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Jumping Ability and Swimming Grab-Start Performance in Elite and Recreational Swimmers

Nat Benjanuvatra, Katie Edmunds, and Brian Blanksby

This study examined the relationships between the performances of a swimming grab start and each of countermovement jump for distance, countermovement jump for height, squat jump for distance, and squat jump for height. Nine elite and 7 recreational female swimmers performed 6 trials in each of the 4 jumping techniques and six 25-m freestyle sprints after a grab start. Elite participants performed significantly better in the start performances, and this was attributed to the greater horizontal impulse. Correlations in the elite group revealed that grab-start performance was not related to performance of any jumps. This suggests that the grab start is independent of the jumping techniques for this group, and performance of one skill might not translate to performance in the other. Significant correlations were found between performance of the grab start and the 4 jumps in the recreational group, possibly because of adoption of an "incorrect" motor pattern that might be similar to those of the jumps. This study highlighted the importance of practicing the start as a whole skill during training.

Key Words: starts and turns, swimming and aquatic skills

The start is an influential component of swimming because it can have a major impact on the race outcome. This is especially true for distances over 50 m, when the start could contribute up to 30% of the total race time. Results from the 1999 Pan Pacific Swimming Championships indicated a significantly high correlation between start times and performances in most swimming events of various distances and strokes (Mason & Cossor, 2000).

A common starting technique in swimming is the grab start, which is characterized by a two-legged takeoff similar to that of a two-legged countermovement jump. The knees and hips are flexed so that swimmers can hold the front edge of the block with their hands. The arms work as stabilizers to support and maintain balance (Figure 1). After the starting signal, both arms swing forward and the legs drive powerfully off the block (Blanksby, Nicholson, & Elliott, 2002). The hips, knees, and ankles extend forcefully in an attempt to maximize horizontal velocity. Explosive power of the lower limbs has been recognized as an important component

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of a good start (Arellano, Llana, Tella, Morales, & Mercade, 2005). Positive correlations between leg-extension power, vertical jump, and starting performances have been reported (Miyashita, Takahashi, Troup, & Wakayoshi, 1992; Pearson, McElroy, Blitvich, Subic, & Blanksby, 1998). Hence, one might consider that improvements in jumping abilities could enable swimmers to generate greater horizontal velocities while minimizing time spent on the block. Anecdotally, swimming coaches have used jump training to enhance athletes' explosive power to decrease block time and increase horizontal velocity.

Improving strength and power of the lower limbs might not necessarily transfer to improved starting performance. Recently, Breed and Young (2003) examined the effects of a resistance-training program on swim-start performance when using the grab, track, and swing start techniques. A commonality between vertical jumping and diving was suggested in that both these countermovement jumps (CMJs), with and without arms, were correlated significantly with flight distances in all three starting techniques. Resistance training did not improve the flight distances for any starts. The authors suggested that improvements in jumping ability might not have transferred to dive-start performances because of the specific skills involved in starting (Breed & Young). For example, swimmers need to change and maintain body positions during flight and then prepare for streamlined entry. Similarly, Davies, Murphy, Whitty, and Watsford (2001) reported no significant improvements in the start performance of competitive swimmers after 6 weeks of training using plyometric jumping activities. This was despite finding a 10% increase in vertical-jump performance. The lack of transfer to skill performance could have been a result of participants in the experimental group not practicing starts over the 6-week plyometric-training period.

Figure 1 — Illustration of the grab-start position.

Both the grab start and the vertical jump can be described as explosive ballistic skills that appear to share similar action elements. It has not been shown whether they actually are similar or whether one should expect that any improvement in one will lead automatically to an improvement in the other. According to Arellano et al. (2005) and De La Fuente, Garcia, and Arellano (2002), who reported no relationships between vertical CMJs and grab-start performances, this relationship appears unclear. Arellano et al. stated that a significant proportion of force development during the grab start was independent of gravity because it takes place in the horizontal direction, a key distinction that needs to be considered when comparing the two tasks. Furthermore, variations in the starting posture and jump or dive directions might impose different limb-segment interactions and muscle-recruitment patterns. A study comparing squat jumps for distance and for height, however, revealed no differences in the magnitude of the peak ground-reaction forces (GRFs), only directional distinctions (Ridderikhoff, Batelaan, & Bobbert, 1999). Those authors also found no differences in the velocities of the center of mass at takeoff. Currently, it is uncertain whether similar results would be achieved if the jumps were performed with a countermovement. It is also unclear whether there are relationships between jumping for distance and the swimming grab start.

Robertson and Stewart (1997) found that the hip was the most important contributor to the work done during a swimming grab start. In addition, the knee and ankle moments were generated almost simultaneously rather than sequentially. This coordination pattern appeared to be similar to that of a vertical jump, in which all three joints have been shown to generate moments simultaneously (Robertson & Fleming, 1987). In contrast, Lee, Huang, Wang, and Lin (2001) compared the pattern of muscle-contraction characteristics of the lower limbs during the grab start with squat jumps and CMJs. Their results showed similar movements of the lower limbs in the grab start, squat jump, and CMJ. The work patterns of the muscles were different, however, as the net muscle–joint moments and power in the grab start were considerably more complex than in the two jumping techniques. Lee et al. suggested that swimming coaches should emphasize the total movement and dynamics of the start, not just strength and power, for athletes during practice.

Swimming starts do not depend solely on the strength and explosiveness of the starters. Other features such as the angle of projection at takeoff, body position during flight, and water-entry angles also contribute to the total start performance. Hence, in this study we first investigated the differences in the temporal and GRF characteristics of the grab start between elite and recreational swimmers with an aim to identify the key features at takeoff that lead to better grab-start performance. We hypothesized that the elite group would record lower start times to 5 and 15 m than the recreational group. In addition, we examined the relationships between the grab-start performances and GRF characteristics of four different jumping techniques in elite and recreational swimmers. Because swimming starts require the swimmers to project their bodies forward, we hypothesized that jumping-for-distance measures would be more closely related to grab-start performances. In addition, we hypothesized that the start performances of the elite swimmers would be more closely related to the performances of the four jumping techniques than with the recreational group. Based on the assumption that the elite swimmers were proficient at performing the grab start, any performance variations would be more closely related to differences in the strength and power of the lower limbs rather than technical variations in any of the components of the start.

Method

Sample

After receiving approval from the Human Rights Committee at the University of Western Australia, we obtained informed consent from all participants. Nine elite female competitive swimmers and 7 regularly trained recreational female swimmers with limited practice experience in the grab-start technique participated in the study. The participants' mean height, mass, and age are recorded in Table 1.

Testing Procedures

Participants were required to attend two testing sessions. One session was conducted in the gait laboratory, where all jumping trials were performed. The grab starts were recorded in a separate testing session at the aquatic center.

Jumping Trials. Before the jumping trials, participants were asked to warm up following a standard protocol. Participants performed six trials of maximal-effort CMJs for height (CMJ-Height), six trials of maximal-effort CMJs for distance (CMJ-Distance), six trials of maximal-effort squat jumps for height (SQJ-Height), and six trials of maximal-effort squat jumps for distance (SQJ-Distance). The four jumping conditions were administered in a block-randomized order in which participants performed all six trials of one condition before beginning the next. All jumps were performed with bare feet to account for any effects created by different shoes. To eliminate any variation in the contributions from the arm swings, participants performed all jumps with their hands on their hips. They were asked to maintain a stationary position on the force plate for at least 3 s before each jump. This was to provide a static period on the force–time curve and enable detection of the initial movement with greater accuracy. Participants were allowed practice trials to ensure that they performed the jumps with correct techniques. A rest period of at least 3 min was allowed between jumps to avoid any onset of muscle fatigue.

The GRF data were collected at 500 Hz with an AMTI force plate (Watertown, MA) and were used to calculate horizontal and vertical impulses, resultant velocity at takeoff, and jump heights. Only the jump distances achieved in the jumping-for-distance trials were measured directly from the heels of the participants using a standard measuring tape.

In addition, video footage of each trial was recorded at 50 Hz from the sagittal plane with a digital video camera. This footage was used during data processing to ensure that only valid trials were included in the analysis.

Grab-Start Trials. Grab-start testing was carried out in the aquatics laboratory. Participants were required to perform the grab start using the competition starting

Table 1 Participant Characteristics, *M* ± *SD*

Group	Age (years)	Mass (kg)	Height (m)
Elite (*n* = 9)	19.00 ± 1.30	65.48 ± 10.35	1.67 ± 0.06
Recreational (*n* = 7)	22.00 ± 3.09	57.53 ± 5.88	1.69 ± 0.07

protocol, underwater streamlining and kicking action, and "break out" to reach the surface and swim front crawl with maximal effort for 25 m. The grab starts were performed on a custom-built instrumented starting block consisting of two force plates mounted side by side (Figure 2). The dimensions of the block were in accordance with regulations set by the world swimming-governing body FINA. Force data were collected at 500 Hz using custom-programmed data-collection software. They were filtered using a Butterworth low-pass filter (16 Hz) before processing. The following variables were derived from the GRF data: reaction time, movement time, total time spent on the block, net horizontal impulse, net vertical impulse, resultant velocity at takeoff, and takeoff angle.

Two Sony digital video cameras (50 Hz) were used to determine time to 5 m (T5) and time to 15 m (T15). One camera was positioned perpendicular to the swimmers' line of motion in the underwater viewing area 5 m from the starting edge of the pool. The other camera was placed on a tripod 15 m along the edge of the pool and also perpendicular to the swimmers' line of motion. Both the 5-m and 15-m gates were calibrated at the beginning of each testing session. Two light-emitting diodes (LEDs) were placed in the field of view of both cameras. Each LED was connected to an auditory starting stimulus. As the starter triggered the stimulus, both LEDs were illuminated simultaneously with the starting signal. T5 and T15 were determined as the periods from when the LED first illuminated until the apex of the swimmer's head reached the 5- and 15-m lines, respectively.

Statistical Analysis

Initially, a series of one-way analyses of variance (ANOVAs) was used to evaluate the differences in jumping and starting performances between the elite and recreational groups. Relationships between the independent variables were examined using Pearson's product–moment correlation.

Figure 2 — The starting block with the force plates mounted.

Results

Swim-Start Performances and Characteristics

Elite swimmers were significantly faster in their swim-start performances to both 5 m and 15 m ($F = 8.48$, $p < .05$, and $F = 24.75$, $p < .01$, for T5 and T15, respectively). The elite group generated significantly greater horizontal impulses ($F = 10.55$, $p < .01$) and shallower takeoff angles than the recreational group ($F = 6.13$, $p < .05$). Start characteristics of the elite and recreational groups are summarized in Table 2.

In the elite group, there was a significant correlation between horizontal impulses and T5 ($r = .701$, $p < .05$), with variations in horizontal impulses accounting for 49% of the variance in T5. In contrast, T5 and T15 of the recreational swimmers were not correlated with any of the GRF measurements, although a significant correlation between T5 and vertical impulses would have resulted in the $\alpha < .10$ value ($r = .707$, $p = .07$). The lack of significance at $\alpha < .05$ was possibly a result of our small sample size that reduced statistical power. Both T5 and T15 of the recreational participants correlated significantly and strongly with reaction time ($r = -.878$, $p < .01$, and $r = -.793$, $p < .01$, for T5 and T15, respectively) but not with movement time or total time spent on the block. All correlations between the block characteristics and T5 and T15, for both the elite and recreational groups, are reported in Table 3.

Jumping Performances and Characteristics

The performances and characteristics of the four jumping techniques are summarized in Table 4. The one-way ANOVAs revealed no significant differences between the two groups in any of the jumping-for-height performances. In contrast, the elite group performed better than the recreational group in CMJ-Distance and SQJ-Distance ($F = 4.99$, $p < .05$, and $F = 4.70$, $p < .05$, respectively).

Table 2 Differences in Grab-Start Characteristics Between the Elite and Recreational Groups

Characteristic	Elite, $n = 9$	Recreational, $n = 7$
Reaction time (s)	0.15 ± 0.02	0.15 ± 0.02
Movement time (s)	0.80 ± 0.05	0.84 ± 0.04
Total time spent on the block (s)	0.95 ± 0.05	0.99 ± 0.04
Horizontal impulse (N/kg)	3.60 ± 0.23**	3.17 ± 0.30
Vertical impulse (N/kg)	4.76 ± 1.40	6.13 ± 2.42
Velocity at takeoff (ms^{-1})	4.10 ± 0.35	4.38 ± 0.71
Takeoff angle (°)	27.45 ± 5.99*	39.62 ± 13.19
Time to 5 m (s)	1.95 ± 0.11*	2.10 ± 0.09
Time to 15 m (s)	8.15 ± 0.34**	8.96 ± 0.31

*Significant difference from the recreational group ($p < .05$). **Significant difference from the recreational group ($p < .01$).

Table 3 Correlations Between Grab-Start Performance and Various Temporal and Ground-Reaction-Force Variables in the Elite and Recreational Groups

	Elite, *n* = 9		Recreational, *n* = 7	
	T5	T15	T5	T15
Reaction time (s)	–.188	–.020	–.878**	–.793*
Movement time (s)	.639	.532	.401	.335
Total time spent on the block (s)	.578	.552	–.066	–.090
Horizontal impulse (N/kg)	–.701*	–.494	–.438	–.111
Vertical impulse (N/kg)	–.091	.131	.707[a]	.395
Velocity at takeoff (ms^{-1})	–.482	–.190	.631	.250
Takeoff angle (°)	–.048	–.214	.603	.231

Note. T5 indicates time to 5 m; T15, time to 15 m.

[a]Trend toward significance.

*Correlation is significant at the .05 level (2-tailed). **Correlation is significant at the .01 level (2-tailed).

Table 4 Differences in Jumping Characteristics Between the Elite and Recreational Groups (ANOVAs)

	Elite, *n* = 9	Recreational, *n* = 7
Countermovement jump for height		
horizontal impulse (N/kg)	0.19 ± 0.04	0.18 ± 0.04
vertical impulse (N/kg)	2.33 ± 0.13	2.28 ± 0.18
velocity at takeoff (ms^{-1})	1.99 ± 0.11	2.05 ± 0.13
jump height (m)	0.20 ± 0.02	0.21 ± 0.03
Squat jump for height		
horizontal impulse (N/kg)	0.18 ± 0.04	0.19 ± 0.06
vertical impulse (N/kg)	2.27 ± 0.14	2.21 ± 0.16
velocity at takeoff (ms^{-1})	1.93 ± 0.10	1.94 ± 0.15
jump height (m)	0.19 ± 0.02	0.19 ± 0.03
Countermovement jump for distance		
horizontal impulse (N/kg)	2.20 ± 0.18	2.07 ± 0.18
vertical impulse (N/kg)	1.61 ± 0.10	1.60 ± 0.20
velocity at takeoff (ms^{-1})	2.51 ± 0.15	2.43 ± 0.16
jump distance (m)	1.47 ± 0.15*	1.31 ± 0.12
Squat jump for distance		
horizontal impulse (N/kg)	2.15 ± 0.18	2.00 ± 0.15
vertical impulse (N/kg)	1.61 ± 0.12	1.60 ± 0.20
velocity at takeoff (ms^{-1})	2.46 ± 0.16	2.39 ± 0.15
jump distance (m)	1.41 ± 0.14*	1.27 ± 0.10

*Significant difference from the recreational group ($p < .05$).

Relationships Between Jumping and Starting Performances

Pearson's product–moment correlations between jumping and grab-start performances are presented in Table 5. In the recreational group, although the takeoff velocities of the four jumping techniques did not correlate significantly with the takeoff velocity of the grab start, they correlated strongly and significantly with T5. The takeoff velocities of each jumping technique can explain at least 74% of the variance of T5 in swimmers in this group. In addition, T5 also correlated strongly with the performances of both jumping-for-height techniques. Performances in CMJ-Height and SQJ-Height can account for 91% and 85% of the variance, respectively, of T5. In contrast, no jumping variables correlated significantly with velocity at takeoff of the grab start or T5 in the elite group. In this group, the only significant correlation found was between SQJ-Distance and T15.

Discussion

The aims of this study were to determine whether there was common variance in the relationships between the performance and GRF characteristics of four different jumping techniques and the swimming grab starts of elite and recreational female swimmers. Explosiveness and a powerful leg drive have been found to be important components of the swimming grab start (Maglischo, 2003). In addition, the skill components of being able to take off at an appropriate angle and then adjust the body alignments during flight to ensure optimal water-entry postures are vital for

Table 5 Correlations Between Jumping and Grab-Start Performance in the Elite and Recreational Groups

	Elite			Recreational		
	$V_{Takeoff}$ (ms^{-1})	T5 (s)	T15 (s)	$V_{Takeoff}$ (ms^{-1})	T5 (s)	T15 (s)
CMJ height						
$V_{Takeoff}$ (ms^{-1})	.262	–.495	–.576	–.683	–.950**	–.485
jump height (m)	.277	–.496	–.588	–.674	–.955**	–.483
SQJ height						
$V_{Takeoff}$ (ms^{-1})	.135	–.341	–.639	–.608	–.912**	–.635
jump height (m)	.136	–.319	–.622	–.607	–.920**	–.634
CMJ distance						
$V_{Takeoff}$ (ms^{-1})	.067	–.405	–.646	–.649	–.862*	–.631
jump distance (m)	.182	–.110	–.637	–.652	–.468	–.394
SQJ distance						
$V_{Takeoff}$ (ms^{-1})	–.044	–.182	–.666	–.451	–.858*	–.471
jump distance (m)	–.005	–.206	–.724*	–.268	–.431	–.233

Note. $V_{Takeoff}$ indicates velocity at takeoff; T5, time to 5 m; T15, time to 15 m; CMJ, countermovement jump; SQJ, squat jumps.

*Correlation is significant at the .05 level (2-tailed). **Correlation is significant at the .01 level (2-tailed).

optimal starts. The current study demonstrated that, although the resultant velocities generated at takeoff by the elite and recreational groups were similar, the elite group was significantly faster to reach the 5-m mark. Analysis of the GRF data revealed that the elite group generated greater horizontal impulses. Therefore, they took off with greater horizontal velocity at a lower takeoff angle (Table 3). The results of the correlation further emphasize the importance of horizontal impulse. It was the only variable significantly correlated with T5 in the elite group. Arellano et al. (2005) also found the force in the horizontal direction to be an important variable in swim-start performance.

Analyses of the four jumping techniques revealed contrasting results between the jumping-for-height and jumping-for-distance measures. The differences between the elite and recreational groups in both CMJ-Height and SQJ-Height were not statistically significant. On the other hand, elite swimmers were able to jump farther than the recreational group in both CMJ-Distance and SQJ-Distance. Both formats of the vertical jump have been used as functional tests of lower limb strength to measure the efficacy of various strength-training methods (Cordova & Armstrong, 1996; Deane, Chow, Tillman, & Fournier, 2005). Hence, the performance distinctions in the grab start between the elite and recreational swimmers, as represented by T5 and T15, were not related to strength differences between the two participant groups. The fact that elite swimmers were able to jump farther than the recreational group might be because they were more accustomed to having to project the body forward as required by the two jumping-for-distance techniques.

To further examine the influence of lower limb strength and power on the performance of the grab start, the relationships between jumping and grab-start performances were examined in each of the participant groups independently. We hypothesized that the relationships between grab-start performances and the athletes' jumping abilities would be stronger among elite swimmers than in the recreational group. This hypothesis was derived on the basis that highly skilled athletes might display a reasonably homogeneous proficiency level for the skills being tested. Thus, swimmers with a strength and power advantage would perform better in the starting phase of a swimming race. Results of the correlation analyses revealed that jumping performances in all four techniques were related to start performances only in the recreational group, not the elite group. Previous comparisons between the vertical jump and swimming start have demonstrated similar patterns (Arellano et al., 2005; Breed & Young, 2003; Pearson et al., 1998). For example, Arellano et al. reported no significant relationships between the CMJ impulse and any of the grab-start variables in state- and national-level swimmers. Although Breed and Young reported a positive correlation between vertical-jump height and flight distance of the grab start, their participants were not trained swimmers and had to be taught the dives for the study. In addition, the 10% improvement in CMJ performances after training did not translate into greater flight distances in the grab start. The lack of improvements in the start performances reported in their study could have occurred because their participants did not have the necessary skills to transfer the improved strength and power into better starts. Perhaps the levels of specificity between the two tasks are sufficiently different that an immediate transfer of performance does not occur.

Although explosive power of the lower limbs has been regarded by swimming coaches as an important factor in a successful start, the current results and evidence from previous literature question the validity of this assumption. The lack of relationships between the grab start and jumping performances could be attributed to the fact that the four jumping techniques do not adequately represent the technique of the grab start. Lee et al. (2001) demonstrated that the kinetic pattern of the grab start was more complex than those of the CMJ and the squat jump, in which the push-off was characterized by the positive work done by the knee, hip, and ankle extensors to generate extension moment. The grab start was characterized by a sequential flow of hip-, knee-, and ankle-extensor activities. In the initial phase, the hip extensors contracted eccentrically and the knee flexors contracted concentrically to lower the hips. This was followed by concentric activities of the hip extensors to initiate the push-off. The knee extensors then contracted to extend the legs and to generate propulsion in the horizontal direction. The fact that significant correlations were observed between the performances of the four jumps and the grab start in the recreational swimmers could be attributed to their lack of the skills necessary for an optimal grab start. Because segmental kinematics and kinetics were not measured in this study, whether there were different kinetic patterns between these two groups of swimmers or whether the recreational group would display a kinetic pattern resembling those of the CMJ and the squat jump requires further investigation.

An earlier study from our laboratory examined preferred versus nonpreferred swim-start techniques (Blanksby et al., 2002). No single start technique was found to be superior, but swimmers did best at what they had practiced most. In addition, all swimmers improved their dive-start performances, which implied that all swimmers, including elite ones, could benefit from more training time spent on dive starts. This “room for improvement” at all levels might help explain some of the similarities found between the disparate participants in the current study. In addition, further research is required to conclusively determine the benefit of various modalities of strength training on start performance, an important component of swimming races.

Conclusion and Practical Implication

The distinct feature of the grab start performed by elite swimmers was the significantly greater impulse generated in the horizontal direction than that of a group of recreational swimmers. Lower limb strength and power were considered important factors for a successful start. When the grab starts were examined in relation to the four jumps, no significant relationships were found between the performances of the swimming grab start and the four jumping techniques in the elite participants. Although the CMJ and squat jump have been used as functional tests of lower limb strength, they could not predict the starting performance in elite swimmers. The lack of relationships between the jumps and the grab start was attributed to differences in the coordination patterns of the motor skills. The results of this study highlight the importance of skill-development phases for athletes. Coaches should not only focus on physical attributes such as strength during practice but also include the dynamic and the motor pattern of the skills being developed. Following the principle of specificity, swimmers appear to benefit from formal inclusion of dive starts in training. Training progression could include maximum-effort horizontal jumps off the starting block, with feet-first entries, as a “halfway house” to develop force application horizontally and correct movement sequencing. Such an activity could have better transfer capabilities than vertical-jump practices commonly used.

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