Intracyclic Velocity Variation and Arm Coordination Assessment in Swimmers With Down Syndrome

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This study examined the differences in intracycle velocity variation and arm coordination in front crawl in swimmers with Down syndrome in three breathing conditions. International swimmers with Down syndrome (N = 16) performed 3 × 20 m front crawl at 50 m race speed: without breathing, breathing to the preferred side, and breathing to the nonpreferred side. A two dimensional video movement analysis was performed using the APASystem. Breathing conditions were compared using Repeated Measures ANOVA. Swimming velocity was higher without breathing and intracyclic velocity variation was higher while breathing. Swimmers tended to a catch up arm coordination mode for both breathing conditions and a superposition mode when not breathing. These data reflect arm coordination compromising swimming performance, particularly when comparing with non disabled swimmers in literature. The physical and perhaps cognitive impairment associated with Down syndrome may result in a disadvantage in both propulsion and drag, more evident when breathing.

Keywords: adapted swimming, intellectual disability, biomechanics, crawl stroke

Down syndrome is a genetic impairment caused by the presence of abnormalities in chromosome 21, presenting a unique etiology that affects many areas of development (Antonarakis, Lyle, Dermitzakis, Reymond, & Deutsch, 2004;
Recent biomedical and molecular studies suggest that this chromosomal anomaly determines several alterations in protein expression patterns (Cabello et al., 2009). This results in changes in particular biomechanical, physiological, anatomical, and behavior characteristics that may have serious repercussions on health status and social context of people with Down syndrome and their families (Henderson, Lynch, Wilkinson, & Hunter, 2007). Indeed, the combination of physical and cognitive limitations, typically exhibited by individuals with Down syndrome and reportedly due to differences in the cerebellum as compared with the general population (Latash, Latash, & Meijer, 2000) may contribute to motor performance dysfunction (Lahtinen, Rintala, & Malin, 2007). Difficulties with motor skills can affect performance in various tasks of daily living (Fegan, 2011). It is also important to highlight the influence of the environmental context in the motor performance of individuals with Down syndrome (Charlton, Ihsen, & Lavelle, 2000).

Poor physical fitness due to a more sedentary lifestyle may induce functional deterioration, increased overweight and reduced bone mass development (González-Aguero et al., 2010). Conversely, the application of a competition-oriented training program in athletes with Down syndrome seems to improve their general physical and metabolic condition, increases self esteem, and leads to greater autonomy and social integration (Perán, Gil, Ruiz, & Fernandez-Pastor, 1997). Nonetheless, studies that focus on those with Down syndrome involved in physical activity in general and swimming, in particular, are scarce. It has been reported that muscle power, swimming technique, and body hydrodynamic drag influence swimming performance (Smith, Norris, & Hogg, 2002; Toussaint & Beek, 1992; Vilas-Boas et al., 2010). A systematic review of the literature by our group concluded that nonactive persons with Down syndrome have less muscle power, lower cardiovascular fitness, and have a higher BMI in comparison with persons with Intellectual Disability and nondisabled persons but that training interventions were moderately to highly effective (Slagmolen, 2011). Biomechanical studies focused on elite competitive swimmers with Down syndrome are thus needed to improve training intervention strategies and therefore swimming ability and performance.

The intracyclic velocity variation (IVV) and the index of coordination (IdC) are two biomechanical parameters of current interest (Figueiredo, Toussaint, Vilas-Boas, & Fernandes, 2012; Psycharakis, Naemi, Connaboy, McCabe, & Sanders, 2010; Seifert, Toussaint, Alberty, Schnitzler, & Chollet, 2010). Potentially relevant information on swimming performance might be provided by IVV, which has been considered an indicator of swimming efficiency (Vilas-Boas, Fernandes, & Barbosa, 2011). IdC is a measure of temporal synchronization of movement between the arms in crawl swimming in which one arm is moving backward underwater (propulsion), while the second arm is finishing the underwater phase and subsequently recovering forward above water. This measurement actually assesses the lag time between propulsive phases in left and right arm and provides information on the management of crawl arm propulsion (Chollet, Charlies, & Chatard, 2000). Three coordination modes are described for front crawl: *catch-up* (lag time between the propulsive phases of the two arms, IdC < 0), *opposition* (when the propulsive phase of one arm starts exactly when the other arm ended its propulsive phase, IdC = 0%), and *superposition* (when the
propulsive phases of the two arms overlap, $\text{IdC} > 0\%$). The IVV and IdC are complementary. The IdC gives temporal information on the swimmer’s ability to coordinate propulsive actions (Schnitzler, Seifert, Ernwein, & Chollet, 2008) and IVV provides kinematic insight into the consequences of various combinations of propulsive and resistive forces.

In front crawl, as a consequence of the need to breathe, swimmers roll their body further when taking a breath than when not (Payton, Bartlett, Baltzopoulos & Coombs, 1999), and it has been suggested that breathing laterality in front crawl leads to adaptations that can compromise stroke technique and organization, influencing arm coordination, increasing arm movement asymmetry, and thus causing a discontinuity between the propulsive actions of the two (Lerda & Cardelli, 2003; Seifert, Chollet & Allard, 2005; Tourny-Chollet, Seifert, & Chollet, 2009). These disturbances were found to be even greater in less accomplished swimmers (Lerda & Cardelli, 2003). Therefore, the analysis of the interactions between breathing pattern and stroke organization appears to be essential for assessing the swimmer’s skill level (Figueiredo, Seifert, Vilas-Boas, & Fernandes, 2012; Lerda & Cardelli, 2003). In addition, asymmetries in arm stroke actions could be related to preferred breathing side and essentially effect propulsion. In general, swimmers inhale consistently to the same side, stabilizing this automatism as well as the lag time between the propulsive actions of the two arms (Cardelli, Lerda, & Chollet, 2000; Lerda & Cardelli, 2003). Greater arm asymmetry between sides has been seen when breathing on the nonpreferred and thus less practiced side. Systematic as well as alternating breathing to the nonpreferred side is in fact recommended as a training form to help reduce arm coordination asymmetry (Seifert, Chehensse, Tourny-Chollet, Lemaitre, & Chollet, 2008).

Competitive swimmers with Down syndrome with extensive training and competition experience might nonetheless be less accomplished with regard to swimming speed. It is first of all not clear what exactly the particular movement characteristics of these swimmers are. Furthermore, it is not apparent if the same breathing automatism might be found in experienced swimmers with Down syndrome as is seen in experienced swimmers without a disability. There is, for example, both an increased prevalence of non-right-handedness and evidence for reduced asymmetries in manual performance that might lead to additional problems while breathing in swimmers with Down syndrome even after extensive practice (see e.g., Mulvey, Ringenbach, & Jung, 2011). The first question is then what are some basic movement characteristics of front crawl stroke in experienced competitive swimmers with Down syndrome? The following question is how does a perturbation such as breathing affect arm coordination and therefore propulsion in these swimmers? A final question asks if the effects of this perturbation differ when breathing to the preferred (practiced) from the nonpreferred (nonpracticed) side.

The purpose of this study was therefore to characterize the IVV pattern of the hip, and the IdC, in competitive swimmers with Down syndrome performing front crawl at high intensity. We hypothesize that breathing will result in clear adaptations to the front crawl swimming technique, which become more striking when breathing to the nonpreferred side. Therefore, IVV and IdC were studied in three breathing conditions: nonbreathing and breathing to the preferred and nonpreferred sides.
Method

Participants

Sixteen competitive swimmers, 10 males and 6 females, with Down syndrome participated in this study. Swimmers were recruited from the Portuguese National Team after contacting their respective coaches. They had all qualified and competed at World Championship level within the 2 years before testing. The mean (± SD) values of physical and training background characteristics are presented in Table 1. All participants provided informed written consent and the study was approved by the University ethics committee. Parental consent was also obtained.

Procedures

Age, previous competitive experience, training sessions per week, water training per training session, and flexibility and/or weight training per training were recorded in a questionnaire completed by the coaches. All procedures were performed in the morning before the swimming evaluation. Participants wore light clothing without shoes. Body Mass and percentage of body fat were assessed using a Tanita Inner scan, BC-532 (Tanita, Hoofddorp, The Netherlands). Stature was measured using a stadiometer Seca model 708 (Seca, Hamburg, Germany). Arm span was assessed using a tape measure.

Before video recording a familiarization and warm up period was provided consisting of at least 10 min crawl swimming with at least 50% of the time spent on breathing to the nonpreferred side. Both researchers and coaches were present to assure that familiarization was consistent for all swimmers.

Each swimmer then performed $3 \times 20$ m front crawl with $30$ min rest in randomized order in an indoor $25$ m pool at a velocity corresponding to their personal $50$ m race pace in three breathing conditions: without breathing, breathing to their preferred side, and breathing to their nonpreferred side. After each trial, swimmers

Table 1  Mean ± SD Values of Age, Anthropometric Characteristics, and Physical and Water Training Background Characteristics ($N = 16$: 10 males and 6 females)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Mean ± SD</th>
</tr>
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<tbody>
<tr>
<td>Age (yrs)</td>
<td>20.5 ± 4.8</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>146.9 ± 13.1</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>57.4 ± 11.1</td>
</tr>
<tr>
<td>Fat body mass (%)</td>
<td>17.2 ± 9.5</td>
</tr>
<tr>
<td>Arm span (cm)</td>
<td>146.7 ± 13.1</td>
</tr>
<tr>
<td>Previous competitive experience (yrs)</td>
<td>3.0 ± 1.8</td>
</tr>
<tr>
<td>Training sessions per week *</td>
<td>5.1 ± 1.1</td>
</tr>
<tr>
<td>Water training per training session (hrs)</td>
<td>1.4 ± 0.2</td>
</tr>
<tr>
<td>Flexibility and/or weight lifting per training session (hrs)</td>
<td>1.0 ± 0.3</td>
</tr>
</tbody>
</table>

Note: * In general training sessions per week are over 11 months a year.
were informed of their performance, which was expected to be within ± 2.5% of the target 50 m race velocity. If this was not the case, the participant repeated the trial after a 30 min interval. The nonbreathing condition was considered as a control situation since there is the least disturbance due to body roll. Each participant performed one trial in each situation. The preferred breathing side was the right side for all participants.

Two synchronized digital cameras (DCR-HC42E Sony, Japan), placed in a sealed housing (SPK—HCB, Sony, Japan), recorded two complete underwater arm stroke cycles (50 Hz). A side view camera was placed at the bottom of the pool, at 1.90 m depth and 11.5 m from the test lane. The frontal view camera was positioned at 0.5 m depth. The recorded space was calibrated using a bidimensional rigid calibration structure (2.10 m × 3 m). Subsequently, kinematic analysis was done using the APASystem (Ariel Dynamics Inc., USA), digitizing manually, field by field. Nine anatomical points: the right hip (femoral condyle), and on both sides finger tips, wrist, elbow, and shoulder, were digitized. Bidimensional reconstruction was done using a DLT procedure (Abdel-Aziz & Karara, 1971). After residual analysis for a range of frequencies, 5 Hz was selected as the optimal cutoff frequency for the smoothing of the data using a low pass digital filter incorporated in the software as was also suggested by Winter (1990).

All parameters were calculated as the mean of the two recorded arm stroke cycles (right or left finger tip in water to following finger tip in water). Horizontal swimming velocity was calculated from the mean frame by frame displacement of the hip over one stroke cycle divided by cycle time (0.02 s). Stroke rate was determined from the arm cycle duration, and SL was obtained from the horizontal displacement of the hip during a stroke cycle. Stroke length was also expressed relative to Arm Span. For the assessment of IVV, the coefficient of variation of the hip velocity (femoral condyle) in a complete stroke cycle was taken (SD/Mean*100). This is the SD of the mean of the field to field hip velocities over an entire stroke cycle. Arm coordination was assessed by using the IdC (proposed by Chollet et al., 2000), which was expressed as a percentage of overlapping of right and left arm propulsion as compared with the mean duration of two arm strokes. The propulsive phase lasted from the beginning of the hand’s backward movement (x axis) until the time when the hand released from the water (pull and push phases), and the nonpropulsive phase started at the hand release and included the hand entry into the water (recovery, entry, and catch phases). In accordance with Chollet et al. (2000), the stroke phases were determined using the following digitalized coordinates: entry and catch of the hand in the water corresponded to the time from the hand’s entry into the water to the maximal forward coordinate of the hand; the pull phase corresponded to the time from the beginning of the hand’s backward movement to the hand’s arrival in the vertical plane to the shoulder; the push phase corresponded to the time from the hand’s position below the shoulder to its release from the water and recovery corresponded to the time from the hand’s release from the water to its following entry into the water. The duration of a complete arm stroke cycle was the sum of the durations of the propulsive and nonpropulsive phases as follows:

\[
\text{Duration}_{\text{complete cycle}} = \left[ \left( \text{Entry and catch} + \text{pull} + \text{push} + \text{recovery} \right)_{\text{left arm}} + \left( \text{Entry and catch} + \text{pull} + \text{push} + \text{recovery} \right)_{\text{right arm}} \right]/2
\]
The index of coordination (IdC) calculated the time gap between the propulsions of the two arms as a percentage of the duration of the complete arm stroke cycle (Chollet et al., 2000). IdC was the mean of IdCleft and IdCright:

$$\text{IdC}_{\text{left}} = \left( \frac{\text{Time}_{\text{end of push for left arm}} - \text{Time}_{\text{beginning of pull for right arm}}}{\text{Duration}_{\text{complete cycle}}} \right) \times 100$$

$$\text{IdC}_{\text{right}} = \left( \frac{\text{Time}_{\text{end of push for right arm}} - \text{Time}_{\text{beginning of pull for left arm}}}{\text{Duration}_{\text{complete cycle}}} \right) \times 100$$

**Statistical Analysis**

Data were tested for normality using the Shapiro-Wilk test. Descriptive statistics (Mean and SD) were used to characterize the sample. A Repeated Measures (ANOVA) was applied to analyze the effect of the three breathing conditions within swimmers. A Bonferroni post hoc test was used to identify specific differences between breathing conditions for each variable. Spearman rank correlations were also calculated within the three breathing conditions, between IVV and IdC and swimming velocity, as well as with secondary outcomes stroke rate (SR) and stroke length (SL). The level of significance was set at p value less than 0.05. Data were analyzed using the SPSS version 17.0 (SPSS Inc., Chicago, Illinois, USA).

**Results**

The mean and SDs for the parameters studied in the three breathing conditions (without breathing and in both inspiratory conditions) are shown in Table 2. Significant within-group differences were found for velocity, IVV, IdC, and Stroke rate. Significantly higher velocity and lower IVV values were found during stroke cycles without breathing. A coordination mode, with a mean value close to 0%, was observed while breathing to the preferred side and a lower IdC was seen when breathing to the nonpreferred side. In the nonbreathing cycles, swimmers with Down syndrome moved toward a superposition coordination mode with values significantly higher than those obtained while breathing. The Spearman rank correlation between IdC in nonbreathing and the preferred and nonpreferred breathing conditions was 0.94 for both sides and 0.84 between preferred and nonpreferred conditions. Only four swimmer did not decrease IdC when moving from nonbreathing to preferred side breathing (M change = –1.63 ± 4.3%) and only two did not decrease IdC from nonbreathing to nonpreferred side breathing (M change = –2.94 ± 4.2%).

Stroke rate when not breathing was significantly higher than when breathing to the nonpreferred side. There were no differences found in SL and SL/arm span. There was also no correlation between IdC and swimming speed and a significant negative Spearman rank correlation (–.63) was only found between IVV and velocity in the nonbreathing situation. There was also no significant relationship between IdC and IVV.

No significant within-group differences were found in stroke phase duration in the three inspiratory conditions. When a deeper analysis of the inter arm
coordination values was carried out, it was found that the sum of nonpropulsive phases (entry and catch plus recovery) did not differ from the sum of propulsive phases (pull + push) in any breathing conditions (cf. Figure 1, panel A). The percentage difference in relative duration of these arm movement phases, however, between propulsive and nonpropulsive phases was more distinguishable in the cycles without breathing as compared with both breathing situations (4% vs. -1%). When the various stroke phases were analyzed (cf. Figure 1, panel B), there were no significant differences between the percentage contribution of entry and catch, pull, push and recovery phases in any breathing condition.

Complementary to this data, in Figure 2, the mean and SD of IdC values are given for both the left and right arms in the breathing conditions tested. Although there were no statistically significant differences found in the non breathing cycles, IdC values from both left and right arms were on the mean positive, corresponding to a greater superposition coordination mode; however, in the breathing cycles to the preferred side (always right), the IdC values of the left arm were negative (catch up), whereas values for the right arm were positive (superposition). In addition, in nonpreferred side arm cycles, the IdC values of the right arm were negative (catch up) and the IdC values of the opposite arm were positive (superposition). Indeed, in cycles without breathing and to the preferred side, the right showed ~1% and ~5%, respectively, more superposition than the left arm, whereas in breathing cycles to the non preferred side, the right arm had ~3% more catch up than the left arm.

**Discussion**

To better characterize the technique of swimmers with Down syndrome and the impact of breathing a number of stroking parameters were assessed such as IVV and IdC in three front crawl breathing conditions performed at a velocity corresponding to 50 m race pace. The typical characteristics of persons with Down syndrome could directly influence these parameters and thus swimming performance. Swimmers with Down syndrome seem to swim slower with a low maximum SR in relation to values of able bodied swimmers at “sprint” race pace (Schnitzler et al., 2008). At similar absolute speeds, swimmers with Down syndrome appear to show higher
Figure 1 — Mean ± SD percentage values of the sum of propulsive and nonpropulsive stroke phases (panel A) and of entry and catch, pull, push and recovery phases (panel B) in the three inspiratory conditions.

Figure 2 — Mean IdC as shown by bars and SD values as indicated by lines for the left and right arms separately in the three breathing conditions tested.
SR, IdC, and especially IVV compared with experienced able bodied swimmers reported in the literature (Seifert et al., 2010). As compared with inexperienced swimmers reported in the literature at similar maximal swimming speed, SR was again higher for swimmers with Down syndrome but with similar IdC values (Lerda & Cardelli, 2003). Swimmers with Down syndrome decrease IdC toward catch–up from nonbreathing to preferred breathing side conditions and even further when breathing on the nonpreferred side while IVV increased. Changes in the IdC of the arm movement opposite to the breathing side are largely responsible for these changes.

During a single arm cycle in front crawl, the relationship between drag and propulsive force changes constantly (Nigg, 1983). The mean velocity of a swimmer is the result of the combination of propulsive and drag forces. Velocity increases with the first and decreases with the last (Toussaint & Beek, 1992). It has been reported that individuals with Down syndrome have a lower mechanical power output due to abnormal muscle control and tone and decreased strength, which has been linked to motor delays and abnormal movement patterns (Almeida, Corcos, & Hasan, 2000) and anthropometric traits, such as smaller stature and higher percentage of body fat (Pelayo, Sidney, Kherif, Chollet, & Tourny, 1996). This all could contribute to a decrease in propulsive potential and greater hydrodynamic drag in swimmers with Down syndrome, negatively affecting their swimming.

To obtain high performances, swimmers must have good control and combination of both SR and SL (Chollet, Pelayo, Tourny, & Sidney, 1996; Pelayo et al., 1996). In fact, the SL and to a lesser degree SR are considered to be discriminating factors between (faster) expert and less expert swimmers (Costill, Lee, & D’Acquisto, 1987; Craig, Boomer, & Gibbons, 1979). Stroke rate values for swimmers with Down syndrome seemed to be lower than those referred to in literature for experienced nondisabled swimmers for 50 m sprint pace (Seifert, Chollet, & Rouard, 2007). This is possibly related to coordinative disorders and the lower forces these swimmers can exert. Swimmers also appear to show short SL, which could also be due to the short arm span of the swimmers examined here (see Lahtinen et al., 2007). Their higher SR as compared with nonexperienced swimmers at similar maximal speeds also supports this possibility of a lower stroking effectiveness (Costill et al., 1987).

The exploration of a swimmer’s preferred mode of arm coordination provides information on his motor organization. Therefore, IdC also could be an important indicator of a swimmer’s skill namely of inter arm coordination (Chollet et al., 2000). IdC values at maximal velocity found in literature reach zero or higher indicating opposition or superposition coordination of the arm propulsion (Seifert, Chollet, & Bardy, 2004; Seifert, Chollet & Rouard, 2007). Similarly, and despite the high variability, IdC values of swimmers with Down syndrome, at maximal velocity, correspond on average to opposition coordination. Seifert et al. (2004) pointed out that only elite swimmers attained high velocity in the sprint. Thus, only these swimmers superpose their arm actions to overcome the greater forward resistance. The velocity values for swimmers with Down syndrome, however, are lower than able bodied elite and even those of less expert swimmers, suggesting that the relative opposition coordination and even superposition found in some cases is not due to an increase in propulsive actions, but to a technical shortcoming. Seifert, Chollet, and Chatard, (2007) pointed out that some less expert swimmers spend more time
in the propulsive phases due to slow hand velocity and thus did not generate high force. The relatively high values for IdC compared with the actual swimming velocity of swimmers with Down syndrome here might reflect this fact.

The IdC values in the sample studied range from very high to low. The mean IdC values and large variability seen were in agreement with Satkunskiene, Schega, Kunze, Birzinyte, and Daly (2005) for a sample of 18 swimmers with physical impairments measured at 100 m race speed. This did not, however, concur with data for a sample of 14 French national and regional swimmers (Seifert et al., 2010) at 8 speeds from 60% to 100% of maximum sprint. Nonetheless, at speeds similar to those of the swimmers with Down syndrome in our study, both groups of French swimmers showed extremely low mean IdC ($M$ = 18%; range 13–22%).

In the analysis of the stroke phases, it was found in fact that swimmers with Down syndrome have a relative duration of propulsive and nonpropulsive phases at maximal velocity similar to elite swimmers without disability (Millet, Chollet, Chalies, & Chatard, 2002; Seifert et al., 2004). Actually, Chollet et al. (2000) found that IdC increased with the swim velocity, given that swimmers increased the propulsive phases of pull and push and reduced the nonpropulsive phase of entry and catch. Compared with nondisable swimmers, however, the recovery phase of swimmers with Down syndrome seem to be longer and consequently the entry and catch phases lower (Millet et al., 2002; Seifert et al., 2010), suggesting that swimmers with Down syndrome, in general, begin their propulsive phase sooner after the hand enters the water, perhaps interfering with the propulsive phase of the other arm and even causing addition drag. This also seems to result in a higher IVV especially when breathing.

Stroke rate, SL, and velocity are resultants and do not provide a clear measure of swimming technique or coordination (Seifert et al., 2004). The IVV is, however, a better indicator of technical skill (Vilas-Boas et al., 2011). The values obtained in the current study for IVV when breathing seem to be higher than those presented for swimmers without disabilities reported by Schnitzler et al. (2008) and for the French swimmers of Seifert et al. (2010; IVV = 0.14 ± 0.04 & 0.15 ± 0.02) at similar swimming speed. In swimmers with Down syndrome, the nonpreferred breathing condition clearly showed the highest IVV (0.29 ± 0.09). It should be pointed out that the differences in IVV within swimmers with Down syndrome between breathing and nonbreathing cycles are greater than the differences in IVV between national and regional French swimmers supporting the importance of this result.

**Breathing Conditions**

In front crawl, the breathing action requires a longitudinal body rotation. Extreme body roll influences hydrodynamic and streamline position, compromising swimmers technique and velocity (Vezos, Gourgoulis, Aggeloussis, Kasimatis, Christoforidis, & Mavromatis, 2007). It should be noted that there were no significant differences in the SL values between breathing conditions, although speed was slightly decreased when breathing. It appears that competitors with Down syndrome do not change their SL in inspiratory cycles; however, SR decreased in breathing cycles and this was significant on the nonpreferred side. Cardelli et al. (2000) pointed out that less expert swimmers show a longer duration of inhalation than elite swimmers, perhaps interfering with the continuity of their motor coordination.
thus limiting SR and velocity in breathing cycles. These swimmers usually do not train for breathing to their nonpreferred side, therefore differences between breathing patterns could partially reflect lack of familiarity with certain breathing patterns and/or difficulties in taking advantage of their experience. Experienced able bodied swimmers ($N = 11$) did not significantly decrease SR when breathing to the nonpreferred side, nor did they swim significantly slower in this condition (Seifert et al., 2008). The swimmers with Down syndrome examined here had been training on average five sessions per week over 11 months per year and for 3 years. They all had also taken part in international level competition with their peers. For these swimmers, breathing, even to the preferred side, causes disturbance of SR, IdC, and IVV, which are only expanded when breathing to the nonpreferred side. It should be pointed out that the SR of swimmers with Down syndrome is high (greater than 38.4 cycles/min) when compared with the regional level able bodied swimmers of Seifert et al. (2010) at similar speed (25 cycles/min) coupled with an entry catch phase twice the duration of that of swimmers with Down syndrome in our study. The entry catch phase of the inexperienced swimmers studied by Lerda and Cardelli (2003) was also much longer than that of swimmers with Down syndrome at similar maximal speed and IdC values.

Lerda and Cardelli (2003) suggest that there is a greater discontinuity in the arm actions linked to breathing and that breathing laterality causes a lag time between the propulsive actions of the two arms. Therefore, the differences between IVV values in the inspiratory cycles, compared with cycles without breathing, may be due to less continuity of application of propulsive force as well as increases in hydrodynamic drag, which tends to increase the IVV in breathing cycles even more so on the nonpreferred side.

Since velocity is negatively affected by breathing, a change in coordination pattern is needed to avoid a greater IVV. According to Lerda and Cardelli (2003), IdC values decrease when breathing. In the current study, the disturbance caused by breathing indeed changed the arm coordination toward greater catch-up. This again corroborates the findings of Seifert et al. (2005) indicating that less-expert swimmers’ technique is more disturbed by breathing. Breathing also tends to amplify the asymmetry of left and right arm coordination of swimmers with Down syndrome, leading to a catch up coordination of the nonbreathing arm and a superposition of the breathing arm, perhaps to balance the body roll alterations (see Figure 2). This was also found by Seifert et al. (2008) in able bodied sprint swimmers breathing on the nonpreferred side. Somewhat surprisingly, in Seifert at al.’s study, no specific training of nonpreferred breathing or warm up was mentioned. The purpose was to examine the spontaneous adaptations. In the current study, the absolute left-right asymmetry actually decreased slightly when breathing on the nonpreferred side as compared with the able bodied swimmers of Seifert et al. (2008) where the asymmetry increased in this condition.

Swimmers with Down syndrome seem to show less proficient biomechanics, suggesting that both anthropometric and coordinative features might explain the above mentioned differences between swimmers with Down syndrome and those without. This ineffectiveness might also be related to a lack of feel for the water, i.e., the hand tends to slip through the water during propulsion. The hand and forearm are not able to find “grip” in the water to push the body forward. Although swimmers with Down syndrome have a low SR at maximal speed, their maximal speed
is itself low and national level swimmers studied by Seifert et al. (2010) used a 30% lower SR to obtain comparable speeds and with much greater catch up (lower IdC).

Swimming talent is certainly associated with “feel” for the water, since it helps the swimmer selecting the angle of hand attack providing the optimal combination of drag and lift forces at each moment of a pull (Toussaint, Hollander, Berg, & Vorontsov, 2000). In fact, Wakayoshi, D’Acquisto, Cappaert, and Troup (1996) suggested that a breakdown of stroke technique is most likely a result of the swimmer’s inability to maintain a grip on the water, as reflected by the reduced distance covered per stroke, e.g., at the end of a 100 m race. A lack of strength can also be a contributing factor here. The swimmer is not able to maintain a correct arm and hand position because of insufficient strength to overcome the water resistance.

In summary, in swimmers with Down syndrome, biomechanical characteristics of the front crawl movement, namely IVV and IdC, are different than those found for both experienced and less experienced able bodied swimmers in the literature examined under comparable conditions. Both drag and propulsion are affected in swimmers with Down syndrome more than can be expected only from lack of swimming training. These characteristics are further disturbed by breathing and more so when breathing to the nonpreferred side, confirming the hypothesis. There is nevertheless no evidence here that particular characteristics of Down syndrome influence the biomechanical impact of breathing to the unpracticed nonpreferred side more than could be expected from the limited literature results for able bodied swimmers.

**Perspectives**

Although the findings in this study contribute to the characterization of front crawl in trained swimmers with Down syndrome, further studies are needed to complement knowledge in this particular population. It is important to note that this study focused exclusively on competitive swimmers, and these results might not be generalized to persons with Down syndrome who are not experienced swimmers. One limitation of the current study comes from the fact that we do not have a control group and have not assessed the level of cognitive impairment of the swimmers. Recent literature suggests that disturbed coordination is in fact a genetic trait and less related to IQ itself (Mulvey et al., 2011). The swimmers were not used to the swimming pool where this experimental procedure took place, and it is possible that the familiarization might not have been optimal. Furthermore the 2.5% speed accuracy required and checked with a stop watch was not adequate. The swimming speed of the nonbreathing condition was faster than when breathing. It is also a little unusual that all swimmers had the same preferred side to breath since persons with Down syndrome would be expected to show more diversity in this respect. There is no literature regarding handiness and preferred breathing side. In swimmers with Down syndrome, some test of laterality might be of use in future swimming studies.

To develop research in competitive swimmers with disabilities, a longitudinal study could contribute to better assess the effects of technical improvements with obvious reference to the biomechanical parameters analyzed. It is also essential to compare swimmers with Down syndrome with other swimmers of varying expertise as well as noncompetitive swimmers and at varying swimming speeds. Furthermore only arm coordination is dealt with while there is no consideration
of leg kick. A long entry catch phase can be compensated not only by a good push of the opposite arm but by a good explosive leg kick perhaps.

Finally, the majority of studies of swimmers without disability centered their attention on front crawl swimming. Although this is the first study on trained swimmers with Down syndrome, other swimming strokes need to be examined. Finally the study of physiological parameters such as aerobic energy use and lactate kinetics could contribute to knowledge of training control assessment in this population.

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The contribution of the last two authors must be considered equal.

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