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Tethered Force Production in Standard and Contra-standard Sculling in Synchronized Swimming

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Studies carried out in synchronized swimming are scarce, inclusively with respect to the biomechanical analysis of sculling. The purpose of this study was to measure the force produced in standard and contra-standard sculling, using a 30 s maximal tethered synchronized swimming test. 13 synchronized swimmers performed a 2x30 s maximum intensity tethered synchronized swimming test, in standard and contra-standard sculling conditions, respectively. The variables were: absolute and relative maximal force, the time when maximal force occurred, the mean force, the mean values of maximal and minimal force, and the fatigue index. Results showed that higher values of maximal force were found in the standard sculling. The Fatigue Index evidenced that the maximal force declined with time in all participants and in both sculling conditions.

Key words: biomechanics, sculling, synchronized swimming, tethered swimming

INTRODUCTION

Synchronized swimming is a technical and physically demanding sport, in which the strength and the velocity of movements are combined with high flexibility requirements (Chu, 1999). In this sport, sculling is an often-used technique, consisting in underwater arm stroke patterns whose purpose is the production of hydrodynamic force. This force will allow support, balance and propulsion of the swimmer's body (Chu, 1999).

Although the importance of sculling in synchronized swimming is undeniable, very few studies were conducted, and none seem to have quantified the force produced by the swimmer. The appearance of fatigue during sculling was also not yet studied. Knowing that there is a high relationship between strength and performance in swimming (Risch and Castro, 2007), and that strength training (with emphasis on neural adaptations) explains, in part, the specific positive changes in velocity and aerobic performance due to a better economy of movement (Hoff et al., 2002), the purpose of this study was to measure the force and the fatigue produced in standard and contra-standard sculling in synchronized swimming, using a 30s maximal tethered test.

METHODS

Thirteen synchronized swimmers with the same performance level v vvolunteered to participate in this study. Mean (± SD) physical characteristics of the sample were: age 15.8 (2.1) years; body weight 50.5 (8.2) Kg; height 160.9 (7.4) cm; arm span 161.2 (9.7) cm.

A 30 s tethered swimming protocol was used in order to determine individual force to time - $F_{(t)}$ - curves in two conditions: (i) standard sculling (movement towards the head, with the body placed in supine position, the arms in the lateral of the trunk, the wrist in dorsal flexion and the hand palm oriented toward the feet) and (ii) contra-standard sculling (movement towards the feet with the body in supine position, the arms in the lateral of the trunk, the wrist in palmar flexion and the hand palm oriented towards the head). After familiarization with the equipment and a standardized warm-up, each subject performed a 30 s maximum intensity tethered synchronized swimming test. Individual $F_{(t)}$ curves were obtained with the subjects attached by a non-elastic cable to a strain-gauge system (Globus, Italy). The beginning and the end of the test were established through an acoustical signal produced by a researcher. Tests were conducted in an indoor, heated (27.5ºC), and 2 m deep swimming-pool.

The absolute and relative maximal forces (Fmax and RFmax, being RFmax = Force.body weight^{-1}), the time at which Fmax occurred (FmaxTime), the mean force (Fmean), the average of Fmax (FmaxAvg = average of all force values in the first 5 s of the test), the average of minimal force (FminAvg = average of all force values in the last 5 s of the test) and the fatigue index (FI (%) = ([FmaxAvg-FminAvg)/FmaxAvg]x100) were computed. The force values of the first 2 s test were eliminated in order to remove the high inertial values associated with the first pull (Fig. 1).

After the normality of the distributions was confirmed (Kolmogorov-Smirnov test), T- Test for repeated measures was used to compare mean values of each variable obtained for standard and contra standard sculling techniques. Pearson product-moment correlation coefficient was also computed for the study of relevant association of variables. Significance level was established at 95% ($p<0.05$).

RESULTS

Absolute and relative values of Fmax, FmaxTime, Fmean, FmaxAvg, FminAvg and the FI are presented in Tables 2 and 3 for standard and contra-standard sculling.

Table 1. Individual and Mean ± SD values of absolute maximal (Fmax) and relative (Relative Fmax) force, the time when the Fmax occurred (Fmax Time), mean force (Fmean), the average of maximal and minimum forces (FmaxAvg and FminAvg, respectively) and the fatigue index (FI) in standard sculling (n=13).

Swimmer	Fmax (N)	Relative Fmax (N/Kg)	FmaxTime (s)	Fmean (N)	FminAvg (N)	FmaxAvg (N)	FI (%)
#1	30.8	0.60	4.9	12.9	8.7	15.8	44.7
#2	42.9	0.82	7.0	22.1	19.8	25.5	22.3
#3	36.1	0.63	2.7	21.5	16.4	26.5	38.3
#4	18.6	0.42	2.6	5.6	3.9	10.3	61.8
#5	33.3	0.74	8.6	14.0	9.2	20.6	55.4
#6	50.1	1.13	4.2	24.8	20.4	32.5	37.2
#7	51.9	0.83	7.9	26.8	24.7	29.9	17.5
#8	23.9	0.72	6.7	7.0	4.7	10.6	55.8
#9	39.7	0.87	5.5	14.1	8.2	18.9	56.9
#10	39.0	0.74	2.5	20.1	14.4	26.0	43.2
#11	62.6	0.99	4.3	14.0	5.8	26.4	78.1
#12	49.4	0.90	3.4	9.8	4.9	14.7	66.8
#13	51.9	1.04	8.2	24.0	20.6	30.1	31.6
X ± SD	40.8±12.4	0.80±0.19	5.3±2.2	16.7±7.0	12.4±7.3	22.1±7.5	49.9±17.6

For almost all the subjects, higher absolute and relative Fmax values were found in standard sculling (Table 1 and 2). Mean differences were statistically significant for both values. The values of FI evidence that the F, despite all the fluctuations observed (see an example in Fig. 1), decreased during the 30 s effort in all participants and in both sculling conditions. With the exception of Fmax absolute and relative values, none of the remaining variables showed statistical significant differences between standard and contra-standard sculling actions.

The correlation study demonstrated the following findings: (i) age correlated significantly with Fmax ($r=0.77$), with Fmean ($r=0.66$), and with FmaxAvg ($r=0.71$), but only for the contra-standard action; (ii) body mass correlated significantly with Fmax ($r=0.66$ and $r=0.76$) and with FmaxAvg ($r=0.51$ and $r=0.66$), respectively, for the standard and contra-standard sculling; (iii) body height only correlated with Fmax ($r=0.54$) for the standard sculling; (iv) arm span correlated significantly with Fmax for both sculling actions ($r=0.73$ for the standard and $r=0.63$ for the contra-standard) and (v) FI correlated negatively with FmaxAvg (r=-0.58) and Fmean (r=-0.81) for standard action, and with FminAvg (r=-0.91 and r=-0.54) for both sculling variants.

Table 2. Individual and Mean ± SD values of absolute maximal (Fmax) and relative (relative Fmax) force, the time when the Fmax occurred (Fmax Time), mean force (Fmean), the average of maximal and minimum forces (FmaxAvg and FminAvg, respectively) and the fatigue index (FI) in contra-standard sculling (n=13).

Swimmer	Fmax (N)	Relative Fmax (N/Kg)	FmaxTime (s)	Fmean (N)	FminAvg (N)	FmaxAvg (N)	FI (%)
#1	32.2	0.63	2.3	15.5	8.3	24.4	66.2
#2	37.2	0.71	4.1	21.4	17.0	25.9	34.3
#3	30.4	0.53	4.8	15.5	11.3	19.5	41.9
#4	31.1	0.70	9.6	16.6	12.2	20.6	40.6
#5	32.9	0.73	4.9	13.5	11.5	18.5	37.7
#6	35.4	0.80	3.4	16.2	13.9	20.0	30.4
#7	41.9	0.67	3.1	15.8	11.9	20.8	42.8
#8	24.0	0.72	2.9	12.5	10.5	14.7	29.0
#9	30.0	0.67	6.9	16.3	14.7	19.3	23.7
#10	34.0	0.64	6.2	18.9	13.7	25.4	47.2
#11	43.6	0.69	2.5	24.3	18.6	32.7	43.2
#12	35.8	0.66	8.1	19.1	16.8	23.8	29.2
#13	40.8	0.82	3.9	23.4	19.6	26.5	26.2
X ± SD	34.6±5.4*	0.69±0.07*	4.8±2.3	17.6±3.6	13.8±3.4	22.5±4.6	37.9±11.3

*Different (p<0.05) from respective value of standard sculling (Table 2).

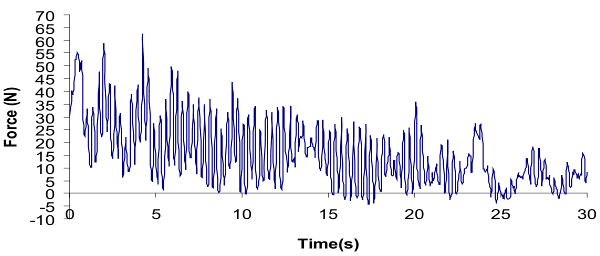

Figure 1. Example of an individual F(t) curve (unfiltered data) in standard sculling. The cut point of the two first s of force values, correspondent to the first pull, is marked.

DISCUSSION

To our knowledge, besides a case study of our group (Diogo et al., in press), this is the first time that $F_{(t)}$ curves and FI, characterizing standard and contra-standard sculling actions, were assessed. Comparing the present results with the specialized literature was not possible since values of force (or tethered force), and FI assessed in synchronized swimming were not found. Studies conducted with swimmers showed significantly higher levels of semi-tethered or tethered force compared to those of the present study (e. g. Kjendlie e Thorsvald, 2006; Strojnik et al., 1999; Wirtz et al., 1999), which may be explained by: (i) longer amplitudes of the front crawl underwater phases; (ii) higher front crawl propulsive continuity, due to the existence of three underwater phases, in opposition to the sculling technique that only have two phases (Rackham, 1974) and (iii) the use of both upper and lower limbs during swimming.

Accordingly to the significant difference found between mean values, almost all the synchronized swimmers reached higher values of Fmax in standard sculling comparing to the contra-standard condition. A similar result was observed in our pilot study in which the force values produced by a synchronized swimmer and a female swimmer in standard and contra-standard sculling were compared (Diogo et al., in press). Fmax values were higher in standard sculling in both subjects. We hypothesized that this higher Fmax production in standard sculling may be due to a higher resemblance of the standard sculling with the swimming movements and to the possibility of being a more "natural" action from the anatomical point a view.

Earlier studies conducted in swimming showed that the relationship between the maximal, mean and minimum forces exerted during the tethered swimming test varies according to age, maturational state and competitive level (Sidney et al., 1996; Vorontsov et al., 1999; Morouço et al., 2008). Indeed, the difference in age and maturational state may contribute to explain the differences in force levels attained by our subjects. The correlation value obtained between age and the other variables showed a significant relationship with Fmax only in contra-standard sculling. Height can be another explanation for the above-referred results, as there is a direct relationship between this parameter and peak force (Risch and Castro, 2007). Eventually, longilineal individuals produce lower values of hydrodynamic resistance, reflecting higher peak force values in tethered swimming (Toussaint and Beek, 1992), which is consistent with the significant relationship between body height and Fmax obtained in the present study. However, once in tethered swimming the displacement of the swimmer relatively to the water is null, this effect is more likely related to a scaling effect, being the functionality of muscles related to the square, or the cube of the linear dimensions (depending on considering the muscle cross sectional area or the muscular volume).

There may also be other factors that may influence the sculling force production, namely the hand configuration, regarding hydrodynamic characteristics, which can provide different production of lift force constraining the best performance (Ito, 2006). Additionally, the relative contribution of the hand to the propulsive force is dependent on the arm configuration (Lauder and Dabnichki, 2005). Unfortunately, we did not dispose of video images during the tethered swimming test, which would enable a detailed analysis of the sculling movement. However, we dispose of the arm span measurements. In fact, since it is commonly accepted that longer limbs will imply higher propulsion, it was not surprising to observe a high direct relationship between arm span and Fmax. Moreover, it is known that the differences in force level can also be explained by differences in technical level (Risch and Castro, 2007). However, this relationship can only be tested with the use of video images during the tethered swimming test, which will enable a detailed analysis of the sculling movement.

Morouço et al. (2008) mentioned that swimmers who reach high peaks of force are not able to maintain it for long periods of time. This statement is not supported by the present data, since an inverse relationship were observed between FI and FmaxAvg and Fmean (standard action), and with relative Fmax (contra-standard action). In contrast, FI presented significant negative correlation values with FminAvg in both sculling conditions, which means that fatigue is less visible in the swimmers who have higher average of minimum peak forces. This result appeals for a kinematic plus tethered force production combined analysis of the sculling movement, once swimmers with higher FminAvg seems to be more proficient.

CONCLUSION

The principal difference observed in force production between standard and contra-standard sculling was found for Fmax, with its absolute and relative values being higher for standard sculling. Mean force decreased during the 30 s effort in all participants and in both sculling conditions.

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Pulling Force Characteristics of 10 s Maximal Tethered Eggbeater Kick in Elite Water Polo Players: A Pilot Study

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This paper aimed to define the basic kinetic and mechanical characteristics of 10 s maximal tethered eggbeater kicks in elite water polo players in the chest-forward position with hands above the water. The study involved 14 male elite water polo players. The following measurements of the kinetic characteristics of pulling force were taken: the duration of a single leg eggbeater kick, the maximal (peak) force values, the average force values, the impulse of force, the single leg eggbeater kick rate of force development and the single leg eggbeater kick frequency. Reliability analysis showed high statistical significance of the measurement results of the test at ICC=0.9681. Besides, the pulling force realized at FmaxEBK and FavgEBK was determined to have changed significantly at the time interval of 10s. The resulting models could help towards the development of the water polo training technology, as well as the establishment of a new method to test the specific leg fitness in elite senior water polo players.

Key words: eggbeater kick, tethered pulling force, water polo

INTRODUCTION

Water polo players realize all of their technical and tactical (TE-TA) tasks from two basic positions in the water: the horizontal and the vertical position (Dopsaj & Thanopoulos, 2006). Although the general physiological load indicators categorize water polo as a sport that requires a high level of aerobic endurance, a great number of TE-TA activities are realized through the maximal interval intensity in shorter intervals in which the energy is dominantly supplied by an anaerobic-alactic system – the ATP/CP system (Smith, 1998).

Calculations, based on time and motion analysis, have indicated that field players spend only 45% to 55% of game time in the horizontal body position. The remainder of the time is spent performing activities in predominantly vertical body positions, with or without contact with the opponent, and with a moderate to high intensity, as indicated by heart rate recordings in some studies (Platanou, 2009).

In water polo, duel play is the players' basic position in both the offense and the defense. The position essentially enables players to block the opponent by holding their arms so as to perform the TE-TA elements, using the eggbeater kick technique simultaneously (Sanders, 1999; Dopsaj & Thanopoulos, 2006). Essentially, the eggbeater kick is also used to raise the upper body for the purpose of receiving a pass, passing, shooting for goal, or blocking the opponent's shooting, passing or receiving actions. The eggbeater kick is a cyclic action of the lower limbs with the actions of the right and left sides being similar but opposite in phase, meant to sustain the body in the elevated position or to push the opponent's body strongly (Sanders, 1999).

Previous studies have established that most water polo realizations from the vertical position, with or without contact with the opponent, are done at the maximal and/or submaximal effort intensity in the anaerobic alactate energy system (Smith, 1998; Platanou, 2004; Takagi et al., 2005; Platanou, 2009), which points towards the conclusion that the specific training of the lower extremities indirectly affects game effectiveness. However, so far no research has published studies of the pulling force characteristics realized in water and by eggbeater kick techniques within the effort system which is dominant in competitions.

This paper aimed to define the basic kinetic and mechanical characteristics of 10 s maximal tethered eggbeater kicks in elite water polo players in order to define a descriptive model of the characteristics measured in the population of highly trained water polo players.

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