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Sofia Margarida Soares dos Santos

SYNCHRONIZATION MODEL IN BREASTSTROKE ON ELITE ATHLETES AND ADAPTED SWIMMING:
A SYSTEMATIC REVIEW

Master thesis in the scientific area of Exercício e Saúde em Populações Especiais advised by the Professor Doutor Luís Manuel Pinto Lopes Rama and presented to Faculdade de Ciências do Desporto e Educação Física of Universidade de Coimbra.

October of 2020

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ABSTRACT

Background: Synchronization model in breaststroke has been studied in elite swimmers for the past years, but a gap is around adapted swim and synchronization in different types of disability.
Objective: The aim of this review was to identify and synthesise the most significant literature about synchronization model in breaststroke on elite athletes of swimming and adapted swim.
Methods: We performed a systematic review of Web of ScienceTM Core Collection, Pubmed and Scielo databases according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines. The following keywords were used: "swim*" and "breaststroke". Each word was associated with the terms "synchronization model", "sync*" and "elite athlete". In another search were used the words "adapted swim" and "breaststroke", other "breaststroke" and "coordination" and ("leg" or "arm" or "propulsion" or "recovery"). Finally, the keywords "handicapped" and "swimming". The selection was for the original articles in English containing relevant data about breaststroke, elite athletes in swimming and adapted swim and synchronization in breaststroke.
Results: The search returned 324 records. After seeing duplication, 262 articles remain (we withdrew 62) and then screening against set criteria, was done. In the end, 25 papers were selected this systematic review. The most common topics of analysis were about breaststroke, elite athletes in swimming and adapted swim and synchronization in breaststroke.
Conclusions: For different factors, breaststroke shows a complete and complex synchronization model that can be different in athletes with or without disabilities.
The limitations detected in the review studies suggest that future research should include breaststroke synchronization in people with distinct disabilities.

Key Words
Breaststroke; synchronization model; elite athletes; adapted swim

RESUMO

Fundo: O modelo de sincronização no nado de bruços tem vindo a ser estudado em atletas de elite nos últimos anos, mas existe uma lacuna acerca da natação adaptada e coordenação em diferentes tipos de deficiência.

Objetivo: O objetivo desta revisão sistemática foi identificar e sintetizar a literatura mais significativa sobre o modelo de sincronização no nado de bruços em atletas de elite na natação pura e adaptada.

Métodos: Esta revisão sistemática teve como ponto de partida as bases de dados Web of ScienceTM Core Collection, Pubmed e Scielo de acordo com as diretrizes PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses). As seguintes palavras-chave foram usadas: "swim*" and "breaststroke". Cada palavra foi associada aos termos "synchronization model", "sync*" e "elite athlete". Noutra pesquisa foram usadas as palavras "adapted swim" and "breaststroke", outra "breaststroke" and "coordination" and ("leg" or "arm" or "propulsion" or "recovery"). Finalmente, as palavras-chave "handicapped" and "swimming". A seleção dos artigos teve como base os originais escritos em Inglês que continham dados relevantes sobre bruços, atletas de elite na natação pura e adaptada e coordenação no nado de bruços.

Resultados: A pesquisa resultou em 324 artigos. Depois de eliminar os duplicados, 262 artigos permaneceram (62 foram eliminados). Após uma nova triagem referente aos critérios definidos, 37 artigos foram totalmente lidos. No final, 25 artigos fizeram parte desta revisão sistemática. Os tópicos de analise mais comuns foram acerca de bruços, atletas de elite na natação pura e adaptada e coordenação no nado de bruços.

Conclusões: Para diferentes fatores, bruços mostro um completo e complexo modela de sincronização que pode diferir em atletas com ou sem deficiência.

As limitações observadas nos artigos analisado sugere para o futuro pesquisa que possa ser elaborada incluindo a coordenação no nado de bruços em pessoas com diferentes tipos de deficiência.

Palavras-chave

Bruços; modelo de sincronização; atletas de elite; natação adaptada

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ABREVIATIONS AND ACRONYMS

APA	American Psychiatric Association
ASD	Autism Spectrum Disorders
B.C.	Before Christ
cm	Centimetres
DS	Down Syndrome
FCDEF	Faculdade de Ciências do Desporto e Educação Física
FINA	Fédération Internationale de Natation
Hz	Hertz
IPC	International Paralympic Committee
IQ	Intelligence Quotient
m	Meters
min or ‘	Minutes
m/s -1	Meters per second
n	Sample
P	FINA score
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-analyses
S	Freestyle, Backstroke and Butterfly
SB	Breaststroke
SM	Medley
S1 to S17	Para swimming classification
T1 to T4	Intervals
WHO	World Health Organization
WPS	World Para Swimming
º	Degrees
>, < and =	Greater, lesser and equal
±	More or less
%	Percentage

CHAPTER I. SYSTEMATIC REVIEW

INTRODUCTION

According to FINA (International Swimming Federation) “Swim is an individual or team sport that involve the use of arms and legs to move the body through the water”. Usually, this sport is based in a pool, sea, lake or river. References of 200 B.C. reveal swim as recreational in painting, but only in 1538 was written the first book about that “The swimmer or a dialogue about the art of swimming”.

In a sportive organization, the individual events predict the realization of different distances proves in Butterfly, Backstroke, Breaststroke, Freestyle and Medley. Collectively, the relay combines experts in those four techniques or the all in Freestyle stroke. For each one of the swimming strokes there is a definition according to FINA Rules: Butterfly: event realized in ventral position, where both of arms raise simultaneously out and forward of water, combined with dolphin movement; Backstroke: the swimmer is in the back position, doing alternate kick and arm rotation also backwards; Breaststroke: event in a ventral position where both hands move simultaneously forward, out and backwards starting in front of the chest, and the leg movement is like a frog; Freestyle: an event where the swimmers can use any other technique but it is usual Front Crawl. Is realized in ventral position and characterized by alternate movements of arms and legs, the legs have a continuous movement up and down.

To increase the performance, through the evolution of breaststroke, some different ways to swim were presented. After a rule changing in 1987 (that allowed hands to break the water surface and head could dive below it), according to Colman, Persyn, Daly, & Stijnen (2010) breaststroke could define two different types, flat and undulating.

Flat breaststroke: Where legs suffered the most significant change by removing the inverted V shape replacing it with a circular path and arms change when the shoulders close to the surface and looked them forward.

Undulating breaststroke: That change into a small oscillation similar to butterfly. In view of this constant wave motion, the head was completely submerged during part of the cycle. Which, in part, may have caused the FINA regulation to change with the rule that remains today of “During each complete cycle, any part of the swimmer's head must break the surface of the water.”

In undulating, velocity peaks of centre of mass displacement are higher than in flat, which can explain that deceleration and acceleration of the body above the water surface. About trunk and knew, the hyperextension during a quick kick can maintain a high body centre of mass velocity during vertical body waving.

For Ludovic Seifert, Leblanc, Chollet, & Delignières (2010) the main differences in comparison to the flat style, in the undulating style are:

1. During de in-sweep, the leg extension is deeper and followed by a rising undulation of the feet;

2. The hands and head dive under the water surface during the arm recovery. The forearms recovery happening just above the surface;
3. An upward arm trajectory is observed during the out-sweep of the hands and the in-sweep of the feet;
4. The downward and backward leg propulsion is countered by a plunge downward and forward of the upper half of the body.

The discontinuous propulsive action of legs and arms in breaststroke makes this technique the most challenging in its synchronization of the four strokes. As such, and from here, it is possible to develop the different phases of breaststroke swimming technique, according to Chollet, Seifert, Leblanc, Boulesteix, & Carter (2004).

Its characterization, starting with the arms, includes five different phases, starting with the arm glide (time between the extension of the arms and the beginning of the movement of the hand backwards); as a second moment we have the arm propulsion (time between the beginning and the end of the movement of the hand backwards, being the initial part of the propulsion of the upper limb); there follows the elbow push (time between the end of the hand movement back and the beginning of the hand movement forward and the end of the impulse to the elbow in and back) knowing that this is the second part of the propulsion of the upper limb, in which the elbows must be pressed downwards and inwards, to overcome the inertia of the hand at the end of the arm; the fourth section of the movement is the first part of the recovery of the arms (time between the end of the elbow push and the recovery of the arm until a 90º angle of the arm / forearm is reached); and finally the second part of the recovery of the arms (time between the end of the first part of the recovery and the extension of the arms) ends the movement of the upper limbs. Regarding the legs, five phases are also described from here, starting with the leg propulsion (time between the beginning of the backward movement of the feet - when the legs move in maximum flexion - and the extension of the leg) ; after this, the leg in-sweep (time between the extension of the leg and the union of the legs); in a third moment, the leg glide (time between the leg junction and the beginning of the forward movement of the feet and knee flexion); beginning the last phase, the first part of recovery (time between the end of the recovery of the leg slip, until a 90º angle of the thigh/leg is reached; ending with the second part of the recovery (time between the end of the first part recovery and complete knee flexion, until the end of the forward movement of the feet).

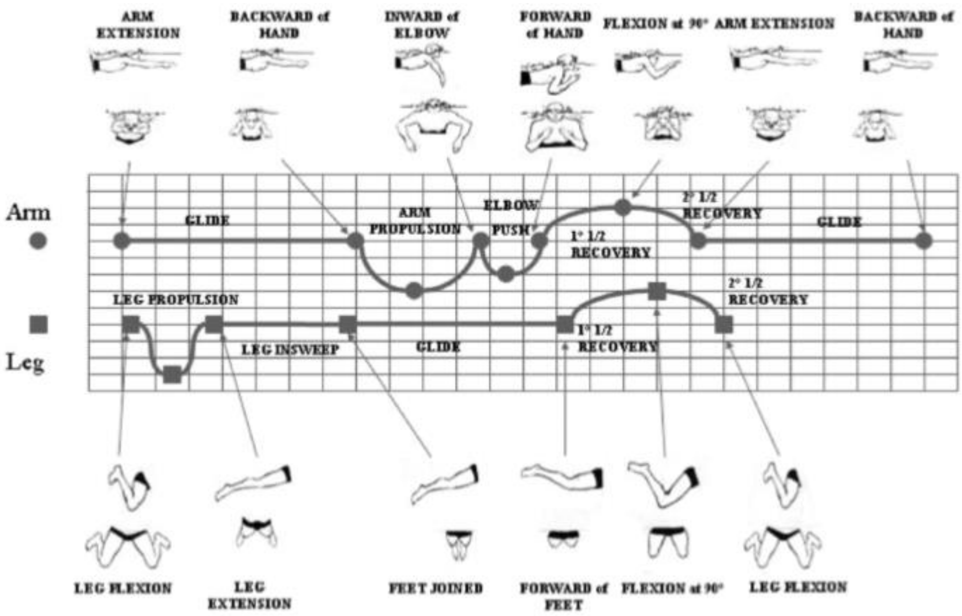


FIGURE 1 - Breaststroke arm and leg phases (Chollet et al., 2004)

This previous description has the consequence of determining the synchronization of arms and legs at different intervals/moments, thus comprising the acceleration of the body (T1) and the respective synchronization in recovery (T2, T3 and T4). T1 defines the duration of the slip, divided into T1a (the time between the end of the leg propulsion and the start of the arm propulsion) and T1b (the time between the end of the leg propulsion and the start of the arm propulsion). T2 has to do with the time between the beginning of the recovery of the arm and the beginning of the recovery of the leg; T3, the time between the end of arm recovery and the end of leg recovery; and finally T4, where the time between recovery at 90º flexion of the arm and recovery at 90º flexion of the leg takes place.

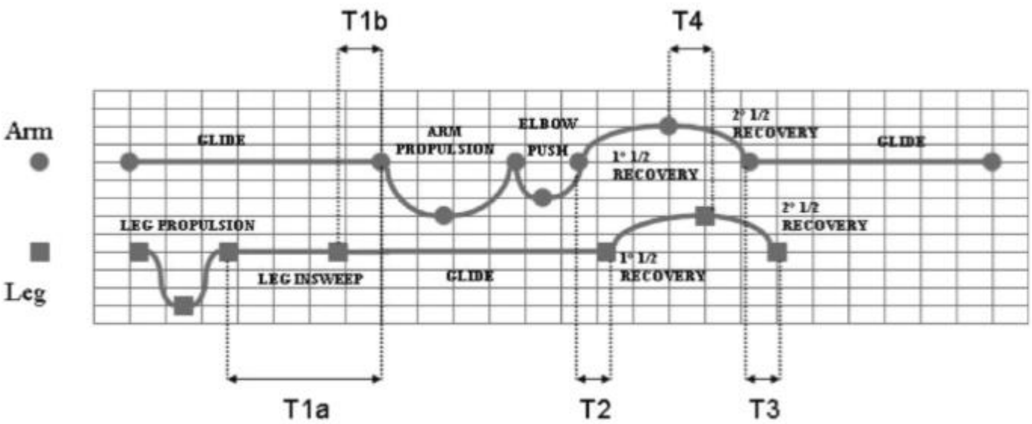


FIGURE 2 - Time gaps between leg and arm phases in breaststroke (Chollet et al., 2004)

So, breaststroke, as a discontinuous stroke, doesn't have a constant velocity (which would be the ideal for all strokes). In a study by Chollet et al. (2004), the data resulting from the analysis of the speed variation identified three types of phases: propulsive phases during which body acceleration occurs; non-propulsive phases corresponding to body deceleration; and corresponding neutral phases, slide or active drag, that is, deceleration of the body. The propulsive phases corresponded to the propulsive phases of the arms and legs and the approximation of the elbows under the chest. The negative or non-propulsive phases were the recovery of arms and legs. The sliding of the arms and legs were characterized as neutral phases due to the hydrodynamic position adopted by the body.

Several conclusions can be drawn about the previously defined intervals: when T1a> 0, the time interval will be positive because the propulsive actions of the arm and leg overlap to maintain speed; when T1a <0, the time interval was negative and the arm slip and the leg insertion or the leg slip added to the leg action insertion occurred simultaneously; when T1b = 0, there was motor continuity (because the arm action started when the leg action ended), even if it was not associated with mechanical continuity; when T1b> 0, then it will be the same situation as T1a> 0 or T1a <0; when T1b <0, there was a negative time interval during which the arm and leg slid simultaneously; when T2 and T3 = 0, there was mechanical continuity between leg and arm propulsion; when T2 and T3 <0, there is a negative time interval because a propelling action overlaps with a negative action; when T2 and T3> 0, the positive interval corresponds to the slip of one pair of limbs during the recovery of the other pair, so no energy was added to the recovery phase since the rest of the body is in an aerodynamic position; when T4 = 0, the 90º angle of leg and foot flexion during the respective recoveries was simultaneous; when T4> or <0, there is a negative interval that indicates the lack of synchronization between the recoveries of the arm and leg.

The synchronization of breaststroke and butterfly swimming is mainly due to the mirror symmetry that occurs during the different phases (in the simultaneous leg and arm) of the two strokes, something that does not happen in front crawl and backstroke where the movements of the extremities are obtained alternately. Specifically, in breaststroke swimming, according to FINA (International Swimming Federation) regulations, this style is the only one that is determined by an arm and kick cycle, in sequence. During this cycle, different bodily mechanisms produce similar propulsion forces. According to Chollet et al. (2004), the synchronization between legs and arms was determined by measuring the time intervals between the different phases of the swim for each pair of motor members, which allowed to analyse the acceleration-deceleration movement of the body.

According to Hugues Leblanc, Seifert, & Chollet (2009) which compared the different swimming techniques, in breaststroke, the decrease in the total time interval resulted from the reduction of phases T1 and T3 from 400m to 50m.

For Jaszczak (2011) and Balan & Shaao (2014) there are three types of coordination of the breaststroke swimming technique:

1. Gliding coordination: Hands start propulsion after the slide;

2. Continuation coordination: Leg propulsion is followed by hand propulsion;

3. Overlap coordination: Propulsion at the end of the leg overlaps with the start of hand propulsion.

Three types of arm-leg coordination (superposition, opposition and glide) were defined by Ludovic Seifert, Komar, & Crettenand (2014). The main differences as to do with the duration of the time gap between propulsive actions of arms and legs and on the swim speed.

The fastest start of leg propulsion was associated with the percentage of leg propulsion duration during each leg kick for Marek Strzala et al. (2013). Probably more time spent in this phase by some swimmers has allowed them to complete a broader recovery.

For the arms Strzała et al. (2014), some studies address the stroke rate and the stroke length ratio may influence some differences in the execution time of the propulsion phase by arms and legs in the cycle or duration of the slide. Differences in the performance of each phase of the movement, although apparently minor, can be translated in the increase of the propulsion force and small modifications in the aerodynamic glide or recovery with limited active drag can increase the speed of the swim in question.

About arm-leg synchronization, several factors were found to take into account:

For Marek Strzala et al. (2013) one of the main findings has to do with the reduction of glide and even the overlapping of the propulsive movements of the upper and lower limbs that significantly influence the speed of the swim. When a swimmer waits for the total joining of the lower limbs to keep the upper limbs apart, the speed decreases from 1.60 m / s-1 to about 1.22 m / s-1. This author also points out that the best way to reduce the deceleration time is to use the overlap time between the end of the kick propulsion phase and the start of the stroke propulsion phase.

In this study, it was also noted the great influence of the lower limbs in the overall propulsion of this swim, concluding that this complex leg movement, also called whip, is quite dependent on the external rotation of the knee, to be performed more extensively.

Other authors also point out that the amplitude of the wavy movements of the hips and feet can contribute to increasing the production of resistance, which also results in less economy of swimming, that is, by raising the thigh during the movement of the foot causing a slight undulation which makes the body drag, increasing resistance.

Comparing more and less experienced swimmers L. Seifert & Chollet (2005) finds out that, with different skill levels, synchronization patterns and technical discontinuity with regard to the Breaststroke swimming technique, the greater time interval in the synchronization between the kick and stroke was highlighted in the propulsion actions of the swimmers with less skill due to technical errors and difficulty in positioning over non-propulsive times. In addition, these elite swimmers are able to swim at the same speed as the lower level swimmers, using a technique with greater mobility, demonstrating greater efficiency and ability to move. Concluding that an elite swimmer can reach the same speed or a higher speed than a non-elite swimmer, using a radically different technique, thanks to the technical work and strategies developed by the training.

Talking about recreational and competitive swimmers Hugues Leblanc et al. (2009) says that the situation in which competitive athletes tend to maintain synchronization through gliding, with low to moderate speed while the rest begin the propulsive phase of the arms. Before the end of the kick, that is, they do not allow sliding, and then have a longer breathing time during the stroke. These recreational swimmers had an exaggerated overlap time after which they started propelling the arm while the kick still accelerated the body. As a result, there was an increase in resistance because his arms were not aligned.

In another study by L Seifert et al. (2011), synchronization profiles were examined during the breaststroke swim cycle where all competition swimmers used a continuous synchronization mode, with more or less time spent on sliding with the body fully extended, thus explaining the small variability in the synchronization profiles.

For Chollet et al. (2004) the independent action of the two pairs of limbs has a joint effect on the propulsion of the body; this is evidence. But in addition to that, the anterior action of the arm is responsible for both the effective increase in propulsion and the effective reduction of the glide.

From biomechanical and energetic points of view Ludovic Seifert et al. (2010) shows that it is more economical to swim at a constant velocity than to have intra-cyclic velocity variations, so, swimmers should minimise the intra-cyclic velocity variations. That minimization provides a good indication about the skill level of a determinate swimmer.

Breaststroke has horizontal action (that is not usually found on the other strokes) that makes more propulsion to get over drag force. Horizontal velocity presents the balance between propulsive force and resistance. According to T. M. Barbosa et al. (2013) when velocity increase, horizontal velocity decrease, which leads to a higher energetic cost.

So, it is important to emphasize that the pattern of synchronization of simultaneous movements in swimming evolves towards increasing speed, that is, efficiency and performance will always be the central focus.

The muscle activation pattern of a movement in swimming is a very important element to maintain high-intensity work to providing the working muscles with sufficient energy. For that reason, several studies included muscle activation in breaststroke swimmers including the one from T. Barbosa, Costa, & Louro (2019).

In world-class swimmers, the recovery time of legs is lower, and knee angle as well according to B. H. Olstad, Zinner, Vaz, Cabri, & Kjendlie (2017). The average speed during glide is higher in world-class than the national and elite level and the patterns of muscular activities are different considering those two different level swimmers. If the muscle activation and coactivation are different for all the muscles, means that muscle activation is more effective in world-class swimmers. World-class swimmers showed no activation in the braquial triceps during the leg propulsion phase. World classes showed an earlier activation in braquial biceps into the leg glide phase than national elite, while one of the worlds champions activated even earlier into this phase, suggesting an even earlier elbow flexion and orientation of the propulsive surface.

It was shown by Vaz et al. (2016) that muscle synchronization during breaststroke is not profoundly affected by expertise, but, specific timing adjustments were observed between arms and legs.

The lack of a pattern means that every swimmer adapts his own motor and neuromuscular characteristics to a unique way of the swim for T. Barbosa et al. (2019).

For Chatard et al. (1992) swimming is an appropriate exercise for people with disabilities for many reasons, like: less weight in water, cardio and synchronization developed, reduction of spasticity and lees fatigue. Performance in swim helps the recovery and reduce weaknesses and health problems (for example, heart diseases).

International Paralympic Committee (IPC) is connected to World Para Swimming (WPS) in performance of adapted swim. The competition involves Paralympics and World, European, National and Regional Championships.

Athletes compete in the individual events, different distances in Butterfly, Backstroke, Breaststroke, Freestyle and Medley. A collective relay combines experts in those four techniques or freestyle. The participation in diverse competitions is separate by sex male and female according to impairment groups.

That classification is based on a combination of locomotor disabilities and reflects the motor function ability of the individuals, so, they are classified in three groups: S1 to S10 (physical impairment), S11 to S13 (vision impairment), S14 (intellectual impairment) and S17 (autism spectrum disorders). The lower the number, the more significant impact on performance. Different strokes require different skills, so, classification is subdivided into “S” events (freestyle, backstroke and butterfly), “SB” for breaststroke and “SM” for the medley.

The different functional classifications caused by different disabilities affect physical training because the classification of an athlete is directly related to performance and training adaptations according to Medeiros et al. (2016). However for Morrien, Taylor, & Hettinga (2017), it was concluded that the current classification system does not always differentiate clearly between swimming groups.

Body composition is related with the disability for Medeiros et al. (2016) and it was studied in order to give data about body structure and composition, joint flexibility, isometric strength, style and performance. Breaststroke is an example of characteristics like flexibility and strength. Proof of that is outward rotation of hip and knee during ankle flection or the flexibility of trunk in undulating breaststroke according to Ludovic Seifert et al. (2010).

About passive drag, anthropometrical measurements and bodies with and without disabilities. For Chatard et al. (1992) passive drag is bigger in elite athletes with the wheelchair, knowing that that weight and hydrostatic elevation are big factors in drag. When it comes to anthropometrical measurements, there are no significant differences according to impairment. Finally, the bodies with and without disabilities, drag increases in people with disabilities but buoyancy is much better than people without disabilities.

Para swimmers with limb deficiency have reduced limb length and surface area that affects their ability to produce propulsion and minimise their resistance in the water. According to Hogarth et al. (2020) limb length changes the performance by about 47 to 87%.

Related to the differences between the fastest time achieved and the times measured, Medeiros et al. (2016) says that the best time achieved in the year was significantly faster than the two time points analysed for comparisons within the S4, S7 and S8-S13 classes and for each gender.

Critical swimming velocity is the concept application of the swimming critical swimming power for Garatachea et al. (2006): the exercise intensity at which the exercise can theoretically be maintained and continued without reaching exhaustion. Swimming velocity was higher for smaller distances and decreased, approaching critical swimming velocity, as trial distances increased

So, to identify and develop the efficiency and performance of elite athletes in the adapted swim, it is important to know and understand the synchronization in breaststroke, which is a gap in nowadays studies. This article presents two aims and in consequence, two chapters: the first was to systematically review and organize the literature about synchronization model in breaststroke on elite athletes of swimming and adapted swim and the second was a proposal for a study to determinate if the synchronization model is similar in athletes with our without disabilities.

METHODS

Search Strategy: Databases, Inclusion Criteria and Process of Selection

A systematic review of the available literature was conducted according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines. To ensure that we have enough publications, the electronic databases Web of ScienceTM Core Collection, Pubmed and Scielo were searched for relevant publications by using the keywords "swim*" and "breaststroke". Each word was associated with the terms "synchronization model", "sync*" and "elite athlete". In another search were used the words "adapted swim" and "breaststroke", other "breaststroke" and "coordination" and ("leg" or "arm" or "propulsion" or "recovery"). Finally, the keywords "handicapped" and "swimming". The publications included in the first search round met the following criteria: (1) contained relevant data concerning breaststroke; (2) were performed on elite athletes in swimming and adapted swim; (3) approach coordination in breaststroke; and (4) were written in the English language. Studies were excluded if they (1) included other styles, like butterfly, freestyle or backstroke; (2) included amateur swimmers; and (3) did contain bioenergetic variables.

Extraction of Data and Quality of the Studies

The search was done since April, 26th to June, 18th according to inclusion criteria in Web of Science, Pubmed and Scielo. The reasons why some articles were excluded were for talking about not humans, other styles like butterfly our freestyle, non-elite athletes and chronic issues with some muscles. A second analysis was made, and all disagreements were resolved by consensus.

For quantitative studies (Bosch, n.d.) have 16 items. Each quantitative study was assessed to determine whether included the following 16 items: objective (item 1), the relevance of background literature (item 2), appropriateness of the study design (item 3), the sample included (items 4 and 5), informed consent procedure (item 6), outcome measures (item 7), the validity of measures (item 8), details of the intervention procedure (item 9), significance of results (item 10), analysis (item 11), clinical importance (item 12), description of drop-outs (item 13), conclusion (item 14), practical implications (item 15) and limitations (item 16).

The outcomes per item were 1 (meets criteria), 0 (does not meet the criteria fully), or NA (not applicable).

The version of the Critical Review Forms used in this study is shown in Electronic Supplementary Material Table S1. A final score expressed as a percentage was calculated for each study. This final score corresponded to the sum of every score in a given article divided by the total number of scored items for that specific research design (16 items). Finally, the classification of the articles can be (1) low methodological quality - with a score <50%; (2) good methodological quality - score between 51 and 75%; and (3) excellent methodological quality - with a score >75%. (APPENDIX I)

To organise the results, the studies were classified into categories established according to the major research topics that emerged from the content analysis.

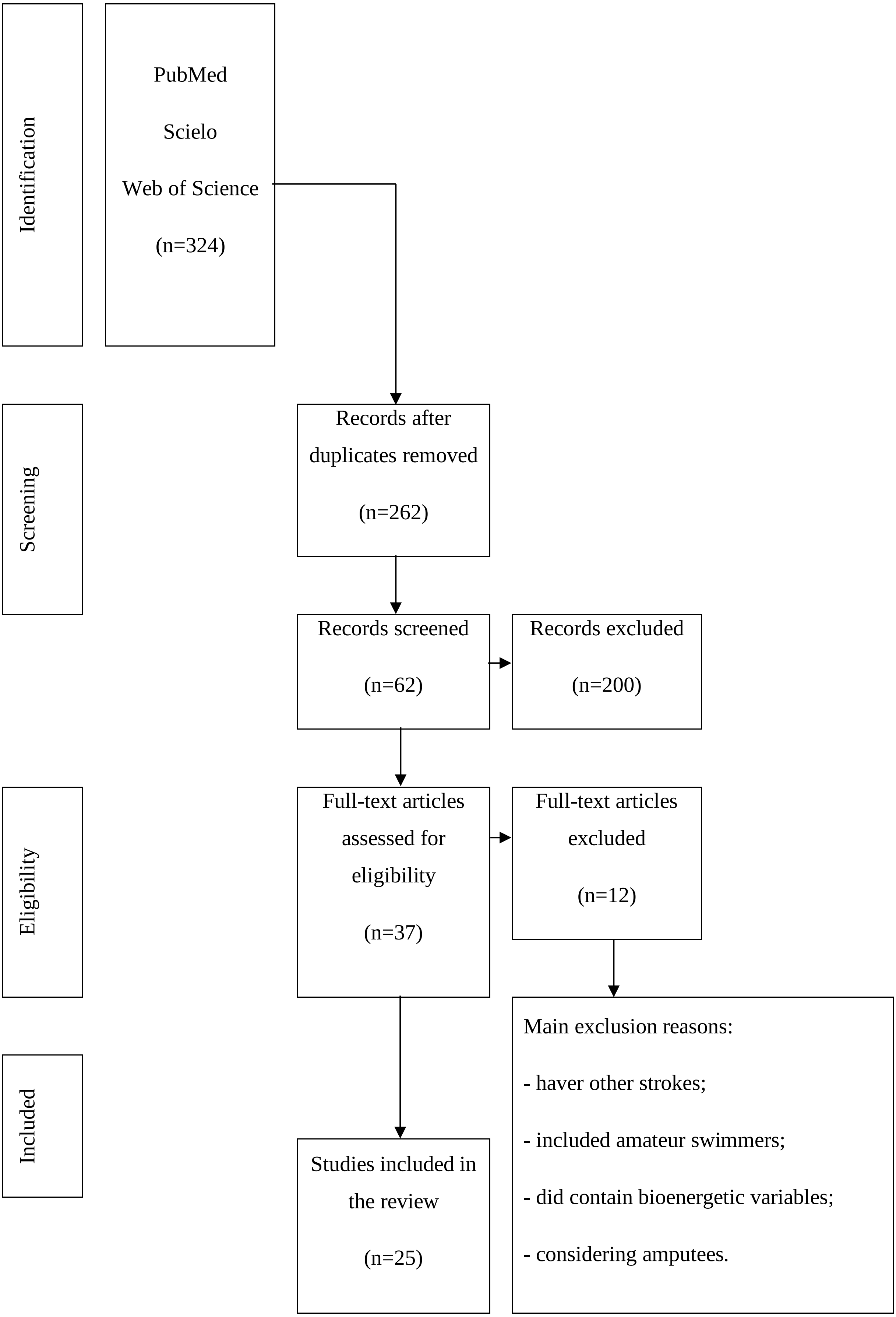
RESULTS

Search, Selection and Inclusion of Publications

The initial search identified 324 titles in the aforementioned databases. These data were then exported to reference manager software (EndNoteTM X7). Any duplicates (62 references) were eliminated either automatically or manually. The remaining 262 articles were then screened for relevance based on their title and abstract, resulting in 200 studies being eliminated from the database. The full text of the remaining 62 articles was examined in more detail; 37 were rejected because they did not meet the inclusion criteria. At the end of the screening procedure, 25 articles were selected for reading and analysis.

The chronological analysis of the articles considered in this review, published no later than the year 2000, evidenced the not so recent developments in this area of research, highlighting that about one third (36%) of the studies were published in the last 5 years (2015 to 2020).

TABLE 1 - Flow chart of the methodology used for searching papers



Quality of the Studies

Concerning the quality of studies, the results were that (1) the mean score for the 25 selected quantitative studies was 80.75%; (2) only one publication scored below 75%; (3) only five studies scored 75%; (4) fourteen publications achieved 81% and (5) five studies have 88%.

General Description of the Studies

There are several topics that involve synchronization in breaststroke, so, one of the ways to present all the studies is categorize them according to research points in breaststroke like (1) arm-leg propulsive and non-propulsive phases, synchronization and its influence on symmetry, (2) intra-cyclic variability (3) neuromuscular activation and (4) breaststroke in adapted swimmers.

Major Research Topic

1. Arm-leg propulsive and non-propulsive phases, synchronization and its influence on symmetry

The way elite athletes swim has been studied for a while in order to increase the performance (like flat and undulating define different techniques). Starting with arm and leg phases, those are decomposed in five phases for both. Propulsive and non-propulsive phases can challenge synchronization, and as we know, breaststroke makes part of symmetric strokes (like the butterfly). Three types of synchronization were described above, and the main differences as to do with the duration of the time gap between propulsive actions of arms and legs and on the swim speed.

TABLE 2 - Experimental studies about arm-leg propulsive and non-propulsive phases, synchronization and its influence on symmetry

Study	Sample	Procedure	Results	Quality score (%)
(Chollet et al., 2004)	French national and international swimmers specialized in the breaststroke (n=16); male and female who participated in this study from 1997 to 2002.	By video device, in a 25m pool, were made three trials in the breaststroke with different velocities (successively increasing) in three different distances (200m, 100m and 50m). For each swimmer, a velocity per trial was defined according to distance (called pace). The velocity that the swimmer in fact achieved was named "velocity". When "velocity" was ±2,5% of the targeted "pace", the swimmer repeated the trial. Whit a cable connected between the waist of the swimmer and an electric generator, was also possible to achieve some velocity curves.	Propulsion of the upper limbs, arm propulsion, the first part of arm recovery, arm recovery, leg propulsion, the second part of recovery and leg recovery all increased between 200 and 50m. Arm and leg glide decreased between 200 and 50m. The elbow push and leg insweep remained stable. The effective propulsion increased with each pace, effective recovery increased between 200 and 50m, and effective glide decreased with each pace while effective leg insweep remained stable.	75%

Study	Sample	Procedure	Results	Quality score (%)
(Takagi & Wilson, 2004)	Elite male and female swimmers from World Swimming Championships in 2001 swimming breaststroke.	Swimmers were analysed during World Swimming Championships (Fukuoka 2001) in lanes 4 and 5 in the preliminary, semi-final and final races of 50, 100 and 200m breaststroke events. When the same swimmer participated several times, the best performance was used.	Stroke length for shorter events was significantly shorter than for longer events. The glide phase in the arm stroke of the qualified group was significantly longer than that for the eliminated group in all events, and for leg motion, the percentage of lift and glide phase tended to be longer in the qualified group than in eliminated one. Percent of simultaneous arm-leg recovery time also increased significantly with an increase in event distance. Percent of simultaneous arm-leg propulsion time decreased significantly with an increase in event distance. Mean hip velocity during a stroke cycle was higher in qualified than eliminated group.	75%

Study	Sample	Procedure	Results	Quality score (%)
(H. Leblanc, Seifert, Baudry, & Chollet, 2005)	French swimmers (male and female) where half of the sample was with national and international level and the other half with regional level (n=40).	By video device, in a 25m pool, were made three trials in the breaststroke with different velocities (successively increasing) in three different distances (200m, 100m and 50m). For each swimmer, a velocity per trial was defined according to distance (called pace). The velocity that the swimmer in fact achieved was named "velocity". When "velocity" was ±2.5% of the targeted "pace", the swimmer repeated the trial. The order was pre-determined and a rest period of 5 minutes was observed.	In upper limbs propulsion, elite showed a longer arm outsweep and shorter arm insweep. For leg phases, insweep was longer in elite (100 and 50m) and glide phase shorter (200 and 100m). The first part of leg recovery was longer on the elite group at 200m. Longer duration at 200m for elite males in effective recovery. In all four groups velocity increased, stroke rate increased, and stroke length decreased. The duration of arm glide decreased with the increase in swimming paces in all groups. The leg recovery phase increased in both elite and non-elite females and non-elite males, but did not change in elite males. In the four groups, effective propulsion increased, and effective glide decreased. For the male group, the actual speed of elite swimmers at 200m was greater than that of non-elite swimmers at 50m.	81%

Study	Sample	Procedure	Results	Quality score (%)
(L. Seifert & Chollet, 2005)	Male and female elite French swimmers specialized in the breaststroke (n=17) that participate in this study between 1997 and 2002.	In a 25m pool, by video device, were made three trials in the breaststroke with different velocities (successively increasing) in three different distances (200m, 100m and 50m). Each pace was based on race simulation and calculated for 12.5m (between 10m and 22.5m on the pool) and started in the water when the swimmer head reach 10m time recorded until the head reached 22.5m. For each swimmer, a velocity per trial was defined according to distance (called pace). The velocity that the swimmer in fact achieved was named "velocity". When "velocity" was ±2.5% of the targeted "pace", the swimmer repeated the trial. The swimmer repeated the trial after a 4 minutes rest.	From 200 to 50m pace, both (male and female) increased their swim velocity and stroke rate. Male and female increased propulsion from the upper limbs and body propulsion. Only female increased their body recovery. For all paces combined, the male had greater leg propulsion and smaller arm glide than female. Only female, from 200 to 50m pace, increased index of flat breaststroke propulsion. Index of flat breaststroke propulsion is higher in male and particularly in sprint distances (100 and 50m).	81%

Study	Sample	Procedure	Results	Quality score (%)
(Hugues Leblanc et al., 2009)	Male swimmers (n=24) in two different groups, one from competition level and the other recreational.	Two trials of 25m, one slow, 5 minutes rest and the second sprinting. The slow pace for competitors was 400m breaststroke and their target time has to be within ±2.5%. For recreational, slow trial was about 20% over their sprint time recorded during the pre-test.	The leg glide was significantly smaller in the recreational group. The propulsion index of the recreational swimmers was significantly smaller in absolute values. Competitive and recreational swimmers significantly diminished their leg glide with the increase of speed.	81%
(L. Seifert & Chollet, 2009)	Elite male swimmers (n=48) work in four different groups representing a stroke speciality.	Four trials of 25m in their speciality at successively increasing speed (400m, 200m, 100m and 50m events) with 4 minutes rest between each trial. There was no breathing, except in breaststroke. The trial was repeated if the target speed race wasn't ±2.5% than expected.	With increased paces, swimmers of each stroke decreased the time gaps (total time gap and index of coordination) between the propulsive phases. In breaststroke, the decrease in total time gap resulted from the decrease in T1 and T3 from the 400 to the 50m.	81%

Study	Sample	Procedure	Results	Quality score (%)
(Ludovic Seifert et al., 2010)	Female swimmers (n=24) separated into two groups according to their performance level (recreational and competitive).	Before the trials, recreational swimmers swam a preliminary trial to establish their performance levels. Competitors performance was based in their best competitive times in the current season. In two different velocities (maximal speed and 80% of the maximal speed), two trials of 25m with 5 minutes rest. They must swim within ±5% of their target time our try again.	In the two speeds, the mean continuous relative phase of the recreational swimmers was close to the in-phase mode. The maximum value of the continuous relative phase significantly decreased between the slow and maximal speeds. The synchronization differences between groups and between speeds resulted from differences in the angles and angular velocities of the elbow and knee, which led to differences in the phases.	81%
(Jaszczak, 2011)	Male university students (n=24) separated into two groups according to leg performance (symmetric or asymmetric).	In a 25m long pool, the participants swam 15m twice at maximal speed in breaststroke. In the first trial the complete movement of breaststroke, in the second trial only arms.	Asymmetry leg movements resulted in an increase of hand movement asymmetry. Only in the group performing incorrect lower limb movement existed statistically significant differences in upper limb movement asymmetry between the two types of swimming.	81%

Study	Sample	Procedure	Results	Quality score (%)
(L Seifert et al., 2011)	Female and male swimmers (n=48) were separated into two groups according to significant differences in their performance level and swimming skills in breaststroke.	One week prior to the experimental trial, the participants swam a breaststroke trial to establish their maximal speed during a 50m swim. The experimental trial consisted of swimming 25m at 80% of the maximal speed. The swimmers were asked to swim within ±5% of their targeted time. If this was not accomplished, the subject had to repeat the trial.	The competitive swimmers had higher speed and stroke length, but similar stroke rate comparing to recreational swimmers. Significantly greater standard deviation of the continuous relative phase curves for the recreational group than within the competitive group.	75%

Study	Sample	Procedure	Results	Quality score (%)
(Ludovic Seifert et al., 2014)	National level breaststroke swimmers (n=7).	In a 50m indoor pool, swimmers had three trials (with 5 minutes rest between each one) of 200m at 70% of the maximal speed (after a warm-up). First trial the synchronization was to their own way, second and third in “maximal glide” and “minimal glide” combined.	There were differences in stroke rate and stroke length between the three synchronization conditions. In the “maximal glide” shorter relative duration of the legs propulsion was observed, so the end of the legs extension occurred earlier in the cycle than in the other conditions. In the “minimal glide” condition, higher mean trunk inclination with a higher minimal angle value of inclination was observed. In the ‘minimal glide’ too, the swimmers increase the relative duration of leg extension without providing higher instantaneous velocity and acceleration of the centre of mass. The energy cost was significantly higher in ‘maximal glide’ than in the two other conditions.	81%

Study	Sample	Procedure	Results	Quality score (%)
(Strzała et al., 2014)	Male swimmers (n=27) specialized in the breaststroke in regional, national or international level.	The participants swim 100m breaststroke race performed in a 25m swimming pool.	Those athletes with a moderate statistically significant impact on the results of velocity during 100m breaststroke were the stroke length indices, while total body length was associated with borderline statistical significance, but with similar strength. Phase separation of the propulsive and non-propulsive arms and leg movement in each cycle allowed to check the influence on the breaststroke surface swimming speed. The result of 100m breaststroke velocity had a significant relation to a portion of the insweep phase.	87%

Study	Sample	Procedure	Results	Quality score (%)
(Staniak & Pastuszak, 2016)	Male elite athletes from Poland national team (n=5).	In a 50m swimming pool, trials were made at submaximal intensity typical of the current practice. The measurement was repeated three times by one athlete, twice by another one, and performed only once by remaining three swimmers (total of 8 trials) because of the absence of the athletes on the next training national team camps.	Characteristic values of the profile regarding the vertical acceleration and angular velocity of pelvic girdle inclination occur within neighbouring characteristic parts of the cycle.	87%

Study	Sample	Procedure	Results	Quality score (%)
(Oxford, James, Price, Payton, & Duncan, 2017)	Competitive specialist breaststroke swimmers (n=26).	After an 800m warm-up in a 25m pool, were made 100m breaststroke. Every athlete was marked on both sides of the body with chloride electrical tape.	Over the four laps, males had significantly higher swim velocity than females. The mean stroke length over the four laps showed significant correlation with average swim velocity. Some participants utilised the overlap coordination technique others utilised glide coordination technique and last group started with the glide coordination technique but changed to the overlap coordination between the 1st and the 4th lap. For the last group, that changed from the glide to the overlap coordination technique, 3 participants altered their synchronization on the final lap, and the other participant changed their synchronization technique on the second lap.	75%

Study	Sample	Procedure	Results	Quality score (%)
(M. Strzala et al., 2017)	Male swimmers from two university swimming clubs (n=34) specialized in breaststroke.	In a 25m swimming pool, within the water start and automatic equipment of timing device, each participant swam 50m breaststroke in speed test.	The change of downward rotation curve related to the upward rotation of swimmer's sacrum during the upper move and inhale action following it was noticeable. Partial correlations between breaststroke cycle synchronization indices arm propulsion, arm recovery, glide or overlap, total time gap and velocity during 50m surface breast were significant and on the average level. The arm-leg lag correlated significantly positively with the minimal values of both longitudinal deceleration and downward rotation.	81%

The main results have shown that, according to different topics.

About arm and leg phases: Propulsion of the upper limbs, arm propulsion, arm recovery, leg propulsion, the second part of recovery and leg recovery all increased between 200 and 50m. However, the leg recovery phase did not change in elite males. Arm and leg glide decreased between 200 and 50m. The glide phase in the arm stroke of the qualified group for final was significantly longer for the eliminated group in all events. In the “minimal glide” condition, higher mean trunk inclination with a higher minimal angle value of inclination were observed. For leg phases, insweep was longer in elite (100 and 50m) and glide phase shorter (200 and 100m). The first part of leg recovery was longer on the elite group at 200m. In the “maximal glide” shorter relative duration of the leg’s propulsion was observed. In the ‘minimal glide’ too, the swimmers increase the relative duration of leg extension without providing higher instantaneous velocity and acceleration of the centre of mass. Only female increased their body recovery.

In propulsive and non-propulsive phases: For upper limbs propulsion, elite showed a longer arm outsweep and shorter arm insweep and male and female increased propulsion for all body. About leg propulsion, for all paces combined, the male had greater leg propulsion and smaller arm glide than female. Phase separation of the propulsive and non-propulsive arms and leg movement in each cycle allowed to check the influence on the breaststroke surface swimming speed.

About time gaps: Swimmers decreased the time gaps (total time gap and index of synchronization) between the propulsive phases.

For synchronization: Percent of simultaneous arm-leg recovery time increased propulsion decreased with an increase in event distance. Some participants utilised the overlap coordination technique others utilised glide coordination technique and last group started with the glide coordination technique but changed to the overlap coordination between the 1st and the 4th lap. The synchronization differences between groups and between speeds resulted from differences in the angles and angular velocities of the elbow and knee. Only in the group performing incorrect lower limb movement existed statistically significant differences in upper limb movement asymmetry between the two types of swimming. Asymmetry leg movements resulted in an increase of hand movement asymmetry. And, there were differences in stroke rate and stroke length between the three synchronization conditions.

In velocity: From 200 to 50m pace, both (male and female) increased their swim velocity and stroke rate. Only female, from 200 to 50m pace, increased index of flat breaststroke propulsion. For males, the actual speed of elite swimmers at 200m was greater than that of non-elite swimmers at 50m and over the laps, they had significantly higher swim velocity. The arm-leg lag correlated significantly positively with the minimal values of both longitudinal deceleration and downward rotation. The mean stroke length over the laps showed significant correlation with average swim velocity. In all groups velocity increased, stroke rate increased, and stroke length decreased. Index of flat breaststroke propulsion is higher in male and particularly in sprint distances (100 and 50m).

Finally, the energy cost was significantly higher in “maximal glide” than in the two other conditions.

2. Intra-cyclic variability

Is known that a constant velocity isn’t possible in swimming strokes, so intra-cyclic velocity must be reduced as much as the athletes can, so they can raise the performance level.

The horizontal velocity is the result of the balance between propulsive force and resistance, so when decreased, can lead to increasing of velocity and a higher energetic cost.

TABLE 3 - Experimental studies about intra-cyclic variability

Study	Sample	Procedure	Results	Quality score (%)
(Ludovic Seifert, Tourny, & Didier, 2007)	Trained male swimmers (n=18) some were national and other regional swimmers.	After a warm-up, each swimmer swam 3 trials of 25m in a pool with also 25m. Between each trial, 2 minutes were given to rest. Each trial was self-paced based on the 200-m, the 100-m and the 50-m race paces, respectively.	For all swimmers, a difference was found for the absolute values of distance covered during the leg-arm lag phase, which became shorter from the 200m to the 50m pace. Differences were found for the acceleration-deceleration time ratio of elite swimmers, which was greater at 50m than at 100 and 200. Elite swimmers covered a greater distance during the arm propulsive phase, and this was significant at the 200m and 100m paces. The index of velocity fluctuation and the acceleration-deceleration time ratio was higher in elite swimmers.	81%

Study	Sample	Procedure	Results	Quality score (%)
(Colman et al., 2010)	International level swimmers were examined (n=45), two groups of women and two groups of men were identified, those using the most undulating and those using the flattest style.	A video was recorded during 25m breaststroke swim with a 100m competitive pace.	In the flattest style, the maximum and minimum velocity of the body's centre of mass differed by 76% from the mean swimming velocity and, in the most undulating style, by only 53%. In the most undulating style, these two extreme mass centre velocity peaks were eliminated during backward and forward trunk rotation. During body waving, a relatively high centre of mass velocity could be maintained.	87%
(T. M. Barbosa et al., 2013)	Young swimmers from regional and national levels (n=45).	After a 1500m warm-up, each swimmer undertook a set of maximal 4 trials of 25m (freestyle, backstroke, breaststroke and butterfly stroke) swims with an underwater start. Data collection was made between 11 and 24m.	The intraciclic velocity variation was higher in the breaststroke, followed by the butterfly, the backstroke and the freestyle.	81%

Study	Sample	Procedure	Results	Quality score (%)
(Marek Strzala et al., 2013)	Male swimmers specialized in the breaststroke (n=23) from the regional and national level.	After a warm-up, the all-out swimming 50m breaststroke speed test was carried out in a 25m swimming pool with similar conditions as in a competition.	The index of glide or overlap was significantly positively associated with the velocity at 50m surface breast. The positive interplay between the two synchronization indices and the percentage of total leg phase and the negative interplay to the total leg recovery was noted.	81%

Study	Sample	Procedure	Results	Quality score (%)
(Van Houwelingen, Roerdink, Huibers, Evers, & Beek, 2017)	Male and female swimmers competing at the Dutch regional level or higher (n=26).	The experiment was performed in the 50 m indoor training pool As a baseline test, participants were instructed to swim 50 m breaststroke at 70% of their maximal velocity After the warm-up participants were instructed to swim 10 trials of 50m breaststroke at a constant speed corresponding to 70% of the maximal velocity. Five different phase relations. Each phase relation was imposed twice in succession.	The velocity profile is clearly affected by phase relations, and therewith leg and arm propulsion and phase relation. Intra-individual standard deviation revealed that was significantly larger for phase relation in 90º. Post-hoc tests showed that intra-cyclic velocity variability for phase relation = 225 and 270˚ were significantly higher than 90˚, 135˚ and 180˚. The post-hoc test showed that the rate of perceived exertion for the phase relation equal to 90˚ condition compared to 180˚ and 90˚ compared to 225˚ were significantly different from each other.	81%

For different phases in breaststroke: Elite swimmers covered a greater distance during the arm propulsive phase. The positive interplay between the two synchronization indices and the percentage of leg phase and the negative interplay to the total leg recovery was noted. About velocity profile, is clearly affected by phase relations, and therewith leg and arm propulsion and phase relation. The index of glide or overlap was significantly positively associated with the velocity at 50m surface breast. The post-hoc test showed that the rate of perceived exertion for the phase relation equal to 90˚ condition compared to 180˚ and 90˚ compared to 225˚ were significantly different from each other.

About velocity: Differences were found for the acceleration-deceleration time ratio of elite swimmers, which was greater at 50m than at 100 and 200. The index of velocity fluctuation and the acceleration-deceleration time ratio was higher in elite swimmers. And the intraciclic velocity variation was higher in the breaststroke, followed by the butterfly, the backstroke and the freestyle.

About centre of mass: In the flattest style, the maximum and minimum velocity of the body's centre of mass differed by 76% from the mean swimming velocity and, in the most undulating style, by only 53%. And in the most undulating style, these two extreme mass centre velocity peaks were eliminated during backward and forward trunk rotation.

3. Neuromuscular activation

The muscle activation pattern of a movement in swimming is a very important element to maintain high-intensity work to providing the working muscles with enough energy. For that reason, several studies include muscle activation in breaststroke swimmers. But, in the end, every swimmer adapts his own motor and neuromuscular characteristics to is a unique way of swimming.

TABLE 4 - Experimental studies about neuromuscular activation

Study	Sample	Procedure	Results	Quality score (%)
(Vaz et al., 2016)	Male and female swimmers (n=16) beginners and elite athletes participated in this study.	After a 15 min warm-up, participants performed 25m breaststroke at 100% of maximal effort. Participants started swimming in the water with a push off from the wall This study was made in a 25m indoor pool.	When considering the lag time, a significant negative shift was observed in four muscles in beginners compared to elite swimmers. Three or four muscle synergies were identified in all swimmers. The difference between populations was not significantly higher than the variability within the beginners. Regarding the lag time, a significant negative shift was observed in synergy 2 (that involves upper limb muscles and is activated during the lower limb recovery phase) in beginners compared to elite.	87%

Study	Sample	Procedure	Results	Quality score (%)
(Bjørn Harald Olstad et al., 2017)	Elite breaststroke swimmers (n=9) including world-class.	Every swimmer had 8 anatomical markers attached to the body. They swam 25m of breaststroke at 60%, 80% and 100% effort.	Was found a decreased in duration and distance during the knee extended phase and an increase in velocity with increased effort. The knee angle at the beginning of the knee extension decreased with increasing effort and different knee angle patterns. The main muscular activation was found during the phase where the muscles acted as prime movers in order to generate propulsion. Before the ankle started going into plantar flexion, was found a high coactivation between the gastrocnemius and tibialis a.	87%

Study	Sample	Procedure	Results	Quality score (%)
(B. H. Olstad et al., 2017)	World class and national level breaststroke swimmers (n=8).	In a 25m long pool, isometric maximal voluntary contractions were made for each one of the 8 muscles. After a 15 minutes warm-up, were made 3 trials of maximal isometric force and hold for 5 seconds and 45 of recovery in some standardized exercises.	World-class spent less time during the leg recovery, began this phase with a smaller knee angle and had a higher median velocity during the leg glide. Compared to the national elite, world-class swimmers showed a difference in the muscular activation patterns for all eight muscles.	81%
(T. Barbosa et al., 2019)	National male swimmers (n=5).	Trials were made in a 50m indoor pool after an 800m warm-up. They consisted on 200m in maximal breaststroke.	The neuromuscular pattern revealed that by the average rectified value the biceps brachii and triceps brachii were increased at the end of the test for some swimmers, while, for others, biceps brachii, deltoid anterior and pectoralis major were increased. Different motor patterns were observed between cycles and swimmers.	81%

A summary of these studies talks about different topics.

For phases of arm-leg breaststroke swim: A significant decrease in duration and distance was found during the knee extended phase and an increase in velocity with increased effort. Still talking about the knee, the angle at the beginning of the knee extension decreased with increasing effort and different knee angle patterns. The main muscular activation was found during the phase where the muscles acted as prime movers in order to generate propulsion. Regarding the lag time, a significant negative shift was observed in synergy, that involves upper limb muscles and is activated during the lower limb recovery phase, in beginners compared to elite. World-class spent less time during the leg recovery, began this phase with a smaller knee angle and had a higher median velocity during the leg glide.

About muscles: Three or four muscle synergies were identified in all swimmers. Compared to the national elite, world-class swimmers showed a difference in the muscular activation patterns for all eight muscles. When considering the lag time, a significant negative shift was observed in four muscles in beginners compared to elite swimmers.

Specifically, in some muscles: Before the ankle started going into plantar flexion, was found a high coactivation between the gastrocnemius and tibialis anterior. And, the neuromuscular pattern revealed that by the average rectified value the biceps brachii and triceps brachii were increased at the end of the test for some swimmers, while, for others, biceps brachii, deltoid anterior and pectoralis major were increased.

For different athletes: The difference between populations was not significantly higher than the variability within the beginners and were observed different motor patterns between cycles and swimmers.

4. Breaststroke in adapted swimmers

Breaststroke in adapted swimmers with mental disabilities is a challenge because the motor and psychomotor dysfunctions are greater and deeper their IQ is, in this case, the studies presented below are from Down Syndrome (DS) and Autism Spectrum Disorders (ASD).

When it comes to elite, breaststroke (SB) show different disabilities classified into three groups, were the lower the number, the greater impact on performance. Several disabilities mean different functional classifications and different associated problems, like the passive drag, anthropometrical measurements and bodies with and without disabilities.

TABLE 5 - Experimental studies about breaststroke in adapted swimmers

Study	Sample	Procedure	Results	Quality score (%)
(Balan & Shaao, 2014)	Young people from with Down Syndrome (n=2)	International Special Olympics propose progression items that were evaluated four in four lessons for eight-months, where they should swim breaststroke correctly breaststroke (respecting arms, kicks and breath synchronization).	Different results for each participant: One started with a very good level of leg synchronization and fulfilled the items until four months of lessons. The other, initiate with a very low level of synchronization, the movement of arms wasn't correct until the end of experimental tests, but after twenty-five weeks he did the specific intersegmental synchronization.	69%
(Hogarth et al., 2020)	Male Para swimmers with limb deficiency (n=174)	Trials of 50, 100 and 400m freestyle, 100m backstroke, 100m butterfly and 100m breaststroke according to limb deficiency and swimming performance.	Higher importance of the thigh and shank in the 100m breaststroke compared with other swim strokes confirms the separate SB class.	75%

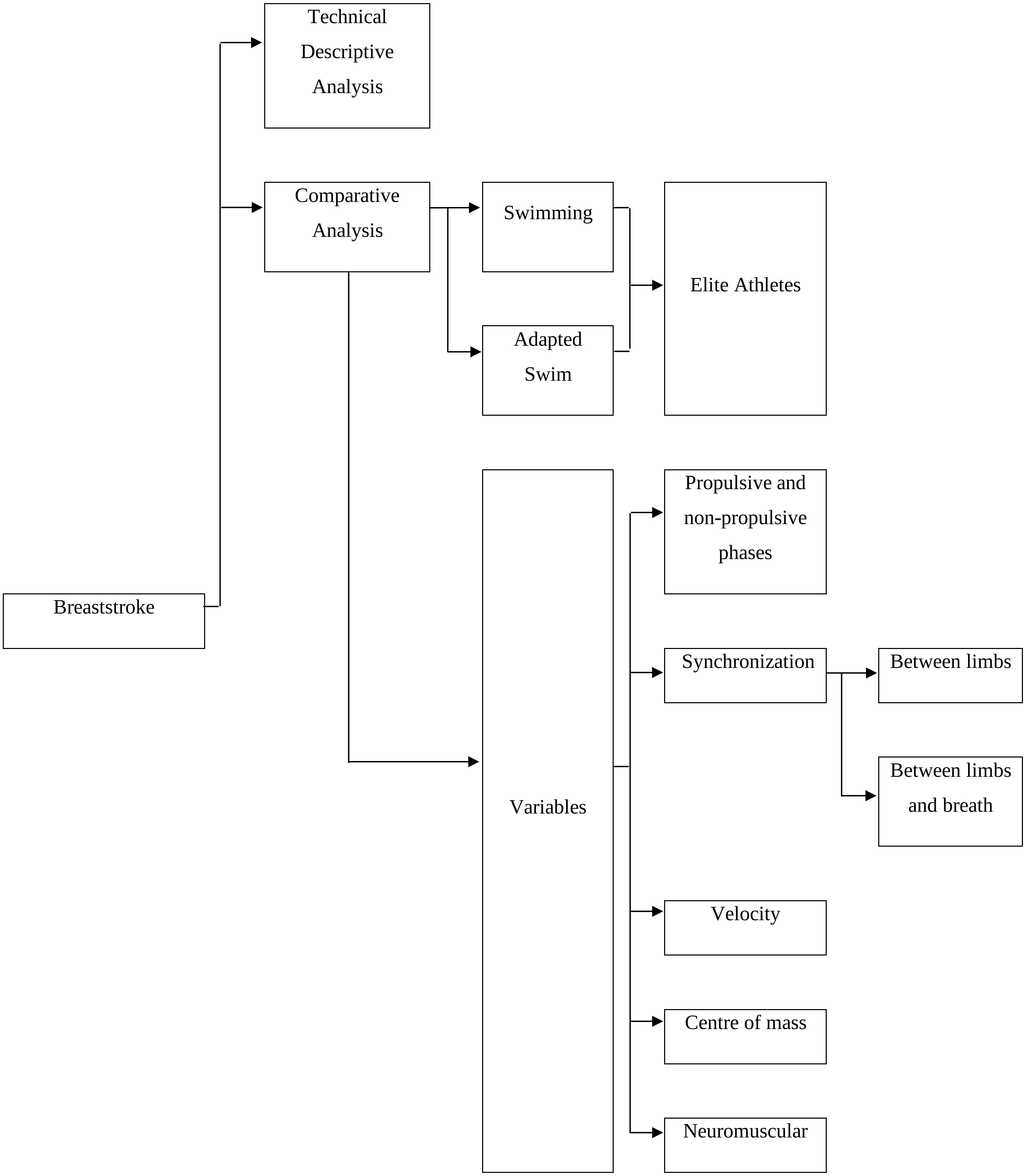
Particularly for breaststroke, predictions that were made in the second study were lower, and prediction error greater. Considering the influence of arms action, the most dissimilar performance was found when comparing breaststroke with backstroke and butterfly. There is a similar or even a superior speed in legs comparing with arms, so, legs might be more propulsive according to the orientation of the several segments. Higher importance of the thigh and shank in the 100m breaststroke compared with other swim strokes.

On the other hand, synchronization and intersegmental synchronization in breaststroke is possible, in more or less time according to different factors, physical, mental, availability for practice or things that don't depend on the participant.

DISCUSSION

The aim of this study was to systematically review the synchronization model in breaststroke on elite athletes of swimming and adapted swim with papers from 2004 to 2020. After the analysis, there are several topics that will be debated next.

TABLE 6 - Topics for analyses



1. Arm-leg propulsive and non-propulsive phases, synchronization and its influence on symmetry

1.1. Propulsive and non-propulsive arm-leg phases

There are several studies that were revised in this topic that are similar in procedure, which helps the discussion and results agree.

For all swimmers, a difference was found for the values of distance covered during the leg-arm leg phase, which became shorter from the 200m to the 50m pace for Ludovic Seifert et al. (2007). At the same time, Strzała et al. (2014) talks about phase separation of the propulsive and non-propulsive arms and leg movement in each cycle, which allowed to check the influence on the breaststroke surface swimming speed.

About upper limbs, the propulsion increased between 200 and 50m by Chollet et al. (2004) and for male and female by H. Leblanc et al. (2005). On elite athletes, they showed a longer arm outsweep and shorter arm inswee in. H. Leblanc et al. (2005) and covered a greater distance during the arm propulsive phase, which was significant at the 200m and 100m paces in Ludovic Seifert et al. (2007).

On leg propulsion, Chollet et al. (2004) prove that increased between 200 and 50m and L. Seifert & Chollet (2005) shows that male had greater leg propulsion, for all paces combined.

The percentage of the simultaneous arm-leg propulsion time decreased significantly with an increase in event distance for Takagi & Wilson (2004) and for L. Seifert & Chollet (2009) with increased paces, swimmers of each stroke decreased the time gaps (total time gap and index of synchronization) between the propulsive phases. The propulsion index of the recreational swimmers was significantly smaller in absolute values, says Hugues Leblanc et al. (2009).

Only female, from 200 to 50m pace, increased index of flat breaststroke propulsion that is higher in male and particularly in sprint distances (100 and 50m) says L. Seifert & Chollet (2005).

When it comes to arm-leg recovery, the percent of simultaneous time also increased significantly with an increase in event distance for Takagi & Wilson (2004) but only female increased their body recovery for H. Leblanc et al. (2005).

Arm recovery (including mainly the first part of arm recovery), increased between 200 and 50m for Chollet et al. (2004).

In Chollet et al. (2004) leg recovery increased between 200 and 50m. First part of leg recovery was longer on the elite group at 200m and increased in both elite and non-elite females and non-elite males, but did not change in elite males for H. Leblanc et al. (2005). For the recreational group, they spent a significantly longer time performing its leg recovery according to Hugues Leblanc et al. (2009).

Arm glide decreased between 200 and 50m for Chollet et al. (2004). On qualified group was significantly longer than that for the eliminated group in all events according to Takagi & Wilson (2004). According to H. Leblanc et al. (2005) the duration of arm glide decreased with the increase of swimming paces in all groups. For all paces combined, the male had smaller arm glide than female for L. Seifert & Chollet (2005).

According to Chollet et al. (2004), leg glide decreased between 200 and 50m. Was shorter in elite (for 200 and 100m) for H. Leblanc et al. (2005) and significantly smaller in the recreational group for Hugues Leblanc et al. (2009).

Takagi & Wilson (2004) says that the percentage of lift and glide phase tended to be longer in the qualified group than in eliminated one. And the shorter relative duration of the leg propulsion was observed, so the end of the legs extension occurred earlier in the cycle than in the other conditions for Ludovic Seifert et al. (2014). For competitive and recreational swimmers significantly diminished their leg glide with the increase of speed according to Hugues Leblanc et al. (2009).

Leg insweep remained stable in this study from Chollet et al. (2004) but for H. Leblanc et al. (2005), insweep was longer in the elite.

The effective propulsion and glide increased with each pace for Chollet et al. (2004) and H. Leblanc et al. (2005) and effective recovery increased between 200 and 50m only according to Chollet et al. (2004).

For three coordination conditions Ludovic Seifert et al. (2014) found differences in stroke rate and stroke length. On the other hand Takagi & Wilson (2004) shows that stroke length for shorter events, was significantly shorter than for longer events.

Asymmetry leg movements resulted in an increase of hand movement asymmetry. Only in the group performing incorrect lower limb movement existed statistically significant differences in upper limb movement asymmetry between the two types of swimming according to Jaszczak (2011).

1.2. Synchronization and velocity

Over the laps, Oxford et al. (2017) prove that males had significantly higher swim velocity than females and (H. Leblanc et al. (2005) that male and female increased their swim velocity and stroke rate, from 200 to 50m pace.

The result of 100m breaststroke velocity had a significant relation to a portion of the insweep phase according to Strzała et al. (2014). On the other hand, Strzała et al. (2014) also says that those athletes with a moderate statistically significant impact on the results of velocity during 100m breaststroke were that showed the stroke length indices, while total body length was associated with borderline statistical significance, but with similar strength.

About different groups in performance, mean hip velocity during a stroke cycle was higher in qualified than eliminated group for Takagi & Wilson (2004), the competitive swimmers had higher speed and stroke length, but similar stroke rate comparing to recreational swimmers for Seifert (2011) and in two speeds, the mean continuous relative phase of the recreational swimmers was close to the in-phase mode for Ludovic Seifert et al. (2010). In several of those groups, velocity increased, stroke rate increased, and stroke length decreased considering H. Leblanc et al. (2005). Considering only males, also H. Leblanc et al. (2005) says that the actual speed of elite swimmers at 200m was greater than that of non-elite swimmers at 50m.

About vertical acceleration and angular velocity of pelvic girdle inclination Staniak & Pastuszak (2016) prove that occur within neighbouring characteristic parts of the cycle. Finally Ludovic Seifert et al. (2010) shows that the maximum value of the continuous relative phase significantly decreased between the slow and maximal speeds.

When the concern is the synchronization, M. Strzala et al. (2017) says that partial correlations between breaststroke cycle synchronization indices arm propulsion, arm recovery, glide or overlap, total time gap and velocity during 50m surface breast were significant and on the average level. And Ludovic Seifert et al. (2010) shows that synchronization differences between groups and between speeds resulted from differences in the angles and angular velocities of the elbow and knee, which led to differences in the phases.

In another study from Oxford et al. (2017), some participants utilised different coordination techniques, and one group that changed from the glide to the overlap coordination technique, 3 participants altered their synchronization on the final lap and the other participant changed their synchronization technique on the 2nd lap.

About energy cost, that was significantly higher in ‘maximal glide’ than in the two other conditions according to Ludovic Seifert et al. (2014).

2. Intra-cyclic variability

2.1. Centre of mass and synchronization

For the centre of mass, Colman et al (2010) studied body waving, where she proves a relatively high centre of mass velocity could be maintained and in the most undulating style, two extreme mass centre velocity peaks were eliminated during backward and forward trunk rotation.

According to Marek Strzala et al. (2013), when the concern is the synchronization, exist a positive interplay between the two synchronization indices and the percentage of total leg phase and the negative interplay to the total leg recovery.

2.2. Velocity

Some tests made for Van Houwelingen et al. (2017) showed that intra-cyclic velocity variability for phase relation = 225 and 270˚ were significantly higher than 90˚, 135˚ and 180˚.

Differences were found for the acceleration-deceleration time ratio of elite swimmers, which was greater at 50m than at 100 and 200 from Ludovic Seifert et al. (2007).

Van Houwelingen et al. (2017) concluded that, the velocity profile is clearly affected by phase relations, and therewith leg and arm propulsion and phase relation.

The horizontal velocity was higher in the breaststroke, followed by the butterfly, the backstroke and the freestyle according to T. M. Barbosa et al. (2013). Also higher (in elite swimmers) were the index of velocity fluctuation and the acceleration-deceleration time ratio for Ludovic Seifert et al. (2007).

About flattest style, Colman et al. (2010) shows the maximum and minimum velocity of the body's centre of mass differed by 76% from the mean swimming velocity and, in the most undulating style, by only 53%.

3. Neuromuscular activation

3.1. Arm-leg breaststroke phases

Bjørn Harald Olstad et al. (2017) considered the main muscular activation was found during the phase where the muscles acted as prime movers in order to generate propulsion.

A significant decrease in duration and distance was found during the knee extended phase and a significant increase in velocity with increased effort and before the ankle started going into plantar flexion, was found a high coactivation between the gastrocnemius and tibialis anterior.

When considering the lag time, Vaz et al. (2016) found a significant negative shift in four muscles in beginners compared to elite swimmers. Was also observed, this time for B. H. Olstad et al. (2017), the synergy that involves upper limb muscles and is activated during the lower limb recovery phase in beginners compared to elite. World-class spent less time during the leg recovery, began this phase with a smaller knee angle and had a higher median velocity during the leg glide.

3.2. Muscles

The neuromuscular pattern revealed that by the average rectified value the biceps brachii and triceps brachii were increased at the end of the test for some swimmers, while, for others, biceps brachii, deltoid anterior and pectoralis major were increased for T. Barbosa et al. (2019) also observed different motor patterns between cycles and swimmers.

Three or four muscle synergies were identified in all swimmers in Vaz et al. (2016) study.

Compared to the national elite, world-class swimmers showed a difference in the muscular activation patterns for all muscles studied by B. H. Olstad et al. (2017).

4. Breaststroke in adapted swimmers

Considering the influence of arms, the most dissimilar performance was found when comparing breaststroke with backstroke and butterfly. There is a similar or superior speed in legs comparing with arms, so, legs might be more propulsive according to the orientation of the several segments. Therefore, in most cases, the swimmer reaches a greater speed at the end of the propulsive phase of the legs, which can vary in two ways: in the flat breaststroke the athletes spend more time sliding and in the undulating breaststroke the stroke raises the body to reach enough depth to increase propulsion.

Another conclusion was that higher importance of the thigh and leg in the 100m breaststroke compared with other swim strokes. When participants start learning breaststroke, the propelling phases of the legs and arms happen practically simultaneously, which reduces speed, the level of synchronization between segments and with breathing. Who started the study with greater synchronization capacity in the lower limb, more easily managed to develop the remaining motor skills to achieve the correct swim.

Limitations and recommendations for future research

This research was made to identify and systematize the synchronization model in elite swimmers and adapted swim. So, the research had her base on Web of ScienceTM Core Collection, Pubmed and Scielo, which can be a limitation not to use other platforms. The biggest limitation was not to find many articles about the adapted swim in breaststroke, that is a huge gap for this sport. That takes us to recommend for the future, the use of experimental works about synchronization in swimmers, for different disabilities and including breaststroke more specifically.

CHAPTER II. EXPERIMENTAL STUDY

INTRODUCTION

After long research, it was expected that we could put some of the knowledge on an experimental study. But we faced a brand-new challenge during 2020 that makes the whole world stop for a while, and all the contact we have with each other was limited to digital platforms. With that said, all sport stopped, society calmed down the pace and people with disabilities (as well as other groups considered at risk) remained even more protected.

According to the American Psychiatric Association (APA, 2018) ASD is "a complex developmental condition that involves persistent challenges in social interaction, speech and non-verbal communication, and restricted/repetitive behaviours "that affects 1 in 160 children. Taking into account the World Health Organization (WHO, 2016) "individuals with ASD often have other concomitant conditions, including epilepsy, depression, anxiety and attention deficit hyperactivity syndrome". Reinforcing that "the level of intellectual functioning in these individuals is extremely variable, extending from a deep commitment to higher levels".

Having Isenhower et al. (2012) has an example, he starts his study about bimanual synchronization in children with ASD saying that "bimanual coordination, the spatio-temporal locking of two limbs in the service of behaviour, is utilized in many daily life skills and is recruited for more complex motor behaviours". That type of synchronization, studied from clapping, circle drawing and drumming (and others) and separated in in-phase and anti-phase, isn't must be studied in people with ASD. Behavioural deficits of autism and interlimb synchronization is well understood and central to motor behaviour, but not in rhythmic interlimb synchronization.

What that study proves is that children with ASD are less able to maintain the required phase, typically developing children spend more time in anti-phase than children with autism and tend to speed up and slow down more within a trial.

So, this study should include the next topics in a way to have experimental tasks to find out if, in perform, there is a comparative analysis of the breaststroke model presented by the athletes in the sample in relation to elite athletes referred to in the existing literature.

METHODS

For all the sample should be collected the anthropometric measurements, of body composition and physical evaluation tests, in order to have their characteristics. That evaluation could be done on the integrated lab of Faculdade de Ciências do Desporto e Educação Física (FCDEF).

Posteriorly and in the practice pool of the sample, should be performed 2 repetitions of 25 meters in breaststroke at maximal velocity, with video registry to analyse the synchronization adapted model.

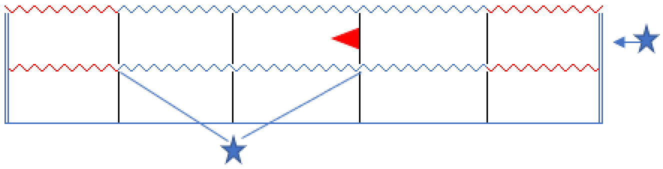


FIGURE 3 - Study design

FIGURE 4 - Time gaps of arm and leg phases (Chollet et al., 2004)**FIGURE 5 -** Study design

Description and selection of the sample

The final sample should be chosen after the anterior authorization from the institution and the respective guardians of all athletes in the study.

FIGURE 6 - Time gaps of arm and leg phases (Chollet et al., 2004)**FIGURE 7 -** Study design

On this study, we assume that, based on recruitment of swimming team with 7 athletes (5 males and 2 females) in S17 (autism spectrum disorders) of the adapted swim, where all athletes share the same environment and submitted to the same practice process.

FIGURE 8 - Time gaps of arm and leg phases (Chollet et al., 2004)**FIGURE 9 -** Study design

Has inclusion criteria should be made the next points:

- Minimal experience of 2 years;
- Have participated in at least 5 competitions in the previous season;
- Do not show any physical or disease-related limitations for swimming.

FIGURE 10 - Time gaps of arm and leg phases (Chollet et al., 2004)**FIGURE 11 -** Study design

For the purpose of characterization, the subjects composing the sample should collect anthropometric measurements, body composition and condition assessment tests carried out in FCDEF integrated lab.

FIGURE 12 - Time gaps of arm and leg phases (Chollet et al., 2004)**FIGURE 13 -** Study design

The study was submitted for prior approval by FCDEF ethics committee. All participants and their legal guardians should give free and informed consent, in compliance with the Helsinki Declaration and the Oviedo Convention.

FIGURE 14 - Time gaps of arm and leg phases (Chollet et al., 2004)**FIGURE 15 -** Study design

FIGURE 16 - Time gaps of arm and leg phases (Chollet et al., 2004)**FIGURE 17 -** Study design

Breaststroke swim protocol

In the usual training environment and pool, a swimming protocol should be performed using the breaststroke technique at maximum speed, with video recording for later analysis of the behaviour of the kinematic variables and the synchronization model adopted.

The swimming protocol consists of a 2 x 25-meter race at maximum speed in the breaststroke technique, with video recording, in a pool of official dimensions of 25 meters.

Two underwater chambers were placed, the first orthogonally between 10 and 20 meters and the second in the frontal plane to the displacement.

The swimmer performs the protocol on track 2 (so that the side chamber can cover a delimited 10-meter course) where the beginning and end should be counted from the movement of the head so that the beginning and end of each cycle is evident. For the analysis of the coordinative model, the propulsive mechanics performed in the 10 central meters was considered with the main objective of identifying the synchronization pattern of lower and upper limbs in breaststroke technique.

The objective should be to perform a comparative analysis of the model presented by the athletes in the sample in relation to elite athletes referred to in the existing literature. Scientific articles of swimming should be used, with relevance for those based on the kinetic and kinematic evaluation of elite athletes specialized in the breaststroke technique, in order to decipher the similarities and differences between the two groups.

Definition and procedure that should be adopted to recall and treat the variables in the study

1. Anthropometric characterization

The procedures for obtaining the values corresponding to the anthropometric variables are presented below.

Height should be measured between the vertex and the ground reference plane, by placing the subjects leaning against a wall, barefoot and standing, with a height of 2 meters on which is a statiometer. The head, adjusted by the observer, for a better use of the Frankfurt plane, being indicated to the subjects to look ahead, filling the chest with air. The measurement corresponds to the distance between the vertex and the ground plane, being presented in centimetres (cm) by the statiometer (Harpenden).

Body mass should be obtained using the InBody 750 Bioimpedance equipment (Tanita TM), explained later.

Wingspan, will measure with a tape measure to mark the distance between the two middle fingers. This measurement is made with the individual standing, as close as possible to the wall, with arms outstretched and fully horizontal, with the palms of the hands facing the wall.

Seated height, the vertical measurement is made between the surface where the individual is seated until the vertex. He or she must be seated well against the wall, looking ahead and filling his chest with air, the measurement being presented in centimetres.

Lengths and widths of the foot and hand are based on their anatomical points and measured in centimetres.

Body composition should be assessed using the InBody 750 Bioimpedance equipment (Tanita TM): which allows the determination of the body composition of 4 compartments (arms, legs and trunk); bone mass, muscle mass, mass corresponding to visceral fat, percentage of fat mass and amount of total body water (intra and extracellular).

2. Neuromuscular evaluation protocol

The neuromuscular variables considered in the study and the respective procedures respected in their measurement are presented below.

Maximum handgrip strength must be obtained using a dynamometer. Three attempts should be made, with the subject comfortably seated, positioned with the shoulder slightly adducted, the elbow flexed at 90º, the forearm in a neutral position and the wrist varying between 0º and 30º of extension.

Power of the lower limbs should be accessed through the evaluation of the maximum distance in a vertical jump with a simultaneous thrust of both feet. For this, the athlete stands upright, perpendicular to the wall, flexing his knees and jumping as high as possible.

3. Evaluation of sportive performance

The variable sports performance for this study must be determined through the FINA Points Table that allows comparisons of results between different events. Assigns punctual values in swimming performance-based annually on the last world record approved by FINA. For short pools, base times are set with the deadline of August 31st. For the long pool, the base times are defined at the end of the year (December 31). From the formula P = 1000 * (base time/swim time) 3, with P being the score, 1000 the base score, the base time of the best performance and the swim time of the athlete in question.

4. Swim protocol

In the swimming protocol, video recording must be performed using underwater video cameras with enough resolution for at least 50 Hz.

The Tracker software, used later, to remove all the necessary data for the calculation of the desired variables, from the gestural swimming frequency, cycle speed, cycle distance, propulsive efficiency and swimming index and duration of the propulsive support and recovery phases of the upper and lower limbs.

To analyse the swimming technique and its synchronization, we will use the criteria summarized in the previous table: stroke frequency, swimming speed, cycle, propulsive efficiency and the swimming index.

All athletes must perform a warm-up task previously defined by the coach as usual.

After a 10 'rest period, athletes are submitted to a protocol of 2 repetitions of 25 meters with a 3-minute interval (2x25 / 3') at maximum speed and starting in the water. During each repetition, the video record of the central 10 meters must be obtained for further analysis.

For evaluation purposes, the record corresponding to the best performance (shortest time at 25 meters) is considered.

The following variables are controlled for the technical characterization of the breaststroke swim:

Stroke frequency of swimming: Calculated through the number of cycles of the upper limbs per unit of time, it is expressed in cycles per minute and determined by the instantaneous frequency. This variable depends on the swimmer's own characteristics;

Distance cover by cycle: It is the distance covered by the athlete during a complete cycle of the upper limbs and can be calculated through the swimming speed and the gestural frequency (measured in meters per cycle);

Propulsive efficiency: This is characterized by the division between the multiplication of the total efficiency of the swim with the total mechanical work, and the energy cost.

Swimming index: Characterized as the swimmer's ability to move at a certain speed with a smaller number of strokes (product of the speed by the cycle distance, measured in meters squared per cycle per second).

For the characterization of the different phases of action of the upper and lower limbs, the following variables are considered by Chollet et al. (2004):

For the arms:

1. Arm glide: Time between the extension of the arms and the beginning of the movement of the hand backwards;
2. Arm propulsion: Time between the beginning and the end of the movement of the hand backwards, being the initial part of the propulsion of the upper limb;
3. Elbow push: Time between the end of the hand movement back and the beginning of the hand movement forward and the end of the elbow thrust inward and backwards;
4. First part of arm recovery: Time between the end of the elbow thrust and the arm recovery until a 90º angle of the arm/forearm is reached;
5. Second part of the recovery of the arms: Time between the end of the first part of the recovery and the extension of the arms.

When it comes to the kick:

1. Leg propulsion This phase has to do with the time between the beginning of the movement behind the feet (when the legs move in maximum flexion) and the extension of the leg;
2. Leg in-sweep: Time between the leg extension and the leg joint;
3. Leg glide: Time between the leg joint and the beginning of the forward movement of the feet and knee flexion;
4. First part of the recovery: Time between the end of the recovery of the leg slip, until an angle of 90º of the thigh/leg is reached;
5. Second part of the recovery: Time between the end of the first part of the recovery and the complete flexion of the knee, until the end of the forward movement of the feet.

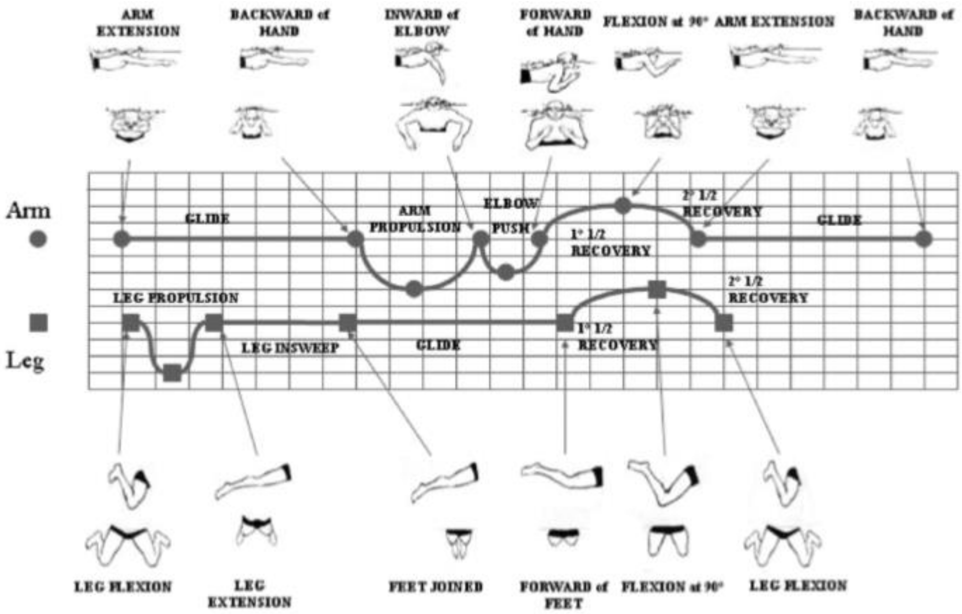


FIGURE 18 - Time gaps of arm and leg phases (Chollet et al., 2004)

The collected data must be presented through descriptive statistics by the values of mean, standard deviation, minimum and maximum. The average values of the collected variables are subject to qualitative analysis by comparison with the values available in the literature representative of high-performance athletes.

CONCLUSION

This investigation has a focal point systematize the information about breaststroke synchronization in swimmers with or without disabilities.

For one hand, some factors influence that synchronization, like the arm-leg phases, the synchronization between phases and breathe, the intra-cyclic variability, the neuromuscular activation and different disabilities.

In the conducted systematic review wasn’t easy to find articles about the adapted swim. One that we found is from 2020, which could mean that this point is pushing the interest for some researchers and coaches for the details about a scientific approach of the swimming sport in this population.

The experimental study shows that it is important to develop knowledge about people with disabilities in different ways of the swim, in this case athletes with ASD in breaststroke.

For breaststroke in particular, there are many particular points that can exalt and enrich the practices in swimmers with and without a disability.

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APPENDIX

Appendix I. Quality of Studies

		(Chollet et al., 2004)	(Takagi & Wilson, 2004)	(H. Leblanc et al., 2005)	(L. Seifert & Chollet, 2005)	(Ludovic Seifert et al., 2007)	(Hugues Leblanc et al., 2009)	(L. Seifert & Chollet, 2009)
Items	1	1	1	1	1	1	1	1
	2	1	1	1	1	1	1	1
	3	1	1	1	1	1	1	1
	4	1	1	1	1	1	1	1
	5	0	0	0	0	0	0	0
	6	0	0	1	1	1	1	1
	7	1	1	1	1	1	1	1
	8	1	1	1	1	1	1	1
	9	1	1	1	1	1	1	1
	10	1	1	1	1	1	1	1
	11	1	1	1	1	1	1	1
	12	1	1	1	1	1	1	1
	13	0	0	0	0	0	0	0
	14	1	1	1	1	1	1	1
	15	1	1	1	1	1	1	1
	16	0	0	0	0	0	0	0
		0,75%	0,75%	0,8125%	0,8125%	0,8125%	0,8125%	0,8125%

(Ludovic Seifert et al., 2010)	(Colman et al., 2010)	(Jaszczak, 2011)	(L Seifert et al., 2011)	(T. M. Barbosa et al., 2013)	(Marek Strzala et al., 2013)	(Ludovic Seifert et al., 2014)	(Strzała et al., 2014)	(Balan & Shaao, 2014)
1	1	1	1	1	1	1	1	1
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1	1	1	0	1	1	1	1	1
0	1	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1
0	0	0	0	0	0	0	1	0
0,8125%	0,875%	0,8125%	0,75%	0,8125%	0,8125%	0,8125%	0,875%	0,6875%

(Staniak & Pastuszak, 2016)	(Vaz et al., 2016)	(Bjørn Harald Olstad et al., 2017)	(B. H. Olstad et al., 2017)	(Oxford et al., 2017)	(M. Strzala et al., 2017)	(Van Houwelingen et al., 2017)	(T. Barbosa et al., 2019)
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
0	0	0	0	0	0	0	0
1	1	1	1	0	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	0	0	0	0	0
0,875%	0,875%	0,875%	0,8125%	0,75%	0,8125%	0,8125%	0,8125%

(Hogarth et al., 2020)	
1	
1	
1	
1	
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0	Mean value of 25 articles
0,75%	0,8075%