THE RELATIONSHIP BETWEEN DRY-LAND RESISTANCE TRAINING AND START PERFORMANCE IN COMPETITIVE SWIMMING: A BRIEF REVIEW

Shiqi Thng[1, 2], Simon Pearson[2] and Justin Keogh[1]

Faculty of Health Sciences and Medicine, Bond University, Gold Coast, QLD, Australia[1]
Queensland Academy of Sport, Nathan, QLD, Australia[2]

The purpose of this study was to review the literature on the relationship between dry-land resistance training and swim start performance in competitive swimming. It is common practice in competitive swimming to use dry-land resistance training to increase muscular strength and power. Given the explosive nature of the swim start, it would appear that high levels of lower body muscular strength and power are necessary to enhance this component in swimming. Performance in total body jumping exercises shared a stronger relationship to start performance than single joint exercises. This may reflect the requirement for force and power to be developed across multiple joints in the swim start.

KEYWORDS: swimming, start, strength, power

INTRODUCTION: A swimming race can be broken down into four key components: the start, turn, finish and the free swim component (Mason & Cossor, 2000). The swim start is defined as the distance to the 15m mark (West, Owen, Cunningham, Cook, & Kilduff, 2011) and is the maximum distance that a swimmer can travel underwater before their head is required to break the water's surface in all strokes except for breaststroke ("FINA Swimming Rules SW 5.3, SW 6.3, and SW 8.5," 2015).
Three primary phases contribute to the swim start; these being the block phase, flight phase and the underwater phase. In the block phase, swimmers react to an auditory stimulus and performs a powerful triple extension of the hip, knee and ankle joints while also pulling on the block with their arms to generate a high enough impulse to propel themselves forward (Riewald & Rodeo, 2015). The block phase is followed by the flight phase, in which the swimmer becomes airborne and finishes when contact is being made with the water (research varies between hand and head contact) (Slawson, Conway, Cossor, Chakravorti, & West, 2013; Tor, Pease, & Ball, 2014). The underwater phase comes next, in which swimmers attempt to maintain a streamlined position through undulatory leg kicks with their arms outstretched in front of the head to minimise hydrodynamic drag-related velocity loss until their head resurfaces just before the 15m mark (Formicola & Rainoldi, 2015).
Dry-land resistance training is commonly prescribed in competitive swimming (Crowley, Harrison, & Lyons, 2017). By overloading the muscles required for swimming with external resistances, dry-land resistance training aims to increase the strength and power production of key propulsive muscles (Cronin, Jones, & Frost, 2007; Dingley, Pyne, Youngson, & Burkett, 2015). Strength and conditioning coaches typically focus on the upper body as these muscles contributes to the majority of propulsive forces during the free swimming portion of the race (Martens, Figueiredo, & Daly, 2015). Recent studies have also highlighted the importance of leg extensor power output to increase a swimmer's ability to execute swim turns effectively (Jones, Pyne, Haff, & Newton, 2017a, 2017b). Given that swim starts also require an explosive lower body movement, the ability to produce high forces using the leg extensors would also likely to be an important factor for an optimal swim start performance. Thus, the aim of this paper is to review the literature on the relationship between dry-land resistance training and swim start performance in competitive swimming.

METHODS: A search was conducted using MEDLINE, Embase and SportDISCUS with full text online databases. The keywords used in the search included "swimming", "swim", "start", "strength" and "power". Studies were included if they were peer-reviewed and written in English. Studies were excluded if they were not peer-reviewed, if they were conference abstracts or articles that did not have full-text access.

RESULTS: Seven studies met the inclusion and exclusion criteria (see Table 1).

Table 1: Relationship between dry-land exercises and swim start performance.

Author	Participants	Swim start Correlation to Dry-land Kinematics	Swim start Correlation to Dry-land Kinetics
Breed and Young (2003)	23 University students (F)	*Grab start* **FD** JH (CMJ): r = 0.60** JH (CMJ-AS): r = 0.74*** *Track start* **FD** JH (CMJ): r = 0.63** JH (CMJ-AS): r = 0.74***	
Benjanuvatra et al. (2007)	9 Elite; 7 Recreational (F)	**T5m** CMJ-JH: r = -0.955* SJ- JH: r = - 0.920** (Recreational only) **T15m** SJ- JD: r = -0.724* (Elite Only)	
Beretic et al. (2013)	27 International level sprint swimmers (M)		**T10m** F_{max} : r = - 0.559**
De La Fuente et al. (2003)	65 University students (44 M; 21 F)		**sPVF** PVF: r = 0.51**
Garcia-Ramos et al. (2016)	20 International level swimmers (F)	**T5m** CMJ- TOV: r = -0.62** SJ- TOV: r = -0 .56* **T5m** BV at 25 %BW: r = -0.66** BV at 50 %BW: r = -0.72** BV at 75 %BW: r= -0.63** BV at 100 %BW r= -0.57* **T15m** BV at 25 %BW: r = -0.63** BV at 50 %BW: r = -0.63** BV at 75 %BW: r= -0.68** BV at 100 %BW r= -0.64**	
Miyashita et al. (1992)	69 National and International level swimmers (M, F)		**T5m** MP: r = - 0.675**
West et al. (2011)	11 International level sprint swimmers (M)	**T15m** JH: r = - 0.69* **sPVF** JH: r = 0.78** **sPHF** JH: r = 0.73*	**T15m** 1RM: r = - 0.74** **sPVF** 1RM: r = 0.62* **sPHF** 1RM: r = 0.71*

M = Males; F = Females; CMJ = countermovement jump; CMJ-AS = countermovement jump with arm swing; SJ = squat jump; TOV = take-off velocity; sPVF = starting peak vertical forces; sPHF = starting peak horizontal forces; PVF = peak vertical forces; T5m = time to 5m; T10m = time to 10m; T15m = time to 15m; JH = jump height; JD = jump distance; BW = bodyweight; RM = repetition maximum; FD = flight distance; F_{max} = leg extensor maximum force production; N = Newtons; m = metres; s = seconds; m/s = metres/second; kg = kilogram; BV = bar velocity; MP = maximal power; *p < 0.05; **p < 0.01; ***p < 0.001

A variety of kinematic or kinetic outputs from dry-land exercises including the countermovement jump (CMJ) (Benjanuvatra, Edmunds, & Blanksby, 2007; Breed & Young, 2003; De la Fuente, Garcia, & Arellano, 2003; Garcia-Ramos et al., 2016) , squat jump (SJ) (Benjanuvatra et al., 2007; Garcia-Ramos et al., 2016) , back squat (West et al., 2011) and leg extension maximum voluntary isometric contraction (MVIC) (Beretić, Đurović, Okičić, & Dopsaj, 2013; Miyashita, Takahashi, Troup, & Wakayoshi, 1992) correlated significantly to aspects of swim start performance. A stronger correlation was observed between dry-land kinematic and kinetic variables to the time to 5m, compared to the time to 10m or 15m. As suggested by De la Fuente et al. (2003), time to 5m is more strongly influenced by the take-off velocity of the swimmer from the start block compared to 10 or 15m, whereby factors such as underwater gliding and underwater undulatory leg kicks become more important. Jump velocities obtained from the CMJ and loaded SJ at four loads correlated significantly to time to 5m and loaded SJ at all four loads correlated significantly to time to 15m (Garcia-Ramos et al., 2016). In comparison to the positive correlations between CMJ and SJ to swim start performance, there were some inconsistencies in the relationships between leg extension MVIC and swim start performance. Garcia-Ramos et al. (2016) found no significant correlation between leg extension MVIC and swim start performance to 5m or 15m. Such a result was in contrast to Beretić et al. (2013), who reported a significant correlation between the maximum force in the leg extension exercise and time to 10m and Miyashita et al. (1992) who reported a significant correlation between maximum power in the leg extension exercise and time to 5m. These discrepancies in the findings for the studies that utilised the leg extension could be due to the difference in participants. Beretić et al. (2013) used a highly homogenous group of subjects consisting only of elite male sprint freestyle swimmers, while Garcia-Ramos et al. (2016) and (Miyashita et al., 1992) utilised a mixed sample of swimmers who competed in races of varying distance and swimming styles.

DISCUSSION: The results of this review suggest that a range of kinematic and kinetic outputs from a variety of dry-land exercises may be representative of lower body strength and power capacities required to maximise swimming start time performance. Performance in explosive total body jumping exercises exhibited a stronger relationship to start performance than single joint exercises such as an isometric leg extension. This may reflect the requirement for force and power to be developed across multiple joints in the swim start and for the ankle, knee and hip joint moments to be coordinated effectively with those of the upper body to maximise take-off velocity. Findings from this review appear consistent with the literature on sprint starts in track and field, with these two starting activities sharing many similarities regarding the importance of a quick reaction to the starting stimulus and the production of high levels of horizontal impulse on the starting blocks (Čoh, Peharec, Bačić, & Mackala, 2017). Specifically, the track and field literature demonstrates that success in sprint-based activities is highly influenced by an athlete's ability to produce force and power in the horizontal direction in order to accelerate from the starting blocks (Morin, Edouard, & Samozino, 2011). Thus, to achieve high peak forces, swimmers have to train with resistances high enough to engage higher threshold motor units associated with type II muscle fibres (Miyashita et al., 1992). A limitation of this literature review is the outdated starting blocks and/or starting positions used in all seven studies. Given that the OSB11 start block being the current starting block used in competitions and majority of swimmers using the kick start technique, it would be appropriate to establish the relationship between dry-land exercises and swim start performance using the OSB11 and the kick start technique.

CONCLUSION: As the swim start requires the lower body musculature to effectively initiate movement off the start blocks, it would appear that dry-land resistance training could be used to develop lower body strength and power to enhance swim start performance. Since this type of loading is low in volume with most swimming programs, the implementation of a dry-land resistance training program becomes increasingly important to increase both peak forces and rate of force development in the lower body to enhance swim start performance.

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