Force production during maximal front crawl tethered swimming

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Title Page

Title: Force production during maximal front crawl tethered swimming: exploring bilateral asymmetries and differences between breathing and non-breathing conditions

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ABSTRACT

The present study focused on propulsive forces applied during tethered swimming. The main aims were to identify asymmetries between dominant and non-dominant arms, quantify the effect of breathing on force application and, explore any association between each variable and swimming performance. Fifteen regional level swimmers completed a maximal front crawl tethered swimming test, with maximal kicking, under four conditions: 1) Dominant arm strokes only, no breathing; 2) non-dominant arm strokes only, no breathing; 3) full stroke, no breathing; 4) full stroke, breathing on the preferred side. The outcome variables were: absolute and normalised (force divided by body mass) minimum, mean and maximum force; stroke cycle time and; impulse. The symmetry index was also calculated, and all variables were correlated with the swimmers' season best times in 50m front crawl. Some bilateral force asymmetries were found, but they did not always favour the dominant side and were not directly linked with swimming performance. There was no strong evidence that force production is higher on the dominant side or that symmetry in force production affects performance. Despite the longer stroke cycle times when breathing, the breathing actions did not affect force production. Faster swimmers often produced higher maximum force values and, sometimes, higher mean force values.

Keywords: Swim, biomechanics, kinetics, performance, strength, training

INTRODUCTION

The goal of competitive swimmers is to maximise propulsion and minimise resistance so that they can complete a swimming race in the shortest possible time. As the relative contribution of the dominant and non-dominant sides is not always identical, asymmetries and their effect on swimming performance has been an area that has attracted much interest in the literature. There are several factors that may cause technique asymmetries, such as genetic and environmental factors, developmental factors, disease factors, overtraining and fatigue, effects of injuries, technique differences and movement habits (Sanders et al., 2011). Sanders (2013) hypothesised that bilateral asymmetries in strength might negatively affect performance due to unbalanced rotational torques created, lower propulsive forces on the weaker side and accelerated fatigue on the stronger side. Although the link between symmetry and swimming performance is complex and yet to be fully understood, asymmetries have often been measured and reported in swimming studies. For example, Psycharakis and Sanders (2008) reported that swimmers had asymmetrical shoulder roll during a 200m front crawl test, but there was no correlation between magnitude of asymmetry and performance. Seifert et al. (2005) reported several patterns of technique asymmetries for 100m front crawl swimmers, with the links between asymmetry and skill level of swimmers varying and not always being consistent.

The propulsive forces applied by a swimmer affect performance, and are therefore among the key variables of interest in swimming research. Because the direct measurement of propulsive forces during swimming is not possible in practice, researchers have attempted to measure propulsive forces during tethered swimming. Custom-made devices are often used for this purpose, with the participants swimming while wearing a belt attached to force-recording equipment through inextensible ropes or steel cables. With no forward swimming movement during such tests, and hence no active drag, it is assumed that the forces recorded represent the propulsive forces of the swimmers. Due to the somewhat different demands to free swimming, some differences in technique may sometimes exist between free and tethered swimming. Morouco et al. (2018) reported similar values for stroke frequency and blood lactate concentration between free and tethered swimming, while Samson et al. (2019)stated that differences might exist occasionally in the hand path during the early parts of the underwater phase. As summarised by Morouco et al. (2015), tethered swimming seems to produce similar muscle activity and physiological responses to free swimming and has good test-retest reliability, making it an appropriate alternative mode to free swimming when the purpose is to calculate the forces applied by the swimmers. Morouco et al. (2015) used a 30 s maximal front crawl tethered test and reported bilateral asymmetries in peak horizontal forces between the stronger and weaker sides. Although links between performance and the magnitude of asymmetry were not explored, peak horizontal force was strongly associated with 50 m sprint performance. Dos Santos et al. (2017) reported similar results when using a 15s maximal tethered test and correlating peak force with 200m performance. It was suggested in both studies that further research on tethered swimming would produce useful information that could improve our understanding of how force application affects swimming performance.

Despite some interesting findings in the tethered swimming literature, there is still a scarcity of data in this area and there are some limitations that could be improved in future studies. First, when exploring bilateral differences it is recommended that handedness and side dominance be assessed through appropriate methods, such as those described by Annett (1970) and Oldfield (1971). In existing tethered swimming research, however, bilateral asymmetries have been calculated as the difference between the ‘stronger’ and ‘weaker’ sides, with the side producing the largest forces defined as the ‘stronger’ side. It is however not known whether the dominant arm, as defined through established handedness assessment methods, would necessarily produce higher forces in swimming than the non-dominant arm. Hence, it would be important to also establish handedness with suitable methods first, and then to use this too as the basis of subsequent comparisons between dominant and non-dominant sides. A second limitation in the literature is that the effects of breathing on the forces measured were usually not controlled or quantified. For example, swimmers undertaking tethered swimming tests had been often instructed to follow the 'normal breathing pattern that they use for a 50m sprint'. This instruction may cause intra- and inter-swimmer variations; some swimmers may take just a single breathe during a 50m sprint, others may opt to breathe in every other stroke, while sometimes a swimmer may change his/her pattern of breathing during the course of the 50m. Breathing actions have been shown to cause technique asymmetries (Psycharakis & McCabe, 2011), and their effects on asymmetries may be different between swimmers of different skills (Seifert et al., 2005). It would therefore be useful in tethered swimming studies to control for the effect of breathing and to quantify the differences between breathing and non-breathing arm strokes. Such information on bilateral force asymmetries and breathing effects on force production could assist coaches in designing training programmes that facilitate performance improvement.

In view of the need for further research in this area, the present study focused on a range of variables related to the propulsive forces applied during tethered front crawl swimming at maximal effort. The main aims were to identify any asymmetries between dominant and non-dominant arms, and the stronger and weaker sides, and to quantify the effect of breathing on force application. In order to explore any association between the variables tested and swimming performance, a further aim was to correlate the force variables with the swimmers' sprint performance level, as indicated by the best times that the swimmers had achieved for 50m front crawl in the 12 months before the test (season best, SB). It was hypothesised that propulsive forces would be higher on the dominant than the non-dominant side, and during non-breathing compared to breathing cycles.

METHODS

Participants

Nine male (21.3±1.0 years, 177.1±5.3 cm, 76.7±4.4 kg) and six female (21.0±2.8 years, 168.4±9.2 cm, 61.5±5.0 kg) university level swimmers volunteered to participate in this study. The 50m front crawl event was among the specialist events of all swimmers, with their SB time being 26.5±1.2s for the male and 30.1±2.4s for the female swimmers. All participants had at least 5 years of competitive swimming training, they had no serious injuries in the last year before the test, and in the days prior to testing they were free from injury and illness and avoided stressful training. Ethical approval was granted by the institutional ethics committee. All swimmers were older than 18 years and were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study.

Procedures

The tethered swimming system used in the present study has been described in detail elsewhere (Psycharakis et al., 2011). In brief, a 7m-long (0.5cm diameter), taut, stiff rope was used. One end of the rope was connected to a climbing belt that was worn by the swimmers around their waist. The other end of the rope was attached to the force transducer with the use of wire rope thimbles and turnbuckles. The force transducer was fixed on the poolside, just above the surface of the water. The system has been shown to be accurate and reliable, and it produces small and acceptable errors in measurements (the highest possible error for the minimum, mean and maximum force is 1.15%, 0.94% and 0.86% respectively).

On testing day, swimmers' handedness (arm dominance) was established with the methods described by Annett (1970) and Oldfield (1971), using a short questionnaire with questions such as "which hand do you use to write a letter / hold a toothbrush / hammer a nail, etc". Each swimmer then performed the personalised warm up that they would normally undertake when preparing to compete in a 50m front crawl race. This was followed by up to three submaximal to maximal practice trials on each of the four testing conditions that were used for the subsequent data collection, for the purpose of familiarisation with the tethered swimming set-up used in the present study. Further familiarisation was not deemed necessary, because all swimmers were already experienced in tethered swimming through their usual training routines.

Following the familiarisation and a minimum of five minutes of passive rest, the testing commenced. The swimmers assumed a horizontal position with the rope fully stretched, and were asked to keep both arms extended forwards and to float in this position without applying any backwards forces. On the researcher's signal (whistle), the swimmers performed three submaximal front crawl arm strokes, followed by seven maximal front crawl arm strokes. The maximal front crawl arm strokes were all performed with maximal kicking, under each of the following four conditions:

- Dominant arm strokes only, no breathing
- Non-dominant arm strokes only, no breathing
- Both arms, no breathing
- Both arms, with breathing on the preferred side on every SC

The order of conditions was randomised and there was a 60 seconds rest between trials. Force data was recorded at 50Hz and filtered through a 5Hz cut-off low-pass fourth-order Butterworth filter. A video camera (50Hz) was fixed on a tripod on the poolside and was synchronised with the force measurement device. This allowed identification of start and end of each stroke cycle (SC). For all four conditions, a SC was defined as the time between hand entry in the water and the subsequent entry of the same hand. For the subsequent data processing, the first and last maximal SC were discarded and the middle five maximal SCs were analysed. All swimmers were using unilateral breathing patterns in training and competitions, and were therefore instructed to breathe on their preferred side during the breathing trial. The preferred breathing side was the same as the dominant side for 13 out of the 15 swimmers, except one male and one female swimmer. All familiarisation and testing took place between the hours of 10am and 1pm. For each of the four conditions, the following variables were analysed:

- Maximum force (Fmax): Single highest value of the five SCs (N)
- Minimum force (Fmin): Single lowest value of the five SCs (N)
- Mean force (Fmean): Mean value across the five SCs (N)
- Normalised Fmin, Fmean and Fmax: Value of force recorded above, divided by body mass (N/kg)
- SC impulse: Calculated for each SC as the product of Fmean and SC time. The mean value across the five SCs (Nsec) was used.
- SC time: Mean value across the five SCs (s)

Because forces in directions other than the swimming direction can also assist in propulsion, e.g. propulsive lift forces, the force values analysed in the present study represent net force values. For the two single arm-stroke trials, the force values were calculated for: a) the dominant and non-dominant sides; b) the stronger and weaker sides. ‘Stronger’ and ‘weaker’ in this context refer to the side where the highest and lowest force value was recoded in each trial. This calculation was performed to facilitate subsequent calculation of overall asymmetry (i.e. regardless of handedness), as well as comparisons with other tethered swimming studies that have used this measure.

Finally, force asymmetries between dominant and non-dominant sides were also quantified with the use of the symmetry index (SI), as described by Robinson et al. (1987), according to the following equation: $SI = ((D-ND)/(D+ND))*2*100$, where D is the force recorded for the dominant side and ND the force recorded for the non-dominant side. As recommended, a value between -10% and 10% for the SI implies symmetry. Non-dominant and dominant side asymmetries are indicated when SI<-10% and when SI>10%, respectively. The SI was not calculated for the normalised variables, because normalised variables produce the same SI as the original values for the same variables.

Statistical Analyses

Descriptive statistics are reported as the mean values ± standard deviation (SD). Normality of distribution was assessed with the Shapiro-Wilk test. Initially, the males and females were compared through either independent t-tests for parametric data or Mann-Whitney tests for non-parametric data. Because between-gender differences were identified in most variables, the remaining statistical analysis was performed for each gender separately. For each variable, we compared: a) dominant and non-dominant side in the single-arm trials, b) stronger and weaker side (in terms of force production, for the single-arm trials only), c) breathing and non-breathing conditions in the full stroke trials. Paired t-tests and Wilcoxon signed rank tests were used for parametric and non-parametric data, respectively. To provide an indication of the magnitude of differences, the effect sizes (ES) were calculated based on Cohen's suggestions (Cohen, 1988), with each pooled SD being calculated as described by Field (2009). In line with Cohen's recommendations, effect sizes of a magnitude of 0.2, 0.5 and 0.8 were considered small, moderate and large respectively. For the non-parametric comparisons, Rosenthal's r was calculated, as described by Field (2009), with effect sizes of a magnitude of 0.1, 0.3 and 0.5 considered small, moderate and large respectively. A Pearson's or Spearman's correlation (for parametric and non-parametric data, respectively) was performed between each variable and the swimmer's SB for a 50m front crawl sprint during the last 12 months before the test, to identify any association between performance level of the swimmers and the variables measured in the present study. Moreover, to identify potential association between asymmetry and performance level of swimmers, SB time was correlated with: a) the SI, b) the absolute values of SI, c) the magnitude of differences in a variable between dominant and non-dominant sides and, d) the absolute magnitude of differences in a variable between dominant and non-dominant sides. The correlations of SB time with a) and c) would reveal any association of handedness with performance, while the correlations of SB time with b) and d) would show any associations between performance and overall asymmetry (between stronger and weaker sides). For all statistical analyses, significance was accepted at $p \leq 0.05$.

RESULTS

Dominant Vs Non-Dominant Arm Conditions

Tables 1 and 2 show the data and statistical analysis for the comparisons between: a) dominant and non-dominant and, b) stronger and weaker sides. With respect to the latter, it should be noted that the side with the highest force value was not always consistent within swimmers. For example, a swimmer may have had a higher Fmin and Fmax value on one side, but a higher Fmean and SC impulse value on the opposite side. For the dominance comparisons, there were no significant differences in any of the variables for either males or females. Normalised Fmean for female swimmers approached significance and had a large ES, with tendency for higher values for the dominant arm. Moderate to large ESs approaching significance and favouring the values for the dominant side were observed for the Fmean and SC impulse in the female swimmers. When stronger and weaker sides were compared, the value on the stronger side was always significantly larger than the value on the weaker side for both genders ($p \leq 0.031$, ESs ranging from small to large), except for Fmean and normalised Fmean for female swimmers (did not reach significance but had moderate and large ESs).

Table 3 shows the SI values for all variables, as well as the swimmer profiles according to SI; i.e., how many swimmers had SI symmetry, and SI asymmetry on the dominant or the non-dominant side. The individual profiles showed some variation between swimmers and variables. At least 12 of the 15 swimmers displayed asymmetrical SI values for Fmin, Fmean and SC impulse. The group SI revealed a tendency for asymmetry in Fmean and SC impulse for both genders. Males had a tendency of asymmetry with higher values on the non-dominant side. On the contrary, females had a tendency of asymmetry with higher values on the dominant side. Fmin for female swimmers displayed asymmetry towards the non-dominant side. The SI values for Fmin for male swimmers, as well as Fmax and SC time for both genders, suggested overall symmetry.

The correlations between variables and SB times showed that faster swimmers were generally producing higher Fmax and Fmean values. For the dominant arm trials and for both genders, SB time had a significant negative correlation with Fmax and Fmean for both actual and normalised values ($-0.961 \leq r \leq -0.672$, $0.009 \leq p \leq 0.047$), except for normalised Fmax for male swimmers ($r=-0.592$, $p=0.093$). For the non-dominant arm trials and for both genders, SB time had a significant negative correlation with Fmax ($-0.976 \leq r \leq -0.670$, $0.009 \leq p \leq 0.048$), except for normalised Fmax for male swimmers ($r=-0.611$, $p=0.081$). For the stronger side, SB time had negative significant correlations with actual Fmax and Fmean values in both genders ($-0.941 \leq r \leq -0.715$, $0.011 \leq p \leq 0.050$), and with normalised Fmax and Fmean values in females ($-0.956 \leq r \leq -0.912$, $0.011 \leq p \leq 0.039$). For the weaker side, SB time had negative significant correlations with actual and normalised Fmax in females ($-0.976 \leq r \leq -0.961$, $0.004 \leq p \leq 0.009$), and with actual and normalised Fmean in males ($-0.744 \leq r \leq -0.686$, $0.022 \leq p \leq 0.041$). There were no significant correlations between SB times and SI, absolute SI, magnitude of differences, absolute magnitude of differences.

Insert Tables 1, 2 and 3 around here

Breathing Vs Non-Breathing Conditions

Table 4 shows the data and statistical analysis for the comparisons between breathing and non-breathing conditions. SC time was significantly longer when breathing for both males and females, with moderate and large ES respectively. There were no other significant differences in pairs of variables.

Almost all correlations between variables and SB time were negative, but significance was reached on some occasions only. For female swimmers, absolute and normalised Fmax values were always significantly correlated with SB times ($-0.956 \leq r \leq -0.930$, $0.011 \leq p \leq 0.022$), while absolute and normalised Fmean values were significantly correlated with SB times for the breathing condition ($-0.924 \leq r \leq -0.903$, $0.025 \leq p \leq 0.036$).

Insert Table 4 around here

DISCUSSION AND IMPLICATIONS

The present study focused on the forces applied during tethered front crawl swimming at maximal effort. The purpose was threefold: to identify differences between SCs performed with the dominant and non-dominant arm only, to identify differences between breathing and non-breathing SCs, and to explore any association between the variables tested and sprint swimming level (as indicated by 50m front crawl SB times). The results revealed some force asymmetries, which did not always favour the dominant side and were not directly linked with swimming performance. Therefore, there was no strong evidence that force production is higher on the dominant side or that asymmetry in force production, regardless of side, affects performance. Despite the longer SC times when breathing, the breathing actions did not affect force values substantially. The findings on both dominance Vs non-dominance and breathing Vs non-breathing are contrary to what was hypothesised. Finally, faster swimmers often produced higher Fmax and, sometimes, Fmean values, in most of the conditions tested.

Dominant Vs Non-Dominant Arm Conditions

Asymmetry in the present study was explored in different ways; by comparing statistically the force values between the dominant and non-dominant arms, as well as between the arm that produced the larger and the arm that produced the smaller force values, and by calculation of the SI. The dominance comparison did not produce any statistically significant differences, although the higher Fmean and impulse variables on the dominant side of female swimmers approached significance and had moderate to large ESs. In line with this trend, the SI suggested an asymmetry favouring the dominant arm for Fmean and impulse. The reason that the statistical comparison did not reach significance may be because of the sample size, so it is possible that a larger sample would have produced significantly different values between the two sides. Bilateral asymmetries on Fmean and impulse were found also for male swimmers, but the pattern was reversed, with the non-dominant side displaying larger values.

Although the reason for the above difference is unclear, it has been mentioned that some degree of asymmetry is considered acceptable due to inherent differences of the human body (Jaszczak, 2008), and such asymmetry is within normal variation and might not negatively affect performance. Indeed, the magnitude of asymmetry in the present study was not directly linked with performance and there was no tendency for any variables to approach significance. It may be possible that the SI values observed in the present study were relatively low (≤15.6%) for any links with performance to show, and that larger asymmetries may affect performance. Because the SI revealed a range of asymmetry profiles between swimmers, it could have been possible that the categorisation according to handedness was affecting group values and masking potential links of overall asymmetry and performance. This was not however the case, as further correlations that we performed between performance and overall asymmetries showed no significance.

Some interesting findings from Evershed at al. (2014) may also offer the basis for an alternative explanation for the asymmetries observed in the current study. Evershed et al. (2014) conducted land tests on swimmers and reported that: a) one-third of subjects that had asymmetry in one or more strength measure appeared to counter-balance one strength deficit with another strength asymmetry such that force output was symmetrical; b) half of the swimmers who displayed clinical strength asymmetry adapted to symmetrical hand force production on land tests, possibly due to compensatory strategies (bilateral strength imbalances or unilateral strength deficit with kinematic compensation). Thus, it may also be possible that swimmers in the present study were using asymmetric force production to compensate for reverse asymmetries elsewhere. For example, a higher force production on the dominant arm may be a compensatory strategy for a higher active drag experienced during the dominant arm stroke, which would then may allow for an overall symmetry in net force during the SC.

Morouco et al. (2015) and Dos Santos et al. (2017) also calculated the SI for Fmax during maximal tethered front crawl swimming. In both studies however, asymmetries were calculated only by subtracting the smaller from the larger force values obtained during the test, so their results are directly comparable only with the absolute SI values in the present study. The absolute SI values for Fmax in our study were 9% for male and 10% for female swimmer, which suggest near asymmetry for males and asymmetry for females. These SI values are very similar to those reported for Fmax by Dos Santos et al. (11%), who tested swimmers of similar age and level to those in the present study. The SI values for peak force reported by Morouco et al. (2015) were nearly twice that figure (19%), with the swimmers in that study being of somewhat higher level and circa 6 years younger on average. This may suggest that the magnitude of SI may differ with age and performance level of the group tested, which would be interesting to explore in future studies.

Breathing Vs Non-Breathing Conditions

As expected, the duration of the SCs was longer when taking a breath. Despite the numerical values for Fmin, Fmax and Fmean tending to be slightly larger during the non-breathing trials, the differences in force production between breathing and non-breathing did not reach significance and only approached significance in one occasion (Fmin for female swimmers). Thus, the breathing actions had a negligible effect on force production. The effect of breathing on force production has not been explored before for tethered swimming, but free-swimming studies on other variables have also sometimes showed that breathing during sprints may have little effect on some technique aspects. For example, Psycharakis and McCabe (2011) also reported longer SC times during sprint front crawl swimming, but despite some body roll changes on the breathing side, the overall shoulder and hip roll values remain unchanged. Despite the lack of differences in force production between breathing and non-breathing conditions in the present study, one would still expect performance to deteriorate slightly when breathing. This is because swimming performance is also affected by resistive forces, which are expected to increase with the turning motions of the head and body when breathing, and could therefore slow down the swimmers even when the propulsive forces remain the same.

Correlations between Force Production and Performance Level

The correlations between force variables and performance level revealed a pattern of faster swimmers producing higher Fmax forces and, to a slightly lesser extent, higher Fmean forces too. These patterns were more evident in female than male swimmers. Fmax emerged as a strong predictor of 50m performance level for female swimmers, as all eight correlations between Fmax and PB times were significant. The large r values of those correlations ($-0.98 \le r \le -0.87$) indicated that Fmax explained a lot of the variance in female swimmers' performance level. The same correlations for male swimmers either reached (for Fmax) or approached significance (for normalised Fmax) in the dominant and non-dominant arm trials, but did not reach or approach significance in the breathing and non-breathing trials. Fmean for female swimmers reached significance in four of the eight correlations performed, and approached significance on two more occasions, suggesting that Fmean is often also a good predictor of performance level. This pattern was less evident for male swimmers, with just two significant correlations (Fmean and normalised Fmean in the dominant arm trials). The findings of the present study are similar to those in previous studies that have attempted such correlations. For example, performance in 50m, 100m and 200m front crawl has been found to have a negative significant correlation with peak horizontal force (Dos Santos et al., 2017; Morouço et al., 2011; P G. Morouço et al., 2015). Morouco et al. (2011) reported negative significant correlations between performance in these events and also Fmean, normalised Fmean and normalised Fmax.

These findings, together with the findings from the present study, seem to reinforce the notion that the peak and mean forces (net or horizontal) produced during tethered swimming are often good predictors of front crawl swimming performance.

Despite the above associations, impulse was not linked with performance. The relationship between impulse and performance level has been rarely explored in previous studies. Dos Santos et al. (2013) did not find any significant differences when comparing the impulse for the faster and slower swimmers in their study, or for those with bilateral and unilateral breathing preference. Morouco et al. (2018) however stated that the maximum impulse a swimmer can produce during a SC may be useful, as together with intra-cycle force fluctuation helped them explain 83% of 50m front crawl performance.

The present study used a tethered test, which obviously means that there was no change in the swimmers' displacement and that velocity was zero. During free swimming, however, the relation between velocity and force is not. Thus, it should be noted that the stronger correlation of Fmax than Fmean in the present study is not the expected mechanical behaviour of these variables (as the impulse, which is linked to Fmean, rather than Fmax, changes momentum), but a consequence of the standard correlation model adopted and the smaller sample size of the gender groups.

Limitations

The present study has some limitations that need to be taken into consideration when interpreting the results. First, due to between-gender differences in most variables, subsequent analysis had to be performed separately for each gender. This resulted in smaller sample sizes, which reduce statistical power. Thus, some of the variables in the present study may also show significant changes if the study is repeated with larger sample sizes. Second, our group contained university level swimmers, whose 50m SB was circa 79% of the world record, and it is therefore not known if the same patterns would exist in elite national and international level swimmers. Third, we chose to compare the force between dominant and non-dominant arms while the swimmers were also performing maximal kicking. This comparison assumes that the maximal kicking between these two conditions would be nearly identical. This is a relatively reasonable assumption for short maximal bouts without breathing; for example, the Fmin in these one-arm trials would most probably be recorded during the arm recovery (when the only propulsions comes from the kicking actions), and the fact that the Fmin values showed no significant differences between conditions suggests that kicking actions were broadly similar. Nevertheless, it is not possible to confirm if there were no differences for any of the swimmers in the propulsive effect of the kicking actions in the two conditions. Performing the trials without any kicking could have been an option, but pilot testing indicated that the lack of propulsive continuity and the demands of tethered swimming would have made this task very difficult without sacrificing body position and normal swimming technique.

Conclusion and Practical Applications

Asymmetries in force production between dominant and non-dominant arms may sometimes exist during maximal tethered front crawl swimming, but they do not necessarily favour the dominant side and the amount of asymmetry does not seem to be associated with the performance level of swimmers. Taking a breath has a negligible effect on force production, but does increase the duration of the SC. Faster swimmers generally had higher Fmax and, often, higher Fmean than slower swimmers, when swimming sprint front crawl under tethered conditions. Thus, from a practical perspective, there is no evidence to suggest that coaches should prioritise the non-dominant side during tethered swimming training or that they should try to reduce/eliminate small force asymmetries. Swimmers and coaches should, however, attempt to increase the Fmax and Fmean forces applied, as they are often associated with improved performance levels. With regard to breathing, propulsive forces of swimmers of competitive level are relatively unaffected, so the training focus could prioritise minimising resistance that may increase with the head and upper body movements when breathing. These conclusions are based on our data on regional level swimmers and, thus, it should be explored in further research if they also apply on elite national and international level swimmers.

Declaration of interest

The authors report no conflict of interest.

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Table 1: Maximal front crawl tethered swimming with dominant and non-dominant arm strokes for male swimmers. Data for all variables and statistical analysis for the comparison between conditions. ‘Stronger’ and ‘weaker’ arm indicate the higher and lower force values recorded, regardless of side.

	Dominant arm	**Non-dominant arm**	**P**	**Effect size**	**Stronger arm**	**Weaker arm**	**P**	**Effect size**
Fmin (N)	29.9, 33.4, 39.2	22.6, 28.4, 33.4	1.000^{np}	0.01^{np}	38.1±19.6	28.2±12.9	0.004*	0.63
Fmax (N)	180.9±41.6	182.0±39.0	0.880	0.03	189.0±37.4	173.9±41.5	0.010*	0.38
Fmean (N)	92.3±22.7	101.2±15.8	0.216	0.46	105.3±16.4	88.2±19.5	0.004*	0.95
SC Time (s)	0.9, 0.9, 1.0	0.8, 0.9, 1.0	0.055^{np}	0.46^{np}	n/a	n/a	n/a	n/a
SC Impulse (Nsec)	54.5, 72.6, 115.4	74.6, 96.0, 112.5	0.098^{np}	0.40^{np}	101.0±29.8	81.5±27.3	0.004*	0.63
Normalised Fmin (N/Kg)	0.4±0.2	0.4±0.3	0.611	0.14	0.5±0.2	0.4±0.2	0.007*	0.63
Normalised Fmax (N/Kg)	2.4±0.5	2.4±0.4	0.918	0.02	2.5±0.4	2.3±0.5	0.010*	0.46
Normalised Fmean (N/Kg)	1.2±0.3	1.3±0.2	0.232	0.50	1.4±0.2	1.1±0.2	0.004*	1.08

Notes: Parametric data are presented as Mean ± SD. Non-parametric data are presented as the following three values: quartile 1 value, median value, quartile 3 value. The p values indicate the significance level. Effect sizes are Cohen’s d for parametric and Rosenthal’s r for non-parametric statistics.

*: statistically significant differences between conditions for $p \leq 0.05$

^{np}: non-parametric statistics

Table 2: Maximal front crawl tethered swimming with dominant and non-dominant arm strokes for female swimmers. Data for all variables and statistical analysis for the comparison between conditions. ‘Stronger’ and ‘weaker’ arm indicate the higher and lower force values recorded, regardless of side.

	Dominant arm	**Non-dominant arm**	**P**	**Effect size**	**Stronger arm**	**Weaker arm**	**P**	**Effect size**
Fmin (N)	15.0±4.3	16.9±4.4	0.382	0.45	18.0±3.8	13.9±3.9	0.023*	1.07
Fmax (N)	135.2±37.3	125.4±28.8	0.138	0.29	137.1±35.4	123.5±30.2	0.014*	0.41
Fmean (N)	66.9±13.6	58.2±10.3	0.103	0.72	66.9±13.6	58.2±10.3	0.103	0.72
SC Time (s)	1.1±0.1	1.1±0.1	0.527	0.13	n/a	n/a	n/a	n/a
SC Impulse (Nsec)	68.2, 73.6, 81.7	59.7, 64.9, 74.7	0.094^{np}	0.50^{np}	74.4±17.1	62.8±12.0	0.031	0.64
Normalised Fmin (N/Kg)	0.2±0.1	0.3±0.1	0.392	0.36	0.3±0.1	0.2±0.1	0.020*	0.84
Normalised Fmax (N/Kg)	2.2±0.5	2.0±0.4	0.151	0.35	2.2±0.4	2.0±0.4	0.008*	0.53
Normalised Fmean (N/Kg)	1.1±0.2	0.9±0.1	0.095	0.90	1.1±0.2	0.9±0.1	0.095	0.90

Notes: Parametric data are presented as Mean ± SD. Non-parametric data are presented as the following three values: quartile 1 value, median value, quartile 3 value. The p values indicate the significance level. Effect sizes are Cohen’s d for parametric and Rosenthal’s r for non-parametric statistics.

*: statistically significant differences between conditions for $p \leq 0.05$

^{np}: non-parametric statistics

Table 3: Mean ± SD values of the Symmetry Index for: minimum force (Fmin), maximum force (Fmax), mean force (Fmean), stroke cycle time (SC time) and stroke cycle impulse (SC impulse). Swimmer profiles based in Symmetry Index are also shown. Non-dominant (ND) and dominant (D) side asymmetries are indicated when SI<-10% and when SI>10%, respectively, with -10% <SI<10% indicating overall symmetry.

Male Swimmers (N=9)					
	Fmin	**Fmax**	**Fmean**	**SC time**	**SC impulse**
Symmetry Index (%)	-3.4.0±34.7	-0.8±12.4	-11.0±21.6	-4.7±5.9	-15.6±21.4
Swimmers with D side asymmetry, ND asymmetry, symmetry	4, 3, 2	2, 2, 5	0, 5, 4	0, 2, 7	1, 6, 2
Female Swimmers (N=6)					
	Fmin	**Fmax**	**Fmean**	**SC time**	**SC impulse**
Symmetry Index (%)	-12.2±33.0	6.5±9.7	13.4±15.6	-1.1±4.0	12.3±13.9
Swimmers with D side asymmetry, ND asymmetry, symmetry	3, 3, 0	1, 1, 4	5, 1, 0	0, 0, 6	4, 1, 0

Table 4: Maximal front crawl tethered swimming under breathing and non-breathing conditions: mean ± SD values for all variables and statistical analysis for the comparison between conditions. The p values indicate the significance level, with an asterisk (*) indicating statistically significant differences between conditions for p≤0.05.

	Male				**Female**			
	Non-breathing	**Breathing**	**P**	**Effect size**	**Non-breathing**	**Breathing**	**P**	**Effect size**
Fmin (N)	86.7±21.5	78.1±32.1	0.220	0.31	51.7±12.8	49.5±15.6	0.599	0.15
Fmax (N)	208.2±30.0	208.2±18.1	1.000	0.00	144.1±36.6	134.5±27.2	0.283	0.30
Fmean (N)	145.6±23.5	143.9±15.4	0.793	0.09	93.6±18.3	88.5±15.4	0.060	0.30
SC Time (s)	1.0±0.2	1.1±0.2	0.015*	0.45	1.2±0.1	1.3±0.2	0.015*	0.97
SC Impulse (Nsec)	146.4±35.9	157.5±21.5	0.190	0.38	113.1±27.2	117.4±24.2	0.262	0.17
Normalised Fmin (N/Kg)	1.1±0.3	1.0±0.4	0.220	0.31	0.8±0.3	0.8±0.2	0.688	0.19
Normalised Fmax (N/Kg)	2.7±0.3	2.7±0.2	0.949	0.02	2.3±0.5	2.2±0.3	0.309	0.36
Normalised Fmean (N/Kg)	1.9±0.3	1.9±0.2	0.802	0.09	1.5±0.2	1.4±0.2	0.052	0.41