Biomechanical Analysis of the Grab, Track and Handle Swimming Starts: An Intervention Study

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ABSTRACT

This study examined the grab, track *and* handle *swimming racing starts by elite-level swimmers. Videography was used to analyse these starts before and after a period of dive start practice. Participants underwent 2–4 sessions weekly until 14±2 practice sessions were completed. Practice sessions comprised 5 grab starts (preferred technique) and 10 handle starts; or 5 grab starts and 10 track starts. The performance criterion measure was time to 10 m. Reaction, movement, block and flight times, flight distance, and the centre of mass at the set position were measured. No significant differences between dive groups in time to 10 m were revealed pre- or post-training. The training period further exaggerated the differences in centre of mass positions in the set position between the three techniques. The handle start revealed a significant change forward in the centre of mass that allowed for decreased movement and block times. The training period improved 10 m, reaction, movement, block and flight times irrespective of the technique used. Hence, regular dive start practice significantly improved the start performances of elite swimmers. Coaches should consider including regular dive practice sessions of approximately 15 minutes to improve dive start performances.*

INTRODUCTION

Swimming performance is measured ultimately by the sum of the time taken starting, stroking and turning. The importance of each of these phases during competition depends on the stroke swum and the event distance. The percentage of total time allocated to starting decreases as the event distance increases (Hay, 1986). Maglischo (1982) stated that an improved start could reduce race time by at least 0.10 s. An examination of the start phase of the 100 m men's butterfly final at the 1996 Olympic Games showed that, 15 m after the start, the second-placed swimmer was 0.40 s slower than the winner, despite his final time being only 0.28 s slower (Schnabel and Kuchler, 1998). While the time a

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swimmer spends starting is less than that spent stroking and turning, an effective start is important for success (Miller *et al.*, 1984; Hay, 1986).

Currently, competitive swimmers tend to use one of three dive start techniques. These are the *grab start*, the *track start* and variations of the conventional *arm-swing start* (Kirner *et al.*, 1989). Most studies have found the grab start to be superior to the conventional start (Bowers and Cavanagh, 1975; Lowell, 1975; Michaels, 1973; Roffer and Nelson, 1972; Wilson and Marino, 1983; Zatsiorsky *et al.*, 1979). The grab start was faster than the conventional start for timed distances of 7.62 m (Michaels, 1973) and 5.50 m (Zatsiorsky *et al.*, 1979). Counsilman *et al.* (1986) found that grab start mean times to 11.43 m were faster (4.16 s) than the track start (4.25 s).

When comparing five starting techniques, including the grab start, and a grab start holding the side of the block, Lewis (1980) found no significant differences in time to 8 m. Gibson and Holt (1976) compared the grab start, conventional and grab variation starts, and found no significant differences in time to 7.62 m. Welcher *et al.* (1999) compared the grab start, *forward weighted* track start and *rear weighted* track start (*slingshot*), and found that there were no significant differences between the three techniques for time to 5 m. They suggested that the slingshot start was the best technique as swimmers achieved greatest horizontal velocity at the 5 m mark, despite most swimmers having had little or no experience with this start.

A new starting technique has been developed with the introduction of handles onto the starting blocks (Figure 1). This *Super Block* was designed by the Anti Wave Company. A handle is incorporated above the flat surface of the block to enable a swimmer to place the centre of mass (CM) in a more forward position prior to the start. To date, only one study has examined the biomechanical factors associated with a successful start using the *Anti Wave Super Block handle start* (Pearson *et al.*, 1998). They examined the racing starts of age-group swimmers of state qualifying level in an attempt to determine whether the handle start from the *Super Block* was faster than other currently favoured starting techniques. As only one training session of 30 minutes was performed three weeks prior to testing, subjects were inexperienced in using this start at the time of testing. Performances to 7 m for the handle start were equal to those of the grab start, which was the subjects' preferred technique. Prior research into swimming starts has suggested that what one does most, one does best (Pearson *et al.*, 1998). Hence, the handle-start study suggested that it could have potential as a fast starting technique if there was an intervention period over an extended time where more learning could take place.

The track start was included, because of its potential to develop increased impulse via a rocking forward motion from the rear to the front foot during the dive, to further examine the merits of the handle-start technique relative to dive starting techniques currently performed by elite level swimmers. The grab start was the preferred competition start used by all the swimmers in this study prior to the training programme.

Hence, the purpose of this study was to examine the grab, track and handle dive starts by elite swimmers. The swimming racing dives were performed before and after an intervention period of dive start practice aimed at improving starting time.

Figure 1 The 'Super Block' (Antiwave, 1996).

METHODS AND PROCEDURES

Sample

After approval from the Human Rights Committee at The University of Western Australia, informed consent was gained from the participants. Five male and seven female national qualifiers of mean age 17.7 ± 4.2 years participated in the study. Previously, all subjects used the grab start as their preferred method of starting, and each swimmer was allocated to either a track-start or a handle-start training group.

Training Procedure

An intervention period of 14 ± 2 (12 to 16) dive start practice sessions was carried out at a 50 m, outdoor pool. During each practice session, the track-start and handle-start groups performed 5 grab-start dives followed by 10 track-start or 10 handle-start dives, respectively. The order of grab-start and track-start/handle-start dives was randomised. During the practice sessions, subjects had specific coaching feedback on technical points of their dive performances based on mechanical factors considered to be important from the diving literature and on opinions from experienced coaches, such as: initial pre-tension of the arm and leg muscles when in the set position (Turner, 1974; Costill *et al.*, 1992), to pull forcefully on the block with the arms in response to the starting signal (Bowers and Cavanagh, 1975; Shierman, 1978; Maglischo, 1982; Hay and Guimaraes, 1983; Costill *et al.*, 1992; Wilson and Marino, 1983; Rutemiller, 1995), thrusting the arms out hard and fully extended when leaving the block (Fitzgerald, 1973; Van Slooten, 1973; Woelber, 1983; Rutemiller, 1995), leaning forward with pre-tension in the arms for the grab and handle starts to move the swimmer's centre of mass further to a more forward position (Bloom *et al.*, 1978; Maglischo, 1982; Wilson and Marino, 1983; Woelber, 1983; Pearson *et al.*, 1998), to drive hard off the blocks with the legs (Guimaraes and Hay, 1985; Costill *et al.*, 1992; Rutemiller, 1995), to project themselves at an appropriate angle off the block and enter the water cleanly to maintain momentum in the glide phase (Maglischo, 1982; Wilson and Marino, 1983; Gallivan and Hoshizaki, 1987; Costill *et al.*, 1992). Subjects attended a minimum of two and a maximum of four practice sessions a week. Once subjects had attended 14 ± 2 practice sessions, they attended a post-intervention testing session within two days of the final practice session.

In the grab start (Figure 2) the swimmer was instructed to stand with the toes curled over the front edge of the block and the feet were 0.15–0.30 m apart. The knees were flexed slightly and the hips well flexed. Subjects then curled the toes of both feet over the front edge of the starting block and grasped the front edge of the block with the hands either outside or between the feet. Subjects were then instructed to lean forward feeling tension in the arms and, on the starting signal, to let go with the hands and drive forward off the block powerfully with the legs, flinging their arms out towards the far end of the pool.

The handle start (Figure 3) is a modified grab start. In the starting position, pressure is felt through the hands such that one would overbalance and fall forward if the hands were released (Pearson *et al.*, 1998). Also, subjects curled the toes of both feet over the front edge of the starting block. When the starting signal was given, the swimmer was instructed to let go with the hands and as a result overbalance towards the water. The arms were then flung forward and the legs pushed powerfully from the block.

The track start (Figure 4) was developed by Fitzgerald (1973). The action is much like that of the grab start, except that one foot is near the back of the starting block and the body weight forward on the front leg. Rutemiller (1995) modified the track start by placing the weight on the back leg. Hence, the centre of mass must move forward during the dive action by transferring weight from the rear leg to the front leg. Each subject was instructed to place the toes of the dominant leg over the front edge of the block and the other leg was placed at a comfortable distance towards the rear of the block. The dominant leg was defined as that with which one would kick a ball. The subject then grasped the front edge of the block with the hands and leaned back to pull on the front edge of the block such that muscle tension was felt in the arms. While in the 'set'

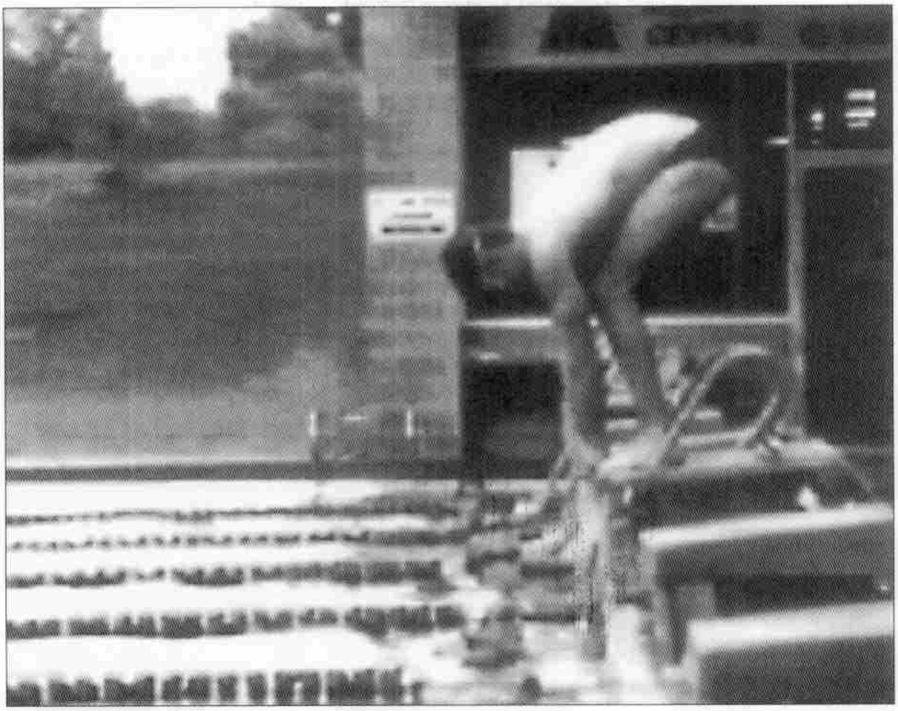

Figure 2 The grab start.

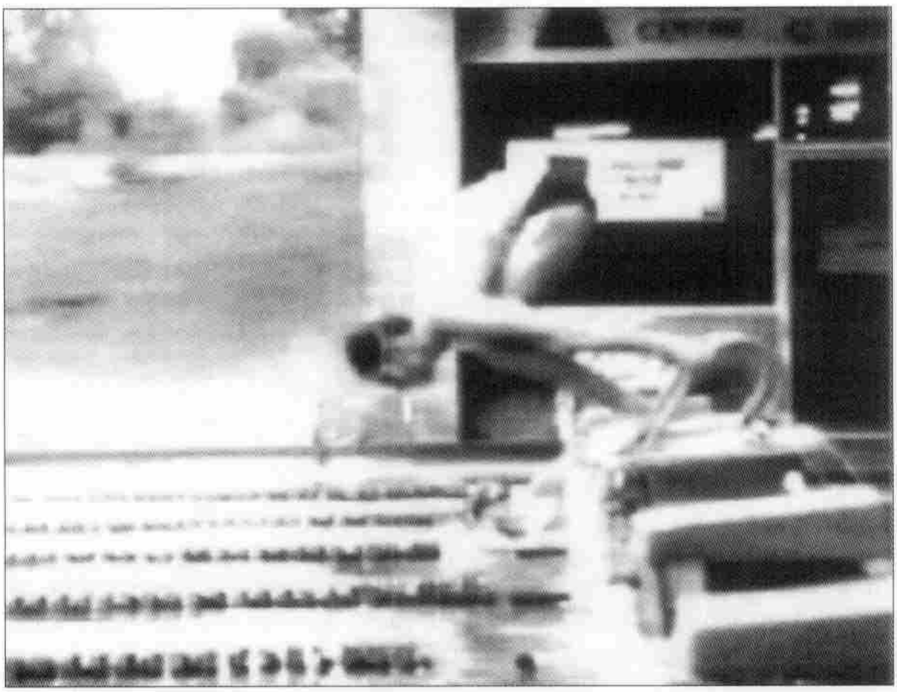

Figure 3 The handle start.

position, subjects were instructed to support the body weight on the back leg and, when the starting signal sounded, to pull on the block with the arms and transfer the body weight to the front leg, which then pushed off powerfully.

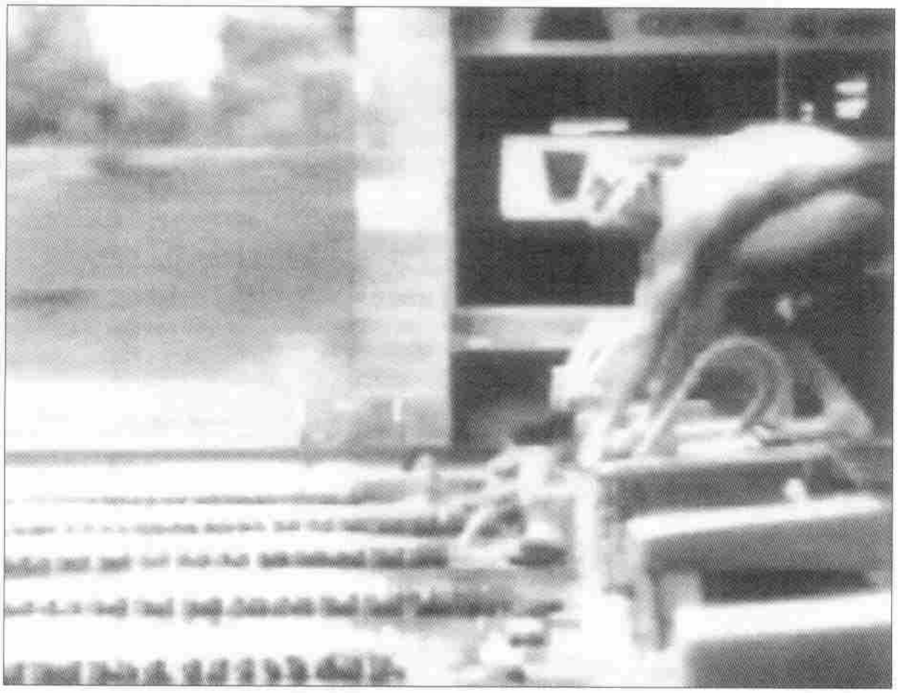

Figure 4 The track start.

Testing Procedure

During pre- and post-intervention testing sessions, each dive followed competition starting protocol and subjects sprinted for 25 m to simulate a racing environment. A qualified coach supervised all testing sessions to ensure dive quality. Before being tested, subjects performed two practice starts of each dive in a separate lane. Then, each swimmer moved to the testing lane in a pre-determined order which was maintained for all testing trials.

Filming Procedure

Three video cameras were used for both the pre- and post-intervention trials. A 25 Hz VHS camera was placed 10 m along the edge of the pool from the end wall such that a clear view of the 10 m line of the trial lane was possible. A light emitting diode (LED) in the field of view of this camera was connected to the starting horn and was illuminated simultaneously with the starting signal. Time codes were superimposed onto the video using a FOR.A Model VTG-33 code imager (to 0.04 s). The 10 m time was the period from when the LED was first illuminated until the vertex of the swimmer's head reached the 10 m line.

A Peak 200 Hz camera, VCR and monitor recorded data and each swimmer's actions on the block. This view was analysed to obtain reaction time, movement time, block time and the position of the centre of mass at the *set* or *take your marks* positions. For practice and feedback purposes it was necessary to define the centre of mass as a fixed point such as the hip (Luttgens *et al.*, 1992; Kreighbaum *et al.*, 1996). This enabled the subjects to visualise their centre of mass position while on the block.

The camera was calibrated by using a 2 m pole marked with 10 cm increments. The pole was filmed while held vertically on the block and parallel to the water surface. Using the Peak Motus Analysis System (Peak Performance Technologies, Englewood, CO, USA), points were marked at the first illumination of the LED (start), first distinguishable movement of the swimmer (reaction time), and take off (the instant the swimmer's feet left the block) (movement time). In most instances, this was muscle contraction in the shoulders for the grab start, releasing the grip on the handle in the handle start, or downward movement of the heel of the rear foot in the track start. Block time was calculated by adding reaction time and movement time. The centre of mass value at set is the horizontal distance of the middle front edge of the starting block to a vertical line through the swimmer's centre of mass.

A second Peak 200 Hz camera with VCR and monitor recorded movements from the block to water entry. This view was used to calculate flight time and flight distance. A synchronising point was placed on the video footage via a trigger on the Peak Event Control Unit. This was used to synchronise the *block* camera with the *block-to-water-entry* camera. This camera was calibrated in the same manner as the block camera.

Flight time was determined by calculating the number of frames from the point of take-off to water entry. Flight distance was determined by subtracting the horizontal distance from the point where the fingertips first broke the water surface to a point on the wall in the middle of the lane at water level.

Statistical Procedures

Each swimmer performed two of each dive at each of the testing sessions (pre- and post-practice) with the dive with the faster time to 10 m of the two chosen for analysis. Descriptive statistics, a repeated measures ANOVA (SPSS Version 8.0 for Windows; SPSS, Inc., Chicago, IL, USA) and a Tukey-b post hoc analysis were used to ascertain any differences between dive groups and whether a significant main effect was recorded ($p < 0.05$).

RESULTS AND DISCUSSION

Time to 10 m

The time to 10 m for all swimmers improved significantly over the period of the study ($p < 0.01$) (Table1) indicating an overall effect of the dive start practice. This supports the view that starts should specifically be practised during training (Rutemiller, 1995). It is important to note that while the grab start was the preferred technique, practice improved grab start performance. The degree of dive practice usually undertaken by the subjects prior to the commencement of this study was not a formal consideration. Rather, dive start practice is mostly carried out during the taper and sprint phase at the end of the season (Rutemiller, 1995). Little dive practice occurs during the early, aerobic conditioning phase of the swimming season when this study was undertaken.

The time to 10 m for the grab-start and handle-start groups improved significantly following the training programme, but the track-start group results remained similar. The mean improvements between pre- and post-intervention time to 10 m were 0.10 s for the grab-start, 0.2 s for the handle-start and 0.10 s for the track-start dives (Table 1). A Tukey-b post hoc analysis showed no significant difference in post-intervention times to 10 m between the grab-start and handle-start, grab-start and track-start or between the handle-start and track-start dives.

Table 1 Means and Standard Deviations for Each Start and Measure

	Total (n = 24)	*Grab (n = 12)*	*Handle (n = 6)*	*Track (n = 6)*
Pre-intervention	*Mean(SD)*	*Mean (SD)*	*Mean (SD)*	*Mean (SD)*
10 m time (S)	4.64 (0.28)	4.62 (0.27)	4.67 (0.29)	4.67 (0.33)
RT (s)	0.22 (0.05)	0.21 (0.05)	0.22 (0.04)	0.23 (0.04)
MT (s)	0.64 (0.05)	0.65 (0.05)	0.63 (0.04)	0.64 (0.07)
BT (s)	0.86 (0.06)	0.86 (0.07)	0.85 (0.04)	0.88 (0.08)
FT (s)	0.30 (0.08)	0.32 (0.07)	0.24^{t} (0.07)	0.30^{h} (0.04)
FD (m)	3.05 (0.67)	3.23 (0.30)	3.01 (0.31)	2.73 (1.25)
CM position (m)	n/a	-0.29^{ht} (0.06)	-0.05^{gt} (0.05)	-0.58^{gh} (0.04)
Post-intervention				
10 m time (S)	4.52 (0.22)**	4.52 (0.25*	4.46 (0.25)*	4.57 (0.14)
RT (s)	0.19 (0.03)*	0.20 (0.03)	0.19 (0.03)	0.19 (0.04)
MT (s)	0.60 (0.09)**	0.63^{h} (0.05)	0.50^{gt} (0.03)**	0.66^{h} (0.12)
BT (s)	0.80 (0.08)**	0.82^{h} (0.06)	0.69^{gt} (0.02)**	0.85^{h} (0.08)
FT (s)	0.28 (0.08)*	0.30 (0.08)	0.24 (0.09)	0.29 (0.05)
FD (m)	3.20 (0.39)	3.27 (0.39)	2.99 (0.38)	3.28 (0.39)
CM position (m)	n/a	-0.26^{ht} (0.05)	0.15^{gt} (0.05)**	-0.68^{gh} (0.05)*

[g] Significantly different from Grab Start ($p < 0.05$).
[h] Significantly different from Handle Start ($p < 0.05$).
[t] Significantly different from Track Start ($p < 0.05$).
* Significantly different from Pre-intervention ($p < 0.05$).
** Significantly different from Pre-intervention ($p < 0.05$).

These results supported Pearson *et al.* (1998), who found no significant differences in time to 7 m between grab-start and handle-start groups. The fact that the handle-start group improved the most, and was previously not practised, tended to support the Pearson *et al.* (1998) conclusion that it does have potential as a preferred starting technique.

The differences in the group sizes and relatively low numbers decreased the statistical power and could have reduced the chance of achieving statistical significance. Although the time improvements were not significant, they could equate to the difference between first and fourth place in an elite swimming event.

Correlations

Pearson correlation matrices are presented in Table 2. A pre-intervention, correlation matrix of all dive groups showed significant positive correlations between time to 10 m with both movement time and block time. This was maintained post-intervention. Thus, a quicker movement time and block time are associated with a faster time to 10 m. The block time also showed a significant, positive correlation with movement time. A significant negative correlation was found between flight time and centre of mass position, indicating that a more forward position of the centre of mass was associated with a shorter flight time.

A significant positive correlation also was revealed between flight time and flight distance. Hence, the longer the swimmer is in the air, the further he/she will travel before entering the water. A significant negative correlation was found between centre of mass position and movement time, and centre of mass position and block time. Therefore, the more forward centre of mass position was associated with a shorter movement time and a shorter block time.

Table 2 Pearson Product Correlation Matrix of Factors Contributing to the Swimming Racing (Grab, Handle and Track) Start (n = 24)

a) Pre-intervention	*Time to 10 m*	*Reaction Time*	*Movement Time*	*Block Time*	*Flight Time*	*Flight Distance*	*CM Position*
Time to 10 m	1.000						
Reaction Time	.203	1.000					
Movement Time	.529*	−.157	1.000				
Block Time	.580*	−.582*	.712*	1.000			
Flight Time	.017	.193	.036	.167	1.000		
Flight Distance	−.125	−.145	.052	−.060	.195	1.000	
CM position	−.004	−.090	−.150	−.188	−.522*	.179	1.000

*p < 0.01 (2-tailed).

b) Pre-intervention	*Time to 10 m*	*Reaction Time*	*Movement Time*	*Block Time*	*Flight Time*	*Flight Distance*	*CM Position*
Time to 10 m	1.000						
Reaction Time	−.306	1.000					
Movement Time	.130	−.420	1.000				
Block Time	.026	−.081	.939*	1.000			
Flight Time	.075	−.127	.051	.008	1.000		
Flight Distance	−.115	−.075	.007	−.037	.882*	1.000	
CM position	−.124	−.063	−.668*	−.709*	−.286	−.300	1.000

*p < 0.01 (2-tailed).

Reaction Time

Results showed that reaction time was not influenced by dive type. When all subjects were pooled, a significant improvement was found between pre-intervention (0.22 s) and post-intervention (0.19 s) RT (See Table 1). This indicated that the dive practice sessions improved the reaction time and there was a quicker response to the starting horn following specific dive training, irrespective of technique used. However, it should be noted, that as normal training was continued during the period of intervention, this may have contributed to the swimmer's improved reaction time. In the absence of a control group, it is reasonable to assume that the specific skill of reacting to a starting signal was a direct result of the dive practice sessions.

Exposure to the starting signal could not be responsible for this improvement as the starting horn was used only for the timed trials and not during training. Hence, the improvement in reaction time might be due to an increased ability of the swimmers to anticipate the starter's commands. When the swimmer concentrates on the starting signal, rather than the starting movements, a faster reaction time results (Henry and Rogers, 1960; in Maglischo, 1982). Maglischo (1982) claimed that when there was 'less to think about' on the block, a decreased reaction time might follow. Therefore, improved reaction time from pre-intervention to post-intervention could be due to swimmers feeling more comfortable about diving following specific training. With decreased anxiety, the swimmers were free to concentrate on the starting signal.

Movement and Block Time

Movement time and block time were positively correlated before and after training. The handle start dive had a significantly quicker movement time than either the grab-start or track-start groups following training. Movement times prior to training were similar for all three groups, and ranged from 0.63 s for the handle start, to 0.65 s for the grab start. Following the training programme, there was no change in movement time for the grab-start and track-start groups, although the handle-start group significantly decreased to 0.50 s.

Time on the block improved (reaction time plus movement time) for all dive groups following the intervention period when all data were pooled. Because of the different centre of mass positions adopted, the track start recorded the longest block time both pre- and post-intervention, followed by the grab-start, and handle-start groups. As the centre of mass in the track start is placed further back on the block, extra time is spent positioning the centre of mass to apply force after the starting signal. Because the centre of mass is already forward on the block with the handle start and grab start dives, time on the block is less. Rather than the track start assuming a full backward stretch, it might be beneficial to move the centre of mass forward to a position that shortens the movement time, but still allows sufficient momentum to be produced.

Flight Time and Distance

The mean flight time for the total group was significantly decreased from

0.30 ± 0.08 s to 0.28 ± 0.08 s following training (Table 1). The fact that flight time was negatively correlated with the centre of mass position on the block could be attributed to achieving greater horizontal velocity when the centre of mass is accelerated over a greater distance. The track start enables swimmers to attain a greater horizontal velocity because two impulses, rather than one, are developed (Costill *et al.*, 1992). Also, the low position of the swimmer during the track start was beneficial in producing horizontal force at take off (Ayalon *et al.*, 1975; Nelson and Pike, 1978).

The flight distance did not change with training. Increased time on the block did not increase flight distance but the distance was covered faster. The flight distance for the grab-start and track-start dives was similar following training (3.27 m and 3.28 m, respectively).

CM Position at the Set Position

The centre of mass was further forward during the handle start than the grab start when the swimmer was in the 'set' position. Significant differences were found between the centre of mass positions of the three dive types, both pre- and post-intervention. However, the centre of mass position differences were greater, post-intervention as the swimmers leaned further forward in the handle start and further back in the track start.

Several authors have claimed that the grab start was superior to the conventional start because the centre of mass was further forward (Ayalon *et al.*, 1975; Bloom *et al.*, 1978; Fitzgerald, 1973; Gibson and Holt, 1976; Maglischo, 1982; Lewis, 1980; Wilson and Marino, 1983). Perhaps the handle-start advantage is that the centre of mass needs to be moved less than in other starts before a propulsive force is applied at an appropriate angle. Relative to the front of the block, the centre of mass positions for the grab start, handle start and track start (pre-intervention) were –0.29 m, –0.05 m and –0.58 m, respectively. Post-intervention, these were –0.26 m, +0.15 m and –0.68 m, for grab start, handle start and track start, respectively.

The handle start enables the centre of mass to be placed further forward of the starting block than with the other starts. Therefore, the centre of mass position is outside the swimmer's base of support, and the upper limbs are solely responsible for preventing overbalancing (Pearson *et al.*, 1998). Therefore, upper limb anthropometry will influence the position of the centre of mass in the handle start.

Observation of the video demonstrated that to place the centre of mass into a more forward position for the handle start, the swimmer increased knee flexion. Increased knee flexion is beneficial for developing a larger force by the lower limbs, as the muscles involved in driving the centre of mass forward are both on stretch and pre-loaded. When using the handle start, the knees already are flexed to a degree equivalent to the smallest knee angle that would be attained during the lower limb counter movement (rapid knee flexion followed by rapid extension) in the grab start. As the swimmer is already in this position during the set phase of the handle start, the block time is decreased after the starting signal is sounded. Although the muscles of the lower limb are pre-loaded, ready for concentric contraction, the disadvantage of having the knees pre-flexed is that the swimmer cannot utilise the same degree of elastic energy that is developed in the muscles when performing a counter movement.

With the track start, the centre of mass was placed further back on the block than for the grab-start and handle-start dives. This position was held by tensing the arms and increasing the swimmer's base of support to enable the adoption of a low starting position (Ayalon *et al*, 1975; Nelson and Pike, 1978). This causes the swimmer to spend extra time on the block but permits a longer force application period in which to create a higher impulse and higher take-off velocity (Welcher *et al.*, 1999). The flight distance increased from 2.73 m pre-training to 3.28 m post-training. This was in agreement with Nelson and Pike (1978), who reported the lower starting position increased the horizontal force at takeoff.

The centre of mass position was significantly and negatively correlated with movement time and block time. The more forward centre of mass position resulted in a faster movement time and block time which concurred with others that the more forward position of the grab start helps swimming time by decreasing block time (Fitzgerald, 1973; Hanauer, 1967; Lewis, 1980; Pearson *et al.*, 1998).

CONCLUSIONS

There were no significant differences in time to 10 m for swimmers using a grab start, handle start or track start before or after 14 ± 2 practice sessions. However, the time to 10 m of the handle-start and grab-start groups significantly improved following the dive start practice sessions. No significant differences occurred between the dive groups for post-intervention values of reaction time, flight time and flight distance. The centre of mass positions for all dive types were significantly different ($p < 0.05$) pre- and post-intervention and, for the handle start, was actually forward of the front edge of the block. The centre of mass positions of the grab start and track start were behind the front edge of the block, with the track start being the furthest back. The training programme was responsible for moving the centre of mass positions of the handle start and the grab start forward, while the centre of mass position of the track start moved further back. Time on the block (movement time plus block time) for the grab start and track start were similar, and higher than that recorded for the handle start. When all groups were pooled, the training programme was successful in significantly improving time to 10 m, reaction time, movement time, block time and flight time. Therefore, regular specific dive start practice and coaching does benefit the athlete. Coaches only need to slightly alter the training programme to incorporate three dive practice sessions per week of approximately 15 minutes each, for four–five prior to competition to significantly improve the starting performance of their swimmers.

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