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Research article

Underwater stroke kinematics during breathing and breath-holding front crawl swimming

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Abstract
The aim of the present study was to determine the effects of breathing on the three – dimensional underwater stroke kinematics of front crawl swimming. Ten female competitive freestyle swimmers participated in the study. Each subject swam a number of front crawl trials of 25 m at a constant speed under breathing and breath-holding conditions. The underwater motion of each subject's right arm was filmed using two S-VHS cameras, operating at 60 Hz, which were positioned behind two underwater viewing windows. The spatial coordinates of selected points were calculated using the DLT procedure with 30 control points and after the digital filtering of the raw data with a cut-off frequency of 6 Hz, the hand's linear displacements and velocities were calculated. The results revealed that breathing caused significantly increases in the stroke duration ($t_9 = 2.764$; $p < 0.05$), the backward hand displacement relative to the water ($t_9 = 2.471$; $p<0.05$) and the lateral displacement of the hand in the X – axis during the downsweep ($t_9 = 2.638$; $p < 0.05$). On the contrary, the peak backward hand velocity during the insweep ($t_9 = 2.368$; $p < 0.05$) and the displacement of the hand during the push phase ($t_9 = -2.297$; $p < 0.05$) were greatly reduced when breathing was involved. From the above, it was concluded that breathing action in front crawl swimming caused significant modifications in both the basic stroke parameters and the overall motor pattern were, possibly due to body roll during breathing.

Key words: Swimming, front crawl, three-dimensional kinematic analysis.

Introduction

In front crawl swimming a breath should be taken during the first half of the recovery and the swimmer's face should be returned into the water during its second half. According to Maglischo (1993) and Costill (1992), during this action, head movements should be coordinated with body roll, to prevent an excessive lift of the swimmer's head out of the water. Moreover, it is expected that front crawl swimmers should continually rotating their bodies around the longitudinal axis at least 45 degrees to each side and spend more time on their sides than in a flat position (Maglischo, 1982). Counsilman (1977), Hay et al., (1993) and Liu et al. (1993) also reported that the body roll angle should be ranged between 35 to 45 degrees on each side during a complete arm cycle. However, most swimmers tend to recover their arms higher on the breathing side and swing them over the water lower and more lateral on the non-breathing side. This forces their body to roll more than 45 degrees toward their breathing side than the non-breathing one (Costill, 1992).

The amount of body roll also seems to depend on the swimming pace. During swimming at sprinting pace, Beekman (1986) found that the maximum body roll angle to the non-breathing side reached a mean value of 47.8°, while the corresponding value for the breathing side was 59.7°. Levinson (1987) also reported body roll angle values of 45° and over 50° for the non-breathing and the breathing side, respectively, in an elite sprint front crawl swimmer. Even greater values were reported from Payton et al., (1999) in approximately 200 m race pace front crawl swimming. The maximum body rolls angles for the non-breathing and the breathing side were 57 ± 4° and 66 ± 5°, respectively. Furthermore, at long distance pace, Liu et al., (1993) reported higher body roll angles. The maximum body roll angle to the non-breathing side ranged in their study between 51.5° and 66.0°, with a mean value of 60.8°. From the above it can be speculated that a degree of asymmetry exists in hand motion between breathing and non-breathing side and body roll angles tend to increase as the distance of the swimming race increases.

Prichard (1993) assumed that front crawl swimmers use body roll to produce lateral, as well as medial sweeps of the hand during the underwater pull (Payton et al., 1999), while Payton et al. (1997) found that body roll affects medio-lateral, as well as vertical hand motions in front crawl swimming. However, an increase in maximum body roll mainly augments the medial motion of the hand and has relatively little effect on the vertical hand motion. Regarding the relative duration of the underwater phases (glide, downsweep, insweep, upsweep and recovery), Payton et al. (1999) did not find any significant alterations due to the breathing action. Moreover, there were not observed notable changes in stroke depth, stoke width and stroke length.

All the above researchers studied the body roll angles of both male and female swimmers. However, the kinematic differences between breathing and non-breathing side has been studied only in male swimmers (Liu et al., 1993; Payton et al., 1999). The lack of information regarding the arm kinematic asymmetries in front crawl female swimmers stimulated the present study, which aimed to investigate the effects of breathing action on the underwater front crawl stroke kinematics in female swimmers.

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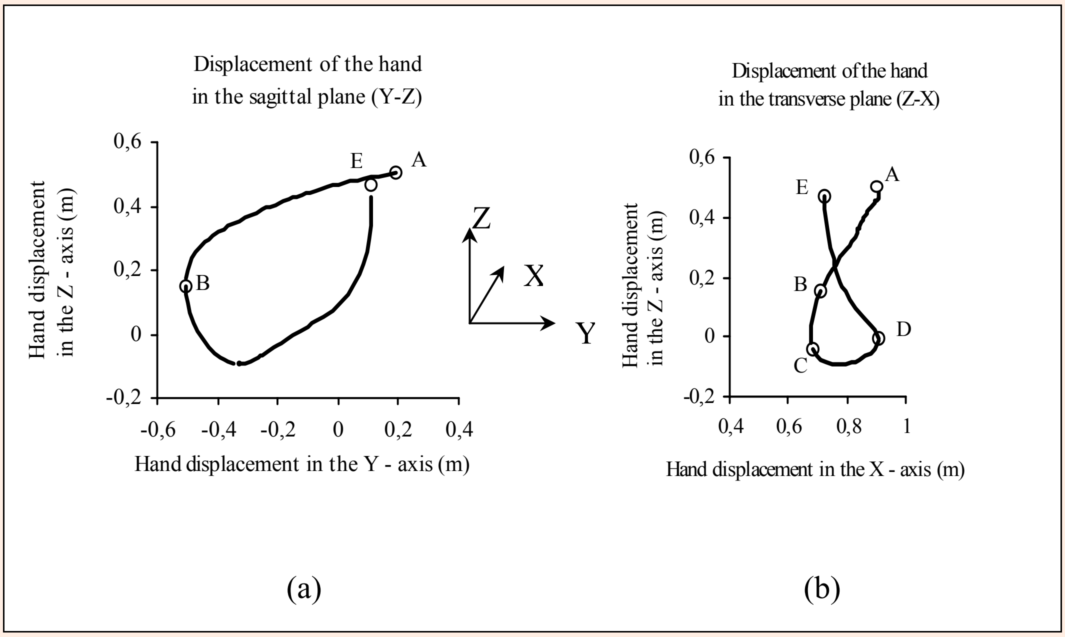

Figure 1. Phases of the underwater pull: (A – B) glide, (B – C) downsweep, (C – D) insweep, (D – E) push.

Methods

Ten female competitive freestyle swimmers (age: 15 ± 1.2 years; height: 1.67 ± 4.1 m; mass: 52.9 ± 3.9 kg) participated in the study. Their best performance in 100 m front crawl ranged from 62.07 s to 77.36 s (68.62 ± 4.34 s), and their average training experience was 8.0 ± 1.5 years.

After a warm – up and the familiarization with the experimental conditions, each subject swam two front crawl trials of 25 m at a constant submaximal speed, approximately equal to 80% of their best performance in the 100 m front crawl. Subjects were asked to breathe in the right side during every stroke cycle during the one of the two trials and not to breathe during the other. All subjects had been trained and used the right side as the preferred breathing side. The order of the trials was randomized and the rest period between them was set to 3 min in order to minimize the effects of fatigue.

The underwater motion of each subject's right arm was recorded using two S-VHS video cameras with a sampling frequency of 60 Hz. The cameras were positioned behind two underwater viewing windows, with their optical axes perpendicular to each other. During each trial, light emitting diodes mounted on each camera were activated from the experimenter to allow the synchronization of the two cameras. A 30 point calibration frame (2.1 X 3.2 X 1.8 m) was placed in the swimming area for the calibration of the recording space volume.

Prior to filming anatomical landmarks corresponding to the 5^{th} metacarpophalangeal joint and the right greater trochander were marked on skin with a water resisted black pen, in order to calculate the kinematics of the hand motion and the mean swimming velocity, respectively. The above points were digitized manually using the Ariel Performance Analysis System (Ariel Dynamics, U.S.A.) and their 3-D spatial coordinates on the transverse (X), sagittal (Y), and vertical (Z) axes were calculated using the Direct Linear Transformation procedure. The raw position-time data were then smoothed using a low-pass digital filter, with a cut-off frequency of 6 Hz.

During data reduction, the total underwater motion of the pulling arm, from hand entry to hand exit, was divided into four phases (glide – downsweep – insweep – push), according to the methodology of Payton and Lauder (1995). The glide phase was defined from the time of the hand's entry into the water to the beginning of its backward movement. The downsweep phase was defined from the end of the glide to the most lateral position of the hand in the transverse axis. The insweep phase from the end of the downsweep to the most medial position of the hand in the transverse axis, and the push phase from the end of the insweep to hand exit (Figure 1).

The following variables were used to describe the kinematics of the pulling arm during the two different experimental conditions (breathing and breath-holding):

- Duration of the underwater pull and the corresponding phases.
- Displacement of the hand during the phases of the underwater pull.
- Pull width, defined as the medial (X – axis) displacement of the hand during the insweep.
- Pull depth, defined as the vertical (Z – axis) displacement of the hand from entry to the deepest point.
- Absolute pull length, defined as the backward (Y – axis) displacement of the hand from its most forward position to its most backward position relative to the water.
- Maximal linear hand velocity during the phases of the underwater pull.

The t-test for dependent samples was used for the statistical treatment of the data and the level of significance was set at $p < 0.05$. The assumption of normally

Table 1. Means duration (±SD) of the phases and the total underwater pull.

	Breathing	Breath-holding	t - value
Glide (s)	.76 (.14)	.68 (.11)	2.540 *
Downsweep (s)	.12 (.04)	.09 (.05)	2.510 *
Insweep (s)	.15 (.03)	.16 (.02)	-1.029
Push (s)	.23 (.03)	.23 (.05)	.000
Total underwater pull (s)	1.25 (.17)	1.16 (.15)	2.764 *

* $p < 0.05$.

distributed samples was verified using the Kolmogorov – Smirnov test.

Results

The results revealed that there was not any significant difference ($t_9 = 1.159$; $p = 0.276$) in the mean swimming velocity between the two measurement conditions (breathing: 1.25 ± 0.05 m·s^{-1}, breath-holding: 1.30 ± 0.14 m·s^{-1}).

Concerning the temporal characteristics of the underwater pull significant differences were observed between the two measurement conditions in the glide and the downsweep phases, as well as in the total duration of the underwater pull. On the contrary, the duration of insweep and push was not significantly affected. During the breathing trials the duration of the glide phase, the insweep and the total underwater pull were significantly greater by an average of 11%, 27.5% and 8% respectively, when compared to breath-holding trials (Table 1).

Regarding the displacement of the hand during the phases of the underwater pull it was observed that breathing caused a significant increase in the lateral displacement of the hand in the transverse axis during the downsweep and a significant decrease in the hand's lateral displacement from the end of the most medial position of the hand in the transverse axis to hand exit, during the push phase. However, the differences in hand displacements during the rest of the phases were not significant. Furthermore, the pull depth, which was defined as the maximum displacement of the hand in the vertical axis from entry to the deepest point of the underwater pull, was found significantly different between the two measurement conditions (breathing – breath holding). More specifically, breathing caused a significant decrease of 7% on the average maximum vertical displacement of the hand. However, the absolute pull length, which was defined as the backward displacement of the hand from its most forward position to its most backward position on the sagittal axis relative to the water, increased significantly during breathing, by an average of 13%, when compared to breath-holding trials (Table 2).

Breathing had also a significant influence on the linear velocity of the hand during the insweep in the transverse and sagittal axes. The maximal linear velocity of the hand during the insweep phase was significantly increased in the transverse axis (X), while in the sagittal axis (Y) it was significantly decreased, comparing with the breath-holding trials. On the contrary, there were not observed any significant differences in the linear velocity of the hand during the push face on the three axes (Table 3).

Discussion

In the present study it was found that during the breathing trials the duration of the total underwater pull was significantly greater than during the breath-holding trials in front crawl female swimming. This increase of the duration of the total underwater pull was mainly attributed to an increased duration of the glide and downsweep phases, which were significantly greater by an average of 11% and 27.5% respectively when breathing, in comparison with breath-holding trials. This finding is in accordance with the observation of Payton et al. (1999) for male swimmers, although they presented lower arithmetic values, probably because in their study the subjects swam in their 200 m front crawl race pace. Nevertheless, it seemed that when a swimmer took a breath the pull time increased to allow extra time for the inhalation to be made (Payton et al., 1999).

Regarding the pull depth, in the present study it was found to be 0.51 ± 0.05 m during the breathing trials and 0.54 ± 0.05 m during the breath-holding trials. These values are much lower than those reported by Payton et al. (1999), Payton and Lauder (1995), Chatard et al., (1990) and Schleihauf et al. (1988), probably because of the different anthropometric characteristics of the subjects in each study. Lower values were also observed in the absolute pull length, which was defined as the backward displacement of the hand relative to the water. In the present study the absolute pull length was found to be 0.54 ± 0.05 m during the breathing trials and 0.48 ± 0.08 m during the breath-holding trials, while Payton and Lauder (1995) and Schleihauf et al. (1988) reported pull lengths of 0.60 ± 0.06 m and 0.64 ± 0.10 m, respectively. Concerning the pull width, which was defined as the medial displacement of the hand during the insweep, there were not observed any differences due to breathing.

This observation is in accordance with the findings

Table 2. Means (±SD) hand displacements during breathing and breath-holding trials.

	Breathing	Breath-holding	t - value
Glide (cm)	93.2 (16.9)	90.0 (19.4)	.713
Downsweep (cm)	9.17 (4.73)	6.19 (5.56)	2.638 *
Insweep (Pull width) (cm)	8.87 (3.64)	8.97 (3.54)	-.130
Push (cm)	5.80 (4.16)	11.8 (6.58)	-2.297 *
Pull depth (cm)	50.5 (5.26)	53.8 (4.91)	-2.317 *

* $p < 0.05$.

Table 3. Mean values (±SD) of the maximum linear velocities of the hand during breathing and breath-holding trials.

	Breathing	Breath-holding	t - value
Maximum linear velocity of the hand in the X – axis during the insweep (m·s^{-1})	1.09 (.30)	.85 (.29)	2.581 *
Maximum linear velocity of the hand in the Y – axis during the insweep (m·s^{-1})	1.84 (.11)	2.09 (.40)	-2.368 *
Maximum linear velocity of the hand in the X – axis during the push phase (m·s^{-1})	1.10 (.46)	1.25 (.48)	-.715
Maximum linear velocity of the hand in the Y – axis during the push phase (m·s^{-1})	1.82 (.21)	1.82 (.62)	-.023
Maximum linear velocity of the hand in the Z – axis during the push phase (m·s^{-1})	2.51 (.39)	2.65 (.43)	-.802

* $p < 0.05$.

of Payton et al. (1999) although they reported greater values. Payton et al. (1999) reported pull widths of 0.28 ± 0.07 m for the breathing trials and 0.27 ± 0.07 m for the breath-holding trials, while Payton and Lauder (1995) presented pull widths of 0.34 ± 0.07 m and Schleihauf et al. (1988) reported values of 0.37 ± 0.08 m. Thus it was hypothesized that breathing and body roll do not affect the medial hand movement in front crawl female swimmers.

Conclusion

In conclusion, the findings of the present study indicate that the breathing action of female swimmers in front crawl swimming significantly increased the duration of the total underwater pull, while no alterations were observed in the stroke width. Moreover, while the pull depth decreased, the absolute backward displacement of the hand increased. These results may add some knowledge concerning the technical effects of breathing action and body co-ordination in female front crawl swimming and should be taken into account by swimming coaches.

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Key points

- The breathing action increases the duration of the total underwater pull.
- The breathing action increases the absolute backward displacement of the hand.
- The breathing action caused significant modifications in the overall motor pattern, possibly due to body roll during breathing.

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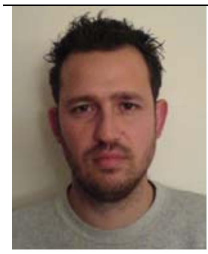

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