



**XIII th
INTERNATIONAL SYMPOSIUM
on BIOMECHANICS and MEDICINE in SWIMMING
PROCEEDINGS**

Tsukuba, Japan, 17 - 21 September 2018

JAPANESE SOCIETY of SCIENCES in SWIMMING and WATER EXERCISE



Swimming speed in men's 100-m freestyle confirms the fairness of the Paralympic Classification System: a meta-analysis

Wellington Gomes FEITOSA, Universidade Federal do Rio Grande do Sul – UFRGS, Porto Alegre, Brasil. Universidade Estadual do Ceará – UECE, Fortaleza, Brasil.
Ricardo de Assis CORREIA, Universidade Federal do Rio Grande do Sul – UFRGS, Porto Alegre, Brasil.
Tiago M. BARBOSA, Nanyang Technological University, Singapore. Polytechnic Institute of Bragança, Bragança. Research Centre in Sports Health and Human Develop, Vila real.
Flávio Antônio de Souza CASTRO, Universidade Federal do Rio Grande do Sul – UFRGS, Porto Alegre, Brasil.

Abstract — Despite an increase in popularity of Paralympic sports, there is a lack of studies on these sports, and controversies regarding the classification system for Paralympian swimmers. The Paralympic classification system features 10 classes to provide fair competition for swimmers with a physical disability. The summary of the clean swimming speed (SS) can provide useful information for the classification system in competitive swimming. The aim of this study was to summarize evidence of the fairness of Paralympic categories of male swimmers with a physical disability, focusing on SS in the 100-m front crawl. Multiple databases (PubMed, EMBASE, ISI Web of Knowledge, SPORTDiscus, Academic Search Premier, CINAHL) were examined for observational studies published until October 2017, on official swimming races. Five studies were found and analyzed ($n = 369$; national and international level). The random effects model was used for this meta-analysis. Statistical heterogeneity among the studies was assessed by the inconsistency test (I^2) and $\alpha = 0.05$. Subgroup analyses were performed with addition of the “class” covariant according to the characteristics of the studies. Bias was analyzed with a forest plot on the OpenMeta[Analyst] software. Increases in SS were related to higher Paralympic classes. Pooling data from all studies and classes, the estimated mean of SS was $1.25 \text{ m}\cdot\text{s}^{-1}$, $SD = 0.05 \text{ m}\cdot\text{s}^{-1}$, $p < 0.01$, $I^2 = 99\%$, $p < 0.01$. The analysis of sub-groups found high heterogeneity ($I^2 > 75\%$, $p < 0.05$). The results suggest that the Paralympic Classification System seems to be fair for the men's 100-m freestyle events. Assessment of studies by close classes and by groups with many classes together, e.g. S1 – S10, increased the heterogeneity of the analysis. However, further studies are necessary to explain possible inconsistencies in the Paralympic Classification.

Key words: Swimming, Physical disability, Biomechanics, Performance

1. INTRODUCTION

Speed is the main outcome to be monitored in swimming biomechanics (Palayo, Alberty, Sidney, Potdevin, & Deckerle, 2007; Morris, Osborne, Shephard, Skin-

ner, & Jenkins, 2016). Thus, above average swimming speeds are a key-factor to excel in this sport (Arelano, 1994). In Paralympic Swimming, competitions are fair when the speeds of a category of the Paralympic classification system are relatively similar, according to the swimmers' physical-motor handicap (Daly, Djjobova, Malone, Vanlandewijck, & Steadward, 2003). In this sense, clean swimming speed (SS) can provide useful information about the Paralympic classification system and its fairness. That said, this study is not intended to use swimming speed as a criterion for classifying swimmers with a disability. The goal was to compare swimming speed based on the actual classifications.

The IPC classification system features 10 classes to provide fair competition for swimmers with physical disabilities (IPC, 2015). Lower classes represent higher levels of physical-impairment. The Paralympic classification system aims to level the playing field across athletes with various levels of impairment (WPS, 2017). In this way, some studies have analyzed the performance of a large number ($n = 369$ subjects) of high-level competitive swimmers in national and international Paralympic swimming events, specifically in the 100m freestyle (Chatard et al., 1992; Daly, Malone, Vanlandewijck, & Sdeadward, 1999; Pelayo, Sidney, Moretto, Wille, & Chollet, 1999).

However, although there are insightful studies on the SS of disabled swimmers (Daly et al., 2003; Zrnzevic, 2016), no meta-analysis is found in the literature. The meta-analysis is able to integrate, combine and summarize these result, making the result more reliable, besides enabling the inclusion of future studies to be published (Pigott, 2012).

The aim of this study was to summarize evidence of the Paralympic categories of physically disabled male

swimmers, focusing on the SS in the 100-m freestyle event.

2. METHODS

2.1. Design

This was a meta-analysis of observational studies on 100-m front-crawl Paralympic swimmers.

2.2. Identification and selection of studies

A comprehensive search of the literature was performed using PubMed, EMBASE, ISI Web of Knowledge, SPORTDiscus, Academic Search Premier, CINAHL for complete studies with titles in English, Portuguese or Spanish, between the database inception and October 31, 2017. The keywords used were “disabled persons” OR “disabled sport” OR “physical disability” AND swimming OR aquatic OR crawl OR freestyle AND performance OR biomechanics OR “swimming speed” OR “swim speed” OR velocity. Inclusion criteria were studies focused on official swim races with male swimmers. Exclusion criteria were: (i) only official swim races, (ii) absence of data and / or incomplete data in the papers and (iii) multiple publications in which results were recycled (i.e. reported more than once), with only one of these studies included. Clean swimming speed is understood without start, turn and finish times (Daly et al., 1999).

2.3. Extraction of results

The following phases were used as criteria for the selection of studies: 1st phase – two researchers assessed the titles and abstracts of the articles identified by the research strategy, independently and in duplicate; 2nd phase – the same reviewers assessed the articles in full and made their selection according to the identification and selection of studies. A third independent reviewer resolved disagreements between reviewers.

2.4. Assessment of risk of bias

Methodological quality was assessed with the Newcastle-Ottawa quality assessment scale for cohort studies (Wells et al., 2007), adapted for observational studies (Sparrenberger et al., 2009). The scale is composed of eight items divided into three domains: group selection (three items, 0-3 points); comparison of groups and factors (one item; 0-2 points); exposure and assessment of the outcome value (three items, 0-3 points). Each item can be awarded a maximum score within each category: selection and results. A maximum of two scores was given for comparability. Low quality was ranged at < 7 points out of 8 (Stang, 2010).

2.5. Data analysis

The meta-analysis was carried out using a random effects model (Borenstein, Hedges, Higgins, & Rothstein, 2010). The inconsistency test (I²) was used to assess statistical heterogeneity, in which the values for heterogeneity were null = close to 0%; low = close to 25%; moderate = close to 50%; high = close to 75% (Borenstein, Hedges, Higgins, & Rothstein, 2010). Subgroup analyses were developed with addition of the covariant Paralympic classification (IPC, 2015). All tests were set with a significance level of $p < 0.05$. The meta-analysis was conducted using the OpenMeta[Analyst] software (Wallace, Schmid, Lau, & Trikalinos, 2009).

3. RESULTS

The research strategy identified 369 potentially relevant studies, but only four were within the scope of this meta-analysis, since they fulfilled the inclusion criteria (Figure 1).

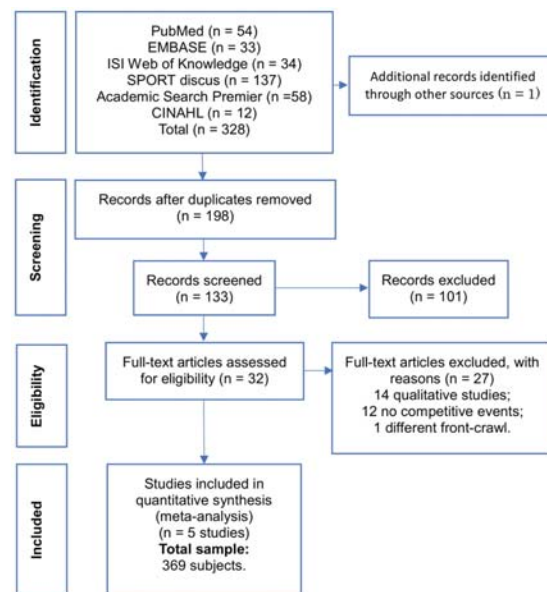


Figure 1. Flowchart of the systematic literature search.

The studies included in the meta-analysis are shown in Table 1. Papers included were published from 1992 to 2016. Regarding the quality of the observational studies included, all studies had high methodological quality (based on the Newcastle-Ottawa quality assessment scale). Regarding the competitive level of the subjects participating in the studies, all studies were carried out on international-level swimmers racing at the 1996 Atlanta Paralympic Games (Daly et al., 1999), 1996 Paralympic Games and the European Championships (Pelayo

et al., 1999) and a study without reference of the competitive event (Chatard et al., 1992).

As far as the division of classes is concerned, increases in SS were related to higher Paralympic class. For the collected data from all studies and classes, the estimated mean of SS was $1.25 \text{ m}\cdot\text{s}^{-1}$ (95% confidence interval: $1.16 - 1.34 \text{ m}\cdot\text{s}^{-1}$), standard deviation = $0.05 \text{ m}\cdot\text{s}^{-1}$, $p < 0.01$, $I^2 = 99\%$, $p < 0.01$ (Figure 2).

A comprehensive subgroup analysis by close classes and by groups with many classes together, within the same classification, e.g. S2 with S2, S3 with S3, S4 with S4, S5 with S5, S6 with S6, S7 with S7, S8 with S8, S9 with S9 and S10 with S10 and between classes, e.g. S3 with S4, S4 with S5, S6 with S6, S6 with S7, S7 with S8, S8 with S9, S9 with S10, showed high heterogeneity ($I^2 > 75\%$, $p < 0.05$).

4. DISCUSSION

The aim of this study was to summarize evidence of physically impaired male swimmers Paralympic Classes focusing on SS in 100-m freestyle event. The present meta-analysis has shown that: (i) as far as the division of classes is concerned, increases in SS were related to higher classes; (ii) Subgroup analysis showed high heterogeneities and statistical differences for SS in all combinations of classes S1 to S10 of male in male 100-m front crawl.

The main result of this study confirms the fairness of the Paralympic classification system by showing that SS decreases with increasing physical-motor impairment (IPC, 2015; WPS, 2017). However, comparisons within the same class, e.g. S3 with S3, are mostly heterogeneous, and close classes are heterogeneous and differ significantly (Wu and Williams, 1999; Daly et al., 2003). These increases in SS according to increases in the classification (high classification, low physical impairment) may be due to several reasons: impaired muscle power, limb deficiency, leg length difference, short stature, hypertonía, ataxia, athetosis and impaired passive range of movement (WPS, 2017).

This large physical-motor variability implies (i) different drag forces in the aquatic environment (Oh, Burkett, Osborough, Formosa & Payton, 2013), (ii) the need to increase stroke rates due to amputations or malformations in the upper-limbs (Figueiredo, Willig, Alves, Vilas-Boas & Fernandes, 2014), or, even (iii) increases in the kicking rate (Osborough, Daly & Payton, 2015) or trunk movements (WPS, 2017).

Although only five studies were assessed by the Newcastle-Ottawa quality assessment scale (Stang, 2010), all studies showed high methodological qual-

ity. One study with similar methodology obtained a slightly lower average (Mannocci et al., 2016). The number of subjects in the meta-analysis was relatively large ($n=369$). Similar meta-analysis on swimming are scarce and recruit a small number of participants (Havríluk, 2005). Meta-analysis are observational studies of evidence supported by the statistical method, which integrate two or more primary studies (Ramalho, 2005). In addition, the larger the sample, the lower the estimated variability and, consequently, the greater the study weight in the estimation of the meta-analysis (Rodrigues and Ziegelmann, 2010; Silva and Otta, 2014).

This meta-analysis researched complete studies with Paralympic competitive swimmers, of international level with one study without reference of the competitive event (Chatard et al., 1992) and studies with reference of the competitive event: 1996 Atlanta Paralympic Games (Daly et al., 1999), 1996 Paralympic Games and the European Championships (Pelayo et al., 1999), 2000 Sydney Paralympic Games (Daly et al., 2003), and 2012 London Paralympic Games (Zrnzevic, 2016). In this sense, it is necessary to consider the age of the studies and to reinforce the need to monitor the swimming speeds of Paralympic swimmers to better understand their performance evolution. An analysis of the average of the competitive results of Paralympic swimmers has shown progression of the times in each competitive event across World Championships and Olympic Games finals from 1992 to 2013 (Konig et al., 2014). This progression must be considered in the swimmers' performance, even if it is not possible to incorporate the results of the competitive overviews because they do not represent the swimming speed without starts and turns.

The Paralympic classification system features 10 classes to provide fair competition for swimmers with physical disabilities (IPC, 2015). Lower classes represent greater level of physical-motor impairment. The Paralympic classification system aims to level the playfield across athletes with the same level of impairment (WPS, 2017). In this way, some studies have analyzed the performance of a large number ($n = 313$ subjects) of high-level competitive swimmers in national and international Paralympic swimming events, specifically in the 100-m freestyle (Chatard et al., 1992; Daly, Malone, Vanlandewijck, & Sdeadward, 1999; Pelayo, Sidney, Moretto, Wille, & Chollet, 1999; Daly et al., 2003).

In relation to the different levels of performance of the swimmers included in this meta-analysis, e.g., Daly et al., (1999) includes only the heat results for all Atlanta participants, while Daly et al., 2003 includes current results only from finalist swimmers ($n = 8$ per class) at 2000 Paralympic Games, a first statistical test was performed

Table 1. Characteristics of the studies: SS values, study weights, 100-m front crawl competition. Class. = classification of swimmers with physical disabilities. For more information, see (Dummer, 1999; Sampedro, Flores, & Tejero, 2016). n = 313; SS in m.s⁻¹; M = mean; Sd = standard deviation.

Study name	Class.	n	SS (M ± Sd)	weight%
Chatard et al., 1992	S1 - S2	8	0.98 ± 0.16	2.70%
Daly et al., 1999	S2	6	0.56 ± 0.06	2.79%
Daly et al., 2003	S2	8	0.64 ± 0.06	2.79%
Zrnzevic, 2016	S2	8	0.72 ± 0.05	2.80%
Daly et al., 1999	S3	11	0.73 ± 0.08	2.79%
Pelayo et al., 1999	S3	7	0.73 ± 0.07	2.78%
Chatard et al., 1992	S3	6	1.20 ± 0.20	2.59%
Pelayo et al., 1999	S4	7	0.94 ± 0.04	2.80%
Daly et al., 1999	S4	14	0.91 ± 0.08	2.79%
Daly et al., 2003	S4	8	1.02 ± 0.05	2.80%
Zrnzevic, 2016	S4	8	1.15 ± 0.02	2.81%
Pelayo et al., 1999	S5	8	1.03 ± 0.09	2.77%
Daly et al., 1999	S5	13	1.02 ± 0.12	2.77%
Daly et al., 2003	S5	8	1.15 ± 0.07	2.79%
Zrnzevic, 2016	S5	8	1.28 ± 0.07	2.79%
Chatard et al., 1992	S5 - S6	7	1.18 ± 0.28	2.45%
Pelayo et al., 1999	S6	8	1.16 ± 0.11	2.76%
Daly et al., 1999	S6	18	1.19 ± 0.12	2.78%
Daly et al., 2003	- S6	8	1.36 ± 0.04	2.80%
Zrnzevic, 2016	S6	8	1.43 ± 0.04	2.80%
Daly et al., 1999	S7	26	1.36 ± 0.07	2.80%
Pelayo et al., 1999	S7	8	1.38 ± 0.03	2.81%
Daly et al., 2003	- S7	8	1.45 ± 0.04	2.80%
Zrnzevic, 2016	S7	8	1.55 ± 0.05	2.80%
Pelayo et al., 1999	S8	8	1.46 ± 0.06	2.79%
Daly et al., 1999	S8	25	1.42 ± 0.06	2.80%
Daly et al., 2003,	S8	8	1.50 ± 0.02	2.81%
Zrnzevic, 2016, 100m	S8	8	1.63 ± 0.05	2.80%
Pelayo et al., 1999	S9	8	1.46 ± 0.03	2.81%
Daly et al., 1999	S9	21	1.52 ± 0.04	2.81%
Daly et al., 2003	S9	8	1.57 ± 0.03	2.81%
Zrnzevic, 2016	S9	8	1.70 ± 0.02	2.81%
Daly et al., 1999	S10	24	1.57 ± 0.08	2.80%
Pelayo et al., 1999	S10	8	1.59 ± 0.04	2.80%
Daly et al., 2003	S10	8	1.68 ± 0.04	2.80%
Zrnzevic, 2016	S10	8	1.81 ± 0.05	2.80%

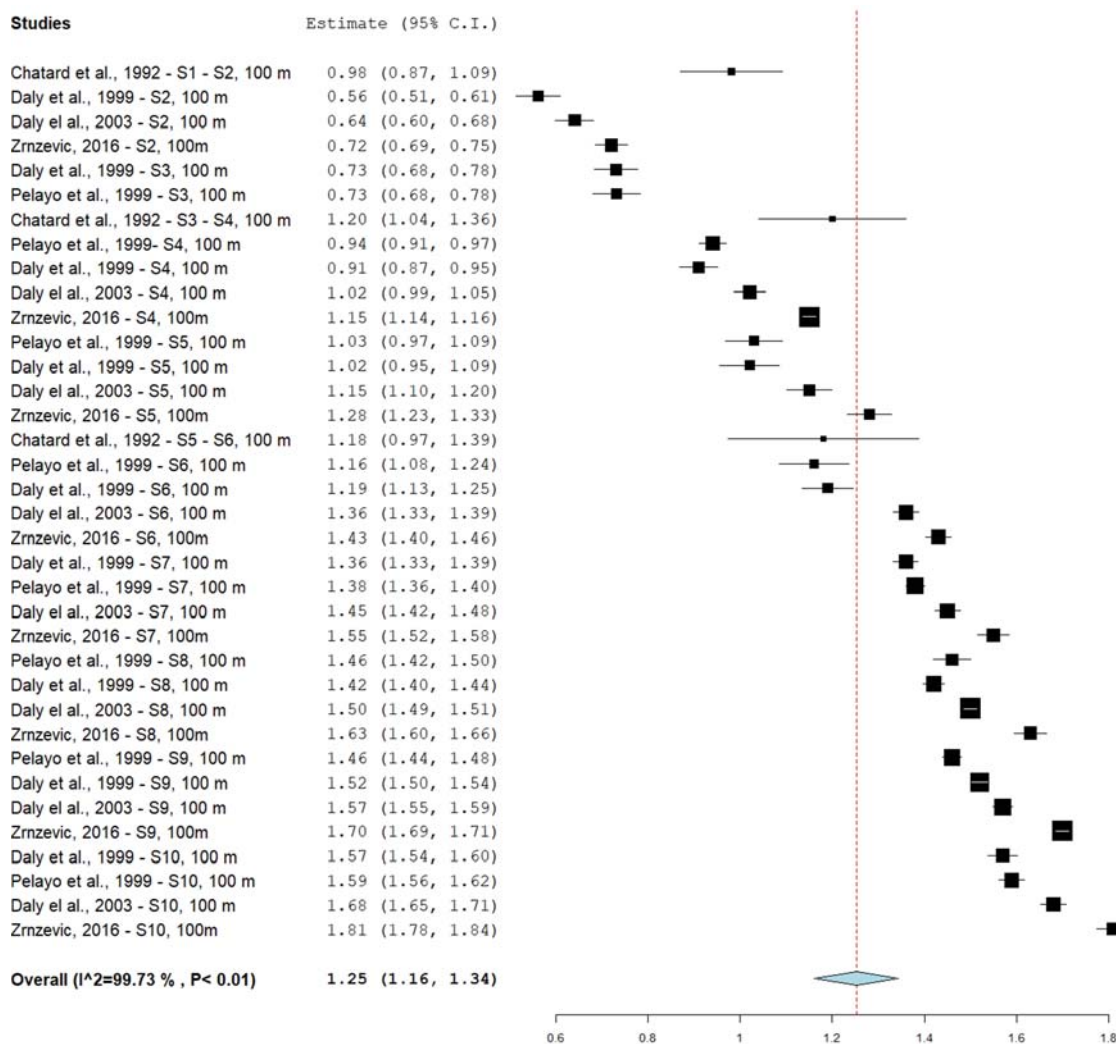


Figure 2. Forest plot derived from continuous random-effects models depicting the swim speed by Paralympic classification (class S1 to S10, male) in tests and races of 100 m freestyle.

to verify the inconsistency of the studies (Figure 1). The inconsistency test (I²) found that there is indeed a great heterogeneity or inconsistency between the studies (I² = 99.58%, p < 0.01). For results with high inconsistency, subgroup analyses are recommended to find the inconsistencies using a random effects model (Borenstein, Hedges, Higgins, & Rothstein, 2010). These results are relevant to demonstrate that analyzes with several classes of Paralympic swimmers increase the heterogeneity between classes.

This meta-analysis goes beyond the base consulted to systematize and consolidate the results found. The functional classification system used in disability swimming in front crawl events was supported for men's 100-m front crawl (Chatard et al., 1992; Daly, Malone, Vanlan-

dewijck, & Sdeadward, 1999; Pelayo, Sidney, Moretto, Wille, & Chollet, 1999; Daly et al., 2003; Zrnzevic, 2016). This meta-analysis allows the inclusion of future studies to summarize a new set of evidence in general analyses and by subgroup of the 10 classes of male swimmers crawl. In this way, more studies are needed to explain possible inconsistencies in the Paralympic classification.

5. CONCLUSION

This meta-analysis suggests that the Paralympic Classification System seems to be fair in the men's 100-m freestyle events when assessed based on swimming speed.

CONFLICT OF INTEREST

Authors do not have any conflict of interest regarding this study.

REFERENCES

- Arellano, R. (1994). Analysis of 50-, 100-, and 200-m Freestyle Swimmers at the 1992 Olympic Games. *J Appl Biomech*, 10, pp. 189-199.
- Borenstein, M., Hedges, L. V., Higgins, J. P., & Rothstein, H. R. (2010). A basic introduction to fixed-effect and random-effects models for meta-analysis. *Res Synth Methods*, 1(2), pp. 97-111. doi:10.1002/jrsm.12 Retrieved from <https://www.ncbi.nlm.nih.gov/pubmed/26061376>
- Chatard, J. C., Lavoie, J. M., Ottoz, H., Randaxhe, P., Cazorla, G., & Lacour, J. R. (1992). Physiological aspects of swimming performance for persons with disabilities. *Med Sci Sports Exerc*, 24(11), pp. 1276-1282. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/1435179>
- Daly, D. J., Djobova, S. K., Malone, L. A., Vanlandewijck, Y., & Steadward, R. D. (2003). Swimming speed patterns and stroking variables in the paralympic 100 m freestyle. *Adapt Phys Activ Q*, 20(3), pp. 260-278.
- Daly, D. J., Malone, L. A., Vanlandewijck, Y., & Steadward, R. D. (1999). Analysis of the men's 100M freestyle at the 1996 Atlanta Paralympic Games. Biomechanics and medicine in swimming VIII. Proceedings of the VIII International Symposium on Biomechanics and Medicine in Swimming, University of Jyväskylä, Finland, University of Jyväskylä, Finland, June 28 - July 2, 1998, University of Jyväskylä. Department of Biology of Physical Activity.
- Dummer, G. M. (1999). classification of swimmers with physical disabilities. *Adapt Phys Activ Q*, 16, pp. 216-218.
- IPC. (2015). Explanatory guide to Paralympic classification in Paralympic summer sports. Bonn: Germany.
- Figueiredo, P., Willig, R., Alves, F., Vilas-Boas, J. P., & Fernandes, R. J. (2014). Biophysical characterization of a swimmer with a unilateral arm amputation: a case study. *Int J Sports Physiol Perform*, 9(6), pp. 1050-1053. doi:10.1123/ijsp.2013-0438 Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/24509528>
- Havriluk, R. (2005). Performance level differences in swimming: a meta-analysis of passive drag force. *Res Q Exerc Sport*, 76(2), pp. 112-118. doi:10.1080/02701367.2005.10599273 Retrieved from <https://www.ncbi.nlm.nih.gov/pubmed/16128479>
- Konig, S., Valeri, F., Wild, S., Rosemann, T., Rust, C. A., & Knechtle, B. (2014). Change of the age and performance of swimmers across World Championships and Olympic Games finals from 1992 to 2013 - a cross-sectional data analysis. *Springerplus*, 3, p 652. doi:10.1186/2193-1801-3-652 Retrieved from <https://www.ncbi.nlm.nih.gov/pubmed/25485195>
- Mannocci, A., La Torre, G., Spagnoli, A., Solimini, A. G., Palazzo, C., & De Giusti, M. (2016). Is swimming in recreational water associated with the occurrence of respiratory illness? A systematic review and meta-analysis. *J Water Health*, 14(4), pp. 590-599. doi:10.2166/wh.2016.266 Retrieved from <https://www.ncbi.nlm.nih.gov/pubmed/27441854>
- Morris, K. S., Osborne, M. A., Shephard, M. E., Skinner, T. L., & Jenkins, D. G. (2016). Velocity, aerobic power and metabolic cost of whole body and arms only front crawl swimming at various stroke rates. *Eur J Appl Physiol*, 116(5), pp. 1075-1085. doi:10.1007/s00421-016-3372-4 Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/27052972>
- Oh, Y. T., Burkett, B., Osborough, C. D., Formosa, D., & Payton, C. (2013). London 2012 Paralympic swimming: passive drag and the classification system. *Br J Sports Med*, 47(13), pp. 838-843. doi:10.1136/bjsports-2013-092192 Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/23935028>
- Osborough, C. D., Daly, D., & Payton, C. (2015). Effect of swim speed on leg-to-arm coordination in unilateral arm amputee front crawl swimmers. *J Sports Sci*, 33(14), pp. 1523-1531. doi:10.1080/02640414.2014.996181 Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/25562689>
- Palayo, P., Alberty, M., Sidney, M., Potdevin, F., & Dekerle, J. (2007). Aerobic potential, stroke parameters, and coordination in swimming front-crawl performance. *Int J Sports Physiol Perform*, 2(4), pp. 347-359. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/19171953>
- Palayo, P., Sidney, M., Moretto, P., Wille, F., & Chollet, D. (1999). Stroking parameters in top level swimmers with a disability. *Med Sci Sports Exerc*, 31(12), pp. 1839-1843. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/10613437>
- Pigott, T. (2012). *Advances in Meta-Analysis* New York: Springer-Verlag

- Ramalho, A. (2005). Manual para redacção de estudos e projectos de revisão sistemática com e sem metanálise Coimbra: FORMASAU.
- Rodrigues, C. L., & Ziegelmann, P. K. (2010). META-ANALYSIS: A PRACTICAL GUIDE. *Rev HCPA*, 30(4)
- Sampedro, S. S., Flores, A. A., & Tejero, J. P. (2016). Evolución del rendimiento en nadadores paralímpicos con discapacidad física: de Pekín 2008 a Londres 2012. *Ed. Físic. Deportes*, 124, pp. 41-48.
- Silva, G. A. d., & Otta, E. (2014). Systematic Review and Meta-Analysis of Observational Studies in Psychology. *RCPs*, 33(2), pp. 137-153.
- Sparrenberger, F., Cichelero, F. T., Ascoli, A. M., Fonseca, F. P., Weiss, G., Berwanger, O., . . . Fuchs, F. D. (2009). Does psychosocial stress cause hypertension? A systematic review of observational studies. *J Hum Hypertens*, 23(1), pp. 12-19. doi:10.1038/jhh.2008.74 Retrieved from <https://www.ncbi.nlm.nih.gov/pubmed/18615099>
- Stang, A. (2010). Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. *Eur J Epidemiol*, 25(9), pp. 603-605. doi:10.1007/s10654-010-9491-z Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/20652370>
- Wallace, B. C., Schmid, C. H., Lau, J., & Trikalinos, T. A. (2009). Meta-Analyst: software for meta-analysis of binary, continuous and diagnostic data. *BMC Med Res Methodol*, 9, p 80. doi:10.1186/1471-2288-9-80 Retrieved from <https://www.ncbi.nlm.nih.gov/pubmed/19961608>
- Wells, G. A., Shea, A., O'Connell, D., Peterson, J., Welch, J., Losos, M., & Tugwell, P. (2007). The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. Retrieved Date Accessed, 31 Dezember 2017 from http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp.
- WPS. W. P. S. Equipment (Ed.) (2017). World Para Swimming: Classification Rules and Regulations, January 2018.
- Wu, S. K., & Williams, T. (1999). Paralympic swimming performance, impairment, and the functional classification system. *Adapted Physical Activity Quarterly*, 16, pp. 251-270.
- Zrnzevic, J. (2016). Race analysis of swimming performances at Paralympic Games (Master Master Thesis). University of Leuven - Faculty Kinesiology and Rehabilitations Sciences, Leuven.