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Health related, daily life activity and sports domain characteristics of swimmers with Down syndrome

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I. Querido, A.; Araújo, D.; Soares, S.; Vilas-Boas, J.P.; Corredeiroa, R.; Daly, D.; Fernandes, R. (2012). 100-m freestyle race analysis of the 5th World Down syndrome swimming championship. **Medicine & Science in Sports & Exercise**, 44 (5): S315.

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LX

Abstract

Down syndrome is the most common genetic cause of developmental disability being associated with abnormalities in chromosome 21 and always accompanied with intellectual disability. Information regarding physical activity and sport participation for persons with Down syndrome is scarce. The general objective of this Thesis was to characterize the physical fitness and body composition profile as well as the daily life physical activity of swimmers with Down syndrome. Furthermore, a biomechanical approach was developed to characterize swimmers with this condition, and compare them to swimmers with intellectual disability and swimmers without disability from the literature. The experiments were conducted with the application of several protocols: the Eurofit Special, a physical fitness test for persons with intellectual disability; video analysis, for the race analysis and the biomechanical approach; the pacer, for the pacing analysis; the WalkinSense, for the daily life activity analysis; and the Qualisys for the kinematical analysis. Results indicated that (i) persons with Down syndrome have less power, less cardiovascular fitness and higher body mass index in comparison to persons with intellectual disability and non disabled; (ii) swimmers with Down syndrome have healthier body composition profiles and present higher levels of physical fitness than untrained peers with the same impairment; (iii) a classification system from the International Paralympic Committee should include the evaluation of the physical fitness profile and the body composition of swimmers with Down syndrome and swimmers with intellectual disability; (iv) Swimming training seems to improve BMI, Fat % and lean body mass, as well as physical fitness condition (especially upper and lower strength) of swimmers with Down syndrome; (v) male swimmers with Down syndrome are faster than female counterparts but both are considerably slower than swimmers without disability and swimmers with intellectual disability; (vi) swimmers with Down syndrome seem to have problems with pacing, both on training and in competition and are not able to take advantage of short term visual feedback to maintain a pacing strategy; (vii) swimmers with Down syndrome present coordinative and efficiency problems on the water. (viii) swimmers with Down syndrome swim at

slower maximum speeds and present lower anthropometric characteristics than intellectual disabled swimmers. This analysis allowed providing new insights on training for persons with Down syndrome and on the current classification system for these swimmers.

Key words: Dow syndrome, swimming, physical fitness, performance, biomechanics.

Resumo

O síndrome de Down é a causa genética mais comum de deficiência do desenvolvimento e está associada a anormalidades no cromossoma 21 e a deficiência intelectual. As informações sobre a participação de pessoas com síndrome de Down em atividades físicas e desporto são escassas. O objetivo geral desta tese foi caracterizar a aptidão física e perfil de composição corporal, bem como a atividade física na vida diária de nadadores com síndrome de Down. Além disso, foi desenvolvida uma abordagem biomecânica para caracterizar nadadores com essa condição e compará-los com nadadores com deficiência intelectual e nadadores sem deficiência referenciados na literatura. Os momentos experimentais foram realizados com a aplicação de vários protocolos: o *Eurofit special*, um teste de aptidão física para pessoas com deficiência intelectual; análise de vídeo para a análise de prova e a abordagem biomecânica; a análise de *pacing*; o WalkinSense, para análise da actividade física da vida diária; e a Qualisys, para análise cinemática. Os resultados indicaram que (i) as pessoas com síndrome de Down têm menos potência, aptidão cardiovascular e maior índice de massa corporal em comparação com pessoas com deficiência intelectual e pessoas sem deficiência; (ii) os nadadores com síndrome de Down têm perfis saudáveis composição corporal e apresentam níveis mais elevados de aptidão física do que seus pares não treinados com a mesma deficiência; (iii) o sistema de classificação do Comité Paralímpico Internacional deve incluir a avaliação do perfil de aptidão física e composição corporal de nadadores com síndrome de Down e nadadores com deficiência intelectual; (iv) o treino de natação parece melhorar o IMC, Fat% e a massa corporal magra, bem como a condição física (especialmente superior e inferior força) de nadadores com síndrome de Down; (v) os nadadores do sexo masculino com síndrome de Down são mais rápidos do que colegas do sexo feminino, mas ambos são consideravelmente mais lento do que os nadadores sem deficiência e os nadadores com deficiência intelectual; (vi) os nadadores com síndrome de Down parecem ter problemas com ritmo, tanto em treino como em prova e não são capazes de tirar proveito do feedback visual a curto prazo para manter uma estratégia de prova; (vii) os nadadores com síndrome

de Down apresentam problemas coordenativos e de eficiência; (viii) os nadadores com síndrome de Down nadam a velocidades mais lentas do que os nadadores com deficiência intelectual e apresentam piores características antropométricas. Esta análise permitiu fornecer novas luzes sobre o treino para as pessoas com síndrome de Down e sobre o sistema de classificação atual para estes nadadores.

Palavras-chave: Síndrome de Down, natação, aptidão física, desempenho, biomecânica.

Chapter 1. General Introduction

Down syndrome is a genetic condition, also known as trisomy 21, and is the most common genetic cause of developmental disability (Hayes & Batshaw, 1993). This condition is associated with abnormalities in chromosome 21 and is always accompanied with intellectual disability (Epstein, 1990; González-Agüero et al., 2010). Although the triplication of the chromosome is the most common defect, translocation and nondisjunction are also described (Pueschel, 1990). The overexpression of genes associated with Down syndrome affect almost every organ system and results in a wide spectrum of phenotypic consequences and in a typical physical phenotype, defined principally in terms of the characteristic facies, hands and feet, congenital heart defect and intellectual disability (Epstein, 1990).

A global estimation of the incidence of Down syndrome is 1 in 800 to 1 in 1200 live births (WHO 2009). The most important risk factor for a Down syndrome birth is the mothers' age. The chances for having a Down syndrome baby increase significantly with advancing maternal age (1/365 at 35 years of the mother and 1/30 at 45 years) (Newberger, 2000). With advances in medical knowledge, Down syndrome infant survival rates, as well as life expectancy in general, continues to increase (Weijerman et al., 2008), being now expected to live longer (Wu & Morris, 2013).

Despite increased longevity, motor impairments related to this condition result in people with Down syndrome being considered fragile and not suited for sporting activities (Perán et al. 1997). Children and adolescents with Down syndrome have been shown to be less active (Sharav & Bowman, 1992) and with higher prevalence of overweight and obesity (Soler & Xandri, 2011). On the other hand, information regarding physical activity in persons with Down syndrome is limited and inconclusive (Frey et al., 2008). Actually, no specific guidelines for adolescents with Down syndrome which take into account impairments such as muscle hypotonicity, low cardiovascular fitness and decreased muscle strength

have been developed (González-Aguero et al., 2010; Matute-Llorente et al., 2013).

In the general population, it is known that physical activity and sport participation results in many health benefits. In children and adolescents, physical activity improves cardiovascular fitness, contributes to a healthier lifestyle and delays cell aging by enhancing the antioxidant defense system (Vicente-Rodriguez et al., 2005; Stewart et al., 2003; Franzoni et al. 2005). Additionally, benefits in social factors associated with sport participation have also been described (Andriolo et al., 2005). In Down syndrome, low levels of physical fitness may induce functional deterioration due to an increase in the prevalence of overweight or obesity, as well as a reduction in bone mass development, which may ultimate result in the aggravation of their clinical manifestations (González-Aguero et al., 2010) (Figure 1).

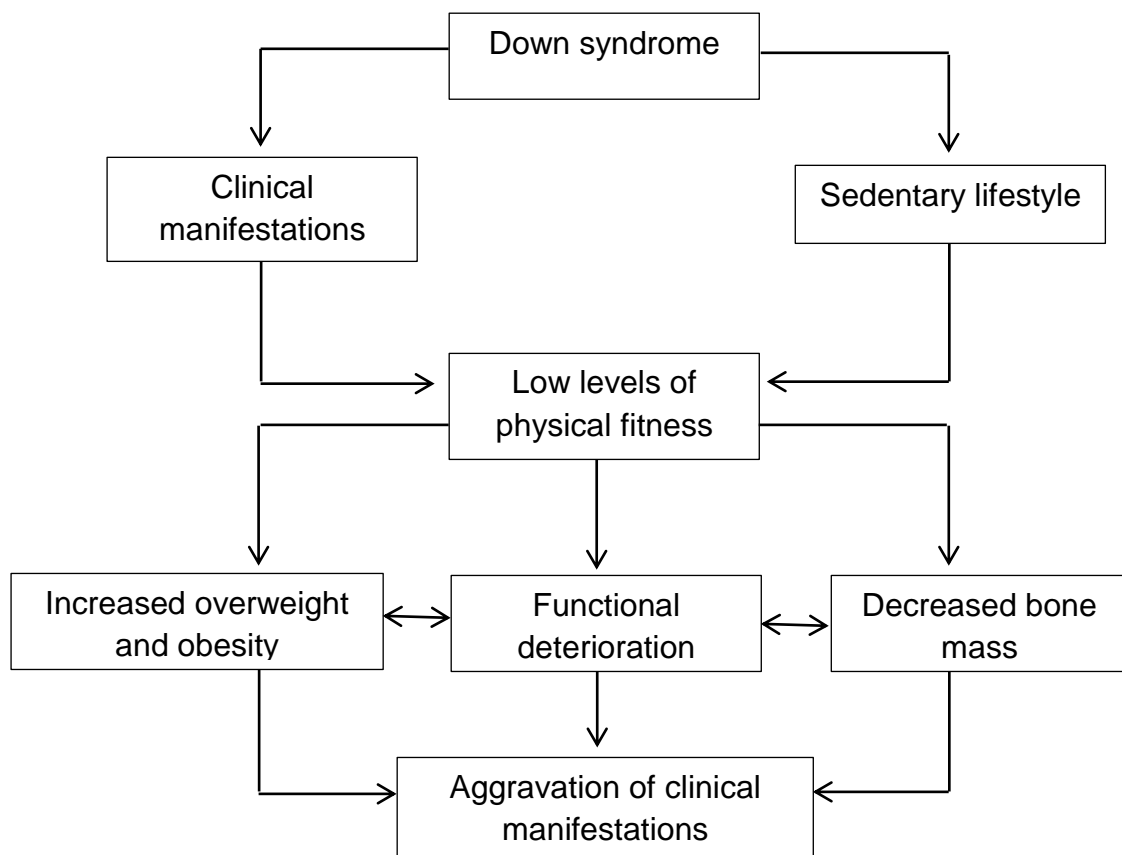


Figure 1. Relationship between Down syndrome, physical fitness and clinical manifestations. Adapted from González-Aguero et al. (2010).

Furthermore, higher levels of physical fitness (especially strength) are fundamental abilities needed by persons with Down syndrome, as their workplace activities might typically emphasize physical rather than cognitive skills (Shields et al. 2010). Muscle weakness also impacts their ability to perform everyday activities, including walking, eating, dressing, and rising from a chair (Carmeli et al. 2002; Cowley et al. 2010). As life expectancy increases in persons with Down syndrome (Glasson et al. 2002), the development and maintenance of muscle strength will become even more important to lead productive lives (Croce et al. 1996).

Accordingly to Van de Vliet et al. (2006), sport is meaningful and important in the lives of many people, including those with intellectual disability and like other members of the society, there are several different reasons for persons with intellectual disability to participate in sport. For some persons, the transition from recreational sport to intensive training and competition is a natural progression for testing personal limits and pursuing athletic dreams and goals. Nevertheless, research has been focusing essentially at inactive participants (Fernhall & Pitetti 2001), while trained individuals are scarcely studied (Van de Vliet et al. 2006).

A deep knowledge of physical fitness, technical and social skills acquisition and overall functioning are needed to effectively include persons with intellectual disabilities in competitive sports (Mactavish & Dowds, 2003). Accordingly to Van de Vliet et al. (2006), these components can be represented in a triangle: the physical potential (physical fitness and skill proficiency), the cognitive potential ("intelligence") and sports performance (the product of the physical and the cognitive potentials). For these authors, the causal relationships between these components should be studied to better understand the sports potential of athletes with intellectual disability.

Persons with Down syndrome can swim at an International level. The International Paralympic Committee (IPC) includes these athletes in the S14 Class, intended for athletes with intellectual disabilities. Accordingly to the World Health Organization (2010), intellectual disability means a significantly

reduced ability to understand new or complex information and to learn and apply new skills (impaired intelligence). This results in a reduced ability to cope independently (impaired social functioning), and begins before adulthood, with a lasting effect on development. Disability depends not only on a child's health conditions or impairments but also and crucially on the extent to which environmental factors support the child's full participation and inclusion in society. The diagnostics of intellectual functioning and adaptive behavior must be made using internationally recognized and professionally administered measures as recognized by INAS (International Federation of sport for athletes with intellectual disability). This Movement adopted the definitions for the eligible impairment types as described in the World Health Organization International Classification of Functioning, Disability and Health (World Health Organization, 2001).

The diagnosis and eligibility of the swimmers will allow them to be included in the competition Classes. This process is called classification and it exists to try to minimize the impact of impairments on a determined sport. The main idea is that this system, that is sport-specific, can ensure a fairer competition, where winners are the ones that present better fitness, skills, tactics and psychological characteristics (<http://www.paralympic.org/swimming/classification>).

In some Paralympic sports, the athletes' disabilities are visible (e.g. running on blades, using a wheelchair, not having the legs), but when it concerns to intellectual disabilities, they are invisible, making them harder to classify. The Paralympic participation of athletes with intellectual disabilities started in the Paralympic Games of Atlanta 1996. After Sydney 2000, the IPC expelled the intellectual disabled from the Paralympic competitions, since it was found proved that at least most part of the Spanish basketball team from Sydney 2000 did not meet the accepted criteria for intellectual disability. For the IPC a more reliable system was needed to prove the intellectual disability of the athletes (<http://www.bbc.com/news/magazine-19371031>). At present, swimming has an updated classification system in place including a cognitive test and competition observation but work is in progress to make this better.

As referred above, persons with Down syndrome have several characteristics, among them intellectual disability. Additionally, their condition implies a genetic cause that can be shown by the karyotype. In this way, the “invisibility” mentioned above does not apply to these athletes. The questions with the recent reentry of the intellectual disabled into Paralympic competition are: (i) does Down syndrome *per se* justifies the creation of a new Sport Class – the S21 Class, since they are virtually absent at IPC competitions?; (ii) are swimmers with Down syndrome affected by their condition in a way that makes them sufficiently different from the present S14 Class? If they are, is it fair that they continue to be included in the S14 Class?

To better understand the physical and cognitive potential of swimmers with Down syndrome discussed above the current Thesis aims to characterize swimmers with Down syndrome, in terms of health related and daily life physical activity and to compare them with control groups of untrained persons or other athletes with Down syndrome as well as literature results. Furthermore, a biomechanical approach was developed to characterize swimmers with this condition, and compare them to swimmers with intellectual disability with similar training experience as well as with the existing literature for both swimmers with intellectual disability and non-disabled swimmers. Experiments and measurements were conducted and presented in **Chapters 2 to 7** of this thesis. In **Chapter 8**, a general discussion is presented based on the results from our studies, combined with the reports of the specialized literature. The main conclusions and references are presented on **Chapters 9 and 10**, respectively.

Considering that physical fitness may be an important contributor to the performance, **Chapter 2** presents a systematic review on physical fitness and training in persons with Down syndrome. The purpose of this Chapter was to give the present state of knowledge on physical fitness and body composition in trained persons with Down syndrome. It was also our intention to examine how these parameters could impact the performance of competitive athletes with this impairment.

Race analysis has been widely accepted in the scientific and coaching community and swimming competition analysis has become a regular feature at most international swimming events, but competitive swimming for Down syndrome seems to be years behind in this aspect (Querido et al., 2012). **Appendices I and II** present results of this kind of approach, with the 100 m freestyle and 200 m backstroke race analysis of an International swimming championship for Down syndrome. In **Chapter 3**, a race analysis of two international swimming championships for Down syndrome is presented, to understand the race behavior of the freestyle events of swimmers with Down syndrome in international competitions. This type of analysis that has been widely used for swimmers without disabilities, allow us to compare the biomechanical race performance of swimmers with Down syndrome with others without disabilities and with intellectual (non-Down syndrome) and motor impairments. The race speed differences among Olympic and Paralympic swimmers with intellectual disability are determined by physical aptitude, fitness (training), use of correct techniques (knowledge) and adapting optimal race patterns (experience). Also, suitable nutrition and rest as well as proper training conditions are necessary to achieve a maximal level of performance (Daly et al. 2006).

The race analysis presented on this Thesis leads that, in fact, differences in race performance can be observed between swimmers with Down syndrome and swimmers with intellectual disability or swimmers without impairment. After observing that much more research is needed in trained persons with Down syndrome, in **Chapter 4**, a study was conducted regarding the body composition and physical fitness levels of swimmers with Down syndrome. In this study, two populations of persons with Down syndrome (swimmers and untrained) were tested to verify if swimmers with Down syndrome are healthier than untrained persons with the same impairment. As this was not a cross-sectional study, in **Appendix III** a small longitudinal study with 6 swimmers with Down syndrome that were evaluated for body composition and physical fitness in 2011 and 2014 is presented.

In fact, swimming practice seems to positively impact the swimmers body composition and physical fitness profile. Taking into consideration the particular characteristics of this population, it was our intention to get more information on the daily life of people with Down syndrome. Are these persons also active at their day-to-day lives? Do they meet the recommended criteria for physical daily activity? Before this study could be conducted, a validation study about the reliability and the accuracy of spatial-temporal gait parameters measured by a new device called the WalkinSense® was developed and presented on **Appendix IV**. This device was used in a study from **Chapter 5**, where 3 groups of persons with Down syndrome (international level competition, recreational training and control group of untrained individuals) were evaluated for five consecutive days and their daily life activity physical activities as well as some anthropometric variables were compared between groups.

One of the considerations of this Thesis is attempting to understand if swimmers with Down syndrome should be kept in the same classification Class as swimmers with intellectual disability. As mentioned above, before a Class separation occurs, a clear demonstration that how characteristics of Down syndrome can impact on their performance, must be made. **Appendix V, VI and VII** focused on coordination issues for swimmers with Down syndrome. Results from these studies seem to reflect the lower coordinative development and technical efficiency of swimmers with Down syndrome. The catch-up coordination mode found in swimmers with Down syndrome for front crawl, along with the higher intra-cyclic velocity fluctuation when compared to non-disabled swimmers demonstrate their inability to maintain continuous propulsive actions and lower swimming ability. Also with the same purpose, the study conducted in **Chapter 7** evaluated swimmers with Down syndrome (Class S21) and intellectual disability (Class S14) with a motion analysis system (Qualisys AB, Gothenburg, Sweden) in 3 x 25 m maximum speed freestyle to evaluate kinematic intra and inter variability. These swimmers were also evaluated and compared for anthropometrics measurements, since these parameters may influence their swimming parameters.

Race strategy is, in our view, another important parameter related to performance and might be a potential problem to athletes with intellectual disability, namely Down syndrome. Concerning the pacing ability, **Chapter 6** focused on the need to understand if swimmers with Down syndrome are able to pace (in training and competition). Eight swimmers with Down syndrome participated in this study, all participants at the 2nd European Swimming Championships for Down syndrome. All swimmers performed a 4x100 m front crawl incremental protocol at 75%, 80%, 85%, and 90% of best time for a 100 m race. Each 100 m was divided in 2x50 m with a 10 sec rest. The first 50 m were conducted with a visual pacer and the second 50 m without, where the swimmer was asked to maintain the speed of the first 50 m. Despite the need of further work in this kind of analysis, this was a first important step and we suggest that potentially, this simple test might be used in a classification test, not only for those with Down syndrome but for persons with other intellectual disabilities.

Therefore, taking into consideration the purposes of this Thesis, the following hypothesis were presented:

- (i) Swimmers with Down syndrome present higher levels of physical fitness and lower values of weight, BMI and fat% than untrained peers.
- (ii) Swimmers with Down syndrome present lower levels of physical fitness and higher values of weight, BMI and fat% than athletes with intellectual disability but not Down syndrome and athletes without disability.
- (iii) Trained individuals with Down syndrome have a more active daily life than recreational and untrained persons with the same condition.
- (iv) Men swimmers with Down syndrome are faster than female counterparts in all race components.

- (v) Men swimmers with Down syndrome are technically more efficient than woman in race components as well as with the stroke rate and stroke length relationship.
- (vi) Swimmers with Down syndrome are, in general, slower than swimmers with intellectual disability and swimmers without disability.
- (vii) Swimmers with Down syndrome present different lap strategy for speed, stroke rate and stroke length than swimmers with intellectual disability and swimmers without disability.
- (viii) Swimmers with Down syndrome have difficulties in following a visual pacing light and are not able to maintain the same speed requested by the pacer without the visual stimulus.
- (ix) Swimmers with Down syndrome swim slower and present different coordination modes and intracyclic velocity variation at maximal speeds than swimmers with intellectual disability.
- (x) Swimmers with Down syndrome present a higher intra-subject variability in biomechanical parameters of speed, stroke rate, stroke length, index of coordination and intracyclic velocity variation than swimmers with intellectual disability swimming at maximal speed.

Chapter 2.

Physical fitness and training characteristics in persons with Down syndrome: a systematic review

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Abstract

Background Persons with Down syndrome are often thought to be incapable of improve their strength and cardiovascular levels, and, therefore, their body composition. The aim of this study was to conduct a systematic review to examine how strength, endurance and body composition might differ in persons with Down syndrome and how these components might be influenced by training. *Method* A search on PEDro, PubMed, SPORTDiscus, Cochrane Library, PsycINFO (OvidSP), ScienceDirect, SpringerLink, Web of Science and Willey Online Library was performed to identify all relevant studies published between 1990 and 2016 on cardiovascular fitness, muscle performance and body composition on persons with Down syndrome. Methodological quality was assessed using the SIGN 50 assessment forms. *Results* One hundred and ninety three potentially relevant studies were identified and 36 were accepted for this review. High methodological quality was found in 15 studies, medium quality in five and low quality in only one study. Heterogeneity among studies in number of subjects, age of the subjects, sample size, period of intervention and reported outcomes made it hard to make an extensive meta-analysis. *Conclusions* Training imposes beneficial effects in strength, endurance and body composition in people with Down syndrome. It is also suggested that values of strength, endurance and body composition are lower in people with Down syndrome. There is further need for qualitative research to determine the exact training effects in persons with Down syndrome.

Keywords: Strength, cardiovascular fitness, body composition, Down syndrome, systematic review.

Introduction

Down syndrome (DS), also known as trisomy 21, is the most common genetic cause of developmental disability, characterized by intellectual disability (ID) and associated metabolic plus musculoskeletal disorders (Hayes & Batshaw 1993). The global estimation of the incidence of DS is 1 in 800 to 1 in 1.200 live births, but with advancing maternal age, the chances for having a DS baby increase significantly, being the most important risk factor (Newberger 2000). A physically active lifestyle is not always common in people with DS, although it is known that regular physical activity is fundamental for general health and well-being in people with and without this condition. In fact, this population often demonstrates a sedentary lifestyle, associated with obesity and lower levels of physical activity and fitness, with sedentary behavior, muscle weakness and hypotonia, higher prevalence of heart defects and circulatory abnormalities, lower maximal heart rate and pulmonary abnormalities (Dodd & Shields 2005).

Physical fitness can be seen as an umbrella term incorporating muscular strength, cardiovascular fitness, body composition and flexibility characteristics, referring to the ability to perform moderate levels of physical activity without undue fatigue (Pollock et al. 1998). Persons with ID have been found to have particularly low levels of cardio respiratory fitness, with young adults with ID (20-30 years old) typically exhibiting cardio respiratory fitness levels comparable to 30-40 years older persons without this condition, or that have suffered a myocardial infarction (Pitetti et al. 1992, Fernhall et al. 1996). Their peak oxygen uptake (VO_{2peak}) is often reported to be between 25-30 $ml.kg^{-1}.min^{-1}$ (Pitetti & Tan 1990), meaning that the low levels of cardio respiratory capacity may impact both their health status and their vocational productivity. In fact, aerobic capacity has also been related to job performance in this population and studies on cardio respiratory capacity in individuals with DS consistently showed cardiovascular fitness levels than persons without DS (Pitetti et al. 1992, Fernhall et al. 1989, Pitetti et al. 1988).

Muscular strength is an essential component for overall health as well and for improving vocational productivity and independence in daily living activities in individuals with ID (Pitetti et al. 1992), with adults with ID have been reported as having lower isokinetic upper limbs strength than sedentary non-disabled adults

(Pitetti et al. 1992). The motor dysfunction in individuals with DS involves impaired muscle control, frequently referred to as “clumsiness” by parents and health professionals (Latash & Corcos 1991), with its neuropathological basis in DS being still unknown. However, cerebellar dysfunction, delayed myelination, as well as proprioceptive and vestibular deficits, have been suggested as possible causes and the delay in motor development is linked to the generalized muscle hypotonia and ligament laxity that causes functional weakness (Galli et al. 2008).

The prevalence of overweight and obesity in adults with ID is reported to be higher than in the general population, with a prevalence of obesity between 10 and 26%, higher in women than men and increasing with age (Pitetti et al. 1992, Fernhall et al. 1996). Studies looking specifically at persons with DS have found an even higher prevalence of obesity, suggesting that overweight and obesity are more prevalent in adults with this condition than in peers without it (Melville et al. 2005). Moreover, it is commonly known that people with DS perform less in sports comparing to their counterparts without DS, but the number of studies is still scarce. The purpose of this review was to document the factors that have an impact or influence on the fitness and performance level of people with DS with accent on strength, cardiovascular fitness and body composition.

Methods

Literature search

The databases of PEDro, PubMed, SPORTDiscus, Cochrane Library, PsycINFO (OvidSP), ScienceDirect, SpringerLink, Web of Science and Willey Online Library were searched to identify all possible relevant studies for this review. The combinations of keywords used to search the databases were Down syndrome, Trisomy 21, Mongols, mental retardation, intellectual disability, strength, force, muscular performance, endurance, aerobic capacity, flexibility, range of motion, VO₂, oxygen uptake, cardiovascular capacities, cardiorespiratory capacities, physical fitness, BMI, fat percentage, anthropometry, obesity, body composition and overweight, with limits being human, published between 1990-2016 and English language. Reference lists were checked and in some cases the authors were contacted by e-mail if only the abstract was available.

Inclusion criteria

Inclusion criteria were defined using the PICO model: (i) population (people with the medical diagnose of DS, with persons with intellectual disability but without DS were excluded because they are physically different and react differently on physical load than Down syndrome persons); (ii) intervention (all types of intervention related to muscle training, cardiovascular fitness training, body composition and flexibility); (iii) control/Comparison ((non-) randomized controlled trials (RCT's), case-control studies (CCS)); and (iv) Outcome (parameters of cardiovascular fitness (VO₂, Ventilation), muscle performance (power, muscle endurance), body composition (fat percentage, fat free mass)). Exclusion criteria are mentioned in the flow chart (Figure 1).

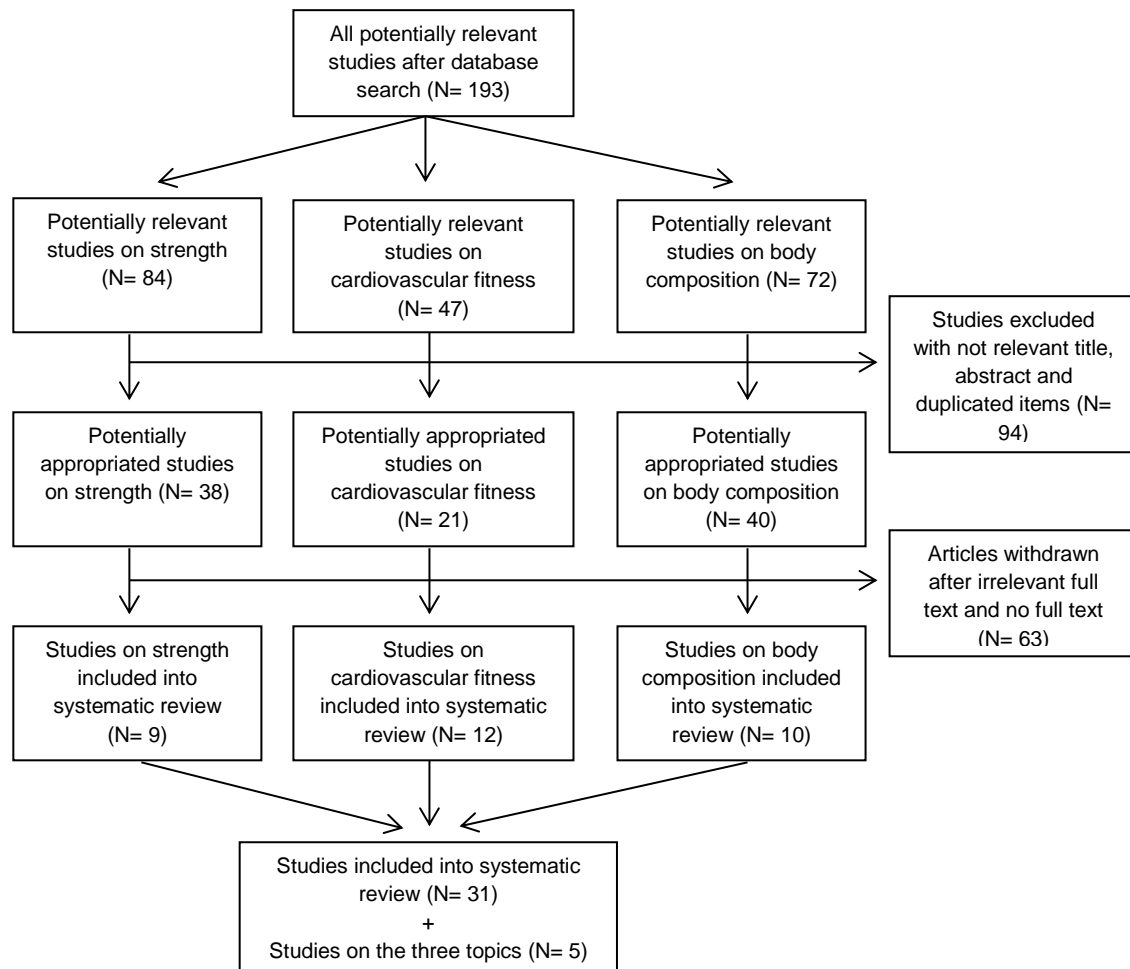


Figure 1 - Flowchart showing selection of studies from all potentially relevant studies to studies on strength, cardiovascular fitness, body composition and the three topics, included in the current systematic review.

Quality assessment

All the databases were examined using the search criteria, with a total of 193 studies identified and inspected. After reading the titles and abstracts, all irrelevant and duplicated were excluded and 99 works remained relevant for the current review (Figure 1). Based on the abstracts, full texts and excluding studies (without full text), 63 more were excluded and 36 studies were identified as relevant for this review. Of these, nine were on strength, 12 about cardiovascular fitness, 10 regarding body composition and five studies related to the three main topics.

Studies were further evaluated using the Scottish Intercollegiate Guidelines Network (SIGN 50) assessment forms that consist of three sections: the first identifies internal validity through eleven elements, the second considers overall assessment of the study (bias) in three elements and the third gives a description of important data of the study with eleven elements. The articles were quoted with a “++” (all or most of the criteria have been fulfilled and where they have not been fulfilled, the conclusions of the study are thought very unlikely to be altered), “+” (some of the criteria have been fulfilled and that those criteria that have not been fulfilled or not adequately described are thought unlikely to alter the conclusions) or “-“ (few or no criteria have been fulfilled and the conclusions of the study are thought likely or very likely to alter).

Results

A total of 36 studies were accepted for this review, nine of which were about strength (Table 1), being seven RCT's and two CCS. Then, 12 studies were about cardiovascular fitness (Table 2a, b), involving five RCT's and seven CCS). In addition, there were 10 studies about body composition in this review (Table 3a, b), being three RCT's and seven CCS. Finally, five studies focused on all of the three components (Table 4), with one RCT and four CCS.

Studies' samples ranged from 14 (Millar et al. 2013) to 1774 (Al Husain 2003), with a mean age starting at approximately five years (Al Husain 2003, Grammatikopoulou et al. 2008) and reaching 64 years (Carmeli et al. 2002). Of the CCS, 10 made a comparison between DS and non-disabled persons (Al Husain

2003, Izquierdo-Gomes et al. 2013, Izquierdo-Gomez et al. 2015a,b, Luke et al. 1996, Matute-Llorente et al. 2013, Melville et al. 2005, Mercer et al. 2001, Pitetti et al. 1992, Samarkandy et al. 2012), two made a comparison between DS and ID subjects (Fernhall et al. 1996, Pitetti et al. 2004), three compared DS with both ID and non-disabled persons (Angelopoulou et al. 2000, Bell et al. 2007, Wee et al. 2015) and four made comparisons in-between research and control groups with DS (Grammatikopoulou et al. 2008, Mendonça et al. 2010, Pastore et al. 2000, Terblanche & Boer 2013).

Methodological quality

High quality was found in 28 studies, of which nine are on strength, nine on cardiovascular fitness, six on body composition and four covering all the referred topics. Medium quality was found in seven studies, of which three included the topic cardiovascular fitness, three body composition and one all the topics. There was only one study with a low quality, focusing on the topic body composition (Al Husain 2003).

Strength

The outcomes of all studies concerning strength in persons with DS can be found in Table 1. The number of participants was variable, with four studies with relatively small sample sizes (from 20 to 26) and five with larger ones (from 30 to 92). Most of the intervention programs took 10 to 12 weeks, with only one study during 6 weeks (Lin & Wang 2012) and another with the duration of 6 months (Carmeli et al. 2002). In general, we can assume positive results for people with Down syndrome after strength training, although a difference in basic strength between persons DS and ID or non-disabled ones, in disadvantage for the DS people was also observable. No study has yet shown that persons with DS achieve levels of strength seen in able bodied persons of similar age.

Cardiovascular fitness

In table 2_{a+b} the outcomes of all selected articles on cardiovascular fitness in people with DS can be found. It is observable a discrepancy between the number of participants in these studies, with nine presenting sample sizes bellow 100

persons (from 14 to 42) and three studies with more than 100 participants (from 111 to 654). There were three RCT's with interventions of 10-12 weeks (Mendonça et al. 2013, Millar et al. 2003 and Ordonez et al. 2013), one with 16 weeks (Varela et al. 2001) and one with 28 weeks interventions (Mendonça et al. 2009). Despite contradictory results, we can assume a benefit in cardiovascular fitness in people with DS, after a cardiovascular intervention, and in post intervention testing time, even though persons with DS perform less in cardiovascular exercises in comparison to ID people and subjects without disabilities.

Body composition

In Tables 3_{a+b} it is possible to observe the outcomes of all studies on body composition in people with DS and, as for the cardiovascular fitness, studies on body composition presented a large variety of sample sizes, ranging between 20 to 1774 participants. The RCT's varied between 12 weeks (Ordonez et al. 2006), 20 weeks (González-Aguero et al. 2013) and 6 months (Curtin et al. 2013). Overall, these three studies found improvements in body composition after the intervention programs, however persons with DS tend to have a greater BMI than people without it, although not all studies found significant differences when compared to other groups.

Physical fitness

Table 4 refers to studies that focused on the components of strength, cardiovascular fitness and body composition. The only RCT concluded that 12 weeks of a combined cardiovascular and strength training caused a significant improvement in cardiovascular, strength and body composition parameters (Rimmer et al. 2004) and all of the three CCS from Izquierdo-Gomez et al. (2013, 2015a,b) emphasize the fact that persons with DS presented lower values for fitness and higher values for body composition variables than their matched peers without DS.

Table 1. Outcomes of selected studies concerning strength in persons with Down syndrome, with type of studies, methodological quality, outcome measures, samples characteristics, intervention programs and significant results.

Study	Shields et al. (2010)	Angelopoulou et al. (2000)	Shields et al. (2008)	Carmeli et al. (2002)	Mercer et al. (2001)	Lin & Wang (2012)	Rosety-Rodriguez et al. (2013)	Shields et al. (2013)	Emara (2016)
Type of study	RCT	Case-control	RCT	RCT	Case-control	RCT	RCT	RCT	RCT
SIGN	++	++	++	++	++	++	++	++	++
Outcome measures	IRM chest press and leg press (kg), timed up and down chair test (s), grocery shelving task (s)	Bone mineral density (g/cm ²), isokinetic muscle strength (Nm)	IRM, muscle endurance (# x 50% of IRM) chest and leg press, timed stairs test (s), grocery shelving task (s)	Peak torque (Nm), peak torque % body weight (Nm/kg), timed up and go test (s)	Peak torque (Nm)	Muscle strength: hip flexors, hip extensors, jip abductors, knee flexors, knee extensors, ankle plantarflexor (lb)	Inflammatory cytokines, fat-free mass, waist circumference	Work task performance, muscle strength and physical activity levels	Muscle strength: hip flexors, hip extensors, jip abductors, knee flexors, knee extensors, ankle plantarflexor (N)
Follow-up	12 weeks	/	11 weeks	6 months	/	/	/		
Subjects (N)	23	26	20	26	34	92	40	68	30
- Intervention 1	11	8	9	16	17	46	24	34	15
- Intervention 2	/	8	/	/	/	/	/	34	
- Control	12	10	11	10	17	46	16	34	15
Drop-out	1 (control)	None	None	None	None				
Inclusion criteria	Down syndrome, 13-18 yr, follow simple instructions in English, fit and well enough to participate	Down syndrome	Down syndrome	Elderly persons with MR and Down syndrome	Down syndrome, 7-15 years, age and gender matched typically developed peers	age 13–18 years and current high school enrollment, diagnosis of DS by board-certified physician, able to follow simple instructions	Male adults with DS, with medical approval for physical activity participation.	Adolescents or young adults with DS aged 14-22 yr, mild to moderate ID, follow simple instructions in English, fit and well enough to participate	Children with DS, authorized for the practice of physical exercise
Age (years)							27.3±3.1		
- Cases 1	15.9±1.5	23.88±4.22	28.8±5.4	63.5±2.0	11.2±2.4	15.6±3.6		17.7±3.4	10.877±0.523
- Cases 2		23.50±3.59	/	/	/				
- Controls	15.3±1.7	25.00±3.30	27.6±9.5	63.3±4.8	11.1±2.4	14.9±3.9		18.2±2.8	10.927±0.581
Gender								38 ♂, 30 ♀	
- Cases	8 ♂, 3 ♀	All males	7 ♂, 2 ♀	6 ♂, 10 ♀	6 ♂, 11 ♀	21 ♂, 25 ♀	All males	19% males	9 ♂, 6 ♀

- Controls BMI	9 ♂, 3 ♀	All males	6 ♂, 5 ♀	4 ♂, 6 ♀	6 ♂, 11 ♀	22 ♂, 24 ♀	26.2±2.8	19% males	8 ♂, 7 ♀
- Cases	25.5±4.4	/	/	/	/	/			26.246±1.331
- Controls	24.0±3.2	/	/	/	/	/			26.25±1.218
Intervention	10 week progressive resistance training, 3 exercises for upper limb, 3 for lower limb	/	10 week progressive resistance training, 3 exercises for upper limb, 3 for lower limb	6 months walking program	/	6 weeks treadmill exercise for 5 min and VR-based exercise program for 20 min, with 10 min break in between	12 week resistance circuit training, with 6 stations. Exercise intensity based on 8RM assessment	10 week progressive resistance training. 3 exercises for upper body, 3 for lower body and 1 for trunk	12 weeks of whole body vibration and physical therapy program
Control	Continued their usual activities	/	Continued their typical daily activities	/	/	/	/	Social program for 10 weeks, once a week	Physical therapy program 3xweek for 12 weeks
Treatment duration	3 x 12 repetitions, 2 times/week for 10 weeks	/	2 to 3 x 10 to 12 repetitions, 2 times/week for 10 weeks	10 to 15 min 3 x week for 25 weeks	/	3 x 35 min sessions a week for 6 weeks	2 series of 6 stations 3 x week for 12 weeks	3 x 12 repetitions of 7 exercises for 10 week, 2x week	3xweek for 12 weeks
Outcome/results (significant)	Lower limb muscle strength +42% improvement in experimental group (MD 36kg, 95% CI 15-58, SMD 0.7). 1RM leg press -15% in comparison to normal subjects.	Isokinetic muscle strength of quadriceps: mean +63% DS vs ID, +129% DS vs control. Harmstrings: +37% DS vs ID, +107% DS vs control.	Upper limb endurance: +73% exp. group (MD 16.7 rep., 95% CI 7.1 – 26.2, p<0.01), upper limb strength: +25% exp. group (MD 8.6kg, 95% CI - 1.3 – 18.5, p= 0.08), upper limb function: + 21% exp. group (MD - 20.3s, 95% CI - 45.7-5.2, p= 0.11.	Knee extension: ♂ +19%, ♀ +23.3%. Knee flexion: ♂ +30.3%, ♀ +67.4%. Walking distance, speed and duration: +180%, +86% and +150%, respectively (p<0.05).	Hip abductor: mean +56% power in normal subjects. Knee extensor: mean +93% power in normal subjects.	Group differences for: hip flexors (F _{1,90} = 6.90, p= 0.01, d= 0.57); hip extensors (F _{1,90} = 5.80, p= 0.02, d= 0.51); hip abductors (F _{1,90} = 8.61, p= 0.004, d= 0.59); knee flexors (F _{1,90} = 4.92, p= 0.03, d= 0.86); knee extensors (F _{1,90} = 4.78, p= 0.03, d= 0.89) and ankle plantarflexors (F _{1,63} = 6.67, p= 0.01, d= 0.51).	The intervention group improved performance in TGUG test (8.7±1.4 vs 7.5±1.3s; p=0.362), fat-free mass (69.9±3.2 vs 71.3±3.0%; p=0.011) and waist circumference (93.8±2.7 vs 92.7±2.5cm; p=0.0416) significantly changed after the training program.	21% increase in upper limb and 30% in lower limb strength compared to control group at week 11.	Significant increase of the strength in all the muscle groups after intervention. More improvement in favor of the study group (p< 0.05).

Table 2a. Outcomes of selected studies concerning cardiovascular fitness of persons with Down syndrome, with type of studies, methodological quality, outcome measures, samples characteristics, intervention programs and significant results.

Study	Fernhall et al. (1996)	Pastore et al. (2000)	Pitetti et al. (2004)	Millar et al. (2003)	Varela et al. (2001)	Mendonça et al. (2009)
Type of study	Case-control	Case-control	Case-control	RCT	RCT	RCT
SIGN	++	+	++	+	++	+
Outcome measures	VO ₂ (ml.kg ⁻¹ .min ⁻¹), minute ventilation (l.min ⁻¹), heart rate (bpm), respiratory exchange ratio (RER)	Forced vital capacity, first-second forced expiratory volume, peak expiratory flow	Running performance (20m shuttle run test, 20MSRT)	Ventilation (l.min ⁻¹), VO ₂ (ml.kg ⁻¹ .min ⁻¹), heart rate (bpm), respiratory exchange ratio (RER), time and grade to exhaustion (min)	Ventilation (l.min ⁻¹), VO ₂ (ml.kg ⁻¹ .min ⁻¹), heart rate (bpm), respiratory quotient (VCO ₂ .VO ₂ ⁻¹), time performing test (min), distance travelled (m)	Fat mass (%), fat free-mass (%), locomotory economy (LE), respiratory exchange ratio (RER), VO ₂ (ml.kg ⁻¹ .min ⁻¹)
Follow-up	/	/	/	10 weeks	16 weeks	28 weeks
Subjects (N)	111	42	514	14	16	24
- Cases	47 (DS)	42 (DS)	119 (DS)	10	8	24
- Control	64 (ID)	/	395 (ID)	4	8	/
Drop-out	None	None	None	None	None	None
Inclusion criteria	Persons with ID, with or without DS	Persons with DS	Persons with DS	Persons with DS	Down syndrome, lived at home and bussed to school, light physical work	Healthy subjects with DS
Age (years)						34.5±7.0
- Cases	26.7±5.7 ♂ 31.7±7.2 ♀	9.8±3.6	14.8±2.6 ♂ 14.8±2.7 ♀	18.4±2.9	22.0±3.8	/
- Controls	26.9±6.4 ♂ 30.4±6.7 ♀	/	14.9±2.2 ♂ 14.5±2.3 ♀	17.0±2.8	20.8±2.3	/
Gender				11 ♂, 4 ♀	All males	All males
- Cases	31 ♂, 16 ♀	25 ♂, 17 ♀	62 ♂, 57 ♀	/	/	/
- Controls	35 ♂, 29 ♀		244 ♂, 151 ♀	/	/	/
BMI						
- Cases	/	/	27.1±6.7 ♂ 24.8±5.4 ♀	/	/	/
- Controls			23.1±6.3 ♂ 24.9±6.7 ♀			
Weight (kg)						66.9±8.9
- Cases		33.0±13.7	64.9±19.7 ♂ 51.3±12.1 ♀	66.5±12.5	62.6±10.7	/
- Controls			62.8±22.8 ♂ 60.8±18.5 ♀	54.8±25.3	60.1±7.4	/
Intervention	/	/	/	10 week treadmill walking program	16 week rowing ergometry training	28 week aerobic exercise intervention,

Control	/	/	/	Did not participate in any regular physical training	regime Did not participate in any regular physical training	ergometer conditioning /
Treatment duration	/	/	/	3 x week for 10 weeks. 10 min warm up, 30 min walking and jogging, 5-10 min cool down	3 x week for 16 weeks. 10 min warm up, 15-25 min training, 10 min cool down	2 x week for 28 weeks. 5 min warm up, 40 min ergometer conditioning (rowing, treadmill stepper, cycling), 5 min cool down
Outcome/results (significant)	VO2 peak: ♂ + 18.5%, ♀ + 26.6% in NDS. HR peak: ♂ + 7.9%, ♀ + 12.6%. VE peak: ♂ + 21.3%, ♀ + 38.3%. RER peak: ♂ + 4.6%, ♀ + 8.5% (p< 0.006).	At same exercise time HR max controls 156±11 vs DS 176±10 (+12.8%) (p<0.001).	20MSRT: ♂ DS 8.6±4.3 laps vs nDS 15.9±12.8 laps (+84.9%); ♀ DS 7.9±4.9 vs nDS 10.2±5.9 (+30.4%).	Average testing time improved from 8min50s to 9min56s (+ 12.5%). No other significant results (p< 0.05).	Treadmill: time + 27%, distance + 23.9% and grade + 25.7% (p< 0.01). Rowing ergometer: time + 22%, distance + 19.1% and resistance + 10.0%.	VO2 peak + 27.8%, time to exhaustion + 7%, Ve peak + 21%.

Table 2b. Outcomes of selected studies concerning cardiovascular fitness of persons with Down syndrome, with type of studies, methodological quality, outcome measures, samples characteristics, intervention programs and significant results.

Study	Mendonça et al. (2010)	Pitetti et al. (1992)	Matute-Llorente et al. (2013)	Ordóñez et al. (2013)	Wee et al. (2015)	Mendonça et al. (2013)
Type of study	Case-control	Case-control	Case-control	RCT	Case-control	RCT
SIGN	++	++	++	++	++	++
Outcome measures	heart rate (bpm), VO ₂ (ml.kg ⁻¹ .min ⁻¹), Ventilation (l.min ⁻¹), respiratory exchange ratio (RER)	heart rate (bpm), VO ₂ peak (ml.kg ⁻¹ .min ⁻¹), Ventilation (l.min ⁻¹), respiratory exchange ratio (RER), cardiac output (Q = l.min ⁻¹), cardiac index (QI = l.min ⁻¹)	VO ₂ peak (ml.kg ⁻¹ .min ⁻¹), HRmax	VO ₂ max (ml.kg ⁻¹ .min ⁻¹), HRmax (bpm), fat mass (%), waist circumference (cm), waist-to-hip ratio, adiponectin and leptin (ng/ml)	VO ₂ peak (ml/kg/min), HR (bpm), BMI (kg/m ²)	VO ₂ peak (ml/kg/min), HR (bpm), BMI (kg/m ²)
Follow-up	/	/	/	/	/	/
Subjects (N)	27	16	42	20	654	25
- Cases	14	16	27	11	151 DS, 180 ID	13
- Control	13	16	15	9	323	12
Drop-out	None	None	None	None	None	None
Inclusion criteria	Persons with DS	Persons with DS	Adolescents with DS, aged 10-18 years and adolescents without disability	Women with DS, sedentary, premenopausal and obese	Adults and children with Down syndrome, intellectual disability and non-disabled, living at home or a group home	Healthy adults with and without DS, no background in regular endurance or resistance training for at least 6 months
Age (years)						
- Cases	35.3±7.8	25.8±4.0	16.5±2.7 ♂ 15.8±3.2 ♀	24.7±3.6	21±8 DS 21±8 ID	36.5±1.5
- Controls	37.5±8.0	26.3±3.0	14.0±3.1 ♂ 13.3±3.1 ♀	25.1±3.9	28±11	38.7±2.4
Gender				All women		
- Cases	9 ♂, 5 ♀	12 ♂, 4 ♀	14 ♂, 13 ♀	/	57 ♂, 47 ♀ DS 131 ♂, 49 ♀ ID	10 ♂, 3 ♀
- Controls	9 ♂, 4 ♀	12 ♂, 4 ♀	7 ♂, 8 ♀	/	74 ♂, 224 ♀	9 ♂, 3 ♀
BMI						
- Cases	29.1±4.3	/	21.8±3.1 ♂ 22.7±4.1 ♀	/	27.4±6.8 DS 23.9±5.6 ID	29.3±1.0
- Controls	26.3±4.8	/	19.9±3.5 ♂ 20.7±3.9 ♀	/	26.2±7.2	26.6±1.3
Weight (kg)						
- Cases	66.5±8.5	68.9±19.0	51.2±11.9 ♂ 46.1±12.5 ♀	69.8±5.7	64.8±19.2 DS 64.6±18.8 ID	68.6±2.6
- Controls	79.7±18.9	72.2±18.0	54.0±17.4 ♂ 47.3±13.2 ♀	67.9±6.1	72.1±26.2	81.2±4.9

Intervention	Constant-load exercise tests at 45% VO2 peak	/	/	10 week aerobic-training program	/	12 weeks combined aerobic and resistance training
Control	Constant-load exercise tests at 45% VO2 peak	/	/	Did not participate in any training program	/	12 weeks combined aerobic and resistance training
Treatment duration	/	/	/	3 x week for 10 weeks. 10-15 min warm up, 30-40 min main activity, 5-10 min cool down	/	3 x week for 12 weeks. 5 min warm up, 5 min light treadmill exercise, 30 min continuous treadmill exercise with intensity adjustments
Outcome/results (significant)	HR peak + 7%, VO2max + 53%, VE peak + 80% (DS vs controls).	nDS: HR + 11.3%, VO2 peak + 44.74%, VE + 50.8%. 3mph walking: nDS Q - 20%, HR - 9.2%, QI - 18.5% (p< 0.01).	VO2 peak: differences DS (35.5±6.4) vs control (43.1±5.0). DS VO2 peak correlated with min spent in MPA and MVPA (r = 0.41 and r = 0.38, p≤ 0.05).	VO2max significantly increased (20.2±5.8 vs 23.7±6.3 ml.kg ⁻¹ .min ⁻¹ ; p= 0.007). Plasma leptin levels (54.6±6.7 vs 45.7±6.1 ng/ml; p= 0.026), fat mass % (38.9±4.6% vs 35.0±4.2%; p= 0.041) and WHR (1.12±0.006 vs 1.00±0.005 cm; p= 0.038) reduced.	DS lowest VO2 peak (25.2±6.3; p< 0.001) compared to ID (37.0±10.5) and non-disabled (36.1±10.4) ml/kg/min.	VO2 peak: + 6% DS, + 6.9% non-DS, no changes on body mass (post-training DS: 67.7±2.5; post-training non-DS: 81.4±4.7 kg) or BMI (post-training DS: 28.9±1.0; post-training non-DS: 26.6±1.2 kg/m ²).

Table 3a. Outcomes of selected studies concerning body composition of persons with Down syndrome, with type of studies, methodological quality, outcome measures, samples characteristics, intervention programs and significant results.

Study	Al Husain (2003)	Ordonez et al. (2006)	Grammatikopoulou et al. (2008)	Luke et al. (1996)	Melville et al. (2005)
Type of study	Case-control	RCT	Case-control	Case-control	Case-control
SIGN	-	++	+	++	+
Outcome measures	BMI (kg.m ²)	BMI (kg.m ²), fat mass (%)	Dietary intake, body weight (kg), height (m), body fat %, BMI (kg.m ²), fat free mass (FFM%), fat free mass index (FFMI), waist-hip-ratio (WHR)	Nutrient intake, fat free mass (FFM%), skinfold thickness (mm)	BMI (kg.m ²), weight (kg), height (m)
Follow-up	/	12 weeks	/	/	/
Subjects (N)	1774	22	34	20	494
- Cases	785	22	23	10	247
- Control	989	22	11	10	247
Drop-out	None	None	None	None	None
Inclusion criteria	Down syndrome	Down syndrome	Down syndrome	Down syndrome	Down syndrome
Age (years)	Below 5 years	16.2±1.0	2 groups: 2-9, 10-18		
- Cases	/	/	16.1±2.2	8.8±2.5	/
- Controls	/	/	4.8±2.5	9.1±2.9	/
Gender		All males	16 ♂, 18 ♀		
- Cases	393 ♂, 392 ♀	/	/	4 ♂, 6 ♂	130 ♂, 117 ♀
- Controls	519 ♂, 470 ♀	/	/	5 ♂, 5 ♀	130 ♂, 117 ♀
BMI					
- Cases	/	/	/	22.1±6.0	29.7±6.4 ♂ 27.4±7.2 ♂
- Controls	/	/	/	19.8±4.7	29.7±6.4 ♂ 26.1±7.7 ♂
Weight (kg)		78.7±4.8			
- Cases	/	/	/	33.8±17.3	61.3±13.4 ♂ 66.0±14.0 ♂
- Controls	/	/	/	35.1±14.2	66.5±17.0 ♂ 71.5±22.7 ♂
Intervention	/	12 week physical exercise intervention on land and in water	/	/	/
Control	/	/	/	/	/
Treatment duration	/	3 x week for 12 weeks, 1 h/session	/	/	/
Outcome/results (significant)	Lower BMI for DS children below 2 years old. After that, trends for a steady increase in mean BMI. 10% of DS children vs 0% controls above cut-off scores for BMI (p< 0.05).	Reduction of weight (-4.6%), fat mass % (-18.2%) and fat mass (-22%).	Waist circumference + 50%, abdominal skinfold + 159%, BF% + 104%, FFM + 157%, BMI + 70%, FMI + 244%, FFMI + 24.6%, energy intake + 93.5% for adolescents in comparison with children.	DS 8.3% shorter than non-DS, DS energy intake 22.3% lower than non-DS (p< 0.01).	Ds mean height ♀ -5.5%, mean weight -7.7% and mean BMI + 3.3% in comparison with controls. No differences for ♂. Overweight, obesity and morbid obesity groups are + 12.3% in DS.

Table 3b. Outcomes of selected studies concerning body composition of persons with Down syndrome, with type of studies, methodological quality, outcome measures, samples characteristics, intervention programs and significant results.

Study	Bell et al. (2007)	Sharav (1992)	Curtin et al. (2013)	González-Aguero et al. (2013)	Samarkandy et al. (2012)
Type of study	Case-control	RCT	RCT	RCT	Case-control
SIGN	++	++	++	++	+
Outcome measures	BMI (kg.m ²)	BMI (kg.m ²), activity (questionnaire), weekly calorie intake	weight (kg), fat%, physical activity (min of moderate/vigorous physical activity), fruit intake (servings/day), vegetable intake (servings/day) and treat intake (kcal/day)	BMI (kg.m ²), weight (kg), height (m), lean body mass (kg), body fat (kg)	BMI (kg.m ²), weight (kg), height (m), triceps skinfold thickness (mm), subcutaneous fat (%), macronutrients and micronutrients intakes (kcal/day, g/day, ug/day, mg/day), mother's education, family income (SR), television viewing (h/day)
Follow-up	/	/	6 months	/	/
Subjects (N)	183	60	21	30	221
- Cases	58	30	10 – NAE 11 – NAE+BI	16	108
- Control	125	30		14	113
Drop-out	None	None	None	5 cases and 1 control	None
Inclusion criteria	Down syndrome	Down syndrome	Down syndrome age 13-26 years, BMI ≥85 th percentile, IQ 45-70, written physician approval and a parent willing to attend sessions	Adolescents with Down syndrome	Down syndrome children aged 5-12 years, healthy siblings
Age (years)	Between 20-68				
- Cases	/	4.1±2.5 ♂ 5.1±2.8 ♂	20.5±4.1 – NAE 20.5±2.4 – NAE+BI	15.27±2.57	8.2±1.7 ♂, 7.9±1.5 ♀
- Controls	/	5.9±2. ♂ 6.9±3.5 ♂		15.80±3.04	8.9±1.4 ♂, 8.1±1.6 ♀
Gender				17 ♂, 7 ♂	
- Cases	34 ♂, 24 ♀	14 ♂ 16 ♂	1 ♂, 9 ♀ - NAE 3 ♂, 8 ♀ - NAE+BI	8 ♂, 3 ♂	62 ♂, 46 ♀
- Controls	71 ♂, 54 ♀	18 ♂ 12 ♂		9 ♂, 4 ♀	60 ♂, 53 ♀
BMI					
- Cases	/	16.2±1.0 ♂ 17.3±2.0 ♂	36.5±6.9 - NAE 35.8±5.4 - NAE+BI	21.47±2.84	17.8±3.6
- Controls	/	17.0±1.0 ♂ 17.7±4.0 ♂	/	24.12±4.67	15.1±2.7
Weight (kg)					
- Cases	/	/	77.3±16.5 - NAE 79.2±14.9 - NAE+BI	47.07±9	/
- Controls	/	/		53.82±12.63	/
Intervention	/	/	6 month nutrition and activity	20 weeks of WBV training	/

Control	ID persons without DS and normal population	DS siblings	education program or a nutrition and activity education+behavioral intervention	/	/
Treatment duration	/	/	16 x 90 min sessions for 6 months	3 x week for 20 weeks	/
Outcome/results (significant)	19.5% ♂ and 34.6% ♀ DS vs 6% ♂ and 8% ♀ non-DS are obese. 73.07% ♀ and 56.19% ♂ DS vs 32% ♀ and 40% ♂ non-DS are overweight and obese. 70.58% ♂ and 95.83% ♀ DS vs 42.29% ♂ and 62.96% ♀ ID are overweight and obese.	DS children are less active than siblings (p< 0.007). DS children has lower caloric intake for height, but not significant.	At 6 months mean body weight in the NAE+BI group was 3.2 kg lower than in the NAE group (95% CI, 1.0-5.5 kg; p= 0.005). Mean group differences sustained at 1 year (3.6 kg; 95% CI, 1.4-5.9 kg; p= 0.002). No between-group differences for fat%.	WBV group higher % declination in fat mass at the upper limbs than control group (p< 0.005). WBV group higher % increase in whole body lean body mass (p= 0.08).	DS children shorter, higher BMI (17.8±3.6 vs 15.1±2.7, p= 0.03), higher TSFTs (9.1±3.2 vs 8.6±2.6 mm, p< 0.001) and excessive subcutaneous fat (9.3 vs 2.7%, p= 0.036) than siblings. % of DS children overweight and obese higher than siblings (20.4 vs 7.1% overweight and 23.1 vs 5.3% obese).

Table 4. Outcomes of selected studies concerning strength, cardiovascular fitness and body composition for persons with Down syndrome, with type of studies, methodological quality, outcome measures, samples characteristics, intervention programs and significant results.

Study	Rimmer et al. (2004)	Izquierdo-Gomez et al. (2013)	Izquierdo-Gomez et al. (2015) ^a	Izquierdo-Gomez et al. (2015) ^b	Terblanche & Boer (2013)
Type of study	RCT	Case-control	Case-control	Case-control	Case-control
SIGN	++	++	++	++	+
Outcome measures	VO2 peak (ml.kg ⁻¹ .min ⁻¹), heart rate (bpm), respiratory exchange ratio (RER), blood pressure (mmHG), IRM (kg), handgrip strength (kg), height (cm), weight (kg), skinfold, BMI (kg.m ²)	BMI (kg.m ²), waist circumference (cm), triceps skinfold (mm), subscapular skinfold (mm), body fat (%), handgrip strength (kg), standing long jump (cm), 4x10 m shuttle-run (s), 20 m shuttle-run (stages)	BMI (kg.m ²), waist circumference (cm), body fat (%), muscular fitness (z-score), motor fitness (sec x -1), cardiorespiratory fitness (laps), total PA (counts/min), moderate PA, vigorous PA and MVPA (min/day)	BMI (kg.m ²), waist circumference (cm), body fat (%), triceps skinfold (mm), subscapular skinfold (mm), waist-to-height ratio, motor fitness (sec x -1), cardiorespiratory fitness (laps), handgrip strength (kg), standing long jump (cm)	BMI (kg.m ²), weight (kg), height (cm), sitting height (cm), arm span (cm), standing on one leg, walking on balance beam, catching balls, throwing to a target, back scratch (cm), sit-and-reach (cm), chair stands (cm), isometric push-up, handgrip strength (kg), modified curl-up, trunk lift (cm), bleep shuttles (n), 8-foot get-up-and-go (s), 16 m modified shuttle run test (laps)
Follow-up	12 weeks	/	/	/	/
Subjects (N)	52	111	200	333	371
- Cases	30	17	100	111	371
- Control	22	94	100	222	371
Drop-out	None	None	None	None	None
Inclusion criteria	Down syndrome	Adolescents with DS aged 12-18, QI over 35, adolescents without DS aged 12-16	Adolescents with DS aged 11-20, QI over 35, not having any physical disabilities impacting PA, sex-matched adolescents without DS	Adolescents with DS aged 11-20, QI over 35, not having any physical disabilities impacting PA, sex-matched adolescents without DS aged 12-18	Persons with DS over 18 years old, cognitive ability to understand the testing protocols
Age (years)					34.0±10.4 ♂ 34.2±10.7 ♂
- Cases	38.6±6.2	15.47±2.03	15.43±2.54	15.77±2.45	/
- Controls	40.6±6.5	13.90±0.96	13.57±1.74	14.07±1.60	/
Gender					199 ♂, 172 ♀
- Cases	14 ♂, 16 ♀	12 ♂, 5 ♀	63 ♂, 37 ♀	70 ♂, 41 ♂	/
- Controls	9 ♂, 13 ♀	49 ♂, 45 ♀	63 ♂, 37 ♀	140 ♂, 82 ♀	/
BMI					29.9±5.6 ♂ 31.9±6.4 ♂
- Cases	/	22.35±4.03	23.78±3.96	23.76±4.11	/
- Controls	/	21.61±3.77	20.85±2.90	21.08±3.48	/
Weight (kg)					74.6±12.9 ♂ 68.6±13.5 ♂
- Cases	80.5±20.0	48.80±9.87	52.61±12.25	52.20±11.92	/
- Controls	76.0±18.2	58.34±13.08	54.98±11.42	55.76±12.50	/

Intervention	12 week cardiovascular and strength training	/	/	/	/
Control	Did not participate in any regular physical/strength training	/	/	/	/
Treatment duration	3 x week for 12 weeks, 30 min cardiovascular, 15 min strength training	/	/	/	/
Outcome/results (significant)	VO2peak + 15.6% (p<0.01), HRpeak + 8.3% (p< 0.01), time to exhaustion + 27% (p< 0.05), maximal workload + 27.1% (p< 0.01), bench press +42.8% (p< 0.001), leg press + 39.1% (p< 0.001), body weight - 1.3% (p< 0.01).	DS adolescents were older than controls (p< 0.001), controls were heavier and taller than DS, even after controlling for sex and age. Differences in triceps skinfold thickness (p= 0.012) and %BF (p= 0.029), however differences disappear once controlled for sex and age (both p> 0.4). Controls scored significantly better in all fitness variables than DS and the results did not changed after controlled for sex and age (all p< 0.001).	DS adolescents were older, heavier and smaller than controls (p< 0.001). after controlling for age, DS adolescents had higher levels of fatness than controls (all p< 0.05). DS had lower fitness levels in all fitness variables (all p< 0.001) independent on age. Moderate to large effects observed in fatness variables (d= 0.65-1.42) and particularly large values in fitness variables (d= 2.05-2.43).	DS adolescents were older, smaller and presented higher levels of fatness and poorer scores in physical fitness variables than controls (all p< =.001).	DS men performed significantly better on all but two tests compared with woman (p< 0.05). significant differences between across age groups were observed for nine of the 13 functional fitness tests (p< 0.05). Muscular strength items, especially leg strength, predicted functional performance in DS men and woman. Aerobic capacity only predicted functional performance in DS men and sit-and-reach flexibility and dynamic balance inly in DS women.

Discussion

The purpose of this review was to document which factors has an impact or influence on the fitness and performance level of people with DS. In addition, we investigated the differences between DS persons, ID persons without DS and non-disabled persons. There is medium to strong evidence that strength, cardiovascular fitness and body composition are weak factors in persons with DS and that these persons perform less in these parameters compared with ID and non-disabled peers.

Strength

Seven RCT studies (Carmeli et al. 2002, Emara 2016, Lin & Wang 2012, Rosety-Rodriguez et al. 2013, Shields & Taylor 2010, Shields et al. 2008, Shields et al. 2013) reported significant effects of strength training in persons with DS. Shields et al. (2008, 2010, 2013) examined the effect of a ten week progressive resistance training on upper and lower limb muscular strength and function. Shields et al. (2008) only found significant improvements in upper limb endurance (number of repetitions at 50% 1 RM) and a trend toward upper limb strength and upper limb function (time on timed stairs test and grocery shelving task). They did not find improvements in lower limb strength, muscle endurance and physical function. On the contrary, Shields et al. (2010) only found differences in lower limb muscle strength, with no improvements in upper limb strength and upper and lower limb physical function. Despite the similar intervention and high quality in both investigations, they found contradictory results. The only clear difference between both studies is the age of the subjects. In the first study (Shields et al. 2008) the mean age of the intervention group was 28.8 ± 5.4 years and in the second one (Shields et al. 2010) research group is 15.9 ± 1.5 years. Other explanations could be the rather small sample sizes, reducing statistical power and thus requiring the effect of the intervention to be larger and the shortness of the intervention (ten weeks). The third study from Shields et al. (2013) augmented considerably the number of participants, although the intervention time is the same. Here, the mean age

was 17.7 ± 3.4 years and, interestingly, the authors found increases in upper and lower limb strength, comparing to control group, meaning that the sample size might have influenced the results.

The study with the largest number of subjects was from Lin & Wang (2012), with a sample of 92 young people with DS. Nevertheless, the intervention program from this study was of only 6 weeks, 3 x week sessions and muscle strength as well as agility performance improved significantly after this time comparing to controls. The authors suggest that a rather short-term training program could be sufficient to DS youth to gain muscle strength. On the other hand, Carmelli et al. (2002) performed a six months walking intervention and found a significant improvement in knee extension and flexion power, with the female subjects experiencing a greater improvement in comparison with the male intervention group. Nevertheless, the intervention group in this study had a mean age of 63.5 ± 2.0 years and although with the longest duration, did not do any specific power training exercise.

The male participants from Rosety-Rodriguez et al. (2013) experienced a 12 week resistance circuit training, 3 x week and considerably improved their cytokines levels, fat-free mass and waist circumference comparing with the control group, indicating the benefits from the strength training in persons with DS. These benefits were also observed in children, after a 12 week (3 x week) whole body vibration and physical therapy program, as children significantly increased strength in all the muscle groups, with more improvement than those who only attended a physical therapy program (Emara 2016). Persons with DS seem capable of improving their strength levels with training, although the optimal duration of the programs are not yet in agreement.

Two CCS (Angelopoulou et al. 2000, Mercer et al. 2001) examined the differences in strength between DS and ID or non-disabled subjects (Angelopoulou et al. 2000) and between DS and non-disabled age and gender matched peers (Mercer et al. 2001). The first study (Angelopoulou et al. 2000) found significant differences in isokinetic muscle strength of quadriceps and hamstrings, with these differences being bigger between DS participants and the non-disabled control group than between DS and ID participants. Mercer et

al. (2001) found similar results in hip abductor power and knee extension power, but they examined only the difference between DS and non-DS. Both studies confirm one another that people with DS are less powerful than persons with ID which are less powerful than the non-disabled persons. The differences between DS and ID persons could be explained by the physical impairments associated with DS, of which ID persons do not have, especially hypotonia, which implicates difficulties in the ability to fully activate the muscles and having control of tension and relaxation (Davis & Sinning 1982).

Cardiovascular fitness

The RCT's about cardiovascular fitness reported significant changes in people with DS after interventions, namely on the work performance (i.e. duration of test by time, level of work attained), although these improvements are not so visible in the cardiovascular fitness parameters (e.g. VO₂peak, VE). An explanation for those results could also be the rather small samples or maybe that the duration of the intervention was not long enough to see clear differences. It could be that training progress in DS persons is more reflected in other outcomes than in VO₂peak, for example. Both Millar et al. (2003) and Varela et al. (2001) reported improvements in average testing time (+12.5%) (Millar et al. 2003) and in treadmill and rowing ergometer time (+27% and +22%), distance (+23.9% and +22%) and grade or resistance (+25.7% and +10%), respectively (Varela et al. 2001). Nevertheless these improvements, neither of the two studies showed significant results on the cardiovascular parameters.

The other three studies on cardiovascular fitness reported improvements in VO₂peak (+27.8%), time to exhaustion (+7%) and Ve peak (+21) (Mendonça et al. 2009), VO₂peak (Mendonça et al. 2013) and VO₂max (Ordonez et al. 2013). These three studies involved slighter higher sample sizes than the referred above, and Mendonça et al. (2009) applied a 28 week intervention, that could promote the improvements that were not founded at Millar et al. (2003) and Varela et al. (2001). Although intensity and duration are comparable in all studies, little is known about the cardiovascular conditions of the participants

pre testing and could happen greater improvements after cardiovascular interventions in persons with low activity levels in comparison with persons who were already more active before the study.

Three CCS compared a group of DS persons with non-disabled ones (Matute-Llorente et al. 2013, Mendonça et al. 2010, Pastore et al. 2000). Pastore et al. (2000) found a higher maximal heart rate in individuals with DS at the same exercise time (+12.8%). Mendonça et al. (2010) found a significantly higher HRpeak (+7%), VO₂max (+53%) and VEpeak (+80%) in controls in comparison with the DS group. The authors also stated that the VO₂ kinetics at onset and recovery of constant-load treadmill exercise is comparable between adults with DS and controls although they have lower VO₂peak. Matute-Llorente et al. (2013) found differences in VO₂peak for DS and control groups, with inferior values for the DS, which is in agreement with the above referred studies.

Three CCS compared DS persons with persons with ID (Fernhall et al. 1996, Pitetti et al. 2004, Pitetti et al. 1992) and one study compared adults and children with DS, ID and non-disabled (Wee et al. 2015). Of these, there is a great difference in the number of participants, being very inferior in the study of Pitetti et al. (1992). Nevertheless, the authors concluded that persons without DS have greater HR, VO₂peak and V_E in rest. During 3mph walking, they found that non-DS persons had lower cardiac output, lower HR, lower cardiac index, lower left ventricular work index and peripheral vascular resistance, therefore suggesting that persons with DS have lower peripheral oxygen extraction whereby higher cardiac output is needed for the same amount of oxygen and higher HR on the same submaximal training level. Another explanation could be a higher BMI, lower lean muscle mass and thus higher muscle strain on same exercise level and higher cardiovascular response.

The study from Fernhall et al. (1996) found a greater VO₂peak, HRpeak and RERpeak in the non-DS participants, men having greater values than women for VO₂peak and VEpeak. Pitetti et al. (2004) compared distances in a 20 m shuttle run test in two groups and subjects with ID scored better than the DS participants that had a significantly higher BMI, which could have an effect on running performance. Finally, Wee et al. (2015) compared 654 individuals,

being 151 with DS, 180 with ID and 323 non-disabled and found that the persons with DS presented the lowest VO₂peak of the three groups (25.2±6.3 ml/kg/min DS, 37.0±10.5 ml/kg/min ID, 36.1±10.4 ml/kg/min non-disabled).

Body composition

Three RCT's were found on the topic of body composition (Curtin et al. 2013, González-Aguero et al. 2013, Ordonez et al. 2006). All of the interventions promoted improvements in the body composition of the participants. At Ordonez et al. (2006) study, participants performed a 12 week cardiovascular and strength training program and significant reductions in body weight, fat mass and fat mass % were observed. Curtin et al. (2013) and González-Aguero et al. (2013) implemented longer interventions (6 month nutrition and activity education + behavioral intervention and 20 weeks of WBV training, respectively) and obtained positive differences in mean body weight (Curtin et al. 2013), fat mass at the upper limbs and whole body lean body mass (González-Aguero et al. 2013). These RCT's confirm that persons with DS are capable of improving their body composition after training interventions.

Five CCS examined the differences between DS subjects and their non-disabled peers (Al Husain 2003, Luke et al. 1996, Melville et al. 2005, Samarkandy et al. 2012 and Sharav 1992). The study of Al Husain (2003) included participants bellow five years of age, so careful in the interpretation of the data is needed. Luke et al (1996) only found significant differences in height and energy intake, which were both lower in DS subjects, with no differences in body composition. Sharav (1992) also did not report differences in body composition in comparison to non-disabled siblings, although the number of participants was higher than those from Luke et al. (1996). Nevertheless, the mean age of the subjects from Sharav (1992) and the fact that overweight and obesity often occur in a later life stadium, could have influenced the results. In accordance is Grammatikopoulou et al. (2008) that compared DS adolescent (10-18 years) with DS children (2-9 years) and found greater waist circumferences, abdominal skinfold, body weight, fat free mass, body mass index, fat mass index, fat free mass index and energy intake in adolescents

compared with the children.

The studies of Melville et al. (2005), with adults, and Samarkandi et al. (2012), with children, highlight the poorer body composition values compared to controls, with overweight and obesity being more frequently present in persons with DS. Similar results were found by Bell et al. (2007), with a sample of adults with DS, ID and non-disabled, with higher BMI for DS.

Physical fitness

Finally, five studies were found to approach the three above referred components (Izquierdo-Gomes et al. 2013, Izquierdo-Gomes et al. 2015a,b, Rimmer et al. 2004, Terblanche & Boer 2013). Of these, only one was a RCT (Rimmer et al. 2004) that implemented a 12 week cardiovascular and strength training and found significant improvements in strength, cardiovascular parameters and body weight. The CCS had high sample sizes (from 111 to 371) and were performed on adolescents with 12-18 years (Izquierdo-Gomez et al. 2013), 11-20 years (Izquierdo-Gomez et al. 2015a,b) or persons over 18 years (Terblanche & Boer 2013). Izquierdo-Gomez et al. (2015a,b) referred the poorer scores in the physical fitness variables and higher levels of fatness from persons with DS compared to their sex matched adolescents without DS, going in accordance with the above mentioned studies. Izquierdo-Gomez et al. (2013) also found score differences in the fitness variables between adolescents with and without DS, but no differences in triceps skinfold thickness and body fat %, once controlled for sex and age. Terblanche & Boer (2013) found important differences between men and woman with DS, with better scores for men, although no references to differences in body composition were made.

In general, we can assume that all three performance aspects can be improved in persons with DS, although they perform less in strength tests, cardiovascular fitness tests and have higher body composition values in comparison with non-disabled and ID people. How much and in which degree is hard to say, since most studies show a similar pattern, but there are still many discrepancies. As conclusion, it can be said that more research is needed on this topic, with

increased samples and longer interventions that could make the interpretation of the results easier and with higher probability of finding clearer data.

Chapter 3.

Swimming race performance of swimmers with Down syndrome

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Abstract

Swimming race analysis has been frequently conducted by coaches and researchers, but not yet for Down syndrome swimmers. Down syndrome is a condition that imposes impaired intellectual functioning and is usually associated with low levels of physical fitness, pacing and coordinative problems that might influence overall swimming performance. We aimed to compare male and female elite Down syndrome swimmers regarding race components speed (start, swim, turn and finish), stroke rate and stroke length, to observe the relationships between those variables and to analyze the pacing strategies used at the 400 m freestyle. The 50, 100 and 200 m freestyle qualifying heats and finals, as well as the 400 m freestyle finals of the 5th and 6th World Swimming Championships DSISO (respectively) were video recorded for analysis. Data allowed to observe that: (i) Down syndrome male swimmers were considerably faster than females on the 50 m (1.26 ± 0.94 vs 1.01 ± 0.11 m/s), 100 m (1.18 ± 0.09 vs 0.92 ± 0.09 m/s) and 200 m (1.01 ± 0.08 vs 0.84 ± 0.08 m/s) freestyle; (ii) male and female swimmers presented a similar stroke rate (43.16 ± 4.87 vs 40.78 ± 5.45 and 38.06 ± 4.50 vs 36.78 ± 5.10 strokes/min for the 100 and 200 m freestyle, respectively) although males attained longer SL (1.65 ± 0.16 vs 1.38 ± 0.17 and 1.61 ± 0.17 vs 1.38 ± 0.17 for the 100 and 200 m freestyle, respectively); (iii) female swimmers demonstrated more difficulties in starting, finishing and turning; (iv) swimmers with Down syndrome are considerably slower than able-bodied and minimal impairments swimmers at the 400 m freestyle race (431.38 s for S21, 254.24 s for able-bodied, 299.03 s for S10 and 297.96 for S13); (v) the 400 m freestyle most used pacing strategies by Down syndrome swimmers were the fast start and negative and the fastest one was the parabolic strategy.

Keywords: Down syndrome, swimming, performance analysis, freestyle.

Introduction

As the final objective in competitive swimming is to cover the race distance in the shortest time possible (Arellano et al. 2001), understanding swimmers behavior in competition through race analysis has been a widely used procedure by coaches and researchers. This type of analyses started in the 1970's with East (1970), continuing in the 1980's with relevant works by Craig et al. (1985), Hay & Guimarães (1983), Pai et al. (1984) and Wakayoshi (1988) and, since then competition analysis has become a regular feature at most international swimming events. In fact, official video above water recording conducted during Olympic Games started in Seul'1988 (Daly et al. 2009) and few year later (Atlanta'1996), Paralympic events also started to be recorded for race analysis (Daly et al. 1999). With the recent reentry of the intellectual disabled S14 Class in International Paralympic Committee (IPC) competitions, there is a need for race analysis for swimmers with intellectual (Daly et al., 2006; Daly et al. 2014).

Swimmers with Down syndrome can compete at an international level in the IPC swimming events (integrated in the S14 Class) and in the Down Syndrome International Swimming Organization (DSISO) venues (where all swimmers compete in the S21 Class). Race speed differences among Olympic and Paralympic swimmers with intellectual disability are determined by physical aptitude, fitness (training), use of better swim, start and turn techniques (knowledge) and adapting optimal race patterns (experience) (Daly et al. 2006). Furthermore, suitable nutrition and rest, as well as proper training conditions, are necessary to achieve a maximal level of performance in swimmers with Down syndrome (Daly et al. 2006). Persons with Down syndrome are known to have impaired intellectual functioning and limitations in adaptive behavior, and, concerning physical fitness, this pathology is usually associated with lower levels of conditioning comparing to persons without disability and subjects intellectually disabled but without Down syndrome (e.g. González-Aguero et al. 2010, Pitetti et al. 2013, Van de Vliet et al. 2006).

Research on Down syndrome competitive swimming is scarce, with a gap of several years regarding investigation for non-disabled swimmers in general and

race analysis in particular (Querido et al. 2012). Nevertheless, these few studies highlight the less proficient swimming ability of these swimmers, despite the fact that these persons seem capable of improving their physical capacities (especially strength) as well as their body shape (Querido et al. 2015).

Some of the questions arising for trained swimmers with Down syndrome are: (i) are male swimmers with Down syndrome faster than their female counterparts and if so where are the differences found?; (ii) do swimmers with Down syndrome adapt the race patterns generally found in the freestyle events within almost all competitors at both Olympic and Paralympic level, as well as international swimmers with intellectual disability?; (iii) do swimmers with Down syndrome adopt pacing strategies at the 400 m freestyle race similar to other groups of swimmers and is the pacing strategies adopted the fastest ones? And (iv) is it fair that swimmers with Down syndrome continue in the S14 Class, or should they have their own Paralympic Class (S21)? We can only answer this question if it is shown that Down syndrome impacts swimming performance differently than other forms of intellectual disability.

Therefore, we aimed to (i) compare men and woman with respect to the race components, speed, SR and SL, (ii) understand the correlations between the analyzed variables for the 50 m, 100 m and 200 m freestyle events and (iii) identify pacing strategies for swimmers with Down syndrome at the 400m freestyle race and compare them to existing data from literature. We hypothesized that (i) men are faster than woman and attain higher SR and SL values, (ii) swimmers with Down syndrome present similar correlations between race components, SR and SL than swimmers without disabilities and swimmers with intellectual disability but no Down syndrome described in the literature and (iii) swimmers with Down syndrome adopt different pacing strategies comparing to other international level swimmers described in the literature.

Methods

Participants

74 male and 62 female who entered at the 50 m, 100 m and 200 m freestyle qualifying heats and finals from the 5th World Swimming Championship DSISO participated in this study. Also, 44 swimmers (24 male and 20 female) from the finals of the 6th World Swimming Championship DSISO were evaluated for the 400 m freestyle event.

Video recording and race time

With the previous approval of the Down Syndrome International Swimming Organization (DSISO) these events were videotaped with 2 side view cameras. The two cameras were placed perpendicular to the swimming direction, 6.5 m from the start, 2.5 m away from and 3 m above the edge of lane 8 of the 25 m competitive pool. Due to constrain of the swimming pool, lane 8 of all races was left out so that the other seven lanes would have better visibility (Figure 1).

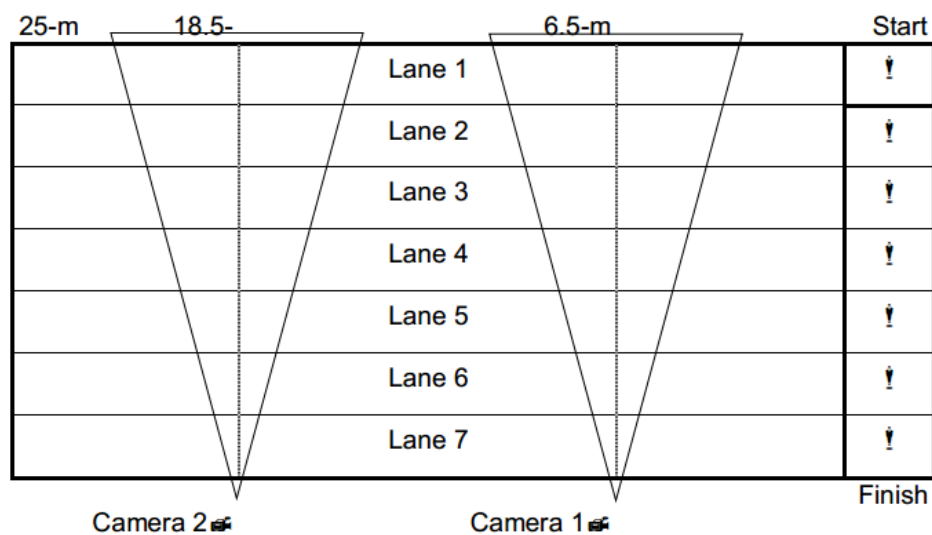


Figure 1. Cameras position on the swimming pool.

Recording began at the referees signal for the swimmers to prepare to start. It was essential for camera synchronization that the start signal itself be recorded on the sound track of both cameras. Furthermore, since the actual race clock was not registered, the cameras had to keep running during the entire race even when there were no swimmers in view. This sound track also included the race announcers' voice so that there could be a double check of which race was in view. An electronic copy of all competition results was obtained from the

server of the timing equipment. Due to a problem with the electronic equipment of the competition, the results only gave final times, and no lap split times.

A commercial software program (Adobe Premier 1.5) was used to analyze the video images. First, the video footage from both cameras, including soundtrack, was captured into the computer for the entire race duration. During this process a frame counter was also saved. The video file from camera 1 was then imported to the Adobe software. This allowed forward and backward frame by frame movement (one video frame has 0.025 s duration). The sound track wave was also visualized and the sound itself made audible. The exact frame at which the start signal was given was identified based on both the change in the sound wave and real audio. This frame number was recorded as the start or zero time. Using pictures from camera 1 the following frame codes were manually registered: (i) the moment the middle of the swimmers' head passed the 10 m mark for each race length following the start and going into and out of the turns at the end of the pool; (ii) the beginning and end of 2 to 8 arm strokes on approach to the turn. On the camera two footage the frame count at the start signal was recorded (zero time) along with the moment the head passed the 5 m mark going into and coming out of the turn. The arm stroke count was made for each race length when approaching the turn and at the end of the pool. For the video analysis, the Dartfish program was used. This program allowed us to make the stroke counting and by drawing a line between the marks from the swimming pool, see the moment that the swimmers' head passed the marks for beginning, turns and finishing times.

All frames counts were then entered into an Excel sheet that calculated the 10 m start and finish times. Turn times were also calculated, although these differed for the two pool ends (2 x 10 m if the swimmer is on the start/finishing side or 2 x 5 m if the swimmer is on the opposite side). The mid pool swimming speed was calculated for each race length as well as the time for the measured stroke count (stroke rate). Stroke rate is the number of complete stroke cycles (e.g. right hand entry to right hand entry) taken each minute (Daly et al. 2003). The distance covered by the swimmers during a cycle (stroke length) was estimated as the division of the mid pool speed (MPS) for the stroke rate (SR): $SL = MPS/SR$ (Daly et al. 2003). Durations of each race segment were thus

known and when summed should be equal to the total race time. Comparison between accounted and real time was checked and faults corrected. Race variables measured included starting, turning, finishing, and the swimming speed (unaffected by starting or turning) at several intermediate points in the race (Daly et al. 2003).

Data processing

As referred for gait analysis (Dobson et al., 2007), the classification methods can be coded as either qualitative or quantitative. Qualitative methods include those “where decisions to group members rely on the judgement and experience of those making the decisions”. These methods can distinguish clinically relevance groups, but also has reproducibility and subjective issues. The quantitative methods are based on objective data and techniques, and it is useful for detecting groups that cannot be easily identified by visual inspection. On the other hand, these processes may uncover “artificial” groups that have no clinical relevance or meaning and impose a structure on the data rather than finding “natural” groups and therefore be possible to divide a homogeneous group or fail on the partition of a heterogeneous group (Dobson et al., 2007). In the present study, combined qualitative and quantitative classification methods were used to group the swimmers for pacing strategy at the 400 m freestyle race.

First, a group of five experts was invited to analyze, by visual inspection, each one of the 44 individual curves for the 400 m freestyle and place them in one of the pacing strategies described by Taylor et al. (2016): parabolic, even, parabolic/fast start, negative and fast start (for a description of the pacing strategies see Taylor et al. 2016). The curves were calculated by the difference between each 50 m lap time and the mean 50 m lap time, derived from the overall race time and expressed as a time deviation in seconds. Secondly, a *k*-means cluster analysis was applied to the data to group the 44 swimmers in the 5 clusters identified in previous studies (Abbiss & Laursen 2008, Mauger et al. 2013, Thompson et al. 2003, Taylor et al. 2016).

Statistical procedures

Descriptive statistics (means and standard deviations) were calculated for all the variables and all data were checked for normality and homogeneity of variance. Student t-tests were computed to compare gender groups and correlation analyses were performed between all variables for the 50, 100 and 200 m freestyle followed by *k*-means cluster analysis applied to the 400 m freestyle data to distribute swimmers in the 5 pacing strategies. The significance level in all analyses was set at 0.05. Statistical analyses were conducted using SPSS version 21.0.

Results

Male swimmers are considerably faster in all race components and speed, and present higher stroke length (SL) values than female (Table 1). For the stroke rate (SR), the differences were only observed on the 50 m freestyle (man attained higher strokes per minute than woman).

Table 1. Mean \pm SD of the race components, speed, stroke rate and stroke length for the 50, 100 and 200 m freestyle events.

	50m freestyle		100m freestyle		200m freestyle	
	Men	Woman	Men	Woman	Men	Woman
Start time (s)	5.69 \pm 0.56 ^a	7.58 \pm 0.96	6.07 \pm 0.47 ^a	7.37 \pm 0.99	6.37 \pm 1.01 ^a	7.77 \pm 0.88
Swim time (s)	24.58 \pm 1.99 ^a	30.86 \pm 3.49	34.45 \pm 2.90 ^a	44.18 \pm 4.49	80.67 \pm 6.86 ^a	97.36 \pm 9.81
Turn time (s)	7.14 \pm 0.62 ^a	9.52 \pm 1.02	32.36 \pm 2.64 ^a	37.94 \pm 3.85	92.03 \pm 8.79 ^a	111.25 \pm 15.87
Finish time (s)	7.53 \pm 0.89 ^a	10.06 \pm 1.39	9.08 \pm 1.32 ^a	10.25 \pm 1.33	10.31 \pm 1.71 ^a	11.72 \pm 1.81
Speed (m/s)	1.26 \pm 0.94 ^a	1.01 \pm 0.11	1.18 \pm 0.09 ^a	0.92 \pm 0.09	1.01 \pm 0.08 ^a	0.84 \pm 0.08
SR (st/min)	50.44 \pm 6.15 ^a	42.03 \pm 5.63	43.16 \pm 4.87	40.78 \pm 5.45	38.06 \pm 4.50	36.78 \pm 5.10
SL (m)	1.52 \pm 0.19 ^a	1.42 \pm 0.11	1.65 \pm 0.16 ^a	1.38 \pm 0.17	1.61 \pm 0.17 ^a	1.38 \pm 0.17

SR = stroke rate, SL = stroke length. Differences between genders are identified as a ($p \leq 0.05$).

For woman, start time has stronger correlations with the final time in the 50 m event (0.83) than to the two longer events (0.75 for the 100 m and 0.76 for the 200 m) (Tables 2-4). The importance of finishing is also diminishing as the races increase (0.94 for the 50 m, 0.88 for the 100 m and 0.82 for the 200 m). SR is related to speed (0.72) and to final time (-0.62) on the 50 m freestyle, but not SL. Neither SR nor SL is related to speed or final time in the 200 m event. For the 100 m event, only SR is related to final time (-0.58).

For men, the turn time presents stronger correlations to the final time than the start time for all the race distances (0.56 vs 0.83 for the 50 m, 0.59 vs 0.94 for the 100 m and 0.87 vs 0.96 for the 200 m) (Tables 2-4). As for woman, the finish time is more important in the shorter distances (0.75 for the 50 m, 0.66 for the 100 m and 0.45 for the 200 m). The influence of SR on speed and final time is different for men, in comparison to woman. This correlation is not significant for the 50 m freestyle (0.36 for speed and -0.42 for final time) but SR is related to speed (0.50 for the 100 m and 0.52 for the 200 m) and final time (-0.51 for the 100 m and -0.50 for the 200 m) for both the 100 m and 200 m events.

Table 2. Significant correlation ($p \leq 0.05$) coefficients for the 50 m freestyle event.

		Start time	Swim time	Turn time	Finish time	Final time	Speed	SR
Swim time	Men							
	Woman	0.74						
Turn time	Men	0.69	0.66					
	Woman	0.80	0.94					
Finish time	Men	0.52	0.61	0.72				
	Woman	0.74	0.61	0.89				
Final time	Men	0.56	0.90	0.83	0.75			
	Woman	0.83	0.98	0.97	0.94			
Speed	Men		-0.97	-0.60	-0.53	-0.84		
	Woman	-0.71	-0.98	-0.93	-0.87	-0.96		
SR	Men		-0.36				0.36	
	Woman		-0.69	-0.57	-0.51	-0.62	0.72	
SL	Men							-0.67
	Woman							

SR = stroke rate, SL = stroke length.

Table 3. Significant correlation ($p \leq 0.05$) coefficients for the 100 m freestyle event.

		Start time	Swim time	Turn time	Finish time	Final time	Speed	SR
Swim time	Men	0.50						
	Woman							
Turn time	Men	0.70	0.86					
	Woman	0.86	0.73					
Finish time	Men		0.62					
	Woman		0.73	0.84				
Final time	Men	0.59	0.97	0.94	0.66			
	Woman	0.75	0.91	0.95	0.88			
Speed	Men	-0.53	-0.99	-0.86	-0.59	-0.97		
	Woman	-0.53	-0.99	-0.78	-0.75	-0.93		
SR	Men		-0.51		-0.50	-0.51	0.50	
	Woman			-0.61	-0.70	-0.58		
SL	Men		-0.29					-0.67
	Woman							-0.76

SR = stroke rate, SL = stroke length.

Table 4. Significant correlation ($p \leq 0.05$) coefficients for the 200 m freestyle event.

		Start time	Swim time	Turn time	Finish time	Final time	Speed	SR
Swim time	Men	0.80						
	Woman	0.71						
Turn time	Men	0.85	0.85					
	Woman	0.76	0.95					
Finish time	Men							
	Woman	0.70	0.76	0.80				
Final time	Men	0.87	0.95	0.96	0.45			
	Woman	0.76	0.98	0.99	0.82			
Speed	Men	-0.80	-0.99	-0.82		0.78		
	Woman	-0.71	-0.99	-0.96	-0.77	0.96		
SR	Men		-0.53			-0.50	0.52	
	Woman				-0.60			
SL	Men							-0.72
	Woman							-0.72

SR = stroke rate, SL = stroke length.

Swimmers with Down syndrome present considerably slower race times and 50 m splits than able-bodied and elite female swimmers with a disability (Table 5).

Table 5. Descriptive statistics for swimmers with Down syndrome (current study), elite able-bodied female swimmers and elite female swimmers with a disability (Classes S10 and S13) (adapted from Taylor et al. 2016).

Class	Descriptive statistic	50m split	100m split	150m split	200m split	250m split	300m split	350m split	400m split	Race time
S21	Mean time (s)	46.35	52.58	54.79	55.31	55.85	56.04	56.16	54.33	431.38
	Lower limit (s)	44.23	50.21	52.45	53.08	53.50	53.62	53.79	51.79	413.08
	Upper limit (s)	48.46	54.96	57.14	57.53	58.19	58.49	58.53	56.86	449.68
S10	Mean time (s)	33.64	36.87	37.96	38.28	38.34	38.45	38.29	37.19	299.03
	Lower limit (s)	32.89	35.88	36.89	37.17	37.24	37.35	37.24	36.24	291.21
	Upper limit (s)	34.40	37.86	39.03	39.40	39.45	39.55	39.34	38.15	306.84
S13	Mean time (s)	33.30	36.87	37.76	38.20	38.21	38.33	38.41	36.88	297.96
	Lower limit (s)	32.55	35.97	36.72	37.18	37.18	37.27	37.27	35.86	290.34
	Upper limit (s)	34.04	37.77	38.79	39.23	39.24	39.39	39.56	37.89	305.58
A-B	Mean time (s)	29.48	31.57	32.04	32.30	32.23	32.49	32.43	31.70	254.24
	Lower limit (s)	29.12	31.10	31.51	31.74	31.64	31.86	31.79	31.04	250.06
	Upper limit (s)	29.85	32.04	32.56	32.86	32.86	32.82	33.07	32.36	258.43

Class = classification, S21 = Down syndrome class, S10 = minimal physical impairment class, S13 = minimal visual impairment, A-B = able-bodied swimmers, Lower limit = lower 95% confidence limit, Upper limit = upper 95% confidence limit.

Differences between the pacing strategies are mostly observed at the end of the race and the negative pacing strategy is the one that presents most differences with other strategies (Table 6).

Table 6. Mean \pm SD of the differences between each 50 m splits for the 5 pacing strategies of the 400 m freestyle event.

Strategies	50m split	100m split	150m split	200m split	250m split	300m split	350m split	400m split
Parabolic (n= 4)	-7.87 \pm 2.06	-2.38 \pm 1.13 ^b	0.61 \pm 1.17	1.29 \pm 0.65	1.56 \pm 1.30	1.55 \pm 1.71	3.97 \pm 2.84 ^{a,b}	1.27 \pm 3.38 ^b
	-7.09 \pm 2.17	-0.85 \pm 1.59 ^c	1.28 \pm 0.70 ^e	1.20 \pm 1.34	1.29 \pm 0.87 ^{c,e}	1.82 \pm 0.63 ^c	1.72 \pm 0.72 ^c	0.62 \pm 2.07 ^{d,e}
Parabolic/Fast start (n= 4)	-9.28 \pm 3.85 ^f	-3.21 \pm 2.04 ^f	0.68 \pm 0.90	1.91 \pm 1.65	3.34 \pm 1.46 ^g	3.41 \pm 1.30 ^{f,g}	3.77 \pm 1.39 ^{f,g}	-0.63 \pm 0.59 ^{f,g}
	-6.14 \pm 1.84 ^h	-0.07 \pm 1.19 ^h	1.40 \pm 0.63 ^h	1.71 \pm 0.99	2.02 \pm 1.13	1.89 \pm 1.05	1.76 \pm 0.96	-2.60 \pm 1.22 ^h
Fast start (n= 15)	-8.48 \pm 2.11	-1.87 \pm 1.15	0.33 \pm 1.06	1.12 \pm 0.80	1.95 \pm 0.53	2.29 \pm 0.61	2.05 \pm 1.43	2.70 \pm 1.49

Total	-7.58 ±	-1.34 ±	0.87 ±	1.38 ±	1.92 ±	2.12 ±	2.23 ±	0.41 ±
(n= 44)	2.39	1.64	0.97	1.05	1.05	1.01	1.52	2.68

Differences between parabolic and even strategies are identified as a, differences between parabolic and negative strategies are identified as b, differences between even and parabolic/fast start strategies are identified as c, differences between even and negative strategies are identified as d, differences between even and fast start strategies are identified as e, differences between parabolic/fast start and negative strategies are identified as f, differences between parabolic/fast start and fast start strategies are identified by g, differences between negative and fast start strategies are identified as h ($p \leq 0.05$).

The mean (\pm SD) race time for the 5 pacing strategies identified were 394.91 ± 46.62 s for the parabolic, 418.77 ± 31.01 s for the even, 435.83 ± 53.49 s for the parabolic/fast start, 429.49 ± 66.69 s for the negative and 448.99 ± 71.97 s for the fast start strategies. There were no differences between strategies for the race time and although the parabolic pacing strategy resulted in the quickest times overall. The most used strategies adopted by swimmers with Down syndrome were the fast start and the negative.

Discussion

The first purpose of this study was to compare men and woman with respect to the race components, speed, SR and SL. Furthermore, it was our intention to understand the correlations between the analyzed variables for the 50 m, 100 m and 200 m freestyle events. The second purpose of this study was to identify pacing strategies for swimmers with Down syndrome at the 400m freestyle race and compare them to existing data from literature.

50 m, 100 m and 200 m freestyle

Men are faster than woman in all race components (start, swim, turn, finish) and speed. Concerning the 100 m and 200 m events, for similar SR values, men attained higher SL values. In the 50 m event men also attained higher SR values. A combination of factors can impact the race performance of these swimmers, namely the physical aptitude, physical fitness, technique (knowledge) and adapting optimal race patterns (experience) (US Department of Energy, 1999). As a contributor to the swimming performance, the physical

fitness differences between men and woman can help to explain the differences in final time and race components. Man attained significantly better results in tests for strength, endurance, coordination, balance and functional test than woman in a study from with adults with Down syndrome (Terblanche & Boer 2013). The man's superiority in abilities such as strength, endurance and coordination can help them swim faster, so they can apply more strength on the water, swim for longer with the same effort, and swim with a better technique. This also agrees with findings for other groups of able bodied and swimmers with impairments (Taylor et al. 2016).

In general, persons with Down syndrome are known to have poorer physical fitness, namely strength, endurance and speed measures, than persons without this condition and persons with intellectual disability, but not Down syndrome (e.g. Carmeli et al. 2002, Cowley et al. 2010, Pitetti et al. 2013, Shields & Taylor 2010). When comparing with the existent literature, a great difference on the final times is found between high level swimmers with Down syndrome and high level swimmers with intellectual disability, and even more with swimmers without disability. For instance, mean race times of 159.34 ± 12.16 s, 162.29 ± 13.85 s and 165.17 ± 14.12 s for 200 m free races in swimmers with intellectual disability or 124.21 ± 7.13 s, 125.50 ± 7.48 and 126.98 ± 6.77 s for swimmers without disability were found (Einarsson et al. (2015), in comparison to the 189.38 s for man and 228.10 s for woman from the current study. For swimmers with intellectual disability final times for the 100 m of 57.85 ± 1.18 s and for Olympic swimmers of 48.94 ± 0.40 s were presented (Daly et al. 2006). Male swimmers with Down syndrome completed the 100 m freestyle in 81.96 s and female in 99.74 s. In particular, for athletes with intellectual disability but not Down syndrome, strength differences between athletes with and without intellectual disabilities are in the range of 4 – 14 % for male and 11 – 27 % for female, being inferior for the athletes with intellectual disabilities (Daly et al. 2014). Van de Vliet et al. (2006) mentioned that high-performance athletes with intellectual disabilities reach fitness levels that are equal to or lower than those of their able-bodied sportive peers. As persons with Down syndrome are known to have lower physical fitness than persons with intellectual disability, it is likely

that athletes with Down syndrome also present poorer physical fitness profiles than the intellectual disabled athletes.

Another problem concerning swimmers with Down syndrome seems to be the pacing strategy. The ability to follow a race strategy might be a potential problem for persons with an intellectual disability and this is an important ability to optimal performance (Querido et al. 2014). In a previous study on race analysis for swimmers with Down syndrome (Querido et al. 2012), it was observed that for the 100 m freestyle these swimmers presented significant differences in speed and stroke rate from the 1st to the 2nd laps, and from the 2nd to the 3rd laps. Especially for stroke rate, there was a marked decrease on the 2nd lap, and a lesser decrease on the 3rd lap. This could mean that swimmers with Down syndrome have trouble on pacing well in the race and it is not in accordance with Daly et al. (2006) that found that for the 100 m freestyle of intellectual disabled swimmers, speed decreases in a stable way as the race progresses and SR shows a strong decrease initially and then stabilizes.

Swimmers with Down syndrome also seem to present a lower swimming ability related to coordinative factors, which might highlight the differences in the final time in comparison to swimmers with intellectual disabilities or swimmers without disability. The biomechanical characteristics of the front crawl movement in swimmers with Down syndrome are different than those found for both experienced and less experienced able bodied swimmers in the literature (Marques-Aleixo et al. 2013). Additionally, both drag and propulsion are affected in these swimmers more than can be expected only from lack of swimming training and suggest that 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 (Wakayoshi et al. 1996). Likewise, a lack of strength can also be a contributing factor, since the swimmer would not be able to maintain a correct arm and hand position because of insufficient strength to overcome the water resistance (Marques-Aleixo et al. 2013).

A pilot study from Querido et al. (2010) had already showed the lower coordinative development of swimmers with Down syndrome and, therefore,

their poorer technical efficiency when compared with swimmers without disabilities associated with poor anthropometric characteristics. Efficiency, IdC and IVV of swimmers with Down syndrome were compared to the existent literature on swimmers without disability and the results point out that the swimming performance of these swimmers seem to be more similar to less proficient swimmers without disabilities (Querido et al., 2010).

400 m freestyle

The final times and 50 m splits for the 400 m freestyle race for swimmers with Down syndrome are considerably higher for these swimmers in comparison to elite female able-bodied and swimmers with minimal physical and visual impairments (Table 5). If the comparisons were made with male swimmers, these differences would be greater, since male swimmers with and without impairments were faster than females (Taylor et al. 2016). Also, the upper and lower limits around the mean split and race times are greater for swimmers with Down syndrome. Able-bodied swimmers present the most consistent pace, with less deviation from the mean and this seems to be an advantage (Abbiss & Laursen 2008). The poorer physical fitness, strength, coordination and velocity fluctuations of swimmers with Down syndrome already referred above can also impact on their performance on the 400 m freestyle.

As for the prevalence of the pacing strategies, the current study showed that the most used strategy adopted by swimmers with Down syndrome was the fast start, followed by the negative one. A similar study from Taylor et al. (2016) referred that even and negative pacing strategies were prominent in all swimming groups (able-bodied, minimal physical impairment – S10, and minimal visual impairment – S13), while the fast start strategy was used only by able-bodied swimmers, the parabolic fast start only employed by swimmers with impairments, and the parabolic strategy adopted by able-bodied and S10 females. Nevertheless, nor the fast start or the negative pacing strategies were the fastest ones since the quickest times were obtained with the parabolic strategy but with only four swimmers applying this strategy. Interestingly, Taylor et al (2016) found that the parabolic pacing strategy was mainly used by able-

bodied swimmers although the quickest times were attained with the negative strategy.

The swimmers with Down syndrome from the current study presented final race times on the 400 m freestyle that were not different between pacing strategies, meaning that these pacing strategies may not be sufficiently different to promote a quickest or slowest race time. These results are in accordance with those of Mauger et al. (2012) who reported that race time was not influenced in a significant way by any single pacing strategy. Nevertheless, the regulation of pace is thought to be primarily dictated by the ability of an athlete to resist fatigue although these mechanisms are still unclear and seems that one of the more influential factors dictating self-selected exercise intensity and optimal pacing strategy during varying exercise tasks is the rate and capacity limitations of various physiological systems (i.e. anaerobic and aerobic supply) (Abbiss & Laursen 2008).

Naturally, the adoption of a pacing strategy is likely to be based upon physiological, biomechanical and psychological factors (Mauger et al. 2012; Thomson 2014) and for swimmers with Down syndrome the question about the consciousness of these choices arise. There seems to be a tendency for a fast start in swimmers with Down syndrome, but more research is needed to understand if this tendency is a conscious choice or not, since that there is a multitude of pacing strategies but this does not exclude the possibility that an optimal pacing strategy for individual swimmers may differ (Taylor et al 2016).

In conclusion, in swimming (i) men are considerably faster than women with Down syndrome; (ii) for similar SR, men are able to attain higher SL than women; (iii) women seem to have more difficulties in performing starts, finishes and especially, turns; (iv) swimmers with Down syndrome are considerably slower than able-bodied and minimal impairments swimmers at the 400 m freestyle race; (v) the most used pacing strategies for swimmers with Down syndrome were the fast start and negative and the fastest one was the parabolic strategy; (vi) the pacing strategies do not seem to be so different between them since the race times were not different.

Limitations and suggestions for the future

There are some limitations to this study that should be taken in account in the future, namely: (i) speed, SR and SL should be analyzed for each race segment (each 25 m) to understand the differences between laps as well as pacing strategy; (ii) swimmers should be followed up in several competitions in a season at the same race distance, to evaluate their between race changes; (iii) the same swimmers should also be observed in heats and finals to understand which race segment was responsible for differences in the end time; (iii) comparing race segments from different studies is difficult due to methodological differences. With the recent reentrance of the intellectual disabled on the International Paralympic Committee, the authors suggest that swimmers with intellectual disability and swimmers with Down syndrome should be analyzed in International competitions with the same methodological procedures to see if there are significant differences in speed, SR, SL and race components and, in this way, achieve a better understanding on the fairness of joining this two groups of swimmers in one single Class: S14 as is presently the case in Paralympic competition; (iv) more research on pacing strategy for swimmers with Down syndrome is needed to understand if one pacing strategy could be more beneficial than others for the final time; (v) Down syndrome athletes, namely swimmers, should be compared to athletes with intellectual disability in terms of their physical fitness profile, to understand if swimmers with intellectual disability present higher physical fitness profiles than swimmers with Down syndrome.

Chapter 4.

Swimmers with Down syndrome are healthier than untrained peers

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Abstract

Purpose: to compare the body composition and physical fitness profile of competitive swimmers and untrained individuals with Down syndrome. Method: the Eurofit Special test, a physical fitness battery designed for persons with intellectual disabilities, was applied to a group of competitive swimmers ($n = 18$) and a group ($n = 19$) of untrained individuals, all with Down syndrome. In addition, measurements were taken to determine body mass and fat mass index. Results: differences were found between swimmers and untrained in height, sum of the four skinfolds, fat%, fat mass index and all items of the Eurofit Special test. Regular swimming training allows persons with Down syndrome to approach Eurofit standards, although lower fitness levels are attained by these persons when compared to athletes with intellectual disability. Conclusions: persons with Down syndrome who train for competitive swimming have more healthy body composition and are stronger, faster and have better balance than untrained peers.

Keywords Down syndrome, physical fitness, body composition, swimming

Introduction

Down syndrome, a form of intellectual disability, is a genetic disorder caused by the presence of the whole (or part) of an extra copy of chromosome 21, with a global incidence estimation of 1 in 1000 to 1 in 1200 live births (Irving et al. 2008). These persons present distinctive physical features, are predisposed to a higher incidence of cardiovascular disease (Hill et al. 2003), diabetes (Hermon et al. 2001), osteoporosis and obesity, and more susceptible to a premature and significant decline in function as they grow older (Rimmer et al. 2004). Despite this, the infant Down syndrome survival rates, as well as life expectancy in general, continues to increase (Weijerman et al. 2008, Wu & Morris 2013).

Lack of regular physical activity has been identified as one of the most significant health risks (WHO 2002), resulting in an increased threat of chronic conditions (e.g. cardiovascular disease and type 2 diabetes) (Chakravarthy et al. 2002) and is considered as a predictor of mortality in the Down syndrome population (Eyman & Call 1991). Literature indicates low fitness levels in these individuals (Fernhall et al. 1989, Pitetti et al 1992, Varela et al. 2001), which may be related to sedentary lifestyles (Draheim et al 2002), limited social and recreational opportunities (Fujiura et al. 1997), and/or low motivation to be physically active (Kosma et al. 2002). Nevertheless, several studies have indicated positive benefits from physical activity participation for these individuals (e.g. Balic et al. 2000, Carmeli et al. 2002, Tsimaras e Fotiadou 2004) and evidence suggests that physical activity can increase physical fitness in this population (González-Aguero et al. 2010).

Specifically, aquatic exercise has been shown to offer benefits for people with intellectual disabilities in terms of cardiorespiratory endurance, muscular endurance, speed, static balance and agility (Yilmaz et al. 2009, Fragala-Pinkham et al. 2008). More recently there has been an increasing interest from people with Down syndrome in competitive swimming (with the participation of 200 swimmers at the World Championships in Italy 2012 and Mexico 2014). Nevertheless, even if physical activity and sport are meaningful to many people, including those with intellectual disabilities, research on this topic has focused

mainly at inactive participants (Fernhall & Pitetti 2001), while trained individuals are scarcely studied (Van de Vliet et al 2006).

The aim of this study was to assess the body composition and the physical fitness profile of competitive swimmers with Down syndrome and to compare them to untrained peers. It was hypothesized that: (i) swimmers present lower values than untrained individuals for Body Mass Index (BMI), percentage of total body fat (fat%) and Fat Mass Index (FMI), and higher values for Lean Body Mass (LBM); and (ii) swimmers present higher physical fitness values than untrained counterparts.

Methods

Thirty-three individuals with Down syndrome participated in this study: 18 were national level trained swimmers and 19 were untrained persons with Down syndrome (experimental and control groups, respectively). All individuals, or their parents, gave written informed consent to participate in this study, which was approved by the local ethics committee and carried out according to the Declaration of Helsinki. Trained swimmers were 22.2 years (SD = 5.4), and practiced 7.4 h per week (SD = 0.8) over the entire year. Untrained individuals were 26.6 years (SD = 8.2), and were involved in two 45 min sessions of none sport specific physical activity a week.

The body measurements included height, weight and four skinfolds (triceps, biceps, subscapular and suprailiac, using a Harpenden skinfold caliper). BMI was defined as body mass (kg, measured using an electronic weighing scale) divided by height squared (m) squared (kg/m^2). The fat% and LBM were derived from the measured skinfolds, using the equation proposed by Durnin & Wommersley (1974) and the FMI was calculated as fat mass/height². All measurements were made on the right side of the body by the same evaluator and were repeated three times, with the mean values being used (Guidetti et al. 2010). The World Health Organization (1995) classification of obesity was used to categorize participants based on BMI: ≤ 18.4 underweight, 18.5-24.9 normal weight, 25-29.9 overweight, 30-39.9 obese and ≥ 40 morbid obese.

To evaluate physical fitness the Eurofit Special test was used, as follows (Skowróński et al. 2009): (i) explosive lower limb strength was determined with a standing broad jump; (ii) upper limb strength was determined using a 2 kg medicine ball push performed with the preferred arm. From a standing position, the ball was placed in the palm, supported by the second hand and pushed forward in a shot put like action; (iii) local muscle endurance was determined by the number of correctly completed sit-ups in 30 s; (iv) speed was measured for a 25 m run from a standing start measured to 0.1 s using a manual stopwatch; (v) flexibility was measured with the sit-and-reach test; and (vi) balance was determined by a walk on a bench. Two test trials (Test A and Test B) were performed without shoes. In test A, the participant approached the bench, stepped onto it and walked forward. If Test A was successful, Test B is attempted. For test B the same process applies, with the bench in the upside-down position. Each test had to be completed in 30 s, with points recorded on the following scale: 1 point if the participant responds to the instructions; 2 point if the participant approaches the bench; 3 points if the participant walks 2 m without support or the entire bench with support (Test A); 4 points if the participant walks along the entire bench without support (Test A); 5 points if the participant walks 2 m without support or the entire bench with support (Test B); 6 points if the participant walks along the entire bench without support (Test B).

The results from the body mass, height and all the Eurofit items were also converted to percentile scores. This facilitated merging of gender groups for this study (14 males and four females swimmers and nine males and 10 females untrained). The norm scales for severe intellectually disabled individuals of 20 years old (top off age for the scale) were used (Skowróński 2007). This table was chosen for two main reasons: (i) most raw scores measured fit this table, particularly the control group and (ii) 20 years was the closest age to the sample studied. Scores outside the scale were given the maximum or minimum points, as appropriate.

Descriptive statistics were calculated for all the variables (raw values as well as percentile scores) and all data were checked for normality and homogeneity of variance. Mean and SD for all variables are presented, with independent samples t-test used to verify if there were differences between groups on

performance and body composition (independently of the sex). Cohen's *d* was calculated for effect size ($d \leq 0.2$ small effect, d between 0.2 and 0.5 moderate effect, and $d \geq 0.8$ large effect) and statistical significance was set at $p \leq 0.05$. Procedures were performed with IBM SPSS Statistics 19 for Windows.

Results

Competitive swimmers presented healthier body composition and better physical fitness profile than untrained peers (Table 1). The swimmers presented significantly higher values for height and lower values for the sum of the skinfolds, BMI, fat% and FMI, all with large effect sizes. Concerning gender differences, male swimmers and untrained individuals were taller and had higher values for LBM and lower values for fat% than female counterparts (Table 1). In the swimmers group, 10 persons were of normal weight, 6 were overweight, and 2 were obese whereas in the untrained group, 7 were of normal weight, 4 were overweight, 6 were obese, and 2 were morbid obese. Thus, 44.4 and 52.6% of the participants were overweight or obese in swimmers and untrained individuals, respectively and 10.5% of the untrained group showed morbid obesity. Table 1 also shows that swimmers with Down syndrome scored significantly better with large effect sizes for long jump, medicine ball, sit-ups, speed, and balance, while for flexibility there was a moderate effect.

Table 1. Mean (SD) and effect size values for the body composition and all variables of the Eurofit Special Test for trained swimmers and untrained subjects, all with Down syndrome.

Variables	Swimmers			Untrained subjects			Effect size Cohen's <i>d</i>
	Males (n=14)	Females (n=4)	Total (n=18)	Males (n=9)	Females (n=10)	Total (n=19)	
BM (kg)	63.8 (11.3)	53.8 (10.4)	61.6 (11.6)	67.5 (11.4)	62.1 (12.8)	64.7 (12.1)	-0.26
Height (cm)	8.4 (5.7) ^a	145.8 (6.4)	155.6 (7.8) ^c	155.1 (5.1) ^b	141.3 (6.7)	147.9 (9.2)	0.91
SS (mm)	47.9 (13.4)	64.1 (22.1)	51.5 (16.5) ^c	70.9 (23.4)	91.8 (28.9)	81.9 (27.9)	-1.32
BMI	25.3 (3.1)	25.9 (6.2)	25.4 (3.8) ^c	28.3 (4.6)	32.9 (13.3)	30.7 (10.2)	-0.76
Fat%	18.8 (3.7) ^a	29.7 (4.7)	21.2 (6.0) ^c	24.2 (4.2) ^b	34.7 (5.3)	29.8 (7.1)	-1.30

LBM	23.5 (3.5) ^a	17.1 (2.6)	22.1 (4.2)	23.1 (2.8) ^b	18.1 (2.8)	20.5 (3.7)	0.40
FMI			9.3 (3.5) ^c			13.6 (6.1)	-0.86
LJ (cm)	123.3 (40.7)	91.0 (10.6)	116.1 (9.1) ^c	89.6 (45.2) ^b	56.5 (32.6)	72.1 (41.6)	1.10
MB (cm)	384.8 (142.3) ^a	252.0 (102.9)	355.3 (143.4) ^c	289.5 (139.1) ^b	200.8 (74.7)	242.8 (116.0)	0.86
Sit-ups	17.4 (3.8)	16.0 (2.8)	17.1 (3.6) ^c	8.7 (8.4)	7.5 (6.7)	8.1 (7.4)	1.56
Speed (s)	5.2 (0.5) ^a	6.4 (0.7)	5.5 (0.7) ^c	6.7 (1.7) ^b	8.6 (1.7)	7.7 (1.9)	-1.53
Flex (cm)	39.0 (8.3)	42.9 (4.4)	39.8 (7.7) ^c	29.8 (11.7)	32.8 (10.1)	31.4 (10.7)	0.57
Bal (pts)	5.5 (0.7)		5.4 (0.6) ^c	4.4 (1.1)	3.6 (1.0)	4.0 (1.1)	1.55

BM = body mass, SS = skinfolds sum, BMI = body mass index, Fat % = percentage of total body fat, LBM = lean body mass, FMI = fat mass index, LJ = long jump, MB = medicine ball, Flex = flexibility, Bal = balance. Differences between genders in swimmers are identified by a, differences between genders in untrained individuals are identified by b and differences between swimmers and untrained individuals are identified by c ($P \leq 0.05$).

Table 2 presents results in percentile scores that are based on norms for severe intellectual disability without Down syndrome. Swimmers presented higher scores for all variables (groups were not different in body mass), with large effect sizes with one exception in a moderate effect of the medicine ball throw. Despite the differences both swimmers and control showed low percentile scores for height (28.8, 14.5 for swimmers), and medicine ball (36.7, 25.3 for swimmers) on the scale used.

Table 2. Mean (SD) and effect size percentile values for all variables of the Eurofit Special Test, body mass and height for trained swimmers and untrained subjects, all with Down syndrome.

Variables (points)	Swimmers (n=18)	Untrained subjects (n=19)	Mean Difference	Effect size (d)
Body mass	51.2 (21.0)	59.8 (22.3)	-8.7	
Height	28.8 (14.5) ^a	16.0 (12.5)	12.8	0.95
Long jump	55.9 (22.6) ^a	27.3 (27.3)	28.6	1.14
Medicine ball	36.7 (25.3) ^a	20.5 (22.0)	16.2	0.68
Sit-up	83.8 (18.8) ^a	39.6 (41.7)	44.2	1.37
Speed	83.4 (9.0) ^a	50.2 (29.0)	33.2	1.81
Flexibility	53.7 (13.8) ^a	33.0 (20.2)	20.7	1.20
Balance	91.1 (9.9) ^a	53.9 (34.1)	37.1	1.48

Differences between groups are identified by a ($P \leq 0.05$).

Discussion

The purpose of this study was to assess the body composition and the physical fitness profile of trained swimmers with Down syndrome and to compare them with untrained individuals with the same condition.

Body Composition

Epidemiological studies often use BMI as a measure of weight status (Melville et al. 2005) since it is a good indicator of body fatness and easily calculated (Husain 2003). Nevertheless, several authors reported that BMI is not sufficient to describe the body composition of individuals (Hall & Cole 2000, Wells 2001, Wells & Fewtrell 2006). Taking this into consideration, the fat mass index was also calculated here, due to the fact that fat mass is in part related to height (Magge et al. 2008). Pitetti et al. (2013) pointed out that ambiguous evidence exists regarding body composition in persons with Down syndrome and that the lack of consistency may involve methodological issues for measuring body composition or the comparison of the weight status using different methods. So, caution is urged when interpreting global statements on body composition in Down syndrome.

Numerous studies have reported that the prevalence of overweight and obesity are substantially higher in individuals with Down syndrome compared to their age-matched peers without disability as well as those with intellectual disability but not Down syndrome (Pitetti et al. 2013). Prasher (1995) reported that 48% of adults with Down syndrome were obese with 27% being overweight and Rubin et al. (1998) found 48% of men and 56% of women to be overweight or obese. In the current study, according to the BMI criteria, 55.6% of the swimmers and 36.8% of the untrained were of normal weight, 33.3% of the swimmers and 21.1% of the untrained were overweight, 11.1% of the swimmers and 31.6% of the untrained were obese, and 10.5% of the untrained were on the morbid obesity range. According to the fat% criteria, a much larger percentage of swimmers (83.3%) and a smaller percentage of untrained (31.6%) were considered normal. A much smaller percentage of swimmers were considered overweight (11.1%), while for the untrained the percentage

rose to 63.2% while 5.6% of the swimmers and 5.2% of the untrained were on the borderline range.

Although the equation described by Durnin & Womersley (1974) to estimate body fat is not specific for Down syndrome, it was nevertheless previously used with this population (Ordonez et al. 2006). These authors calculated the fat% in male adolescents with Down syndrome before and after a 12-week moderate aerobic training program. These adolescents decreased their fat mass percentage after the program (31.8, 3.7% pretest and 26.0, 2.3% posttest). We should note that male swimmers from our study presented much lower fat% than these adolescents (18.8, 3.7%).

In the current study, swimmers presented higher values for height and lower values for the sum of skinfolds, BMI, fat% and fat mass index than untrained peers. The effect size (Cohen's *d*) was large for all of the variables above, indicating that, not only swimmers are different from untrained, but that those differences are great. Gonzalez-Aguero et al. (2010) stated that body composition in this specific population is, in general, poorer than that observed in their peers without Down syndrome, as proven by higher BMI, lower levels of lean mass and reduced bone mass-related parameters. Bertapelli et al. (2013) reported several causes for the augmented obesity in persons with Down syndrome, such as genetic, physiological, and environmental factors. However, as mentioned previously, the common term "obesity" used to describe physical characteristics in individuals with this condition might not always be valid (Izquierdo-Gomez et al. 2013). For instance, a review by Gonzalez-Aguero et al. (2010) reported mixed results and if some studies indicate higher fatness values for people with Down syndrome (Bertapelli et al. 2013, González-Aguero et al. 2011, Mercer & Lewis 2001, Baptista et al. 2005, Pitetti & Fernhall 2004), others present similar levels for persons with Down syndrome relative to persons without (González-Aguero et al. 2011, Baptista et al. 2005, Luke et al. 1996). Despite these uncertainties, people with Down syndrome seem capable of improving their body composition values with training (Ordonez et al. 2006, González-Aguero et al. 2011).

In athletes with Down syndrome or intellectual disability, systematic training seems to lead to healthier body composition, and consequently, a better quality of life (González-Aguero et al. 2010). In a study from Aleixo et al. (2009), with a small number of individuals with Down syndrome, differences in BMI between swimmers (24.3, 4.1) and untrained (36.8, 5.3) were observed, with swimmers being placed on the normal weight range and the untrained individuals at the obesity level. On the other hand, Balic et al. (2000) analyzed 13 trained individuals who participated at the Special Olympics Games and seven sedentary adults, all with Down syndrome, and found no differences between both groups in age, BMI, height, weight and fat%. However, the fact that there were no differences between Special Olympians and sedentary, may be related to the fact that Special Olympics is not performance but participation oriented and this implies that the training process might be less demanding, with fewer sessions per week, less volume, and lower intensity. This training effect may also be the deciding factor for the differences between swimmers from our study and Climstein et al. (1993). These authors evaluated one group of 15 individuals with Down syndrome and one group of 17 non-Down syndrome and most of the subjects were actively involved in the Special Olympics program. When comparing to the present study, Down syndrome individuals from Climstein et al. (1993) presented higher values for fat% (26.1, 5.3%).

Although the studies of athletes with intellectual disability (with or without Down syndrome) are scarce, some authors emphasized the importance of the participation in physical activity programs to improve body composition and consequently physical activity or sport performance. For instance, Van de Vliet et al. (2006) evaluated athletes with intellectual disabilities (but no Down syndrome) and revealed that high-performance athletes with intellectual disabilities reach fitness levels that are, in general, equal to or lower than those of their able-bodied sportive peers and Guidetti et al. (2010) found significant decreases in weight and BMI in athletes with intellectual disability, after a specific training program. In addition in relation to trained persons with intellectual disabilities, a study from Daly et al. (2014) reported Eurofit Test battery results in high performance athletes with intellectual disability (finalists and non-finalists) participating in a World Championships (2004 INAS-FID

Global Games). In comparison to the current study, male swimmers with Down syndrome were much shorter in height (cm) (158.4, 5.7 versus 180.2, 10.7 finalists and 172.4, 8.6 non-finalists), and presented a slightly higher BMI (25.3, 3.1 versus 23.8, 3.9 finalists and 23.4, 3.3 non-finalists). For females, similar comparisons can be made: lower height (145.8, 6.4 versus 164.9, 9.2 finalists and 159.5, 6.0 non-finalists) and higher BMI (25.9, 6.2 versus 20.4, 1.7 finalists and 21.6, 1.8 non-finalists).

Physical Fitness

The Eurofit Special test was created as the original Eurofit Test battery was not always adaptable to this population (Skowróński et al. 2009). When compared to untrained individuals taking part in about 90 min a week of physical activity, swimmers presents better results for all the test items, indicating their better physical fitness profile. This superiority was confirmed when examining the percentile scores (Table 2) as swimmers with Down syndrome are more fit than untrained counterparts, presenting higher levels of strength, balance and flexibility.

Despite the fact that physical fitness is an important contributor to health, in adults and youth, less is known in persons with disabilities, such as Down syndrome (Izquierdo-Gomez et al. 2013). In a review on physical fitness and physical activity in children and adolescents with Down syndrome, Pitetti et al. (2013) point out that peak aerobic capacity (VO_{2peak}) in both youth and adults with Down syndrome is reduced in comparison to their peers without disability and with intellectual disability but not Down syndrome and highlight the fact that these persons can be responsive to aerobic endurance training, particularly with improvements in work capacity. Muscular strength is also inferior in persons with Down syndrome when compared to their peers with normal development or with an intellectual disability but not Down syndrome (e.g. Pitetti et al. 1992, Carmeli et al. 2002, Pitetti et al. 2013, Cowley et al. 2010, Angelopoulou et al. 1992, Horvat et al. 1997, Shields & Taylor 2010). According to Shields et al. (2010), improved strength in persons with Down syndrome has been associated with higher levels of physical activity. Muscular strength is a fundamental ability

needed by persons with disabilities (also with Down syndrome) especially because: (i) their workplace activities typically emphasize physical rather than cognitive skills (Shields et al. 2010); (ii) muscle weakness can impact their ability to perform everyday activities, including walking, eating, dressing, and rising from a chair (Carmeli et al. 2002, Cowley et al. 2010); (iii) as life expectancy is increasing for persons with Down syndrome (Glasson et al. 2002), the development and maintenance of muscle strength is important to lead productive lives (Croce et al. 1996); (iv) improving muscle strength may be important to control the high tendency for osteoporosis that persons with Down syndrome often demonstrate (Angelopoulou et al. 1999).

The current study indicates that swimmers with Down syndrome present higher strength levels (lower strength, with the long jump; upper body strength, with the medicine ball throw and abdominal strength, with the sit-ups) compared to individuals that are not involved in systematic training (Tables 1 and 2). Improvements in muscle strength have been demonstrated by other studies for persons with intellectual disability after participation in a training program (Rimmer et al. 2004, Carmeli et al. 2002, Shields et al. 2010, Shields et al. 2008, Croce & Horvat 1992, Horvat et al. 1993, Stopka et al. 1998). In fact, low levels of physical activity may be one of the reasons for the lower muscle strength observed in Down syndrome population (Roizen & Patterson 2003). Furthermore, Angelopoulou et al. (1999) mentioned that the lower muscles torque of individuals with Down syndrome can be associated with a deficiency in the quantity and quality of their muscle tissue, primarily related to their physically inactive lifestyle and lack of opportunity to practice skills in school and the family setting. There might also be an inability and unwillingness of some persons with Down syndrome to mobilize their neuromuscular mechanisms and to produce a maximal effort in tests of torque (Tsimaras & Fotiadou 2004).

Hypotonia and hyperflexibility, two characteristics of Down syndrome (Hawly et al. 2009, Shields et al. 2009), have an impact on bone mass, muscular strength and power, gait and motor development (Cissik 2012). All of these factors lead to the lower strength levels of persons with Down syndrome, but at the same time accent the importance of physical activity. Swimming can be one of those

activities, since accordingly to Ylmaz et al. (2009), aquatic exercises can be a good way of developing physical fitness and motor skill development for children with intellectual disabilities, as aquatics provide a very unique environment for these children. Perán et al. (1997) stated that participating in competition is fundamental for individuals with Down syndrome. Although there is research on the effects of aquatic exercises on persons without disabilities, little has been done on persons with intellectual disabilities (Einarsson et al. 2015), and more specifically concerning competitive swimming for persons with Down syndrome.

Too often we are left to believe that persons with intellectual disabilities are unable to engage in the level of training or mental preparation required for a high level of competition due to the nature of the impairment (Van de Vliet et al. 2006). As a consequence, lower physical fitness levels are considered by many a direct result of disability. Lifestyle can, nevertheless, not be excluded as responsible for lower physical activity and fitness levels (Draheim et al. 2002). It is thus unclear to what extent the physical fitness levels reported here and elsewhere reflect the full potential of individuals with intellectual disability (Van de Vliet et al. 2006). Indeed, Frey et al. (1999) found that persons with intellectual disabilities who train in a similar manner to their peers without intellectual disability exhibit similar peak exercise responses for several variables, such as VO_2 peak and HRpeak. These data suggest that intellectual disability *per se* does not prevent persons from attaining high peak physiological capacity and physical fitness in general. In fact, Van de Vliet et al. (2006) referred that high-performance athletes with intellectual disabilities reach fitness levels that are equal to or lower than those of their able-bodied sportive peers. For instance, Daly et al. (2014) found that the strength differences between athletes with and without intellectual disabilities are in the range of 4 – 14 % for male and 11 – 27 % for female, being inferior for the athletes with intellectual disabilities. Despite this, much more specific data is needed on high-performance athletes with intellectual disability (Van de Vliet et al. 2006).

Comparing the results from the present study with those of Daly et al. (2014), with high-performance athletes with intellectual disability, male swimmers with Down syndrome only scored better in the sit-and-reach test (cm) (39.0, 8.3

versus 34.0, 15.8 finalists and 35.7, 7.4 non-finalists) while low scores for the long jump (cm) and sit-ups were obtained (123.3, 40.7 for long jump and 17.4, 3.8 for sit-ups versus 197.3, 26.3 and 23.0, 6.8 finalists and 181.9, 39.5 and 20.7, 4.7 non-finalists). Flexibility was slightly higher for female swimmers with Down syndrome (42.9, 4.4 versus 41.0, 8.9 finalists and 38.5, 8.0 non-finalists) but for the long jump and the sit-ups low scores can be observed (91.0, 10.6 and 16.0, 2.8 versus 154.6, 20.2 and 21.5, 6.1 finalists and 157.1, 24.9 and 18.2, 4.3 non-finalists).

As swimmers with Down syndrome from our study present higher levels of strength than untrained individuals with Down syndrome, we are led to conclude that swimmers have increased muscular hypertrophy, which in turn can reduce hypotonicity and balance dysfunctions and increase bone-mass related parameters (González-Aguero et al. 2010). Little is known about the effect of specific strength training in this population. Until recently, swimmers with Down syndrome rarely participated in specific dryland strength training. Van de Vliet et al. (2006) studied elite athletes with intellectual disability and pointed out that good levels of fitness seem to be possible for these athletes, and likely the training effect influenced the data. Likewise with athletes, Balic et al. (2000) found that the active group of Special Olympians with Down syndrome exhibited significantly higher isometric strength than the sedentary group, also with Down syndrome. They suggested that long term exercise training may enhance physical fitness in individuals with Down syndrome.

Balance in people with Down syndrome is also a component of physical fitness that is usually inferior to the general population or individuals with intellectual disability without Down syndrome (Tsimaras & Fotiadou 2004, Connolly & Michael 1986). Muscle hypotonia may be responsible for balance problems that individuals with Down syndrome usually demonstrate (Connolly et al. 1984). The delay of maturation of cerebellum and the relatively small size of cerebellum and brain stem in persons with Down syndrome may also be responsible for the disturbance of balance (Cowie 1970). Despite these characteristics, individuals with Down syndrome seem capable of improving their balance through physical activity participation, and with this improve their well-being and the quality of life

(Tsimara & Fotiadou 2004). The swimmers from the current study presented good balance scores and were exceedingly better than the control group.

As this was not a training study it is incorrect to conclude that differences in physical fitness are an outcome of the swimming training. Nevertheless, a study from Querido et al. (2015) with 6 swimmers with Down syndrome evaluated for body composition and physical fitness in 2011 and 2014, found that in 3 years of training, swimmers with Down syndrome improved their physical fitness profile (especially strength) and their body characteristics (absolute differences between 2014 and 2011 of 1.8 hours training/week (SD = 1.3), -17.7 cm for skinfold sum (SD = 19.2), -2.8 for BMI (SD = 4.2), -4.4 % for Fat% (SD = 4.4), 1.8 kg for lean body mass (SD = 5.0), 21.7 cm for long jump (SD = 44.6), 108.8 cm for medicine ball (SD = 85.2). Some of these differences were not significant, as expected, due to the small sample size.

In summary, it can be said that: (i) swimmers with Down syndrome present a healthier body composition than untrained individuals with Down syndrome, confirming the first hypothesis; (ii) swimmers with Down syndrome present higher physical fitness values than untrained individuals with Down syndrome, confirming the second hypothesis. The present data supports the fact that competitive sport practice, in this case, swimming, may help individuals attain a better physical fitness profile; (iii) in general: for body measurements, swimmers with Down syndrome present similar to higher values than athletes with intellectual disability examined in the literature, and similar to lower values than athletes with Down syndrome. For physical fitness, swimmers with Down syndrome score lower than athletes with intellectual disability, and young adults without disability, with the exception of flexibility. The swimmers with Down syndrome when compared to adults with moderate intellectual disability had less lower and upper body strength, and similar flexibility, abdominal strength, speed, and balance. Improvements in physical fitness are possible for swimmers with Down syndrome and athletes with intellectual disability, although strength seems to be a problem to this population, especially for Down syndrome. Performance directed activities such as swimming must therefore be promoted.

Limitations and suggestions for the future

There are several limitations to the present study. Future studies need a larger number of participants (multi center), if possible. Training characteristic information should be more specific (volume, intensity, dry land training), and food intake characterized. It would also be important to perform an intervention program so it would be possible to conclude the effectiveness of swimming training on physical fitness and body composition. With the reentry of the intellectual disabled in the International Paralympic Committee, the question of the fairness of the Class S14 classification rises again. Is it fair that swimmers with Down syndrome continue in the S14 Class, or should they have their own Class (S21)? We only can answer this question if it is proved that Down syndrome impact on swimming performance differently than other forms of intellectual disability, justifying the creation of the S21 Class. For this, parameters evaluated should include be the physical fitness profile and the body composition characteristics, together with race performance analysis, and other specific tests.

Declarations of interest

The authors report no conflicts of interest. This paper is the product of independent research, partially founded by FCT SFRH/BD/78513/2011.

Chapter 5.

Daily life physical activity of trained persons with Down syndrome

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Abstract

This study aimed to assess the daily life physical activity levels of competitive persons and to compare them to active and untrained individuals, all with DS. Twenty individuals participated: international level (IG), recreational (RG) and untrained (CG). Differences were found between IG and: (i) RG in the number of hours of training/week (12.1 ± 2.1 vs 3.2 ± 3.8 h) and distance walked (2193.5 ± 770.1 vs 957.1 ± 443.4 m) and (ii) CG in weight (55.0 ± 5.9 vs 63.6 ± 5.7 kg), BMI (23.5 ± 2.0 vs 26.3 ± 1.8), hours of training/week (12.1 ± 2.1 vs 1.3 ± 0.4 h), steps/day (7104.4 ± 2451.1 vs 3593.5 ± 1139.1 steps) and distance walked/day (2193.5 ± 770.1 vs 1129.5 ± 396.1 m). Individuals with DS engaged in competitive training can be considered as active persons, even though they did not attain the 10 000 steps/day recommended for healthier adults without disability.

Keywords: intellectual disability, body composition, lower limb activity, sport participation

Introduction

Down syndrome is a genetic disorder caused by the presence of the whole (or part) of an extra copy of chromosome 21, with a global incidence estimation of one in 1000 to one in 1200 live births (Irving et al. 2008). This condition is accompanied with intellectual disability and several clinical characteristics, including distinctive physical features, predisposition to a higher incidence of cardiovascular disease, diabetes, osteoporosis and obesity, and higher susceptibility to a premature and significant decline in function as they grow older (González-Agüero et al. 2010, Hill et al. 2003, Rimmer et al. 2004). Nevertheless, accompanying the improvement in social and medical support systems, survival of persons with Down syndrome has been increasing in the past few decades (Pitetti et al. 2013).

Also changing in the last years has been the increasing acceptance of people with intellectual disabilities in the general community, leading to potentially richer lives for all persons with these conditions (Carr 2008). In close relation to the life improvement of persons with Down syndrome, as for the general population, is the physical activity and sport participation. Health related benefits, such as cardiovascular fitness improvements (Vicente-Rodriguez et al. 2005), healthier lifestyle (Stewart et al. 2003), antioxidant defense system enhancement (Franzoni et al. 2005), as well as benefits in social factors associated with sport participation (Andriolo et al. 2005), have been reported. However, evidence suggests that most persons do not meet the minimum required amount of daily physical activity (Troiano et al. 2008, Temple et al. 2006) and, when concerning persons with intellectual disabilities, studies indicate that this population is less active (Einarsson et al. 2015, Foley & McCubbin 2009, Hinckson et al. 2013, Peterson et al. 2008) and their sedentary time is greater than the typically developed individuals (Dixon-Ibarra et al. 2013).

Furthermore, no specific physical activity guidelines have been developed for adolescents with Down syndrome taking into account the impairment of this population, such as muscle hypotonicity, low cardiovascular fitness and decreased muscle strength (Matute-Llorente et al. 2013). Therefore, quantifying

physical activity in daily life is of great value and the time spent actively during daily life, together with intensity and frequency, are key issues in the analysis of a population's usual physical activity levels (American College of Sports Medicine Stand 1998).

The aim of the current study was to assess the daily life physical activity levels of competitive swimming and athletics with Down syndrome, comparing them to physically active persons and untrained individuals with the same condition. It was hypothesized that trained participants present a higher number of steps/day, walk longer distances on daily life and present lower BMI indexes than the other studied groups. It was also supposed that swimmers and athletes with Down syndrome meet the recommended steps/day criteria to be considered active persons nevertheless their intellectual disability condition.

Methods

Participants

Twenty individuals with Down syndrome participated in this study and were divided in three groups according to sport participation: international level competition swimmers and athletes (IG; N=8; 25.8±7.4 years), recreational swimmers and athletes (RG; N=6; 22.0±4.3 years) and six subjects from a day care Institution that acted as control (CG; N=6; 24.0±7.4 years). All individuals, or their parents, gave written informed consent to participate in the current study, which was approved by the local ethics committee and carried out according to the Declaration of Helsinki.

The IG subjects had been involved in swimming and athletics training for, at least, four years, with 12.1 ± 2.1 h of training per week over the entire season. Recreational practitioners were active in swimming and athletics for four years and practiced 4.2 ± 0.8 h per week, without competitive participation. Control subjects did not participate in any kind of regular or organized sport activity, with < 90 min of nonspecific physical activity a week).

Anthropometry

Stature and body mass were measured to the nearest 0.1 cm and kg using a portable stadiometer and an electronic weighing scale, respectively. All measurements were taken by the same trained researcher with participants in light clothing and barefoot. Body mass index (BMI) was also calculated by the ratio between body mass and stature² and BMI cut-points were used to classify participants as either underweight (≤ 18.4), normal weight (18.5-24.9), overweight (25.0-29.9), obese (30.0-39.9) or morbid obese (≥ 40) (World Health Organization 1995).

Physical activity

Daily physical activity was assessed using the WalkinSense®, which is a CE Mark class I electronic medical device designed to dynamically monitor human lower limb activity. It gathers and processes quantitative information, sending it to a fixed laptop or palmtop computer, via wireless Bluetooth® connection or wired USB cable, to be analyzed with the WalkinSense® software (Tomorrow Options SA, Sheffield, UK). The device (weight 68 g, length 78 mm, width 48 mm and depth 18 mm) contains a micro electro-mechanical system triaxial accelerometer and one gyroscope, and an array of eight force sensing resistors for foot pressure measurements (Querido et al. 2016).

Distance is calculated from the triaxial accelerometer and gyroscope, by a sensor fusion algorithm based on an extended Kalman filter with a velocity zero update at each cycle. The participants and/or their careers were instructed to attach the WalkinSense® over the anterior-inferior surface of the right tibia, from waking in the morning until bedtime for five consecutive days (from Wednesday until Sunday). Verbal and writing instructions were given to both participants and careers about how to wear the device during all waking hours except while bathing, showering and swimming. The careers were also given a sheet so they could take simple notes about the hours and the reasons that the participants had to take off the WalkinSense®. All the data was collected during school/job time, so that the normal routines of the participants were maintained.

Statistical procedures

Descriptive statistics (means and standard deviations) were calculated for all the variables and all data were checked for normality and homogeneity of variance. Kruskal-wallis test was used to identify the differences between groups in anthropometric measures and daily physical activity values followed by Mann Whitney test to make pairwise comparison. The significance level in all analyses was set at 0.05. Statistical analyses were conducted using SPSS version 21.0.

Results

Differences between the IG and the RG were observed for the number of hours of training/week and the travelled distance. The subjects from the CG were considerably heavier, presented higher BMI values and fewer hours of sport engagement than the other participants. Differences between the IG and the CG were also observed for steps and distance (Table 1).

Table 1. Mean and standard deviations (\pm SD) for the anthropometrics and physical activity measures for the international level swimmers and athletes, the recreational training subjects and the control group (all with Down syndrome). Differences between groups were also displayed.

Variables	IG (N=8)	RG (N=6)	CG (N=6)	χ	IG vs	IG vs	RG vs
	Mean \pm SD				RG	CG	CG
					p-values for difference		
Height (cm)	153.3 \pm 6.2	151.8 \pm 6.4	155.4 \pm 4.0	1.1	0.662	0.573	0.394
Weight (kg)	55.0 \pm 5.9	56.3 \pm 5.0	63.6 \pm 5.7	5.2	0.573	0.043 ^b	0.093
BMI	23.5 \pm 2.0	24.4 \pm 0.6	26.3 \pm 1.8	7.5	0.414	0.020 ^b	0.015 ^c
Training units/week (h)	12.1 \pm 2.1	3.2 \pm 0.8	1.3 \pm 0.4	17.0	0.001 ^a	0.001 ^b	0.002 ^c
Steps (n ^o)	7104.4 \pm 2451.1	5222.8 \pm 1746.0	3593.5 \pm 1139.1	8.8	0.282	0.001 ^b	0.240
Steps/min (n ^o)	5.0 \pm 3.7	2.7 \pm 1.0	4.0 \pm 4.0	4.6	0.081	0.181	0.937
Distance (m)	2193.5 \pm 770.1	957.1 \pm 443.4	1129.5 \pm 396.1	12.2	0.001 ^a	0.003 ^b	0.589

BMI = body mass index, IG = international level competition group, RG = recreational training group, CG = control group. a, b and c stands for differences between IG and RG, IG and CG and RG and CG, respectively ($P \leq 0.05$).

Discussion

We aimed to understand if competitive swimmers and athletes with Down syndrome lead more active daily lives and presented better body composition indexes than their recreational training and untrained peers by studying parameters related with the daily life activity. We found that although the IG was involved in a considerably large amount of training hours (this time was not taken in account for the measurements), their daily life was more active than those of the RG and the CG. It was not our intention to analyze what kind of activities these persons did in their daily live, but to understand, by a quantitative analysis, their number of steps and distance walked in day-to-day basis.

There are some literature concerning the number of steps to determine physical activity in healthy individuals, but these are not Down syndrome specific. Therefore, precaution is needed when comparing the data, since they do not take into account the impairment of this population, such as muscle hypotonicity, low cardiovascular fitness and decreased muscle strength (González-Aguero et al. 2010). Tudor-Locke & Basset Jr (2004) suggested that < 5000 steps/day may be used as a “sedentary lifestyle index”, 5000 – 7499 steps/day is typical of daily activity excluding sports or exercise and might be considered “low active”, 7500 – 9999 steps/day likely includes some volitional activities and/or high occupational activity demands and might be considered “somewhat active”, $\geq 10\ 000$ steps/day for “active” individuals and regarding this parameter above the 12 500 steps/day is considered for individuals “highly active”.

The current study shows no differences between the IG and the RG regarding the number of steps in their daily routines, although subjects involved in competitive sports are in the superior part of the “low active” range and recreational swimmers and athletes are in the inferior part. The CG presents a considerably lower number of steps/day, being classified in the “sedentary lifestyle index”. It is also important to notice that these data do not include sports activities so, for both the IG and the RG, there is a considerably amount of time where they are involved in physical activity practice and, thus, being

active. Furthermore, the daily life of IG subjects seems to be more active comparing to the other groups.

There is still a lack of information about the daily life activity and physical activity profiles of persons with intellectual disabilities (with or without Down syndrome). Therefore, it is required much more research, even why it is very difficult to make direct comparisons with other studies due to different methodologies (Einarson et al. 2015, Pitetti et al. 2013). Although information regarding physical activity in persons with Down syndrome and other intellectual disabilities are still inconclusive (Frey et al. 2008), Einarsson et al. (2015) observed that children with intellectual disability are considerably less active and took part in few organized sports after school than typically developed children. More specifically, children and adolescents with Down syndrome have been shown to be as less active than those without this condition (Sharav & Bowman 1992) and, although neither adolescents with and without Down syndrome achieved the recommended 60 min of moderate physical activity daily, the first engaged less time in sedentary, moderate, moderate to vigorous and vigorous physical activity than their age-group peers but more min of light physical activity (Matute-Llorente et al. 2013). A study of adults with intellectual disabilities living in community settings, found a mean of 6621 ± 3366 steps/day (Peterson et al. 2008), staying in-between the results from the current study for the IG () and the RG (7104 ± 2451.1 and 5222.8 ± 1746.0 steps/day) and is considerably higher than those of the CG (3593.5 ± 1139.1 steps/day). Accordingly to these authors, their results are similar to the values of the adult general population (cf. Chan et al. 2003, Sequeira et al. 1995).

Interesting results for children with Down syndrome have been found, evidencing relatively high levels of moderate to vigorous physical activity, but still with short bouts of vigorous activity (only 2.0 ± 0.6 min; Shields et al. 2009). Furthermore, there were found no differences in inactivity, light physical activity or moderate physical activity participation between children with Down syndrome and their siblings (Whitt-Glover et al. 2006), with others indicating that youth with Down syndrome follow a physical activity pattern similar to their unaffected peers, meaning sharp declines in physical activity as children became adolescents (Esposito et al. 2012). Therefore, there was a significant

drop in moderate and vigorous physical activity as children age and this decline in physical activity patterns with age should be confirmed in adults with Down syndrome. The current study indicates that international level competitors and recreational training persons with Down syndrome lead healthier day-to-day lives, giving more steps/day and walking longer distances/day than their untrained peers.

Some studies point out the fact that the differences between persons with intellectual disabilities and the non-disabled ones are likely to have cultural and environmental causes rather than biological justifications (Einarsson et al. 2015, Pitetti et al. 2013), since athletes with intellectual disabilities who have the opportunity to be engaged in sports can reach the same fitness levels as non-disabled athletes (Van de Vliet et al. 2006). This is also valid for the body composition, with this potential lack of biological differences evidencing the need to promote a healthy lifestyle and physical activity for this population (Einarsson et al. 2015). In addition, the prevalence of overweight and obesity is higher in persons with Down syndrome comparing to others with intellectual disability but not Down syndrome or persons without disability (Pitetti et al. 2013, Prasher 1995, Rubin et al. 1998, Soler & Xandri 2011), which is justified by genetic, physiological and environmental reasons (Bertapelli et al. 2013). Despite this, it was pointed out that training can improve the body composition values of persons with Down syndrome (Ordonez et al. 2006, González-Aguero et al. 2011), leading to a better quality of life (González-Aguero et al. 2010).

In the current study, it was evident higher BMI values of the control subjects than in the other groups, probably due to their higher weight. The observation of BMI values let us to conclude that IG and RG are in the normal weight range (23.5 ± 2.0 and 24.4 ± 0.6 , respectively, without statistical differences in-between) and that the CG participants are overweight in average (26.3 ± 1.8). These results are in accordance with some literature where it is emphasized the importance of the participation in physical activity programs to improve body composition (Aleixo et al. 2009, Van de Vliet et al. 2006, Guidetti et al. 2010, Daly et al. 2014, Querido et al. 2015). Although a deeper analysis on the topic is needed, since some studies did not found differences in BMI or weight between active persons and sedentary ones (e.g. Balic et al. 2000), the current study

supports the idea that at least three times/week of sustained physical activity practice might be sufficient to cause a healthier profile for persons with Down syndrome.

Conclusions

International level competitive swimmers and athletes with Down syndrome presented a higher number of steps/day and distance walked in their daily life than recreational trained peers and, especially, untrained adults with the same intellectual disability. There were no differences between groups in height, but untrained participants were heavier and presented higher BMI than the other two groups. Having in consideration the time spent in sports and physical activity was not taken in consideration for the assessment of daily life activity, it is concluded that international level sport competitors with Down syndrome are, in general, active persons, since their steps/day are in the “low active” range, but very close to the “somewhat active” group. This study reinforces the importance of a diary sport practice, since it can help persons with Down syndrome to attain healthier and active lives, with positive consequences on their day-to-day activities, besides the well-accepted physiological and body composition outcomes.

Limitations and suggestions for future

The main limitation of the current study is the limited number of participants in each of the studied groups. However, it is very difficult to get participants willing to participate and wearing a non-usual device for five consecutive days. Nevertheless the time demanding and cost issues of getting a larger sample (due to the need of higher the number of devices) it would be very interesting in conducting a gender analysis by group in the future. Moreover, the determination of the kind of activities that these groups are involved in their daily lives and checking if there are differences in the groups for week and weekend days (in both a quantitative and qualitative analysis) would come in handy.

Chapter 6.

Can swimmers with Down syndrome follow a visual pacer in an incremental protocol?

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Introduction

Down syndrome is one of the most common genetic causes of intellectual disability (Irving et al. 2008). This condition occurs when there is an extra copy of the 21st chromosome. This gene over-expression leads to a highly complex and variable phenotype, in which physical and cognitive development are significantly altered (Cebula & Wishart 2008). In total, there are over 80 clinical features occurring more frequently among individuals with Down syndrome than the population at large (González-Aguero et al. 2010).

Despite this, there is a very pronounced lack of knowledge on factors leading to sport success in these individuals, particularly in swimming. The well known positive relationship between physical activity and health may be even more important for individuals with disabilities. For these individuals physical activity can help them to improve ability to perform daily life activities, a critical factor in maintaining independence (Carmeli et al. 2004, Cowley et al. 2010, Torr et al. 2010). Nevertheless, few investigations report findings in trained individuals with intellectual disabilities (Van de Vliet et al. 2006), even more in the case of a specific disability, such as Down syndrome. Furthermore, too often, one is left with the belief that the nature of the intellectual disability renders it impossible for a person to engage in the level of training or mental preparation required for high level competition (Van de Vliet et al. 2006).

The ability to follow a race strategy might be a potential problem for persons with an intellectual disability. This is important to optimal performance. Little is known about this ability. In a previous study on race analysis for swimmers with Down syndrome (Querido et al. 2012), it was observed that for the 100 m freestyle these swimmers presented significant differences in speed and stroke rate from the 1st to the 2nd laps, and from the 2nd to the 3rd laps. Especially for stroke rate, there was a marked decrease on the 2nd lap, and a little less decrease on the 3rd lap. This could mean that swimmers with Down syndrome have trouble on pacing well in the race. The aim of this study was to verify if swimmers with DS are able to follow a visual pacer, and maintain velocity when swimming without the pacer.

Method

Eight male swimmers with Down syndrome, all participants at the 2nd European Swimming Championships for Down syndrome, in Portugal, took part in the study. All swimmers trained approximately 8 hours a week. They performed a 4x100 m front crawl incremental protocol at 75%, 80%, 85%, and 90% of best time for a 100 m race. Each 100 m was divided in 2x50 m with a 10 sec rest. After each 100 m, swimmers rested for 1 min. The first 50 m were conducted with a visual pacer (Pacer 2 Swim, by KulzerTEC), and the second 50 m without. In this case, the swimmer was asked to maintain the speed of the first 50 m. All swimmers performed 3x50 m at the 1st pace speed with the lights on, to become familiar with the device. Differences (paired t-tests) between target and real times were calculated with and without pacer lights as well as between real time with and without lights (SPSS 17.0) for all intensities. Correlations were also analyzed. Significance was set at $p < 0.05$.

Results

Mean target time ranged from $58.4s \pm 5.9$ (75%) to $48.7s \pm 3.9$ (90%) (Table 1). At all swimming intensities, significant correlations were found between 50 m with the pacer and the target time (0.82 for 75%, 0.92 for 80%, 0.90 for 85%, and 0.98 for 90%) (Table 2). There was a significant difference between target time and time without pacer only at 75% pace ($-5.0s \pm 6.6$). In the other cases there was no systematic difference. Nevertheless the 95% CL of the differences were $>5s$ from the Mean at 75% and 80% and $>3s$ from the mean at higher intensity. Interestingly without pacing lights swimmers performed slower than target at lower intensity and above target at higher intensity ($1.7s \pm 4.27$: 90%).

Table 1. Mean and standard deviation (SD) for the 50 m with and without pacer at 75%, 80%, 85%, and 90% of best time, and target time for each intensity

	Mean (s)	SD	Target Time (s)
75% with pacer	54.70	5.95	58.40

75% without pacer	53.39	7.16	58.40
80% with pacer	53.54	5.15	54.73
80% without pacer	54.10	7.60	54.73
85% with pacer	49.93	5.30	51.50
85% without pacer	51.86	4.21	51.50
90% with pacer	48.08	4.39	48.65
90% without pacer	50.40	5.16	48.65

Table 2. Correlations between the target time, and times with and without pacer for all intensities

	Correlation	Sig	Differences
Pair 1: target time 75% & with pacer 75%	0.82	0.014	-3.69 ± 3.45
Pair 2: target time 75% & without pacer 75%	0.43	0.284	-5.00 ± 6.65
Pair 3: target time 80% & with pacer 80%	0.92	0.001	-1.19 ± 2.04
Pair 4: target time 80% & without pacer 80%	0.42	0.300	-0.63 ± 7.00
Pair 5: target time 85% & with pacer 85%	0.90	0.002	-1.58 ± 2.38
Pair 6: target time 85% & without pacer 85%	0.38	0.356	0.36 ± 4.68
Pair 7: target time 90% & with pacer 90%	0.98	0.000	-0.58 ± 0.98
Pair 8: target time 90% & without pacer 90%	0.59	0.126	1.75 ± 4.27

Discussion

In spite of repeated practice with pacing lights DS swimmers were initially not able to repeat the pace when feedback was removed. Nevertheless when practice was limited to one trial they were more successful. As intensity increased they moved from over estimation (too fast) to underestimation (too slow).

The visual pacer can be a very interesting instrument for swimming training. The training of cadence techniques (pacing) is well known and is often used by trainers and swimmers. The pacer provides the swimmer with visual feedback, that he recognizes allowing the swimmer to evaluate himself and to monitor his performance during a training task in a simple constant and efficient way. In psychological terms it can be an excellent reinforcement for the swimmer who can concentrate much more on the task for example regulation of stroke frequency. As people with Down syndrome have an intellectual disability, there was the question if they could be able to follow a visual stimulus and furthermore retain the information acquired. The swimmers in this study had little or no practice using the lights and the system itself is not always available.

Furthermore as target speed increased swimmers changed from over to underestimation of the required swimming speed. This might be a form of overcompensation. This might indicate that the swimmers were able to use the feedback but that more practice is needed.

Besides the importance that this kind of instrument can have in swimming training, this kind of pacing training can have a good transfer to competition. As it was observed by Querido et al. (2012), swimmers with Down syndrome seem to have difficulties in pacing well in the competition. They presented significant differences in speed and stroke rate between the 1st and 2nd laps, and between 2nd and 3rd laps. If swimmers with Down syndrome are able to use the feedback given by the pacer lights, they can probably be trained and improve this kind of ability. As said before, swimmers from the present study had no practice with this kind of equipment. In the future, could be interesting for coaches to develop this kind of approach with swimmers with Down syndrome, and try to

understand if their swimmers can follow a pacing training and improve in the proposed test. After this, swimmers should be evaluated at the race to understand if this kind of training can actually influence the race performance.

Conclusion

At the moment this study shows that swimmers with Down syndrome are not able to take advantage of short term visual feedback to maintain a pacing strategy. Further work is needed to see if more practice improves performance in the test itself, if this possible improvement is sustained over time and how this exactly influences race performance. Additional work is also needed under more fatiguing situations. Furthermore reference data from swimmers without intellectual disability and for all groups in other strokes is necessary. Potentially this simple test might be used in an eligibility test (classification) not only for those with Down syndrome but for persons with other intellectual disabilities.

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Chapter 7.

Kinematical differences between swimmers with Down syndrome and intellectual disability

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Abstract

Purpose: compare biomechanical and coordinative parameters at maximum velocity between swimmers with Down syndrome and intellectual disabilities. **Method:** nine swimmers (four with Down syndrome and five with intellectual disability) performed three bouts of 25 m each at maximum velocity, that were recorded with a system of motion analysis, the Qualisys. Additionally, anthropometric variables, BMI and percentage of body fat were also assessed. **Results:** swimmers with Down syndrome presented lower height (147.6 ± 5.7 vs 174.0 ± 7.9 cm), acromion height (120.1 ± 6.2 vs 141.8 ± 5.0 cm), sitting height (78.2 ± 2.5 vs 90.6 ± 4.7 cm), arm span (138.8 ± 6.2 vs 174.6 ± 8.7 cm), hand length (15.2 ± 0.7 vs 17.9 ± 0.6 cm), hand width (7.5 ± 0.3 vs 8.4 ± 0.3 cm), foot length (19.4 ± 1.0 vs 23.5 ± 1.3 cm), foot width (7.7 ± 0.5 vs 9.2 ± 0.2 cm) and speed (1.05 ± 1.13 vs 1.33 ± 1.19 m/s) than swimmers with intellectual disabilities. **Conclusions:** swimmers with Down syndrome have disadvantage anthropometrics, slower swimming velocities comparing to swimmers with intellectual disabilities. Swimmers with Down syndrome also appear to present distinctive coordination and intracyclic velocity variation relations from swimmers with intellectual disabilities, indicating their lower swimming efficiency.

Keywords Kinematics, coordination, anthropometrics, swimming

Introduction

Athletes with intellectual disability were re-introduced into the Paralympic Games in London 2012 after being excluded at the end of the Sydney 2000 Paralympics (Burns 2015). In the meantime, the classification system have been changed in a way that demonstrates the impact of a particular impairment on a specific sport, trying to classify the athletes according to the impact severity so that competition is based on skill, training and effort and not on the disability level (Tweedy & Vanlandewijck 2011). Naturally, the question about of what evidence can demonstrate the impact of intellectual disability on high-level performance still raises (Burns 2015).

Down syndrome is a genetic condition that can be proved by the karyotype, presenting a unique etiology and affecting many areas of development. These may result in changes in particular biomechanical, physiological, anatomical and behavioral characteristics, with evident repercussions on health and social context of persons with this condition (Antonarakis et al. 2004, González-Aguero et al. 2010, Henderson et al. 2007). Swimmers with Down syndrome can compete at the International Paralympic Committee (IPC) events included in the S14 Class, dedicated to swimmers with intellectual disabilities. Interestingly, as no swimmers with Down syndrome have yet achieved a level of performance that allow them to participate in a Paralympic event, it seems unfair that swimmers with Down syndrome compete in the same Class as swimmers with intellectual disabilities.

Studies concerning competitive level persons with intellectual disability (also Down syndrome) are still scarce (Van de Vliet et al. 2006). However, persons with Down syndrome are known to have poorer strength, cardiovascular fitness and body composition than persons with intellectual disabilities or non-disabled ones (Angelopoulou et al. 2000, Izquierdo-Gomez et al. 2015, Matute-Llorente et al. 2013) although they are able to improve their physical fitness (Emara 2016, Ordonez et al. 2006, Rimmer et al. 2004, Shields et al. 2010). In swimming, in addition to the swimmers fitness profile, it is important to evaluate their technical level, as velocity (V) depends on stroke rate (SR) and stroke length (SL) and there is a necessity to find the optimal compromise between

these parameters to attain and maintain their optimal velocity (Alberty et al. 2005). Also, the temporal organization of the upper limbs cycle is important to characterize highly skilled performance (Schnitzler et al. 2008), with the Index of coordination (IdC) appearing as a measure of the lag time between the propulsive actions of the upper limbs (Chollet et al., 2000). This index is based on the quantification of the phases of the upper limbs action, being a useful tool to assess swimmers' skill level (Millet et al. 2002, Seifert et al. 2005).

Well related to the swimmers' ability to coordinate their propulsive forces, are the fluctuations of the instantaneous velocity during a total cycle (Miller 1975), commonly known as intracyclic velocity variation (IVV). In the front crawl technique, a highly organized inter-arm coordination can minimize IVV and increase swim efficiency, meaning that IdC evaluates how upper limbs propulsive actions are distributed over time, with IVV being the kinematical consequence of the distribution of propulsion in time (Schnitzler et al. 2010). Previous pilot studies of swimmers with Down syndrome evidenced their poorer coordinative development and, consequently, their lower technical efficiency, comparing to swimmers without disabilities (Marques-Aleixo et al. 2013, Querido et al. 2010), emerging the need of performing more studies on swimmers with this condition, comparing them with swimmers with other intellectual disability.

The aims of this study were to: (i) characterize, from a kinematical approach, the swimming performance biomechanical determinants of swimmers with Down syndrome and intellectual disabilities and (ii) contribute to the understanding and development of high level competitive swimming for disabled persons, analyzing possible differences in the swimming biomechanics of Down syndrome and intellectual disability. It was hypothesized that: (i) swimmers with intellectual disabilities are faster than those with Down syndrome; (ii) swimmers with Down syndrome present higher SR and SL values than intellectual disabled peers; (iii) swimmers with Down syndrome apply different coordination modes and present higher IVV and intra-variability than swimmers with intellectual disability for velocity, SR, SL, IdC and IVV.

Methods

Subjects

Nine trained swimmers were divided in two groups, according to their national classification: swimmers with Down syndrome (S21; N=4; 25.0 ± 6.2 years old) and swimmers with intellectual disability (S14; N=5; 18.0 ± 2.0 years old). Swimmers from both groups were engaged in competitive swimming for, at least, three years, all took part in national competitions and some in international competitions for intellectual disability and Down syndrome. All individuals, or their parents, gave written informed consent to participate in the current study, which was approved by the local ethics committee and carried out according to the Declaration of Helsinki.

Experimental design

Testing took place in a 25 m indoor pool, 1.90 m deep, with a water temperature of 27.5°C . After a moderate intensity individual warm-up, participants performed a 3x25 m front-crawl maximal effort (30 min rest), from a push off start, without breathing from the 7.5 to the 20 m marks. The test was recorded using seven land and eight underwater cameras (Oqus 3+ and Oqus Underwater, Qualisys AB, Gothenburg, Sweden) operating at 60 Hz. The calibrated volume was defined using three calibrations – underwater, overwater and twin (to merge the first and the latter) – according to manufacturer's guidelines. Orthogonal axes were defined as x for the direction of swimming, y for the mediolateral direction and z for the vertical, where $z=0$ defines the water surface.

Data acquisition was performed with Qualisys Track Manager version 2.7 (Qualisys AB, Gothenburg, Sweden) and data post processing employed Visual3D (C-Motion, Germantown, MD, USA) using low pass digital filter of 6 Hz. Each swimmer was equipped with a full body retro-reflective marker setup situated at the anatomical reference points selected, particularly the acromion, lateral and medial humerus epicondyle, radius- and ulna-styloid processes, third distal phalanx, iliac crest, and anterior and posterior iliac spine, for both right and left sides.

In addition, anthropometric variables were measured with a stadiometer Seca model 708 (Seca, Hamburg, Germany) and body composition was assessed with a Tanita Inner scan, BC-532 (Tanita, Hoofddorp, The Netherlands) with swimmers wearing light clothes without shoes.

All parameters were calculated as the mean of two recorded upper limbs cycles, with one cycle considered from the right or left fingertip entry until the same fingertip re-entry. Horizontal swimming velocity was calculated by the mean frame by frame displacement of the hip over one cycle divided by the cycle time, SR was determined by the upper limb cycle duration and SL was obtained from the horizontal displacement of the hip during an upper limb cycle. IVV was determined by the coefficient of variation, expressed in terms of percentage (Schnitzler et al. 2008) and represented as the standard deviation of the instantaneous velocity data divided by the mean velocity of the swimmers' speed during each repetition, multiplied by 100.

IdC was calculated accordingly to Chollet et al. (2000) that divided each upper limb cycle into the following phases: (i) entry and catch, corresponding to the time between the entry of the hand into the water and the beginning of its backward movement; (ii) pull, corresponding to the time between the beginning of the backward movement of the hand and its entry into the plane vertical to the shoulder; (iii) push, corresponding to the time between the positioning of the hand below the shoulder and its exit from the water and (iv) recovery, corresponding from the time between the exit of the hand from the water and its following entry. IdC gives the time gap between the propulsion of the two upper limbs as a percentage of the duration of the complete upper limb cycle and was the mean of IdCleft and IdCright (Chollet et al. 2000):

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

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

Statistical analysis

Descriptive statistics (means and standard deviations) were calculated for all the variables and all data were checked for normality and homogeneity of variance. Kruskal-wallis test was used to identify the differences between groups in body composition measures and a Repeated Measures (ANOVA) was conducted to make pairwise comparison, within subjects' effects and interaction effects. The significance level in all analyses was set at 0.05. Statistical analyses were conducted using SPSS version 21.0.

Results

Swimmers with Down syndrome (S21) are older than swimmers with intellectual disability (S14), but are engaged in similar number of training hours per week. Regarding the anthropometric characteristics, swimmers with S21 were in clear disadvantage comparing to S14 since they presented lower height, acromion and sitting height, arm span and hand/foot length/width (Table 1). Swimmers S14 were heavier than the S21 and no differences between groups were noticed in BMI, body fat percentage and waist-hip ratio.

Table 1. Mean \pm SD values for the anthropometric and training background characteristics of Down syndrome (S21) and intellectual disability (S14) swimmers.

Parameters	S21 (N= 4)	S14 (N=5)
Height (cm)	147.6 \pm 5.7 ^a	174.0 \pm 7.9
Acromion height (cm)	120.1 \pm 6.2 ^a	141.8 \pm 5.0
Sitting height (cm)	78.2 \pm 2.5 ^a	90.6 \pm 4.7
Arm span (cm)	138.8 \pm 6.2 ^a	174.6 \pm 8.7
Hand length (cm)	15.2 \pm 0.7 ^a	17.9 \pm 0.6
Hand width (cm)	7.5 \pm 0.3 ^a	8.4 \pm 0.3
Foot length (cm)	19.4 \pm 1.0 ^a	23.5 \pm 1.3
Foot width (cm)	7.7 \pm 0.5 ^a	9.2 \pm 0.2
Body mass (kg)	51.7 \pm 9.3 ^a	66.3 \pm 3.1
BMI (kg/m ²)	23.1 \pm 3.4	22.1 \pm 2.9
PBF (%)	24.1 \pm 12.7	20.7 \pm 10.1
WHR	0.9 \pm 0.0	0.8 \pm 0.0
Training sessions a week (h)	12.5 \pm 1.9	10.0 \pm 1.4

BMI= Body mass index, PBF= Body fat percentage, WHR= Waist-hip ratio. Differences between groups are identified by ^a.

Table 2. Mean \pm SD for the stroke and coordinative characteristics of swimmers with Down syndrome (S21) and intellectual disability (S14). *P* values for the group differences, repetition differences for each group and interaction between groups and repetitions.

	S21 (N= 4)				S14 (N=5)				Group			Repetition			Group * Repetition
	Mean \pm SD				Mean \pm SD				S21 vs S14			1 vs 2	1 vs 3	2 vs 3	
	1	2	3	T	1	2	3	T	1	2	3	1 vs 2	1 vs 3	2 vs 3	
Speed (m/s)	1.04 \pm 0.21	1.06 \pm 0.15	1.05 \pm 0.11	1.05 \pm 1.13*	1.32 \pm 0.23	1.31 \pm 0.13	1.35 \pm 0.22	1.33 \pm 1.19	0.098	0.028 *	0.046 *	S21= 1.000 S14= 1.000	S21= 1.000 S14= 1.000	S21= 1.000 S14= 1.000	0.898
SR (cycles/min)	49.65 \pm 11.09	45.09 \pm 7.81	42.99 \pm 9.60	45.91 \pm 8.77	50.07 \pm 8.76	53.22 \pm 4.61	52.24 \pm 3.91	51.84 \pm 5.52	0.951	0.091	0.088	S21= 0.194 S14= 0.403	S21= 0.369 S14= 1.000	S21= 1.000 S14= 1.000	0.071
SL (m/cycle)	1.31 \pm 0.27	1.33 \pm 0.17	1.33 \pm 0.24	1.32 \pm 0.22	1.51 \pm 0.08	1.49 \pm 0.01	1.52 \pm 0.09	1.51 \pm 0.05	0.144	0.072	0.134	S21= 1.000 S14= 1.000	S21= 1.000 S14= 1.000	S21= 1.000 S14= 1.000	0.782
IdC (%)	-5.78 \pm 9.51	4.18 \pm 13.46	-6.70 \pm 7.05	-2.77 \pm 6.87	-2.24 \pm 9.58	2.54 \pm 7.13	3.80 \pm 4.94	1.37 \pm 6.38	0.598	0.820	0.034 *	S21= 0.512 S14= 1.000	S21= 1.000 S14= 0.155	S21= 0.214 S14= 1.000	0.236
IVV (%)	23.00 \pm 7.57	24.75 \pm 3.20	20.75 \pm 9.43	22.83 \pm 6.01	17.20 \pm 6.42	19.00 \pm 7.42	17.00 \pm 4.00	17.73 \pm 5.82	0.253	0.195	0.443	S21= 1.000 S14= 1.000	S21= 0.687 S14= 1.000	S21= 0.757 S14= 1.000	0.799

SR= Stroke rate, SL= Stroke length, IdC= Index of coordination, IVV= Intracyclic velocity variation. Differences between groups are identified by *.

Differences between S21 and S14 swimmers were observed on the swimming speed, with the S14 swimmers being faster (Table 2). As for the coordination, despite no differences observed, the S21 swimmers presented negative IdC, corresponding to a “catch-up” coordination mode, while the coordination of the S14 group was higher than zero, meaning a “superposition” coordination mode. There were also no differences between groups for IVV and the three repetitions were not different from each other for all variables and both groups. Differences between groups (Down syndrome and intellectual disability) can be observed in velocity at the second and third repetitions as well as for the IdC at the third repetition.

Discussion

To better understand the technical characteristics of swimmers with Down syndrome, comparing them to swimmers with intellectual disabilities, several parameters were evaluated in a maximum velocity test, with three repetitions. Additionally, body measurements were performed, with swimmers with Down syndrome presenting lower anthropometric measures than swimmers with intellectual disability, meaning that swimmers with this condition present a clear disadvantage for the competitive swimming practice, comparing to swimmers with intellectual disabilities. In fact, swimming performance is known to result from a multifactorial process that involves several scientific domains, such as hydrodynamics, kinematics, energetics and also anthropometrics (Morais et al. 2012). The movement patterns of persons with Down syndrome are conditioned, especially due to problems in muscle and tone control, decreased strength and anthropometric traits, as smaller stature and high percentage of body fat (Almeida et al. 2000, Pelayo et al. 1996), all conditions that may affect their swimming performance.

For the body composition measurements, there were no differences at BMI, percentage of body fat and waist-hip ratio between swimmers with Down syndrome and intellectually disabled ones at the current study, which is a good indicator for swimmers with Down syndrome, as persons with this condition are

often referred as presenting high levels of BMI and fat percentage (Pitetti et al. 2013). In fact, the two groups from the current study present acceptable BMI values, accordingly to the World Health Organization (1995), being at the normal weight range, defined between 18.5-24.9%.

Swimmers with Down syndrome were found to have coordination patterns similar to those obtained by lower proficiency swimmers or younger ones, evidenced by their catch-up coordination mode (Marques-Aleixo et al. 2013, Querido et al. 2010), although these studies did not had a control group, that is a clear advantage of the current study. A negative index of coordination was also found at the current study for swimmers with Down syndrome, whilst for swimmers with intellectual disability the mean IdC was on the superposition mode (IdC > 0%), although there were not differences between the two groups for the mean IdC. Nevertheless, there was a difference at the third repetition of 25 m, that was the only observed difference between groups, aside swimming velocity.

Typically, the fastest swimmers present higher IdC values for equivalent paces and, on the other hand, the IdC increases with fatigue, as velocity decreases (Alberty et al. 2005, Chollet et al. 2000), meaning that high IdC values should not be automatically linked with high velocities but instead associated with propulsive efficiency indicators, such as SL or IVV (Schnitzler et al. 2008, Seifert et al. 2007). The IVV percentages found in the current study are not different for the two groups, but swimmers with Down syndrome seem to present somewhat higher velocity variation. Nevertheless, the interaction between parameters such as SL, IdC and IVV should be better for swimmers with intellectual disability, as they swim faster than swimmers with Down syndrome.

Interestingly, there were not found differences in neither group for the three repetitions, meaning that swimmers with Down syndrome and swimmers with intellectual disability did not differ in intra-variability for the different analysed variables. As persons with Down syndrome combine cognitive and physical limitations, that may contribute to a higher motor performance dysfunction (Lahtinen et al. 2007, Latash et al. 2000), higher variability would be expected.

For further research in the field of swimming for Down syndrome, it is fundamental that the sample sizes should be augmented, as it is a conditioning factor. Despite the fact that there were not found differences between swimmers with Down syndrome and swimmers with intellectual disabilities for most of the variables, the lower velocities found in swimmers with Down syndrome could be at least partially explained by their poorer anthropometric characteristics as well as less efficient relations between coordinative and velocity variations aspects, which reduces their propulsive times.

Conclusions

There are several considerations that can be added: (i) swimmers with Down syndrome have disadvantage anthropometric characteristics comparing to swimmers with intellectual disabilities, although no differences in BMI and fat percentage were found; (ii) swimmers with Down syndrome swim at considerably slower velocity than swimmers with intellectual disability; (iii) there were no significant differences between swimmers with Down syndrome and swimmers with intellectual disabilities in SR and SL; (iv) despite no differences in IdC, and IVV, swimmers with Down syndrome presented a different coordination mode than swimmers with intellectual disabilities (catch-up vs superposition) and higher IVV. The higher intra-variability of swimmers with Down syndrome was not confirmed; and (v) the small sample size might be covering-up some significant results.

Chapter 8. General Discussion

The actual knowledge on trained individuals with intellectual disability, particularly with Down syndrome, is scarce. In general, persons with Down syndrome are less active and have a higher prevalence of overweight and obesity than peers without disability (Sharav & Bowman, 1992; Soler & Xandri, 2011). The benefits of physical activity and sport participation are well known for persons without disability. Accordingly to Mactavish & Dowds (2003), a deep knowledge on physical fitness, technical and social skills acquisitions (and overall functioning) are needed to effectively engage persons with intellectual disabilities in competitive sports. In this sense, it was our aim to investigate: (i) the physical fitness and body composition profiles of swimmers with Down syndrome; (ii) the daily life physical activity of persons with Down syndrome and analyse the possible differences between those who engage in competitive sport and untrained ones; and (iii) competitive swimmers with this condition in biomechanical and coordinative terms, comparing them with swimmers with intellectual disabilities. The final purpose was attempting to conclude if the physical and intellectual impairments of swimmers with Down syndrome are sufficient to promote a performance impact that could put these swimmers in a disadvantage when competing with the intellectual disabled swimmers.

To get an overview of the current state of knowledge on physical fitness and body composition of trained persons with Down syndrome and to examine how could these parameters impact on their performance, a systematic review was conducted (**Chapter 2**). Its main highlights were: (i) a physical intervention program is moderately to highly effective in Down syndrome persons for improving strength, cardiovascular fitness and body composition; (ii) persons with Down syndrome have less power and cardiovascular fitness and higher BMI in comparison with intellectual disabled and non-disabled persons; (iii) more high-level quality research, especially with persons involved in the competitive training process, is required.

Having this in consideration, it seems like persons with Down syndrome deal with low levels of physical fitness and body composition problems, which brings

out the following questions: (i) do competitive swimmers with Down syndrome also present lack of strength, cardiovascular fitness and augmented fat, weight and BMI? (ii) are these swimmers able to improve their fitness and body composition levels leading them to similar levels than trained peers with intellectual disabilities or non-disabled ones? and (iii) can these differences, if existing, impact on their performance? As race speed differences among Olympic and Paralympic swimmers with intellectual disability are determined by physical aptitude, fitness (training), technical expertise (knowledge) and optimal race patterns (experience), as well as suitable nutrition, rest and proper training conditions (Daly et al. 2006), it was also important to analyse the race patterns of swimmers with Down syndrome.

In fact, race analysis has been widely accepted in the scientific and coaching community since 30/40 years ago to understand the swimmers' behavior in competition, but little has been done at international events for Down syndrome. Although methodological issues make it difficult to compare different studies, it is important to carry on this kind of approach so possible differences between swimmers might be identified for further work. In this sense, **Appendices I and II** were pioneer works using this kind of analysis, being possible to concluded that: (i) male swimmers with Down syndrome are significantly faster than female swimmers; (ii) SL is more important for swimming speed than SR; and (iii) turns are an important part of the race performance. Coaches should, therefore, emphasize the relation between SL and SR as well as turns training, especially in female swimmers, to improve their performance.

The conclusions displayed on the literature on race analysis for swimmers with intellectual disability are not in total agreement, meaning that research on this topic needs to continue, with larger samples and more competitions being analysed. If, in some cases no differences were reported in race speed, SR and SL between intellectual disabled, non-disabled and physical impaired swimmers (Daly et al. 2006), others reported difficulties for swimmers with intellectual disabilities when a skill requires adaptation, not being able to take sufficient advantage of experience (Einarsson et al. 2008). In **Chapter 3** a race analysis of freestyle events (from 50 to 400 m) at international swimming competitions

for Down syndrome was conducted and variables as speed, SR, SL and race components time for the 50 to 200 m events and split 50 m times for the 400 m event. The main conclusions goes in accordance with the above referred superiority of male comparing to female swimmers for race speed, SR and SL relationship, highlighting that swimmers with Down syndrome are considerably slower than able-bodied and minimal physical impairments swimmers, from Taylor et al. (2016) as well as a possible higher variability in pacing strategies for the 400 m freestyle.

Results from the Race analysis evidenced differences between swimmers with Down syndrome and other groups of swimmers (non-disabled or intellectual disabled), leading us to the following chapters of this Thesis. As referred above, persons with Down syndrome in general have low cardiovascular and muscular fitness/exercise capacity, demonstrate a greater prevalence of overweight and obesity, with a large percentage not meeting the recommended amount of daily aerobic activity and likely declining their physical activity through childhood and into adolescence (Pitetti et al. 2013). Having this in consideration, **Chapter 4** was conducted focusing on the body composition and physical fitness levels of swimmers with Down syndrome. A physical fitness test, used specifically in persons with intellectual disabilities, as well as body composition assessment were conducted in a group of trained swimmers and untrained persons with Down syndrome (control group). It was observed that swimmers with Down syndrome present a healthier body composition and higher physical fitness values than untrained individuals with the same condition. When comparing these results with those in the literature, swimmers with Down syndrome present similar values of body measurements than athletes with intellectual disability and Down syndrome, but these results did not happened for physical fitness. Swimmers with Down syndrome scored lower than athletes with intellectual disability, and young adults without disability, with the exception of flexibility.

In addition in relation to trained persons with intellectual disabilities, a study from Daly et al. (2014) reported Eurofit Test battery results in high performance athletes with intellectual disability (finalists and non-finalists) participating in a

World Championships (2004 INAS-FID Global Games). In comparison with the present study, male swimmers with Down syndrome were much shorter in height (cm) (158.4, 5.7 versus 180.2, 10.7 finalists and 172.4, 8.6 non-finalists), and presented a slightly higher BMI (25.3, 3.1 versus 23.8, 3.9 finalists and 23.4, 3.3 non-finalists). For females, similar comparisons can be made: lower height (145.8, 6.4 versus 164.9, 9.2 finalists and 159.5, 6.0 non-finalists) and higher BMI (25.9, 6.2 versus 20.4, 1.7 finalists and 21.6, 1.8 non-finalists).

These results suggest that swimmers with Down syndrome can obtain improvements in physical fitness, however, their anthropometric characteristics, lack of strength and reduced cardiovascular capacity (compared to non-disabled athletes or even with intellectual disability) seems to impact on their physical fitness performance. Nevertheless, these data supports the idea that competitive sport practice may help individuals attaining a better physical fitness profile, indicating that performance directed activities (as swimming) should be promoted. As **Chapter 4** was not an intervention study, it was impossible to conclude that the observed differences between swimmers with Down syndrome and untrained persons with the same condition are an outcome of swimming training. So, to minimize this constrain, a longitudinal study was conducted (**Appendix III**) aiming evaluating the effect of swimming training and competition on the body composition and physical fitness profile in persons with Down syndrome. Six trained swimmers were evaluated for physical fitness and body composition in 2011 and 2014 with the absolute differences indicating that there were considerable improvements in the swimmers body shape, as well as in their upper and lower strength. The improvements can be partially explained by the considerable higher number of hours of training per week in 2014, compared to 2011 and the small sample size can be a contributing factor for the lack of differences in other variables (BMI, Fat %, Lean body mass and long jump) thus with improvements in 2014.

It is known that a better physical fitness and body composition, as well as sport participation, can positively impact on the quality of life of persons with Down syndrome (Andriolo et al. 2005, Stewart et al. 2003, Vicente-Rodriguez et al. 2005). However, high percentage of general population do not meet the

minimum required amount of daily physical activity and persons with intellectual disabilities are indicated as even less active (Einarsson et al. 2015, Hinckson et al. 2013, Troiano et al. 2008). Nevertheless, competitive swimmers and athletes with Down syndrome seem to be more active and present better body composition values than recreational and untrained peers (**Chapter 5**).

In the study presented at **Chapter 5**, International level competitive swimmers and athletes with Down syndrome presented a higher number of steps/day and distance walked in their daily life than recreational trained and untrained peers. It is important to state that this evaluation did not consider the time spent in sports and physical activity for the daily life activity assessment. This way, **Chapter 5** reinforced the importance of a diary sport practice, since it can help persons with Down syndrome to attain healthier and active lives, with positive consequences on their day-to-day activities, besides the well-accepted physiological and body composition outcomes. The instrument used to analyse the daily life physical activity parameters was a recent motion analysis device (WalkinSense®), previously validated by our group (**Appendix IV**).

In fact, swimming practice seems to positively impact the swimmers body composition and physical fitness profile. On the other hand, even with the occurrence of these positive benefits from the swimming training, swimmers with Down syndrome do not get similar values to swimmers with intellectual disability or swimmers without disability. One important consideration of this Thesis was attempted to understand how the swimmers' with Down syndrome behavior in the water is like. Do they present similar swimming patterns in terms of efficiency, coordination, speed and simple biomechanical variables to other swimmers (intellectual disabled or without disability)? This is an important part of this Thesis, since one of its concerns is related to the question of whether these swimmers should be kept in the same classification Class as the intellectual disabled swimmers (Class S14) or if they should have their own Class (S21). So, a clear demonstration of how these swimmers' characteristics could impact on their swimming performance should occur.

Appendix V, VI and VII focused on coordination issues for swimmers with Down syndrome. **Appendix V** assessed the Index of Coordination (IdC)

proposed by Chollet et al. (2000) in front crawl and backstroke. It was observed that, in both strokes at high intensities, these swimmers presented a catch-up arm coordination. For the front crawl at these intensities, this coordination mode is usually observed in less skilled swimmers and it is considered as a technical fault for high level swimmers (Seifert and Chollet, 2008; Seifert et al. 2008). For the backstroke it was observed that swimmers with Down syndrome seem to present an augmented hand lag time, which leads to a higher propulsive discontinuity, not so visible in high level swimmers. Despite the fact that these swimmers were international level, their arm coordination does not correspond to the typical values for high level swimmers without Down syndrome, suggesting their less proficient technique.

In **Appendix VI** a more detailed study for the front crawl was developed, aiming to study two coordinative parameters (intra-cyclic velocity fluctuation and index of coordination) and the swimming propelling efficiency of swimmers with Down syndrome. In this study the results indicate the lower swimming ability in swimmers with Down syndrome when compared with swimmers without disabilities. Typical Down syndrome characteristics, as higher percentage of body fat, anthropometric traits and poor muscle strength, could indirectly influence coordination, contributing to higher hydrodynamic drag and an increased lag time between propulsive phases. This difficulty in overcoming high hydrodynamic resistance can also compromise velocity and stroking parameters, as observed by the lower values of SR and SL in the present study compared to studies conducted with elite swimmers with no disabilities. Nevertheless, the fact that these swimmers are involved in a training program, can make them more capable of performing activities of daily living than other persons with Down syndrome, since coordination is required to do so, making it possible to speculate that the participants in this study have better motor skills than their sedentary matches and are therefore more able to perform daily activities (e.g., eating, dressing and walking) (Cowley et al. 2010).

In **Appendix VII** the number of participants was higher than in the previous two studies, and it was found that swimmers with Down syndrome presented biomechanical characteristics of the front crawl movement (namely intracyclic

velocity variation and IdC) different than those found for both experienced and less experienced able bodied swimmers in the literature examined under similar conditions. Both drag and propulsion are affected in swimmers with Down syndrome more than can be expected only from lack of swimming training. These findings highlight the need of evaluate swimmers with Down syndrome and swimmers with intellectual disability in the same conditions to be able to compare them and better understand their differences in performance, if they exist.

In the **Chapter 6**, that aimed to verify if swimmers with DS were able to follow a visual pacer and maintain the swimming speed when swimming without the pacer, we observed that in spite of repeated practice with pacing lights swimmers with Down syndrome were initially not able to repeat the pace when feedback was removed and as intensity increased they moved from over estimation (too fast) to underestimation (too slow). Problems with pacing at the race were also observed on **Appendix I**, where swimmers presented significant differences in speed and stroke rate from the 1st to the 2nd laps, and from the 2nd to the 3rd laps, at the 100 m freestyle. Nevertheless, it was our believe that the pacing training can have a good transfer to competition if swimmers became able to use this kind of feedback with more practice. We proposed that this simple test might be used in an eligibility test not only for those with Down syndrome but for persons with other intellectual disabilities.

As it is well known, the final objective of the swimming race is to cover a determined distance in the fastest time. This achievement involves good relationship between drag and propulsive forces, SR and SL and coordination modes. The first aim of the **Chapter 7** was to compare swimmers with Down syndrome with swimmers with intellectual disability but no Down syndrome of similar level and for that, nine swimmers (four Down syndrome and five intellectual disabled) performed 3 bouts of 25 m at maximum speed, with additional body composition and anthropometric evaluations. It was concluded that swimmers with Down syndrome were in clear disadvantage concerning anthropometrics comparing to swimmers with intellectual disability, since they presented lower values for all the variables. Another important conclusion from

this study was that swimmers with Down syndrome were clearly slower than swimmers with intellectual disability, despite no significant differences for IdC and IVV were observed for Down syndrome or intellectual disability. Further investigation is though needed and augmented samples are urgent as it could be a determining factor for more valid conclusions. In our opinion, the results from the current Thesis indicate that the creation of a S21 Class for swimmers with Down syndrome should be of serious consideration from the International Paralympic Committee.

Chapter 9. Conclusions

After the findings presented at this Thesis, it could be concluded that:

- (i) Persons with Down syndrome have less power, less cardiovascular fitness and higher body mass index in comparison to persons with intellectual disability and non-disabled;
- (ii) Swimmers with Down syndrome have healthier body composition profiles and present higher levels of physical fitness than untrained peers with the same impairment;
- (iii) A classification system from the International Paralympic Committee should include the evaluation of the physical fitness profile and the body composition of swimmers with Down syndrome and swimmers with intellectual disability.
- (iv) Swimming training seems to improve BMI, Fat % and lean body mass, as well as physical fitness condition (especially upper and lower strength) of swimmers with Down syndrome;
- (v) Persons with Down syndrome that train and compete in a regular basis (national and international levels), are more active persons in their daily lives than recreational and, especially, untrained persons with the same condition, as they walk more distance, present a higher number of steps/day and lower body composition values, such as weight and BMI;
- (vi) Male swimmers with Down syndrome are faster than female counterparts in freestyle and woman seem to have more difficulties in performing starts, finishes and especially, turns;
- (vii) For a similar number of strokes per minute, man are able to attain higher SL than woman;
- (viii) The fact that persons with Down syndrome present lower levels of physical fitness than persons without disability or with intellectual disabilities, seems to impact on their swimming performance;
- (ix) Swimmers with Down syndrome present coordination modes similar to lower level swimmers;

- (x) Swimmers with Down syndrome present lower swimming efficiency and higher intracyclic velocity variation than high level swimmers without disability;
- (xi) Swimmers with Down syndrome seem to have problems with pacing, both on training and in competition and are not able to take advantage of short term visual feedback to maintain a pacing strategy.
- (xii) The visual pacer can be an interesting instrument for swimming training for swimmers with Down syndrome, although further work is needed to see if more practice improves performance in the test itself, if this possible improvement is sustained over time and how this exactly influences the race performance.
- (xiii) The simple pacing test might be used in an eligibility test (classification) not only for those with Down syndrome but for persons with other intellectual disabilities.
- (xiv) Swimmers with Down syndrome present anthropometric characteristics that are clearly poorer than those of swimmers with intellectual disability, but no Down syndrome.
- (xv) Swimmers with Down syndrome swim slower than swimmers with intellectual disabilities at maximum bouts; despite no significant differences in other efficiency and coordinative parameters between swimmers with Down syndrome and with intellectual disabilities, their velocity and, consequently, final time is different.
- (xvi) More research is needed, particularly with larger samples, to compare swimmers with Down syndrome and swimmers with intellectual disability but no Down syndrome, to help coaches in the training process and to confirm the need of a new classification system, with the S21 Class.

Chapter 10. References

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Appendix I

100-m freestyle race analysis of the 5th World Down syndrome swimming championships

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Abstract

Down syndrome (DS) is a common genetic cause of intellectual disability but there is a lack of knowledge on factors leading to sport success in these persons. **PURPOSE:** To analyze 100-m freestyle race from the 5th World DS Swimming Championships. **METHODS:** The event was videotaped with two side view cameras, and 34 swimmers (17 men and 17 women) from the preliminary heats were analyzed for start, turn and swim times and stroke length (SL) and rate (SR). Mean and SD were obtained, Student t-tests and repeated measures ANOVA were computed to compare gender groups. Correlation analysis was performed between race components, stroking variables and end results ($p \leq 0.05$). **RESULTS:** There were significant differences between male and females swimmers in start time (6.07 ± 0.47 & $7.37 \pm .99$ s), swim time (34.45 ± 2.90 & 44.18 ± 4.49 s), turn time (32.36 ± 2.64 & 37.94 ± 3.85 s), finish time (9.08 ± 1.32 & 10.25 ± 1.33 s), final time (81.97 ± 6.44 & 99.74 ± 9.63 s), speed (1.18 ± 0.09 & $0.92 \pm .09$ m/s), and SL ($1.65 \pm .16$ & $1.38 \pm .17$ m); no differences between genders were observed for SR (43.16 ± 4.87 & 40.78 ± 5.45 st/min). Differences within laps can be observed on Figure 1. The higher r values were obtained for swim time and final time (men: .97 & women: .91) and final time and turn time (men: .94 & women: .95). Inverse correlations were observed between stroke rate and stroke length (men: -.67 & women: -.76). **CONCLUSIONS:** Male DS swimmers are significantly faster than female counterparts in the 100-m freestyle event. For a similar number of strokes per min, men are able to attain higher stroke lengths than woman. For this specific event, swim and turn times are most determinant for the final time and SL is determinant for swimming speed and not SR.

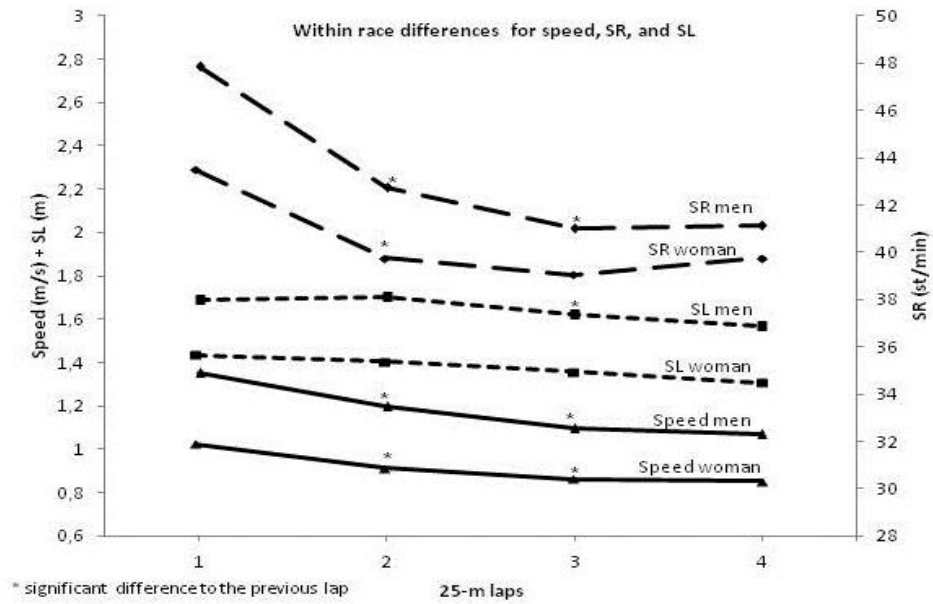


Figure 1. Differences within laps for men and woman, for stroke rate, stroke length, and speed.

Appendix II

200-m backstroke race analysis at the 5th Down syndrome swimming World championships

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Abstract

Introduction

Down syndrome (DS), a genetic cause of intellectual disability, presents physical impairments that may affect their motor performance behavior. Race video recording is essential both to provide feedback of swimmers' performances and to analyze performance influencing factors. Since this has never been done for DS exclusively, the aim of this study is to analyze the 200-m backstroke event from the 5th DS World Championships.

Methods

The event was videotaped with two side view cameras, and 28 swimmers (15 men and 13 women) from the preliminary heats were analyzed for start, turn and swim times and stroke length (SL), rate (SR), and index (SI). Mean and SD were obtained, and Student t-tests were computed to compare gender groups. Pearson correlation analysis was performed between race components, stroking variables and end results ($p < .05$). Results Differences were found between male and female swimmers on start ($7.22 \pm .77$ & 8.42 ± 1.17 s), swim (94.63 ± 12.03 & 109.68 ± 12.98 s), turn (98.67 ± 7.86 & 113.53 ± 10.11 s), finish (10.74 ± 1.35 & 12.98 ± 2.88), and final times (211.25 ± 18.94 & 244.53 ± 24.91 s), SL ($1.59 \pm .18$ & $1.33 \pm .17$ m), SI ($1.34 \pm .25$ & $.96 \pm .14$), and speed ($.86 \pm .09$ & $.74 \pm .07$ m/s). No differences between genders were observed for SR (32.85 ± 4.86 & 34.51 ± 6.01 st/min). Higher significant ($P < .05$) correlations with final time were found for swim (.93), finish (.81), turn (.78), and start times (.76), for men, and swim (.97), followed by turn (.92), start (.84), and finish times (.72), for woman. Inverse correlations were found between SR and SL (-.62 men & -.83 woman).

Discussion

As observed in previous studies with other populations (Arellano et al., 1994; Daly et al., 2003), male DS swimmers are significantly faster than their female counterparts in the 200-m backstroke event and demonstrated longer SL and higher SI, for a similar SR, implying that SL is more important for swimming speed than SR. For this event, swim and finish times are most determinant for final time in men, and swim and turn times in woman. In accordance with Chatard et al. (2003), starts were not of major importance for the final time. Since swimmers spend more time turning in a 25m pool than in free swimming, and considering that this race component is also related to final time, coaches should emphasize turning on the training process, so that swimmers will be able to improve their performance.

Appendix III

The added value of water for swimmers with Down syndrome

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Abstract

Introduction

Aquatic exercise has specifically been shown to offer benefits for people with intellectual disabilities in terms of cardiorespiratory endurance, muscular endurance, speed, static balance, and agility (Yilmaz et al. 2009; Fragala-Pinkham et al. 2008). However, even if physical activity and sport are meaningful to many people, including those with intellectual disabilities, studies in trained individuals are scarce (Van de Vliet et al. 2006). The purpose was to evaluate the effect of swimming training and competition on the body composition and physical fitness profile in persons with Down syndrome.

Methods

The Eurofit Special test, a physical fitness battery designed for persons with intellectual disabilities, was applied to six trained swimmers with Down syndrome in two different moments (January 2011 and November 2014). In addition, body measurements were taken to Body Mass Index (BMI) and Lean Body Mass (LBM) determination. Statistical procedures were performed with IBM SPSS Statistics 19 for Windows. Non-parametric tests (related samples) were used due to the small sample size.

Results

The six swimmers were $18,7 \pm 5.4$ years in 2011 and 22.8 ± 5.2 years in 2014. Results for hours of training a week, anthropometrics (weight, height, skinfolds sum, Body Mass Index - BMI -, Fat %, Lean Body Mass - LBM), and Eurofit Special (long jump, medicine ball, sit-ups, speed, flexibility, and balance) are presented on Table 1. Significant differences were found in hours of training a week, height, and the medicine ball.

Table 1. Descriptive statistics and absolute difference between the results in the second and first evaluation moments (2014 and 2011).

	Mean \pm SD 2011	Mean \pm SD 2014	Absolute difference (2014-2011)
Hours training/week*	9.8 \pm 3.5*	11.7 \pm 4.1	1.8 \pm 1.3
Weight (kg)	56.5 \pm 8.9	55.4 \pm 10.1	-1.0 \pm 8.5
Height (cm)*	148.3 \pm 6.5*	153.0 \pm 8.5	4.7 \pm 3.8
Skinfolds Sum (cm)	58.7 \pm 21.9	42.7 \pm 14.5	-17.7 \pm 19.2
BMI	26.4 \pm 4.8	23.6 \pm 2.3	-2.8 \pm 4.2
Fat %	24.4 \pm 8.7	20.6 \pm 7.0	-4.4 \pm 4.4
LBM (kg)	42.7 \pm 8.1	44.2 \pm 10.5	1.8 \pm 5.0
Long Jump (cm)	86.7 \pm 26.3	108.3 \pm 33.9	21.7 \pm 44.6
Medicine Ball (cm)*	309.5 \pm 91.5*	418.3 \pm 116.5	108.8 \pm 85.2
Sit-ups	17.2 \pm 2.3	17.8 \pm 1.5	0.7 \pm 3.8
Speed (s)	5.9 \pm 0.7	5.9 \pm 0.7	0.0 \pm 0.5
Flexibility (points)	32.0 \pm 2.4	32.5 \pm 1.2	0.5 \pm 1.2
Balance (points)	5.2 \pm 0.4	5.3 \pm 0.5	0.2 \pm 0.4

Discussion

Persons with Down syndrome are considered to have higher BMI and lower levels of LBM (Gonzalez-Aguero et al. 2010) than persons without Down syndrome. In the present study swimmers had an inferior BMI, Fat %, and a higher LBM values in 2014. In fact, in 2014 these swimmers are included in the normal weight category (18.5-24.9), accordingly to the World Health Organization (1995) classification. This did not happen in 2011. Also, in 2014 swimmers presented improvements in all physical fitness items, with exception for speed. Greater differences in flexibility, balance, and abdominal strength were not expected. One possible explanation for these improvements can be the augmented hours of training per week. Swimmers train every part of their bodies in the water, and this can improve their physical fitness condition (especially strength) and body characteristics.

Conclusion

Some of the observed differences between Eurofit Special test and anthropometric variables between years 2014 and 2011 were not statistical

significant, as expected. This could be due to the small sample size. The absolute differences between the results in 2014 and 2011 indicate that there were considerable improvements in the body shape of the swimmers as well as in their upper and lower strength.

Appendix IV

Reliability and accuracy of spatial-temporal gait parameters measured by the WalkinSense®

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Abstract

The WalkinSense® is a relatively new device designed to monitor walking exercise. The purpose here was to assess its reliability and accuracy when analyzing spatial-temporal gait parameters. Forty two young adults performed 3 x 400 meters walking at moderate intensity on a 400 meter standard track, using both the WalkinSense® and a pedometer. The between-trial reliability was excellent for all variables, with ICC values ranging from 0.90 to 0.98. The absolute and percentage differences between the WalkinSense® and the track length were (mean \pm standard deviation) -36.7 ± 45.0 m (CI_{95%} -44.6, 28.6) and $9.2 \pm 11.3\%$ (CI_{95%} -11.2, 7.2), respectively. The absolute and percentage differences between the WalkinSense® and the pedometer for number of strides was 0.7 ± 10.5 strides (CI_{95%} -1.2, 2.6) and $0.1 \pm 4.0\%$ (CI_{95%} -0.7, 0.8), respectively. The WalkinSense® system showed excellent reliability for assessing spatial-temporal gait parameters. Considering accuracy, users should be aware of the limitations of the device, which in this study ranged between -0.7 and 0.8% and between -11.2 and 7.2%, for number of strides and travelled distance, respectively.

Keywords: WalkinSense®, gait analysis, pedometer, physical activity, sports medicine

Introduction

The WalkinSense® (Tomorrow Options SA, Sheffield, UK) assesses physical activity and plantar pressures during walking and running. This device provides information on travelled distance, average speed, stride length and frequency, duration of the activity and plantar pressures on eight foot regions for periods up to several days (Castro et al. 2011, Castro et al. 2014). It is useful in the field of sports medicine, as it monitors the levels of physical activity and provides information to aid prevention and rehabilitation of lower limb related injuries.

Before a device is used in clinical or research contexts, it should demonstrate acceptable reliability (difference between two or more measurements using the same instrument under the same testing conditions) and accuracy (difference between the values of a known quantity - reference standard - and that measured by the new device) (Portney & Watkins 2009). Although classification criteria for determining reliability are straightforward (Youdas et al. 1991), the level of accuracy usually depends on the application of the device.

The plantar pressure parameters recorded by the WalkinSense® showed acceptable reliability and accuracy (Castro et al. 2014, Healy et al. 2012), but only one preliminary study addressed the reliability of spatial-temporal gait parameters (Castro et al. 2011). Castro et al. (2011) obtained consistent data with good reliability across all spatial-temporal gait parameters analyzed.

The purpose of the current study was to assess the reliability and accuracy of the spatial-temporal gait parameters acquired by the WalkinSense®. We hypothesized that: (i) the WalkinSense® would show good to excellent between-trial reliability for the measured parameters; and (ii) the WalkinSense® would show values of accuracy (with 95% confidence intervals) better than 10% in measuring distance travelled and number of strides.

Research methods

Participants

Based on Mean and SD of travelled distance from a previous study [1], a minimum of 39 participants were needed for comparisons between WalkinSense® and a reference standard accepting an alpha error level of 1%, and a beta error level of 20%. Forty two young adults (21 from each gender), age (mean \pm standard deviation) 23.9 ± 3.9 yrs, height 1.70 ± 0.09 m and body mass of 66.3 ± 9.7 kg, were recruited. Anthropometric parameters were recorded for participants' characterization and not impacted on the results. Exclusion criteria were any traumatic-orthopedic impairment, pain or difficulty with independent gait. This study was approved by the local ethical committee and all participants gave their written consent.

Equipment

The WalkinSense® (weight 68 g, length 78 mm, width 48 mm and depth 18 mm) is a CE Mark class I electronic medical device designed to dynamically monitor human lower limb activity. It gathers and processes quantitative information, sending it to a fixed laptop or palmtop computer, via wireless Bluetooth® connection or wired USB cable, to be analyzed with the WalkinSense® software (Tomorrow Options SA, Sheffield, UK). The device contains a micro electro-mechanical system triaxial accelerometer and one gyroscope, and an array of eight force sensing resistors for foot pressure measurements. Distance is calculated from the triaxial accelerometer and gyroscope, by a sensor fusion algorithm based on an extended Kalman filter with a velocity zero update at each cycle. Simultaneously, a commercially available electronic pedometer, the Omron Walking-Style II (HJ-113-E, Omron Healthcare CO, Kyoto - Japan), previously shown to be an accurate and reliable

device (Crouter et al. 2003, Schneider et al. 2003, Melanson et al. 2004, Holbrook et al. 2009, Zhu & Lee 2010), was used for comparison.

Protocol

All participants performed three trials on a 400-meter running track in a single session. The WalkinSense® was attached over the anterior-inferior surface of the right tibia, and the pedometer was attached at the lateral (right) surface of the coxal region, between the greater trochanter of femur and iliac crest. After measuring body mass and height, participants familiarized themselves with the WalkinSense® and pedometer by walking a short distance (30 meters). Afterwards, each participant walked 3 x 400 meters at a self-selected gait speed.

Data Analysis and Statistics

Six spatial-temporal gait parameters were analyzed: duration, number of strides, travelled distance, mean speed, stride length and stride frequency (see Table 1).

Table 1. Definition of the six spatial-temporal gait parameters analyzed by the WalkinSense®.

Variables	Description
Duration (s)	Time to complete one trial
Strides (strides/trial)	Number of strides, i. e., two successive placements of the same foot, for each trial
Travelled distance (m)	Distance recorded during each trial
Average speed (m/s)	Speed recorded during each trial
Stride length (m)	Average length of all strides from each trial
Stride frequency (stride/min)	Number of strides per minute

All statistical analyzes were performed using the SPSS v.17 software (SPSS Inc, Chicago, USA) and descriptive statistics were presented.

i) Reliability

For assessing the reliability of the WalkinSense®, the two-Way mixed model (type: consistency) intra-class correlation coefficient (ICC) was used and the between-trial reliability (three trials) for each spatial-temporal gait parameter was calculated. An intraclass correlation coefficient of (ICC) ≤ 0.69 was poor, 0.70-0.79 fair, 0.80-0.89 good, and ≥ 0.90 as excellent (Youdas et al. 1991).

ii) Accuracy

The accuracy of the WalkinSense® in measuring two parameters was assessed: travelled distance and number of strides. Track length (400 meters) was the reference for distance, whilst the pedometer was the reference for stride count. The absolute and percentage differences, and 95% confidence intervals (CI_{95%}) between the travelled distance recorded by the WalkinSense® and the track length, as well as for stride count of the WalkinSense® and the pedometer, were calculated. For the travelled distance, 5% difference intervals around the 400 meters were also assessed. Bland-Altman plots were also constructed using GraphPad Prism 6.

Results

i) Reliability

The between-trial reliability was excellent for all parameters with ICC values ranging from 0.90 to 0.98 (Table 2).

Table 2. Mean, standard deviation (SD), intraclass correlation coefficients (ICC) and 95% confidence interval (CI_{95%}) for all variables recorded by the WalkinSense® and for the comparative instrument.

Variables	Mean	SD	ICC	CI _{95%}
Duration (s)	268.0	27.0	0.96	0.93 – 0.98
Strides (strides/trial)	264.4	18.9	0.90	0.84 – 0.94
Strides pedometer (strides/trial)	265.1	20.3	0.95	0.91 – 0.97
Distance (m)	363.3	45.0	0.96	0.94 – 0.98
Average speed (m/s)	1.4	0.2	0.97	0.94 – 0.98
Stride length (m)	0.81	0.1	1.00	0.99 – 1.00
Stride frequency (stride/min)	59.1	3.4	0.98	0.96 – 0.99

ii) Accuracy

The absolute and percentage differences between the travelled distance obtained by WalkinSense® and the true distance of the track were -36.7 ± 45.0 m (CI_{95%} -44.6, 28.6) and $-9.2 \pm 11.3\%$ (CI_{95%} -11.2, 7.2), respectively. For stride count, the absolute and percentage differences between the WalkinSense® and pedometer were 0.7 ± 10.5 strides (CI_{95%} -1.2, 2.6) and $0.1 \pm 4.0\%$ (CI_{95%} -0.7, 0.8), respectively.

The Bland-Altman plots of the difference between the WalkinSense® and the pedometer are reported in Figure 1. The average difference for stride count was -1.4 ± 8.8 with limits of agreement (95%) from -18.7 to 15.8 (Figure 1). 92% of the tests are inside the limits of agreement.

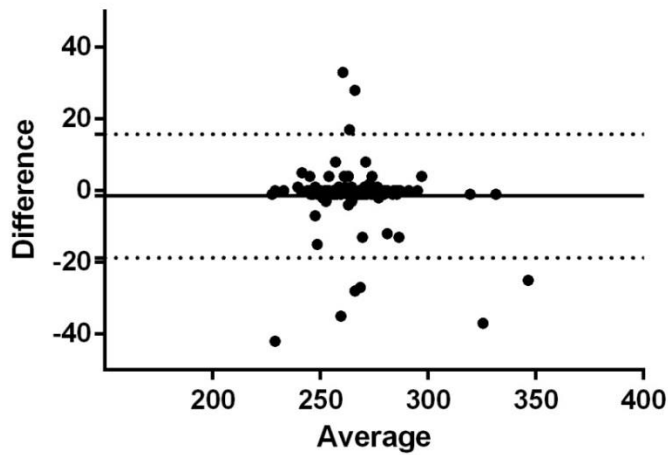


Figure 1. Bland and Altman plot of comparison between the WalkinSense® and the pedometer. Average difference line (solid line) and 95% CI (dashed lines) are indicated.

The interval with the highest frequency of measured travelled distances was 360-379 m (Figure 2). Almost 50% of the measurements (48%) were within the 360-379 and 380-399 intervals.

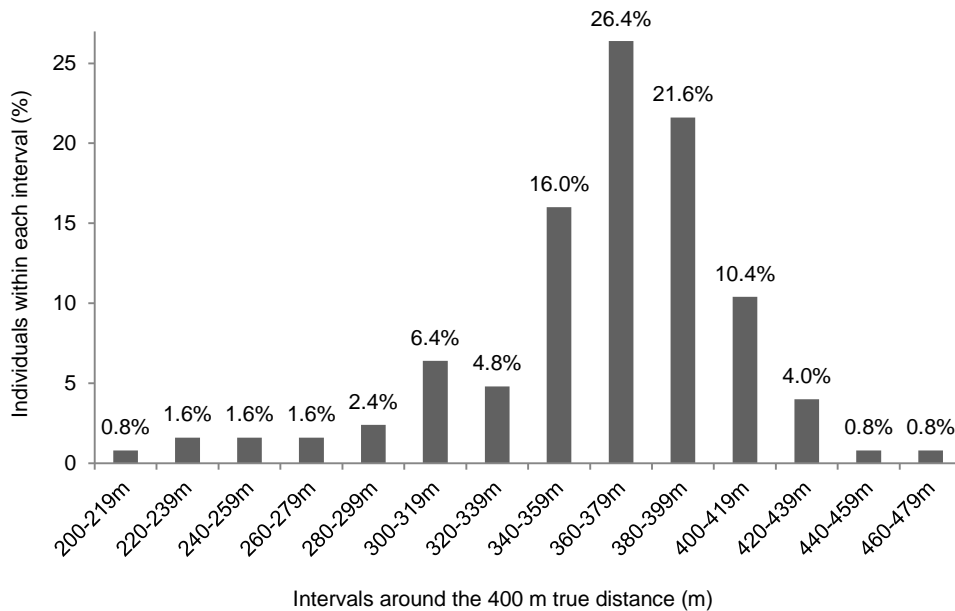


Figure 2. Percentage of individuals for each 5% intervals of the true distance (400m) with the WalkinSense®.

Discussion

The current study assessed the reliability and the accuracy of the WalkinSense® and a field experiment was conducted with the participants using the WalkinSense® and a pedometer simultaneously. The WalkinSense® showed excellent between-trial reliability, supporting our hypothesis. Our hypothesis was also confirmed for accuracy of stride count. A small 95% confidence interval (-1.2%, 2.6%) was found. The hypothesis was not confirmed for travelled distance and the 95% confidence interval (-7.2%, 11.2%) was larger. Users need to analyze findings and decide whether or not this level of accuracy is acceptable for their applications.

The WalkinSense® device previously demonstrated excellent reliability, and accuracy for plantar pressure parameters similar to other widely used devices (Pedar and FScan) (Castro et al. 2014, Healy et al. 2012). Spatial-temporal parameters have received much less attention in the literature (Castro et al. 2011). The authors (Castro et al. 2011) assessed 15 participants using two WalkinSense® devices in a 10 meter track and good to excellent reliability was found (ICC of 0.88 for travelled distance, 0.98 for gait speed, 0.96 for step length and 0.99 for step frequency). It is important to note that the WalkinSense® device presents only stride parameters (i.e. stride length and stride frequency). In the mentioned study (Castro et al. 2011), the authors integrated data from two devices to calculate step parameters. In the present study, the participants used one WalkinSense® device and stride parameters were analyzed. It is very likely that reliability values for step and stride parameters are similar. Thus the results from both studies are in agreement and suggest WalkinSense® with good to excellent reliability for spatial-temporal parameters.

With regard to accuracy, the current study found a difference of 0.7 ± 10.5 strides between the WalkinSense® and the pedometer, considered an accurate device to measure walking strides [11]. A source of error often mentioned is slow walking speeds (Melanson et al. 2004, Basset et al. 1996, Le Masurier &

Tudor-Locke 2003). Several studies reported the accuracy of pedometers (Tudor-Locke et al. 2002, Holbrook et al. 2009, Zhu & Lee 2010) at similar self-selected speeds to the current study (1.4 m/s). Crouter et al. (2003) observed mean values for stride count that were within 1% of the real number of strides which is similar to our result.

The accuracy of the WalkinSense® for measuring travelled distance is less good. This is in agreement with observations for other devices, such as pedometers, that are more accurate in counting strides and less accurate in calculating travelled distance (Schneider et al. 2002). The body attachment position may have contributed to the underestimation of travelled distance (Norris et al. 2013). According to Fujiki et al. (2009), the ankle is affected by complex rotational components, along with the impact from the ground, probably influencing the final findings. The stride length values were also smaller than expected, but it was not the aim of this study to assess the accuracy of this parameter.

There are several study limitations to consider: (i) only between-trial within-session reliability was analysed; (ii) only the accuracy of two spatial-temporal gait parameters was explored (iii) the test could have been video recorded, to confirm stride count afterwards. However, this limitation is minimized as previous studies found good reliability and accuracy for pedometers [6-11, 13-14]. We suggest future studies using WalkinSense®: (i) the between-session reliability of spatial-temporal and plantar pressure parameters, (ii) the accuracy for duration, average speed, stride length and frequency, (iii) the influence of walking and running speed on the reliability and accuracy of the device.

Conclusion

The WalkinSense® system showed excellent within-session reliability for spatial-temporal gait parameters and accurate values for stride count. However, as substantial differences between the travelled distance recorded by this

apparatus and the true distance were observed, users should be aware of errors with 95% confidence interval between -11.2% and 7.2%.

Appendix V

Front crawl and backstroke arm coordination in swimmers with Down syndrome

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Abstract

The aim of this study was to characterize the Index of Arm Coordination (IdC) in swimmers with Down syndrome (DS). The IdC for the front crawl (N=6) was $-11.3\% \pm 5.2\%$ and for the backstroke $-13.5 \pm 4.8\%$. This indicates that all swimmers demonstrated a catch-up mode coordination in both strokes. Swimmers with DS did not adapt their arm coordination as usually occurs in swimmers with higher level of proficiency. In front crawl significant positive correlations were found between IdC and the push phase as well as the propulsive phase. An inverse correlation was found between IdC and the non-propulsive phase. In backstroke, the catch-up coordination mode was used by all swimmers. In this study hand lag time values far above those of elite swimmers were observed. There was an inverse relationship between IdC and velocity.

Key words: down syndrome, arm coordination, front crawl, backstroke

Introduction

Although cyclic activities, such as swimming, have traditionally been assessed by velocity, stroke rate and stroke length, recent studies have shown that the evaluation of arm coordination provides new information to the classic analysis (Chollet et al., 2008). For assessing arm coordination, Chollet et al. (2000) proposed the Index of Coordination (IdC), which seems to give relevant information on a swimmer's skill. In the alternating strokes, i.e. front crawl and backstroke, arm coordination is quantified as the time between propulsive phases of the right and left arms, i.e., by the time lag between the propulsion moments of consecutive strokes. According to Chollet et al. (2000), three possible modes of coordination can be found: (i) catch-up, with significant discontinuity between propulsion moments of both arms ($\text{IdC} < 0\%$); (ii) opposition, showing continuity between propulsive phases of both arms ($\text{IdC} = 0\%$) and (iii) superposition, in which overlapping of propulsive phases is seen ($\text{IdC} > 0\%$).

Studies focusing specifically on swimmers with Down syndrome (DS) are very scarce. Since individuals with DS typically have a combination of physical and cognitive limitations that significantly affect their motor performance and contribute to a high variability of their motor behavior (Epstein, 1989; Lahtinen, 2007), it is important to understand if these typical characteristics, such as lower muscular strength, higher percentage of body fat and anthropometric traits are reflected in their inter arm coordination. The purpose of this study was therefore to characterize the IdC in alternating strokes performed by swimmers with DS, as well as to establish the relative duration of the propulsive and non-propulsive phases.

Methods

Six international level swimmers with DS volunteered to participate in this study (age: 20.2 ± 4.8 years, height: 154.3 ± 12.1 cm, weight: 58.4 ± 14.1 kg and fat

mass: 16.4 ± 11.6 %). The participant's guardians provided informed written consent to take part in the study, which was approved by the local ethics committee.

All swimmers performed 2 x 20 m swims at maximal intensity, the first in front crawl (non breathing cycles) and the second in backstroke. Two digital cameras (Sony® DCR-HC42E), placed inside a sealed housing (SPK - HCB), recorded two complete underwater arm stroke cycles in the lateral and frontal views. The lateral camera was placed at a depth of 2 m and 11.5 m from the lane in which the participant swam. The frontal camera was placed at 0.5 m depth. A rigid calibration frame (2.10x0.70-m) was recorded at the beginning of the trials for calibration purposes. Subsequently, each frame (50Hz) was digitized manually using the APASystem (Ariel Dynamics Inc., USA). Nine anatomical points were used: the hip (femoral condyle), and on both sides of the body, the longest finger tips, wrist, elbow and shoulder of each swimmer. After bi-dimensional reconstruction using a DLT procedure (Abel-Aziz and Karara, 1978), a low pass filter of 5 Hz was used.

The front crawl arm stroke was divided into four phases (Chollet et al., 2000): (i) entry and catch (time between the entry of the hand into the water and the beginning of its backward movement); (ii) pull (time between the beginning of the hand's backward movement and when it reaches a vertical plane with the shoulder); (iii) push (time from the position of the hand below the shoulder to its release from the water) and (iv) recovery (time from the point of water release to water re-entry of the arm, i.e., the above water phase). In backstroke, each arm stroke was divided into 6 phases (Chollet et al, 2006): (i) entry and catch (time between the entry of the hand into the water and the start of its backward movement that is followed by a diagonal hand sweep); (ii) pull (time between the beginning of the hand's backward movement and when the line shoulder-hand is at 90° to the truck); (iii) push (time from the point hand at shoulder level and the end of the hand's backward movement); (iv) hand lag time (time during which the hand stops at the thigh after the push phase and before starting to move upward to clear the water); (v) clearing (time from the beginning of the

hand release upward to the beginning of its exit from the water) and (vi) recovery (time corresponding to the point of water release to water re-entry of the arm).

The duration of the propulsive phases of front crawl and backstroke was the sum of the pull and the push phases. The duration of the non propulsive phases was obtained by the sum of the catch and the recovery phases (for front crawl) and the addition of the catch, hand lag time, clearing and recovery phases (for backstroke). The duration of a complete arm-stroke was the sum of the propulsive and non-propulsive phases. The IdC was considered as the time gap between the propulsion of the two arms and expressed as a percentage of the duration of the complete arm stroke cycle.

Mean \pm SD were calculated for all variables (all data were checked for distribution normality with the Shapiro-Wilk test). Pearson correlation coefficient was applied and the level of significance was established at 95% ($p < 0.05$).

Results

The individual and mean \pm SD values for all stroke phases, the propulsive and non-propulsive stroke phases, the IdC (all expressed in percentage of a total cycle duration) and corresponding swimming velocity are presented in tables 1 and 2 for front crawl and backstroke, respectively. All swimmers showed negative IdCs. All used a catch-up coordination mode in both swimming strokes.

Table 1. Individual and mean \pm SD values for the arm stroke phases, propulsive and non-propulsive phases, IdC and velocity in all out front crawl swims in persons with Down syndrome.

Subject	Catch (%)	Pull (%)	Push (%)	Recovery (%)	Propulsive (%)	Non propulsive (%)	IdC (%)	V (m.s ⁻¹)
1	40.9	10.4	24.6	24.1	35.0	65.0	-13.6	0.9
2	25.5	17.6	28.9	28.0	46.5	53.5	-4.2	0.7
3	32.3	13.3	22.2	32.2	35.5	64.5	-17.7	0.9
4	6.5	12.0	24.5	57.9	36.5	63.5	-13.9	1.0
5	28.9	14.1	27.5	29.5	41.6	58.4	-5.6	0.9
6	30.1	17.5	21.6	30.8	39.1	50.9	-12.5	1.2
Mean \pm SD	27.5 \pm 11.5	14.2 \pm 2.9	24.9 \pm 2.9	33.6 \pm 11.8	39.0 \pm 4.4	61.0 \pm 4.4	-1.3 \pm 5.2	0.9 \pm 0.2

Table 2. Individual and mean \pm SD values for the arm stroke phases, propulsive and non-propulsive phases, IdC and velocity in all out backstroke swims in persons with Down syndrome.

Subject	Catch (%)	Pull (%)	Push (%)	Hand lag (%)	Clear (%)	Recovery (%)	Propulsive (%)	Non propulsive (%)	IdC (%)	V (m.s ⁻¹)
1	7.2	14.2	20.1	9.9	16.1	32.5	34.3	65.7	-9.6	0.6
2	3.0	23.7	17.8	3.7	22.4	29.4	41.5	58.5	- 10.4	0.7
3	9.4	17.6	17.5	4.9	23.6	27.0	35.1	64.9	- 14.9	0.7
4	2.5	12.6	21.4	10.7	27.7	25.1	34.0	66.0	- 16.4	0.8
5	3.3	19.1	21.8	5.6	32.5	17.7	40.9	59.1	-8.7	0.6
6	4.3	16.6	16.0	2.5	23.0	37.6	32.6	67.4	- 21.2	0.8
Mean \pm SD	5.0 \pm 2.8	17.3 \pm 3 .9	19.1 \pm 2.3	6.2 \pm 3.3	24.2 \pm 5.5	28.2 \pm 6.8	36.4 \pm 3.8	63.6 \pm 3.8	- 13.5 \pm 4.8	0.7 \pm 0.1

phases, IdC and velocity in all out backstroke swims in persons with Down syndrome.

In the front crawl, a significant relationship was found between the IdC and the relative duration of the push phase ($r = 0.88$), as well as with the propulsive phase ($r = 0.92$), as observed in Figure 1A. An inverse relationship was found between the IdC and the non-propulsive phase ($r = -0.92$). No significant

relationships were observed between the IdC and the catch phase ($r = -0.06$), the pull phase ($r = 0.52$), the recovery phase ($r = -0.30$) and swimming velocity ($r = -0.48$).

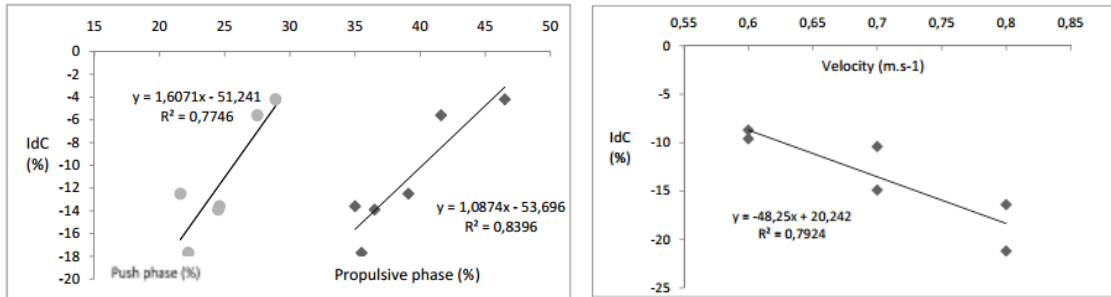


Figure 1. Relationship between IdC and the push and propulsive phases in front crawl (A panel left). Inverse relationship between IdC and velocity in backstroke (B panel right).

In backstroke, there was a significant inverse relationship between IdC and velocity ($r = -0.89$), as observed in Figure 1 (B). No significant correlations were observed between IdC and all the other parameters: catch phase ($r = 0.10$), pull phase ($r = 0.37$), push phase ($r = 0.57$), hand lag time phase ($r = 0.26$), clearing phase ($r = 0.02$), recovery phase ($r = -0.56$), propulsive phase ($r = 0.73$) and non-propulsive phase ($r = -0.73$).

Discussion

Swimming technique is one of the major factors influencing swimming performance. To better characterize the technique of swimmers with DS, arm coordination was assessed in the alternating strokes front crawl and backstroke using the IdC. In addition the relative duration of each arm stroke phase, together with relative duration of propulsive and non-propulsive phases were determined. To our knowledge, no work has been done on arm coordination in swimmers with DS.

In both strokes when performed at high intensities, the catch-up arm coordination was observed exclusively. For the front crawl, the use of a catch-up coordination mode is usually considered by coaches and instructors as a technical fault (Seifert and Chollet, 2008) and is observed in less skilled swimmers (Seifert et al., 2008). This coordination mode does seem to be efficient at slow paces, as it favors a glide phase following propulsive actions (Seifert et al., 2004b). These authors found that when the velocity increases above a critical value, a transition from catch-up to superposition mode is seen. In the present study swimmers performed a maximal intensity protocol and the use of catch-up coordination appears to be indicative of a less proficient technique. Interestingly, Seifert et al. (2004a) showed that women have more negative IdC values than men due to their higher fat mass values, different fat mass distribution, lower arm strength, and as a result greater difficulty in overcoming forward resistance. These are also characteristics of individuals with DS (Aleixo et al., 2009). Other physical characteristics, such as a smaller propulsive surface, also found in swimmers with loco-motor disabilities, can also influence their inter-arm coordination (Satkunskiene et al., 2005). The direct relationship found between the IdC and the push phase and propulsive phases, also described in the literature on able bodied swimmers (Figueiredo et al., in press) emphasizes the importance of the propulsive phase duration in an arm stroke.

In backstroke, the catch-up coordination mode is the only pattern of arm coordination used, with IdC values varying between -25% and -5% (Seifert and Chollet, 2008). This fact seems to be due to the limited shoulder range of movement and to the alternating body-roll (Chollet et al., 2008), which impose a particular arm coordination and an additional stroke phase - clearing phase (Lerda and Cardelli, 2003). This clearing phase prevents continuity between the propulsive phases of the two arms. This is only found when a three-peak stroke pattern is used, creating some propulsion in the beginning of the upsweep (Maglisho, 2003). This three-peak stroke pattern was not seen in the present study. On the contrary, a hand lag time phase was found in all swimmers in accordance with Chollet et al. (2006) and Chollet et al. (2008). These authors

pointed out that this arm phase can affect the arm coordination in backstroke, since it leads to propulsive discontinuity, explaining why elite swimmers limit their hand lag time to approximately 2% of the stroke cycle duration (a much lower value than found in the present study). The very existence of this phase is, however, controversial because some studies (e.g. Lerda and Cardelli, 2003; Lerda et al., 2005) did not report this.

Although the participants in this study are international level Down syndrome swimmers, their arm coordination does not correspond to the values of typical elite swimmers without DS, suggesting the presence of technical faults or physical shortcomings (e.g. higher hand lag time). The IdC values of the present swimmers are closer to those found by Cardelli (2003) for less expert swimmers (-11.3%) compared to more expert backstrokers (-9.7%). The inverse correlation between IdC and velocity was also found by Chollet et al. (2008), corroborating the findings elsewhere of higher (less negative) IdC values at higher swimming velocities.

Conclusion

International level swimmers with DS presented a catch-up arm coordination mode in front crawl, which may be associated with less proficient arm coordination. Trained swimmers usually change from catch-up to superposition with increasing velocities. The catch-up coordination mode was also found in all swimmers for the backstroke. This is in concordance with the literature on less skilled swimmers and for skilled swimmers at low velocities. The high values of hand lag time contributed to this.

It can also be pointed out that this instrument can be very helpful to coaches in better understanding underwater stroke phases. These findings also emphasize the importance of augmenting the propulsive phases of the arms and, with this, diminishing the lag time of the swimmers. Technical mistakes can also be detected through the study of the arm coordination.

Appendix VI

Coordinative characterization of front crawl swimmers with Down syndrome

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Abstract

Objective: Literature regarding the performance of swimmers with mental disabilities is scarce. Thus, it was purposed to carry out a Down syndrome characterization on front crawl swimming, examining several parameters: velocity, intra-cyclic velocity fluctuation, arm coordination, propelling efficiency and stroke parameters. *Design:* Six international level Down syndrome swimmers performed a 20 m maximal intensity front crawl bout. Video analysis was used to assess intra-cyclic velocity fluctuation of the hip, arm coordination and propelling efficiency. *Results:* It was observed that velocity, stroke rate, stroke length, index of coordination and propelling efficiency were lower for swimmers with Down syndrome when compared to the literature for swimmers without disabilities, which seems to reflect the lower coordinative development and technical efficiency of people with Down syndrome. However, these swimmers presented a direct relationship between velocity and stroke length ($r=0.83$, $p<0.05$) and between index of coordination and stroke rate ($r=0.90$, $p<0.05$), as is presented in the literature for swimmers without disabilities. Additionally, intra-cyclic velocity fluctuation was higher in swimmers with Down syndrome, evidencing an inability to maintain continuous propulsive actions. This fact is also evidenced by their catch-up coordination mode (negative index of coordination) that is typical for normal young stages of development. *Conclusions:* These findings suggest that lower swimming ability is evident in Down syndrome swimmers when compared with swimmers without disability. However, our subjects are involved in a training program and therefore probably more able to better perform activities of daily living when compared with other Down syndrome subjects, since coordination is a requirement for the training program. In addition, coordination is essential to maintain physical independence.

Key Words: swimming; mental disability; coordination; intra-cyclic velocity fluctuation

Introduction

Down syndrome is a genetic disorder that occurs when a third copy of human chromosome 21 is present; its incidence is one in 800 newborns (Galante et al., 2009). It has been reported in specialized literature that individuals with Down syndrome present a combination of physical and cognitive limitations that significantly affect their motor performance and contribute to high motor behavior variability (Epstein, 1989; Lahtinen, 2001). In addition, it has been suggested that persons with Down syndrome show a delay in the development of gross and fine motor skills leading to motor dysfunction (Galante et al., 2009) as well as exercise intolerance that can lead to a sedentary lifestyle (Aguiar et al., 2008). However, recent studies have reported that physical exercise can improve motor function in Down syndrome persons (Wu et al., 2007). This is particularly important since it is known that impaired motor skills can affect daily living skills and may have a negative impact on quality of life (Cowley et al. 2010). Even so, studies that focus on the specificities of subjects with Down syndrome involved in physical exercise programs, particularly in swimming, are scarce. Since muscle strength, technique, and hydrodynamic drag are important swimming performance influencing factors (Smith et al. 2002, Swaine & Reilly 1983, Toussaint & Beek 1992), coordination studies regarding the specific characteristics of swimmers with this specific intellectual disability are also needed.

Regardless of the specificity of the studied population, it is widely accepted that coordinative factors have a significant influence on swimming performance (Toussaint & Beek 1992). Of these, intra-cyclic velocity fluctuation (dv) and arm coordination are two informative and currently explored coordinative parameters. Intra-cyclic velocity fluctuation is frequently used to characterize swimming performance, being considered an inverse indicator of swimming efficiency (Kolmogorov & Duplischeva 1992). Arm coordination has been evaluated through the index of coordination (IdC, proposed for front crawl by Chollet et al., 2000), assessing the lag time between left and right arm propulsive phases, and giving temporal information about the organization of

arm propulsive actions. However, as the IdC does not provide data about the intensity of the forces acting over the swimmer's body, the combination of dv and IdC seems to be useful: dv gives kinematic data regarding the consequences of propulsive and resistive force combinations, whereas IdC gives temporal information about swimmers' ability to coordinate their propulsive actions (Schnitzler et al. 2008).

Since the above parameters, as well as their combination, have not been previously studied in swimmers with Down syndrome involved in a systematic physical exercise training program, we purposed to carry out a Down syndrome characterization on swimming regarding the dv of the hip as well as the IdC in a high intensity front crawl. In addition, to obtain a more detailed coordinative characterization of this specific population, front crawl propelling efficiency (η_p) was assessed and related with the dv and IdC parameters.

Design and Methods

Participants

Six international level swimmers with Down syndrome participated in the present study. The individual and total mean \pm SD values of physical and training background characteristics are described in Table 1.

All participants provided informed written consent (parental consent was also obtained) to participate in the study, which was approved by the local ethics committee, in agreement with the Declaration of Helsinki.

Table 1. Individual and total mean \pm SD values of age, height, body mass, years of previous competitive practice and training units per week for swimmers with Down syndrome in the present study.

Swimmer	Age (years)	Height (cm)	Body mass (kg)	Years of previous competitive practice	Training units per week
1	23	160	60.0	3	5
2	20	156	52.3	1	6
3	22	172	78.9	3	5
4	16	156	57.4	1	6

5	13	137	36.4	1	6
6	26	145	65.1	6	3
Mean±SD	20.0(4.8)	154.3(12.1)	58.4(14.1)	2.5(2.0)	5.2(1.2)

Procedures

Subjects performed a 20 m maximal intensity front crawl swim bout. Two digital cameras (Sony® DCR-HC42E) inserted into a sealed housing (SPK - HCB) recorded (50Hz) two complete underwater arm stroke cycles without breathing in the sagittal and frontal planes. The sagittal plane camera was placed laterally at the bottom of the pool, at 2 m depth and 13.5 m from the start wall. The frontal plane camera was placed at 0.5 m depth and aligned with the swimmer. For calibration of the recorded space a bi-dimensional rigid calibration structure (2.10 x 3 m) was used with 13 calibration points. Subsequently, a kinematic analysis was done for each swimmer using the APASystem (Ariel Dynamics Inc., USA), digitizing nine anatomical points (manually and frame by frame): the hip (right femoral condyle) and the finger tips, wrist, elbow, and shoulder on both sides. The average swimming horizontal velocity, stroke rate (SR), stroke length (SL), dv and arm coordination were assessed using kinematical data. For the dv assessment the coefficient of variation of the velocity/time curves of the hip in a complete stroke cycle was used. Arm coordination was assessed using the IdC for two complete arm strokes, measuring the lag time between the propulsive phases of each arm, and expressed as the percentage of the overall duration of the stroke cycle (Chollet et al. 2000). Following Chollet et al (2000), the propulsive phase begins with the start of the hand's backward movement and ends at the moment where the hand exits from the water (pull and push); the non-propulsive phase initiates with the hand's water release and ends at the beginning of the propulsive phase (recovery, entry and catch). For the front crawl technique, three coordination modes are proposed (cf. Chollet et al. 2000): (i) catch-up, when a lag time occurs between the propulsive phases of the two arms (IdC < 0%); (ii) opposition, when the propulsive phase of one arm starts as the other arm ends its propulsive phase (IdC= 0%); and (iii) superposition, when the propulsive phases of the two arms overlap (IdC > 0%).

Finally, arm stroke efficiency was calculated according to the model proposed by Zamparo et al. (2005), yielding the average efficiency for the underwater phase only (η_F), as indicated in Equation 1:

$$\eta_F = [(v \cdot 0.9) / (2\pi \cdot SR \cdot l)] (2/\pi), \quad (1)$$

where v is the mean velocity of the swimmer, SR is expressed in Hz, and l is the average shoulder-to-hand distance (assessed trigonometrically by measuring the upper limb length and the average elbow angle during the insweep of the arm pull). Also in Equation 1, velocity is multiplied by 0.9 to take into account that about 10% of forward propulsion in the front crawl is produced by the legs (Deschodt et al. 1990). It was assumed that $\eta_F \sim \eta_p$.

Statistical Analysis

Descriptive statistics (mean and standard deviations) were used to characterize the sample. Spearman Correlation coefficients were obtained to test the significant relationships between variables. The level of significance was set at $P < 0.05$, with data analysed using SPSS version 17.0 (SPSS Inc., Chicago, Illinois, USA).

Results

Mean and standard deviation values for the studied parameters were 0.98 ± 0.15 m.s⁻¹, 0.20 ± 0.07 , $-11.26 \pm 5.25\%$ and 0.28 ± 0.04 , for velocity, dv , IdC and η_p , respectively. The IdC value corresponds to catch-up coordination. SR and SL were also assessed, being 41.22 ± 4.07 cycles/min⁻¹ and 1.42 ± 0.19 m.cycle⁻¹, respectively. Correlation coefficients computed between all the studied variables are presented in Table 2.

Inverse significant relationships were observed between IdC and SR , while direct significant relationships were observed between velocity and SL . η_p was not related with any of the studied parameters, and IdC and dv were not

significantly related.

Table 2. Correlation matrix regarding the coefficients between velocity (v), intra-cyclic velocity fluctuation (dv), arm coordination (IdC), propelling efficiency (η_p), stroke rate (SR) and stroke length (SL).

	v	dv	IdC	η_p	SR	SL
v	1					
dv	-0.14	1				
IdC	0.26	0.43	1			
η_p	0.03	-0.14	0.03	1		
SR	0.12	0.58	0.90*	-0.23	1	
SL	0.83*	-0.54	-0.09	0.29	-0.29	1

* $P < 0.05$

Discussion

It is well accepted that the mean velocity of front crawl cycles results from the combination of propulsive and drag forces (Toussaint & Beek 1992). In fact, during a swimming cycle, there are systematic velocity fluctuations due to the modification of the body segments' positions (Nigg 1983). These velocity fluctuations negatively affect swimming performance, in particular due to the swimmer's overcoming of inertia. Therefore, knowing that swimming technique is one of the main determinants of a swimmer's propulsion and resistance, several biomechanical related parameters were assessed during an all-out effort to conduct a coordinative characterization of swimmers with Down syndrome. To the best of our knowledge, this approach has never been tried before. The main findings of the present study evidenced a lower coordinative development of the studied subjects and, therefore, their poorer technical efficiency when compared with swimmers without disabilities. Firstly, swimmers with Down syndrome presented lower height and arm span than the swimmers without disabilities (cf. Mazza et al. 1994, Pelayo et al. 1996), reflecting worse anthropometrical characteristics for swimming practice. In fact, slender and

taller swimmers have hydrodynamic advantages that reduce drag and increase propulsion. Additionally, a lower arm span implies lower distance traveled by stroke, which justifies their lower SL compared to the normal swimming population (cf. Seifert et al. 2007). These physical characteristics of Down syndrome have previously been pointed out in sedentary subjects (Epstein 1989, Lahtinen 2001).

The 20 m maximum front crawl test was conducted at high intensity to better simulate competition conditions. At near maximum swimming velocities, the dv values obtained in swimmers with Down syndrome were higher than those presented for swimmers with no disabilities who also performed at high exercise intensities (cf. Figueiredo et al. 2009, Schnitzler et al. 2008). Since the dv is an indicator of a swimmer's technical skill (Costill et al. 1987), the uniform distribution of the propulsive actions during the cycle represents a fundamental indicator of swimming efficiency, depending not only on the propulsive force but also on global motor synchronization, as well as on the ability to maintain low drag values during non-propulsive phases (Craig et al. 1979). Therefore, the observed high dv values seem to reflect a low technical efficiency in swimmers with Down syndrome compared with swimmers without disabilities, which seems to be justified by their abnormal muscle control and tone that are linked to motor delays and irregular movement patterns (cf. Almeida et al. 2000). In fact, since people with Down syndrome have low muscle tone and ligamentous laxity, they will have more difficulty performing the ideal swimming technical model, diminishing propulsion and increasing drag.

The IdC is also an important indicator of a swimmer's skill, in particular of his or her arm coordination (Chollet et al. 2000). In this study, the observed mean IdC value was lower in people with Down syndrome than for swimmers with no disability, even when compared with non-elite swimmers at national and regional levels (Chollet et al. 2000, Seifert et al. 2007). In fact, swimmers without disabilities tend to change their arm coordination from catch -up to opposition or superposition modes as velocity increases (Chollet et al. 2000, Seifert et al. 2007). Thus, the catch-up mode is adopted for slow velocities and

by less skilled swimmers, which evidences that swimmers with Down syndrome resemble non-proficient normal subjects.

Typical Down syndrome characteristics could indirectly influence coordination: swimmers with this syndrome present higher hydrodynamic drag as a result of a higher percentage of body fat and anthropometric traits (Epstein 1989, Lahtinen 2001) which, in addition to deficiencies in muscle strength (Almeida et al. 2000), can contribute to an increased lag time between propulsive phases (resulting in an even more negative IdC value). This difficulty in overcoming high hydrodynamic resistance can also compromise velocity and stroking parameters, as observed by the lower values of SR and SL in the present study compared to studies conducted with elite swimmers with no disabilities (cf. Pelayo et al. 1996, Schnitzler et al. 2008, Seifert et al. 2007, Swaine & Reilly 1983). However, when comparisons are made with less expert swimmers, the differences are not so evident, even at high velocities (cf. Cardelli et al. 2000).

It has been suggested that the IdC increase with swimming velocity could be a strategy adopted by high-level swimmers to maintain a constant dv despite increases in both propulsive and drag forces (Schnitzler et al. 2008). Indeed, an increase in both SR and propulsive impulse is expected when a swimmer swims faster, but this also leads to a quadratic increase in total drag (Kolmogorov & Duplischeva 1992). Thus, if no changes occur in the coordination pattern, a greater dv is expected. As the obtained IdC values in the present study are significantly negative, it suggests that these swimmers were not able to reach more “continuous” coordination modes at maximal velocities, which can also explain the high dv values observed. In fact, the correlation coefficient between IdC and dv was moderate (although non-significant from the statistical point of view). Moreover, according to Lerda and Cardelli (2003), IdC values seem to decrease in inspiratory cycles due to higher discontinuity in the arm actions linked to breathing. This should be taken into account in future studies by observing whether breathing laterality will impose any difference in the lag time between the propulsive actions of right and left arms.

Furthermore, the η_p values found for swimmers with Down syndrome are lower than for elite swimmers without disabilities (cf. Zamparo et al. 2005). However, when compared to pre-pubertal or older groups of swimmers (45-54 years old), similar results can be found (cf. Zamparo 2006). Zamparo (2006) reported that η_p depends essentially on the distance covered per stroke (reinforced in the present study by the strong relation between v and SL), whereas anthropometric characteristics play a minor role in η_p determination. Indeed, the low values of η_p in the present study can indicate that most of the swimming power output is wasted in giving water un-useful kinetic energy, revealing a technical inefficiency of the swimmers with Down syndrome (as already suggested by the dv and IdC values). Additionally, Down syndrome swimmers—similarly to elderly swimmers—have a decline in muscle strength and power that play a major role in development of SL and, hence, of η_p (Zamparo 2006).

The obtained results in the current study are unique and indicate that lower swimming ability is shown in Down syndrome swimmers when compared with swimmers without disabilities. This finding was expected since Down syndrome is characterized by impaired motor coordination. However, these Down syndrome subjects are involved in a training program, being more capable of performing activities of daily living when compared with other Down syndrome subjects, since coordination is required to do so. It is possible to speculate that the Down syndrome subjects in this study have better motor skills than their sedentary matches and are therefore more able to perform daily activities (e.g., eating, dressing and walking), leading them and their families to be more independent and to have a better quality of life. Thus, future studies comparing trained Down syndrome persons with sedentary Down syndrome persons are needed to analyse the impact of exercise on the health and daily living of Down syndrome persons and their families.

Dedicatory

We dedicate this study to our beloved colleague, Professor Maria Adília Silva.

Appendix VII

Intracyclic velocity variation and arm coordination assessment in swimmers with Down syndrome

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Abstract

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

Introduction

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; González-Aguero, Vicente-Rodríguez, Moreno, Guerra-Balic, Ara, & Casajús, 2010). Recent biomedical and molecular studies suggest that this chromosomal anomaly determines several alterations in protein expression patterns (Cabelof 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 under-water 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, $IdC > 0\%$). 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 (\pm *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.

Table 1. Mean \pm SD Values of age, anthropometric characteristics, and physical and water training background characteristics ($N = 16$: 10 males and 6 females).

Parameters	Mean \pm SD
Age (yrs)	20.5 \pm 4.8
Height (cm)	146.9 \pm 13.1
Body mass (kg)	57.4 \pm 11.1
Fat body mass (%)	17.2 \pm 9.5
Arm span (cm)	146.7 \pm 13.1
Previous competitive experience (yrs)	3.0 \pm 1.8
Training sessions per week ^a	5.1 \pm 1.1
Water training per training session (hrs)	1.4 \pm 0.2
Flexibility and/or weight lifting per training session (hrs)	1.0 \pm 0.3

Note. ^a In general training sessions per week are over 11 months a year.

Before video recording a familiarization and warm up period was provide 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 were informed of their performance, which was expected to be within \pm 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 fingertip in water to following fingertip 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 (0.02s). 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:

$$\text{Duration}_{\text{complete cycle}} = [(\text{Entry and catch} + \text{pull} + \text{push} + \text{recovery})_{\text{left arm}} + (\text{Entry and catch} + \text{pull} + \text{push} + \text{recovery})_{\text{right arm}}] / 2$$

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 IdC_{left} and IdC_{right}:

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

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

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 = $-1.63 \pm 4.3\%$) and only two did not decrease IdC from nonbreathing to nonpreferred side breathing (M change = $-2.94 \pm 4.2\%$).

Table 2. Mean \pm SD Values of velocity, IVV, IdC, stroke rate, stroke length, and stroke length/arm spam, in the studied breathing conditions.

	Without breathing	Breathing preferred side	Breathing non preferred side
v ($\text{m}\cdot\text{s}^{-1}$)	$1.04 \pm 0.13^{a,b}$	0.95 ± 0.15	0.93 ± 0.16
IVV	$0.17 \pm 0.05^{a,b}$	0.23 ± 0.07	0.29 ± 0.09
IdC (%)	$1.85 \pm 11.67^{a,b}$	-0.72 ± 11.73	-2.71 ± 11.31
SR (cycles/min)	43.13 ± 5.76^b	40.07 ± 4.41	38.41 ± 4.48
SL (m/cycle)	1.49 ± 0.19	1.43 ± 0.16	1.45 ± 0.18
SL / Arm spam	1.12 ± 0.16	1.07 ± 0.15	1.09 ± 0.17

Note. ^a Significantly different from preferred side and ^b significantly different from non preferred side ($p \leq 0.05$)

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 (-0.63) 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.

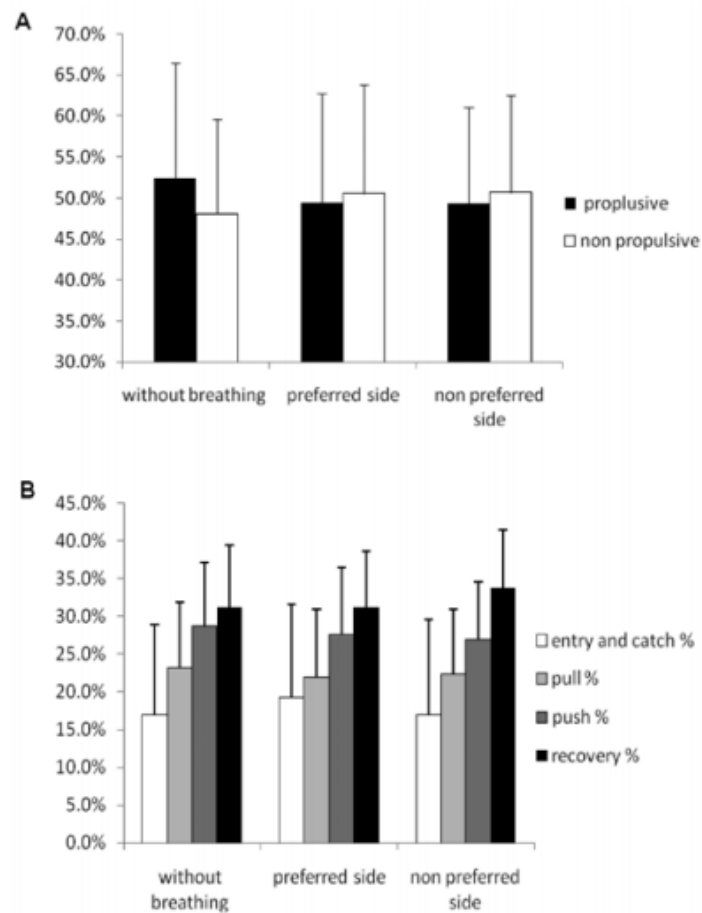


Figure 1. Mean \pm SD percentage values of the sum of propulsive and nonpropulsive stroke phases (panel A) and of entry and catch, pull, push and recovery phases (panel B) in the three inspiratory conditions.

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.

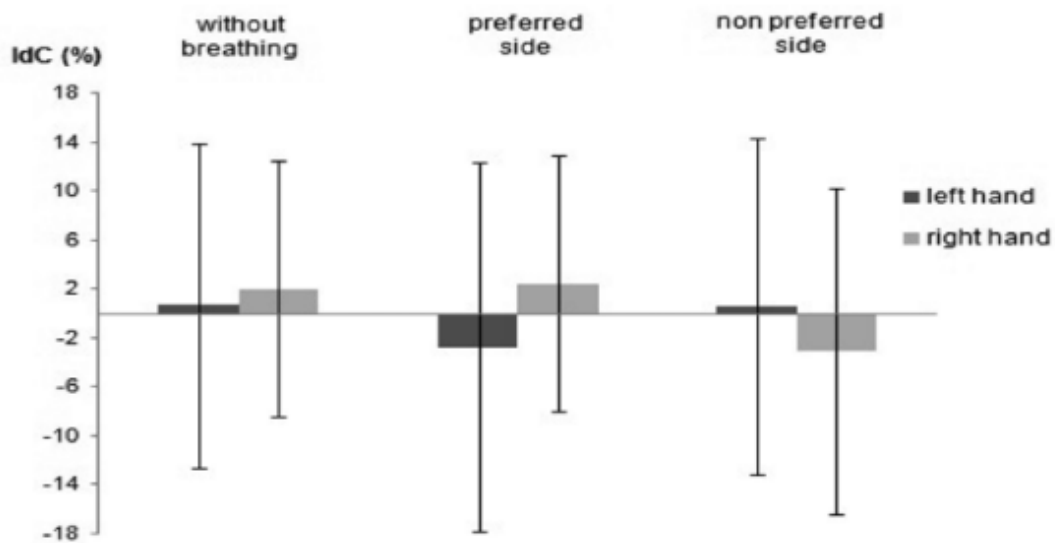


Figure 2. Mean IdC as shown by bars and SD values as indicated by lines for the left and right arms separately in the three breathing conditions tested.

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 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, Chabies, & 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 nondisabled 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; $IVV = 0.14 \pm 0.04$ & 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, Christo-foridis, & 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 et 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 generalize 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 handedness 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.

Acknowledgment

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