8 ± 10.2	38.0 ± 33.2	25.5 ± 12.5

Table 2 Dive Start Variables Influenced by Identified Covariates

Identified Covariates	*F* Value	*df*	Power	Variables Influenced	
				Kinematic/Temporal	Kinetic
Block Time	656.79	1	1.000	TT ($p \leq 0.01$)	N.S.
	6.57	1	0.673	TT10M ($p \leq 0.05$)	
Flight Time	454.91	1	1.000	TT ($p \leq 001$)	N.S.
	5.39	1	0.588	TT10M ($p \leq 0.05$)	
Peak Horizontal Force	15.07	1	0.954	TT10M ($p \leq 0.01$)	N.S.
	15.02	1	0.953	FD ($p \leq 0.01$)	
Vertical Velocity at Take-off, V(y)	72.93	1	1.000	FD ($p \leq 0.014$)	VFF ($p = 0.000$)
	98.68	1	1.000		V(x) ($p = 0.000$)
	7.62	1	0.736		

Note. TT = Total Time, TT10M = Time to 10 m, FD= Flight Distance, N.S. = No significant difference.

Table 3 Dive Start Variables Influenced by Group, Dive Type, and Combined Group and Dive Type

Identified Covariates	Power	Variables Influenced
Group Type	0.489	TT10M, F = (4.22,1), $p = 0.05$
Dive Type	0.726	TOA, F = (1.18, 1), $p = 0.015$
	0.660	PVF, F = (6.37, 1), $p = 0.022$)
Group and Type combined		N.S.

Note. TT10M = Time to 10 m, TOA = Take-off Angle, PVF = Peak Vertical Force, N.S. = No significant difference.

Discussion

This study hypothesized that significant differences would be found in kinetic and kinematic variables between the new one-handed track start and the conventional track start after an intervention period. Results showed significant differences in five variables (time to 10 m, peak vertical force of the lower limbs, horizontal velocity at take-off, flight distance, and total time) and demonstrated that the conventional track start was superior to the new method when considering overall dive performance (time to 10 m).

The reported times to 10 m for both techniques were similar to previous cited findings using elites swimmers performing the grab and track techniques (McLean et al., 2000; Blanksby et al., 2002; Lyttle & Benjanuvatra, 2005). In addition, the swimmers remained the fastest over 10 m using their preferred technique. Mechanically, this variable encompassed all of the observed from the start signal to the end of the trial.

The results showed that the dive performance variables block time, flight time, and peak horizontal force of the lower limbs directly influenced time to 10 m. It is therefore recommended that coaches use these variables as primary indicators to improve dive start performance during training sessions. When comparing the swimmers' respective block time and flight time for each dive type, no significant difference was found; however, when both these variables were summed, significant differences were revealed for each dive type. Thus, overall swim entry was significantly faster when the swimmers used the conventional method; the time the swimmer spent on the blocks and in the air was reduced when using two hands. Furthermore, the swimmers' flight time and total time results in the current study were similar to those observed in previous dive start literature while using elite subjects (Blanksby et al., 2002; McLean et al., 2000; Allen et al., 1999).

Significant differences were found in peak vertical force of the lower limbs when comparing the two different dive starts; swimmers generated greater vertical force off the block while using the conventional track start. This might reflect the fact that grabbing the block with two hands may produce a larger preload on the force plate than a one-arm grab and might also suggest that the one-handed start allowed unwanted rotation in the body and displacement in the lateral direction. In contrast to horizontal velocity off the blocks, when controlling for covariance, there were no significant differences found in horizontal force or horizontal impulse generated. The swimmers in the current study displayed overall force characteristics, including the horizontal impulse (mean 124.8 ± 22.6 N·s), similar to those found in previous track start literature (Breed & McElroy, 2000). The upper- and lower-limb ground reaction force generation was also similar to reports in previous track start literature (Breed & McElroy, 2000; Breed & Young, 2003; Kruger et al., 2002; and Lyttle & Benjanuvatra, 2005). As peak force was achieved during the rear foot push off, it is suggested that the swimmers' dominant leg be placed to the rear of the block. Although it has been suggested by Breed & McElroy (2000) that the contribution and role of the arms in the track start represented one-third of the total horizontal impulse, this study did not concur: Less than one-third of the total horizontal impulse was produced by the swimmers' arms when using both starting techniques.

In previous studies, increasing flight distance was shown to be a key component of dive performance (Pearson et al., 1998; Breed & McElroy, 2000). In the current study, swimmers achieved significantly greater flight distance when using the new technique. Although swimmers covered more distance off the block using the new dive style, longer flight distance did not equate to faster overall performance times. This finding may indicate that there is a trade-off between flight distance and horizontal velocity generated at take-off. Hence, in concurrence with Allen et al. (1999), flight distance was not deemed to be an influencing factor of track start dive performance to 10 m.

The results also found that swimmers generated significantly greater horizontal velocity at take-off when using the two-handed track start. The attainment of greater horizontal velocity has been seen as a benefit to overall dive performance as it allows the swimmer to enter the water at a greater speed and thus eliminate some of the loss in speed due to impact with the water.

The current study showed no significant differences in take-off angles, which ranged from 0.7° to 8.6° for the track start and from 0° to 5.4° for the one-handed track start; previous findings using elite dive starts have shown optimal take-off angles range from −5° to 10° (Lyttle & Benjanuvatra, 2005).

Irrespective of dive type, the intervention group performed significantly better on time to 10 m. Irrespective of group type, the track start had significantly greater peak vertical force of the lower limbs and take-off angle than the one-handed start. There was no difference in the variables when dive type and group were combined.

Experimental error margins aside, the results of this preliminary investigation suggest that the four covariate variables (block time, flight time, peak horizontal force of the lower limbs, and vertical velocity) may directly influenced dive performance and consequently are considered most important in the future training of dive starts. Coaches and competitive swimmers should focus on improving leg strength and power to maximize horizontal force of the lower limbs and vertical velocity off the blocks. Future research could investigate the optimum foot placement of the one-handed technique while using higher speed cameras and a longer training intervention.

Significant kinematic and kinetic differences in the track start and one-handed track start were found, suggesting that upper-body alterations associated with the new one-handed method significantly changed the

biomechanics of the track start. Although swimmers gained greater distance off the blocks, the results indicated that the changes in technique led to a reduction in dive performance over 10 m. The conventional track start was significantly faster over 10 m and therefore may be seen as a superior start after a short intervention period. Coaches and swimmers should place emphasis on the most significant dive variables found, including the generation of as much peak horizontal force of the lower limbs off the blocks while gaining a favorable take-off angle and optimal amount of vertical velocity to maximize time in the air.

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