A PILOT INVESTIGATION INTO FORCE PRODUCTION IN TETHERED SWIMMING AS AN INDIVIDUAL MONITORING TOOL

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Gaining an understanding of the physical capabilities and capacities that underpin the performance of a complex skill are important to help guide performance development at the elite level. The purpose of this study was to improve understanding of the force generating characteristics that relate to performance in elite swimmers. Three elite butterfly swimmers were tested over six weeks to examine the interactions between force-derived variables from 30 s of maximal tethered swimming and maximal 50m swimming performance, both performed using the butterfly stroke. Mean force, peak force and impulse per stroke all displayed very strong relationships with 50m swim time (r > -0.8) and distance per stroke (r > 0.8) in group analysis. Peak force and impulse per stroke were better than mean force at discriminating variations in performance for an individual.

KEYWORDS: butterfly, propulsion, testing, strength

INTRODUCTION: In order to optimise the performance of athletes, coaches and scientists must be able to break down performance into subcategories in order to assess where their athletes are progressing and what aspects need work. It is also necessary to ensure that supplementary training completed by the athlete outside of their specific performance environment (such as gym-based training for swimmers) is improving performance, not hindering it in other ways.

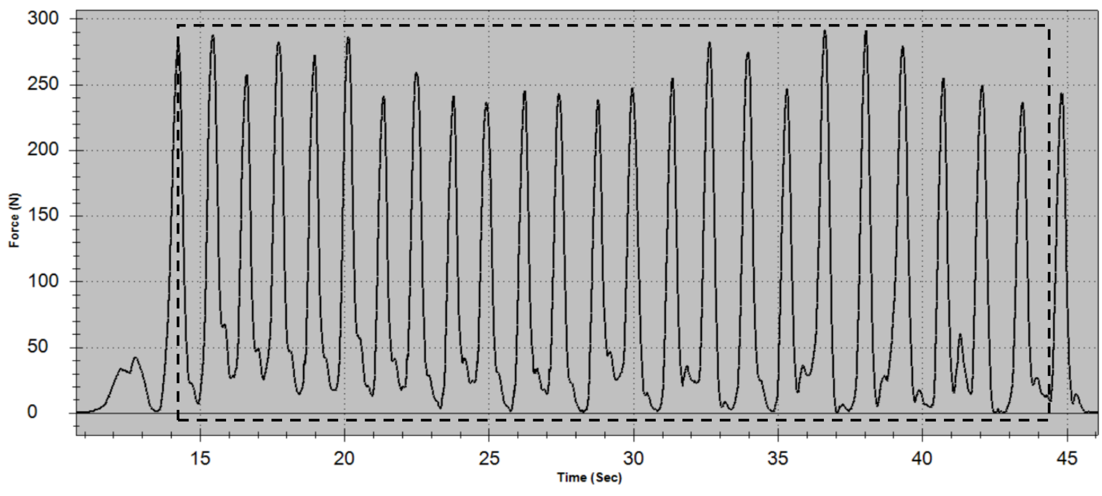
The velocity of a swimmer is determined by the propulsive force produced (Lauder, Dabnichki, & Bartlett, 2001) and the drag created by the swimmer’s body (Gatta, Cortesi, Swaine & Zamparo, 2018). This relationship means a change in force will result in a change in swimming velocity, if drag remains constant, however the forces involved in propulsion are not easily measured in swimming as there is a highly complex interaction between the variables: force, surface area and drag (Gatta, Cortesi, Swaine, & Zamparo, 2018). Tethered swimming is a methodology by which it is possible to create an environment where both drag and velocity are zero, and force can be measured in the pool (Pessôa Filho & Denadai, 2008). Previous studies have found a significant relationship between tethered force output and swimming performance across all strokes (Morouco, Keskinen, Vilas-Boas, & Fernandes, 2011), although this relationship weakened as the length of the event increased (Wilke & Madsen, 1990). However, while there have been a number of studies in this area it should be noted that the majority have looked at cross-sectional relationships rather than the longitudinal relationship between changes in tethered swim force and swimming velocity over time, and those that have looked longitudinally have primarily been in front crawl.

Dry-land strength or resistance training is a supplementary modality that could be expected to positively influence propulsive force. However, the evidence around positive transfer from the gym to swimming performance has been mixed (Crowley, Harrison & Lyons, 2017), although this is not entirely unexpected in a highly technical sport such as swimming with multiple factors influencing end performance. Given this, tethered swimming is considered one of the most sport-specific ergometers to determine propulsive swimming forces (Pessôa Filho & Denadai, 2008), and may provide an intermediate modality to assess the transfer of basic strength to swimming performance. It is also worth noting that this relationship may not be expressed in the same way for the different strokes, with Morouco et al. (2011) showing that the simultaneous bilateral strokes (butterfly and breaststroke) produce significantly higher peaks and greater fluctuation in force, than the alternating strokes (front crawl and backstroke). Additionally, there has been minimal investigation into the relationship between force application in tethered swimming and stroke length and stroke rate, as the determining factors of swimming velocity, which may help elucidate the potential mechanisms of transfer. The aim of this preliminary investigation was therefore to examine the relationships, at both an individual and group level, between the forces produced during tethered swimming and key performance metrics in a maximal 50m swimming effort for elite butterfly swimmers.

METHODS: Three elite butterfly swimmers (one male international, one female international, one female national level) were involved in the study. Data were collected for six successive weeks during normal training sessions, on the same day and time of a standard weekly training cycle in the same 50m pool. Data collection comprised of two elements:

1. *Tethered swim force testing:* An IMADA ZTA-1000N digital force gauge (factory calibration, confirmed using known masses up to 40kg) was mounted onto the pool starting block using straps to ensure the load cell would not move during testing. Following warm up, a 5m tether connected the force gauge was attached to the swimmer using a belt around their waist. Each athlete was instructed to swim maximally from the start of the test to ensure that the athletes were not pacing themselves throughout the effort. Each effort was 30 s from the first stroke (Figure 1), and the completion of the trial was signalled to the swimmer via a manually triggered underwater LED light.
   Data were captured using IMADA Force Recorder Standard v 1.02 software. Signal analysis was performed using custom software written in Microsoft C# to determine:
   - Mean force for the first 10 s (Start Force), last 10 s (Finish Force), and the entire 30 s trial (Mean Force).
   - Average peak force from each stroke cycle across the 30 s trial (Peak Force)
   - Fatigue index = [Finish Force / Start Force]
   - Impulse per stroke and Stroke Rate (SR-T)
2. *50m swimming performance:* The exact content of each training session varied week to week but all contained a minimum of two maximal 50m efforts completed from a push start off the wall (as opposed to a dive start). All maximal push 50m efforts were recorded using a Canon XA30 video camera. From each session the fastest two push 50m efforts were used for more detailed video analysis, with the averages of these two efforts being used for statistical analysis. Variables obtained were 50m time (the key performance measure), stroke rate (SR-S), and distance per stroke (DPS).

Figure 1: Example force data from a tethered swimming trial using the Butterfly stroke. Dashed lines indicate the area used for analysis (30 s from first stroke peak force).



Statistical analysis was performed using IBM SPSS v24 and examined the results from both an individual athlete and group perspective. Data were analysed for correlation between tethered swimming force variables and swim performance measures using bivariate analysis.

Magnitude of correlations was defined using the adapted Cohen scale proposed by Hopkins (http://www.sportsci.org/resource/stats/effectmag.html).

RESULTS: Of the tethered swimming metrics analysed, mean force, peak force, and impulse per stroke all showed notable relationships with swimming performance, as represented by 50m swim time (Table 1). Of these, peak force had very large correlations across all individuals and grouped data, while mean force and impulse per stroke had very strong group correlations but the strength of relationships was more variable for individual swimmers.

Table 1: Correlations between variables obtained from tethered swimming and push 50m swim time

	Athlete 1	Athlete 2	Athlete 3	**Group**
Mean Force (N)	-0.731	-0.407	-0.667	**-0.865**
Peak Force (N)	-0.861	-0.756	-0.993	**-0.849**
Fatigue Index (%)	-0.230	-0.351	0.310	**-0.433**
Impulse per Stroke (N.s)	-0.833	-0.615	-0.715	**-0.869**
Stroke Rate (str/min)	0.451	0.447	0.138	**0.282**

Key: Light grey shading indicates large correlations; Dark grey shading indicates very large or stronger correlations

The observed relationships of tethered swimming metrics with DPS (Table 2) and stroke rate during normal swimming [SR-S] (Table 3) are displayed below. While DPS shows very large correlations for grouped data with mean force, peak force and impulse per stroke, the strength of relationships for individual athletes is generally weaker and varies in direction for Athlete 3 compared to Athlete's 1 and 2. Overall mean force and peak force would seem to be the best discriminators of variation in DPS both within and between individuals.

Table 2: Correlations between variables obtained from tethered swimming and distance per stroke (DPS) in push 50 swim efforts

	Athlete 1	Athlete 2	Athlete 3	**Group**
Mean Force (N)	0.540	0.461	0.688	**0.868**
Peak Force (N)	0.698	0.622	0.450	**0.931**
Fatigue Index (%)	0.073	0.296	-0.147	**0.470**
Impulse per Stroke (N.s)	0.657	0.603	-0.400	**0.938**
Stroke Rate-T (str/min)	-0.504	-0.403	0.760	**-0.519**

Key: Light grey shading indicates large correlations; Dark grey shading indicates very large or stronger correlations

In contrast to the results for DPS, tethered swimming variables appear to discriminate fairly well for individual variations in SR-S with large to very large correlations for individual athletes shown between SR-S and peak force, impulse per stroke and mean force. However there is virtually no relationship between tethered swimming metrics and SR-S at a group level, other than a large correlation with SR-T.

Table 3: Correlations between variables obtained from tethered swimming and stroke rate in push 50 swim efforts (SR-S)

	Athlete 1	Athlete 2	Athlete 3	**Group**
Mean Force (N)	0.772	0.590	0.343	**-0.001**
Peak Force (N)	0.713	0.828	0.889	**-0.219**
Fatigue Index (%)	0.119	0.112	-0.594	**-0.240**
Impulse per Stroke (N.s)	0.757	0.625	0.821	**-0.192**
Stroke Rate-T (str/min)	0.028	-0.359	-0.445	**0.652**

Key: Light grey shading indicates large correlations; Dark grey shading indicates very large or stronger correlations

DISCUSSION: The purpose of this study was to assess and quantify the relationships between force-based measures during tethered swimming and performance metrics during maximal push 50m swimming efforts. Higher mean and peak force values were both shown to have a strong positive relationship with swimming performance, which is in line with previous research (Morouco, 2011). However, this study also observed an equally strong overall/group relationship between performance and a new impulse per stroke metric, and identified that the peak force and impulse per stroke variables had a closer relationship to intra-athlete variations in performance than mean force. This indicates that, for the purposes of monitoring changes over time for an individual butterfly swimmers, the ability to generate high forces through the propulsive phase is a better indicator of swimming specific strength than the ability to maintain relatively higher forces through the recovery phase of the stroke cycle. The metrics may also reflect slightly different things in the swimmer(s), where mean force comparing across a population takes more account of technical proficiency (i.e. ability to maintain force throughout a cycle), but when tracking an individual, their technique tends to be relatively stable and therefore the physiological condition (i.e. available muscular force for the primary propulsive phase) is a bigger source of short term variation in swimming speed.

This study also examined the relationship between variables derived from tethered swimming and the determining factors of swimming speed (DPS and SR-S). While DPS showed very strong correlations with mean force and peak force in the grouped analysis, there were no variables displaying meaningful relationships with DPS consistently across the three individuals. Possible explanations include that this may reflect technical differences in the way swimmers apply force throughout the propulsive phase to increase DPS. Alternatively it may reflect the importance of the propulsion-drag interaction in the way the body moves through the water to produce DPS in normal swimming.

Stroke rate during normal swimming (SR-S) was interesting in that there were no notable over-arching relationships to any of the tethered variables (other than SR-T, as expected: mean difference of -1.2 str/min). However, peak force and impulse per stroke both showed strong to very strong positive correlations with SR-S for all individuals. This indicates the importance of available muscular force in underpinning propulsion (typically associated with DPS), and the speed of movement associated with reducing cycle time and increased SR-S.

CONCLUSION: The variables useful for differentiating performance between individuals in any athletic population are not always the same as those that underpin performance changes for an individual. In the case of force gauge assessment in a tethered swimming test, whereas mean force has been shown to effectively discriminate between individuals, peak force and impulse per stroke appear to be more sensitive metrics for tracking changes in propulsive force capacity (event-specific strength) in an individual butterfly swimmer. However, these are preliminary findings only, and further investigation should be completed with a greater number of swimmers, for a longer period of time, and across other strokes.

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