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Relationships between head-out aquatic exercise kinematics and musical cadence: Analysis of the side kick

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Abstract

Background: Head-out aquatic exercises became one of the most popular physical activities within the health primarily and thirdly prevention system. Music is seen as one of the most important aspects when conducting head-out aquatic exercise sessions. **Research question:** Is there any relationship between musical cadence and the kinematic behaviour when performing aerobic head-out aquatic exercises? It was hypothesized that an increase in music cadence will would impose a decrease of the segment range of motion. **Type of study**: Experimental, prospective. **Methods:** Six young and clinically healthy women with at least one year of experience conducting head-out aquatic classes were videotaped in the frontal plane, with a pair of cameras providing a double projection (above and below the water surface). Subjects performed an incremental protocol of five bouts (120b.min^{-1}, 135b.min^{-1}, 150b.min^{-1}, 165b.min^{-1} and 180b.min^{-1}) with 16 full cycles of the "side kick" exercise. Data processing and calculation of segmental (i.e. hands and feet) and anatomical landmark (i.e. centre of mass) were performed using the software *Ariel Performance Analysis System* and applying the *DLT* algorithm. **Results:** There was a decrease in the cycle period during the incremental protocol. The relationships between the segmental lateral and vertical displacements with the musical cadence were not significant. The segmental velocities on the lateral and vertical components showed significant increases throughout the incremental protocol. **Conclusions:** The data suggest that segmental velocity increases with increasing cadence, reducing the cycle period and maintaining the segmental displacements. **Keywords:** basic aquatic exercise, music rhythm, range of motion, segmental velocity, aquatic therapy

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Introduction

In the last couple of decades head-out aquatic exercises has become one of the most popular physical activities within the primary health and prevention system. Since then, massive research has been produced in order to better understand the role of head-out aquatic exercises in subjects' and populations' health[1]. Indeed, such studies aimed to characterize the physiological acute and/or chronic response to performing head-out aquatic exercises[2-10]. However, the comprehensive knowledge about the biomechanical (i.e. kinematical) behaviour performing this aquatic activity is limited. Few studies were developed to characterize the kinematics of basic head-out aquatic exercises[11].

From a technical point-of-view, aerobic head-out aquatic exercises are categorized into six main groups[12]: (i) walking; (ii) running; (iii) rocking; (iv) kicking; (v) jumping and; (vi) scissors. Each one of these exercises can be performed in a variety of ways to bring diversity to the sessions. When included in training programmes, the purpose of these exercises is to improve cardiovascular fitness[13]. Considering exercise diversity, most of the research focuses on the walking and running groups[14-16]. Few analyzed rocking[3,11,13] or jumping[17-19] exercises. However, very little attention was paid to the scissors[20] and kicking groups[20] of exercises. Moreover, kicking is one of the basic head-out aquatic exercises performed most often in aquatic activities classes.

Music has been seen as one of the most important aspects when conducting head-out aquatic exercises sessions. The majority of instructors plan their sessions based on the characteristics of their music. The music metrics allows instructors to: (i) achieve the predetermined intensity of exertion; (ii) synchronize subjects during a given routine or choreography and; (iii) motivate subjects. To be able to achieve the appropriate intensity of exertion and synchronize subjects, the instructor has to be familiar with the concept of ''water tempo''. The ''water tempo'' is characterized by the count of only one beat in every two musical beats in the music tempo[21]. The count of that musical beat is synchronized with the execution of a given segmental action of the basic exercise being performed.

The research on the influence of the music characteristics in the subject's acute response is limited. The technical literature reports that music cadence between 130 and 150b.min^{-1} are the most suitable for head-out aquatic exercises[21]. The Aquatic Exercise Association guidelines reports cadences between 125-150b.min^{-1} [2]. At least one empirical study suggests that for healthy and physically active subjects, instructors should choose music cadences between 136 and 158b.min^{-1} [3] when performing the basic exercise, the "Rocking Horse". However, to the best of these authors' knowledge, there is no detailed research attempting to understand the relationship between musical cadence and hypothetical kinematical variations in the performance of basic head-out aquatic exercises. Once again, the technical literature suggests that with increasing cadence subjects might decrease the segment's range of motion to keep with the music metrics[2,21]. Even so, empirical data demonstrates that when performing the "Rocking Horse" the segmental range of motion from the centre of mass, hands and feet did not present significant relationships with increasing cadences[11]. Thus it is not clear whether or not variations in musical cadence will impose significant changes in the exercise kinematics.

The purpose of this study was to analyze the relationships between the aerobic head-out aquatic exercise "Side Kick" kinematics and the musical cadence, when immersed to the level of the xiphoid process. It was hypothesized that increasing musical cadence will decrease the cycle period and therefore the segmental range of motion, as suggested by the technical literature.

Methods

Subjects

Six young women, non-pregnant, clinically healthy and physically active, holding a degree in the Sports Sciences and with at least one year of experience conducting head-out aquatic classes, volunteered to participate in this study. Subjects reported no previous history of orthopaedic or musculoskeletal injuries in the previous six months to this study. Table 1 presents the characteristics of the subjects. All procedures were in accordance with the Declaration of Helsinki with respect to human research. The Institutional Review Board of the Polytechnic Institute of Bragança approved the study design. The women were informed of the experimental risks and signed an informed consent document before the investigation.

Table 1: Characteristics of women studied

Variable	Mean	1 SD	Maximum	Minimum
Age (years)	23.67	0.52	24	23
Height (m)	1.64	0.07	1.74	1.58
Body Mass (kg)	57.42	4.78	65	52
Body Mass Index (kg.m^{-2})	22.17	2.56	27	20
Aquatic fitness classes (min.wk^{-1})	260	87.64	420	180

Procedures

Each subject performed a basic head-out aquatic exercise called the "Side Kick". The "Side Kick" consists of standing on the right leg, while the left leg makes abducts and kicks to the side. Simultaneously, the arms move to the opposite side of the kicking leg. Then the subject hops vertically and changes the support to the left leg, while the right one performs the abduction and the kick. At the same time, the arms move to the other side. The ''Side Kick'' was always performed with the water surface at the level of the xiphoide process. Figure 1 illustrates the basic head-out aquatic exercise studied. The exercise was performed using the ''water tempo'' according to the standard recommendations from the technical literature[21] that was already reported in some scientific papers as well[3,11,13].

The protocol consisted of five sets of 16 full repetitions of the "Side Kick" exercise, at the "water tempo", immersed up to the prosessus xiphoideus (i.e. breast). The bouts' intensities were 80%, 90%, 100%, 110% and 120% of the cadence reported by Barbosa et al.[3] to achieve a 4mmol.l^{-1} of blood lactate, representing 120b.min^{-1}, 135b.min^{-1}, 150b.min^{-1}, 165b.min^{-1} and 180b.min^{-1}, respectively. The musical cadence was electronically controlled by a metronome (Korg, MA-30, Tokyo, Japan) connected to a sound system. All women were familiarized with the concept of ''water tempo'' and followed the music metric throughout the test. At every two musical beats the women changed their support from one leg to the other. However, when necessary, the evaluators gave verbal encouragement or cues to the subjects to maintain the appropriate synchronization between the musical cadence and segmental action. All subjects completed the protocol's five bouts. Thus overall, 30 bouts were assessed. The water temperature was 30ºC and the relative humidity was 75%.

Figure 1: The basic head-out aquatic exercise "Side Kick"

Data collection

The protocol was videotaped independently in front plane with a pair of cameras providing a dual projection from both underwater (GR-SXM25 SVHS, JVC, Yokoama, Japan) and above (GR-SX1 SVHS, JVC, Yokoama, Japan) the water's surface. The study included kinematical analysis of the full cycles (Ariel Performance Analysis System, Ariel Dynamics Inc., USA) through a VCR (Panasonic, AG 7355, Japan) with a frequency of 50Hz. Zatsiorsky's model adapted by de Leva[22] was used, dividing the trunk in two articulated segments and including an overall number of 19 body landmarks to be digitized in each frame. To create a single image of dual projection as previously described [23], the independent digitalization from both cameras was reconstructed with the help of a calibration object (0.675x0.855m; 6 control points) and a 2D-DLT algorithm[24]. For the analysis of the curve of the centre of mass kinematics, a filter with a cut-off frequency of 5Hz was used, as suggested by Winter[9]. For the segmental kinematics, a cut-off frequency of9 Hz was used, close to the value proposed by Winter[9]. A double-passage filtering for the signal processing was performed. The following were assessed: (i) the cycle period; (ii) the 2D (vertical and lateral components) linear variation of the position from selected anatomical landmark and segments (centre of mass, hands and feet) and; (iii) the 2D (vertical and lateral components) velocity of the same anatomical landmark and segments (i.e. centre of mass, hands and feet).

Statistical analysis

The normality of the distributions was assessed with the Shapiro-Wilk test. For qualitative assessment, mean intra-cyclic curves normalized to time for 2D centre of mass' displacement and velocity were computed with MATLAB (version 6 R12, MathWorks Inc., Massachusetts, USA). For descriptive analysis, mean plus one standard deviation were computed as central tendency and dispersion measures, respectively. For each relationship, the mathematical model with the best adjustment and lowest standard error of the estimation was adopted. All relationships presented a better adjustment when linear regressions were computed. Therefore linear regression models were used to describe the relationships between musical cadence and the kinematical variables (2D displacements and 2D velocities), as well as their coefficients of determination. For qualitative and effect size assessments it was defined that the relationship was: (i) very weak if $R^2<0.04$; weak if $0.04\leq R^2<0.16$; moderate if $0.16\leq R^2<0.49$; high if $0.49\leq R^2<0.81$ and; very high if $0.81\leq R^2<1.0$. The level of statistical significance was set at $P\leq0.05$. Post-hoc power (i.e. retrospective power) was computed using the obtained sample size and effect size to determine what the power was in the study, assuming the effect size in the sample is equal to the effect size in the population.

Results

Figure 2 presents a qualitative analysis from the centre of mass kinematics during the second bout at 135b.min^{-1}. For qualitative assessment it was performed the mean plus one standard deviation intra-cyclic variation of the centre of mass' lateral displacement, vertical displacement, lateral velocity and vertical velocity from all women performing the second bout at 135b.min^{-1}. The centre of mass' lateral displacement is presented by a single-modal or parabolic profile. On the other hand, centre of mass' vertical displacement is characterized by a bi-modal profile. The centre of mass' lateral velocity has a multi-peak profile. Finally, the centre of mass' vertical velocity is presented by a bi-modal profile. Analyzing the standard deviation profile, both vertical curves (displacement and velocity) have a reduced data dispersion, while the lateral ones (i.e., displacement and velocity) have a moderate dispersion.

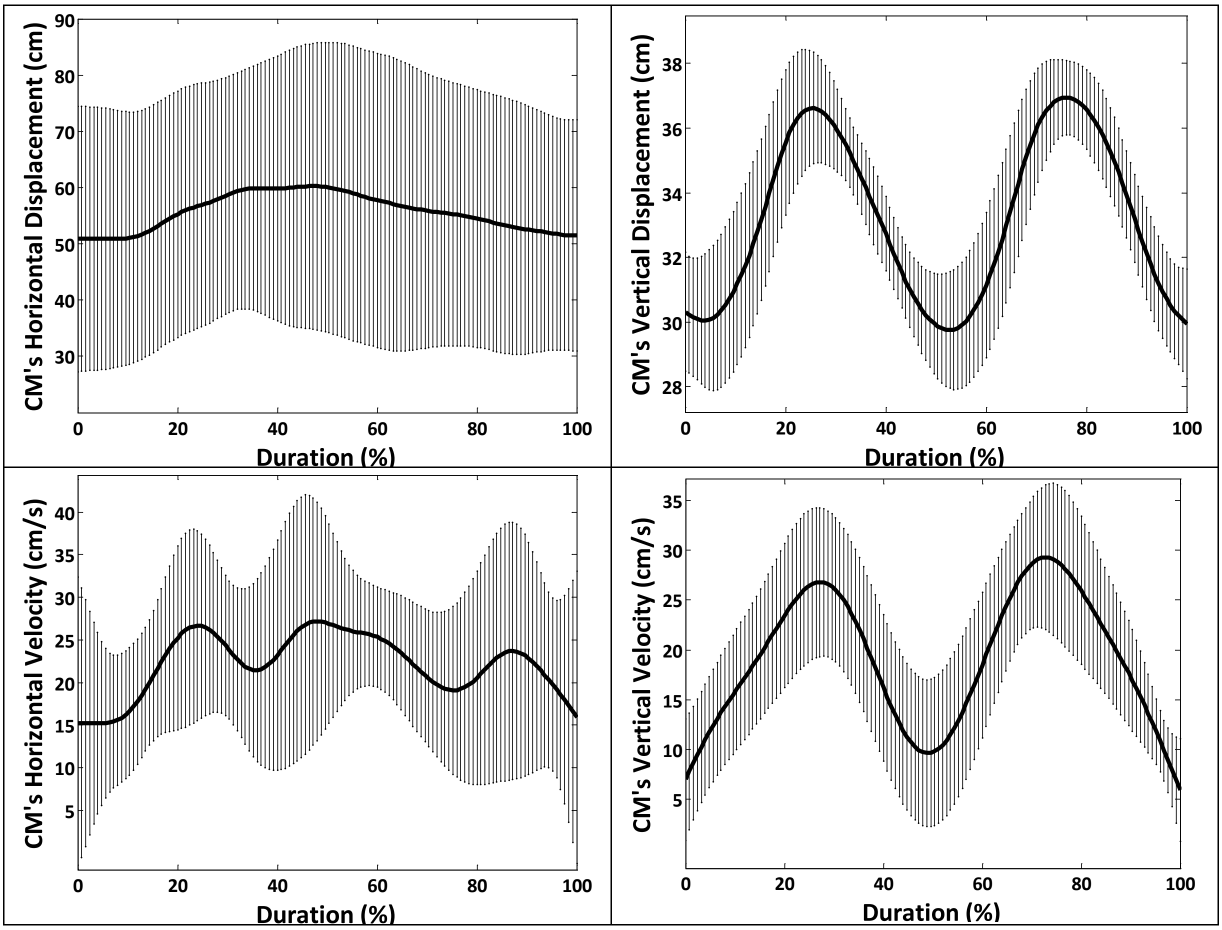

Figure 2: Mean plus one standard deviation intra-cyclic variation of the centre of mass kinematics from all subjects performing the second bout at 135b.min^{-1}

Figure 3 is a simple scattergram from the cycle period according to the musical cadence imposed. There was a significant, negative and very high relationship between both variables (R^2=0.83; P<0.01; retrospective power=1.00).

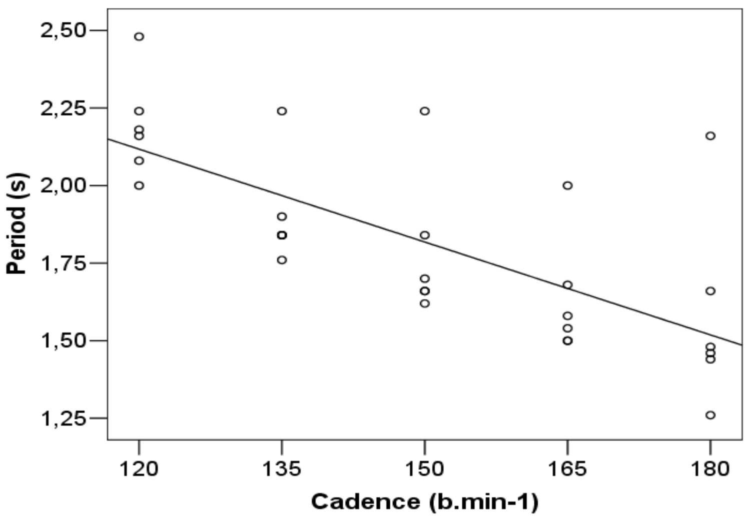

Figure 3: Simple scattergram for the relationship between the cycle period and the musical cadence

Figure 4 is a simple scattergram for the relationship between the centre of mass kinematics and the musical cadence imposed. There was a negative, moderate and significant relationship between the lateral and vertical centre of mass displacements and the cadence imposed (R^2=0.25; P=0.01; retrospective power=1.00 and R^2=0.27; P<0.01; retrospective power=1.00, respectively). Increasing cadence imposed significant differences in the centre of mass velocities. The lateral one presented a positive and moderate relationship (R^2=0.48; P<0.01; retrospective power=1.00), while the centre of mass vertical velocity was not significant (R^2=0.06; P=0.20; retrospective power=0.00).

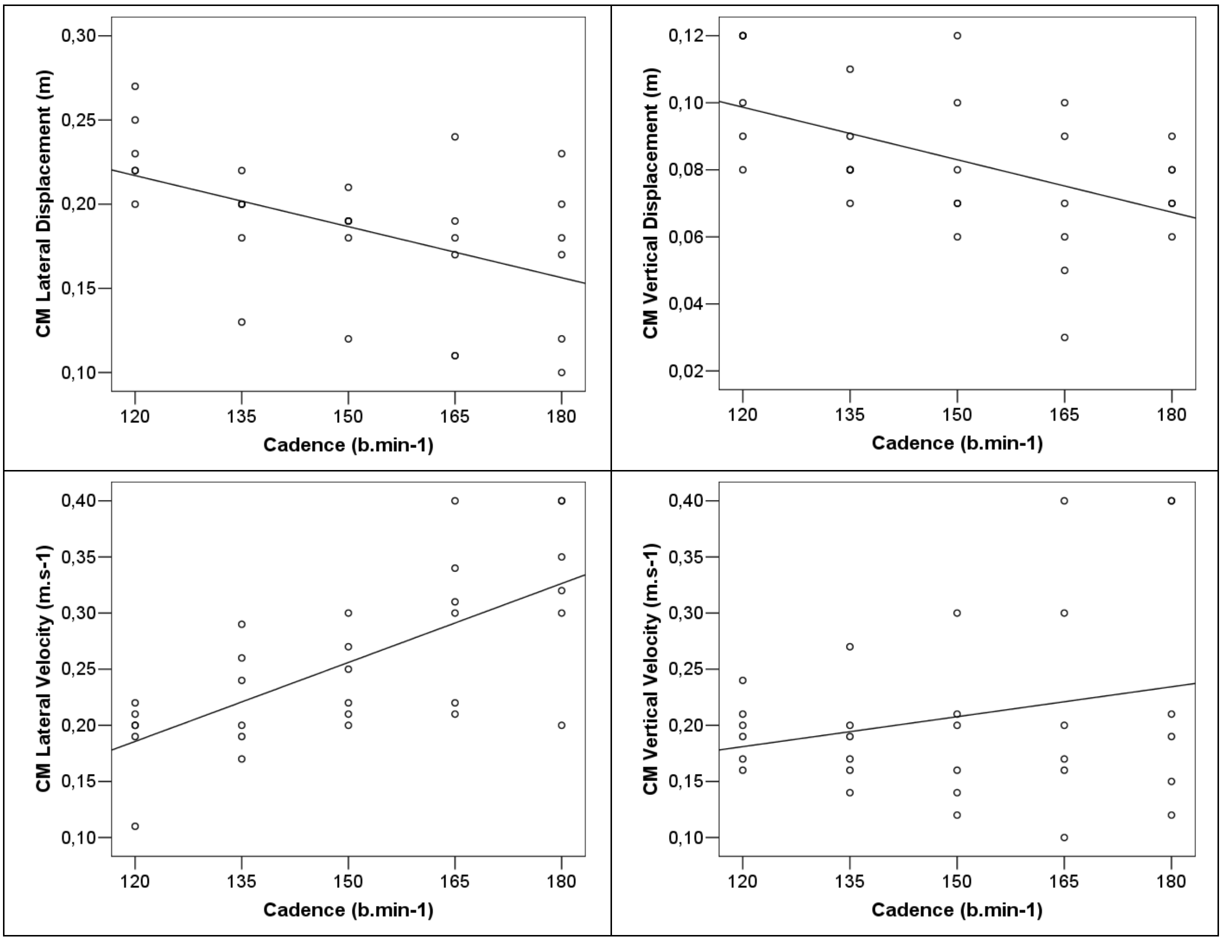

Figure 4: Simple scattergram from centre of mass' kinematics according to the musical cadence imposed

Figures 5 and 6 respectively are simple scattergrams from the right- and left-hand kinematics, according to the musical cadence. There were no relationships between the right hand lateral and vertical displacements and the cadence imposed (R^2=0.01; P=0.65; retrospective power=0.00 and R^2=0.01; P=0.66; retrospective power=0.00, respectively). For the right hand lateral and vertical velocities, there was a positive, moderate and significant relationship with the increasing cadence (R^2=0.47; P<0.01; retrospective power=1.00 and R^2=0.27; P<0.01; retrospective power=1.00, respectively). There were none relationships between the left hand lateral and vertical displacements and the cadence imposed (R^2=0.01; P=0.63; retrospective power=0.00 and R^2=0.12; P=0.06; retrospective power=0.00, respectively). Increasing cadence imposed non-significant relationship between the left hand lateral velocity (R^2=0.09; P=0.10; retrospective power=0.00), and positive, significant and moderate relationships between the left hand vertical velocity and musical cadence (R^2=0.28; P<0.01; retrospective power=1.00).

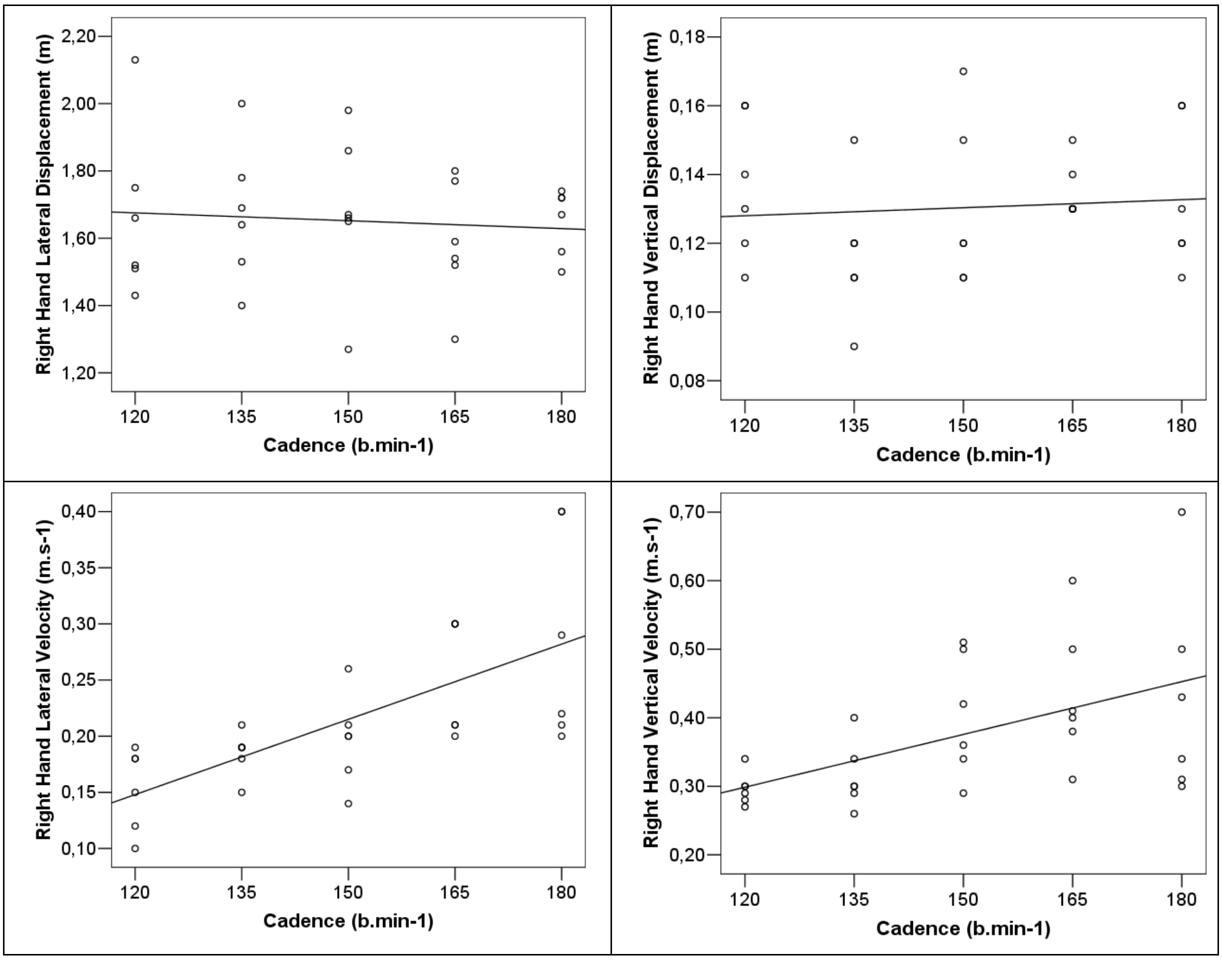

Figure 5: Simple scattergram from the right hand's kinematics according to the musical cadence imposed

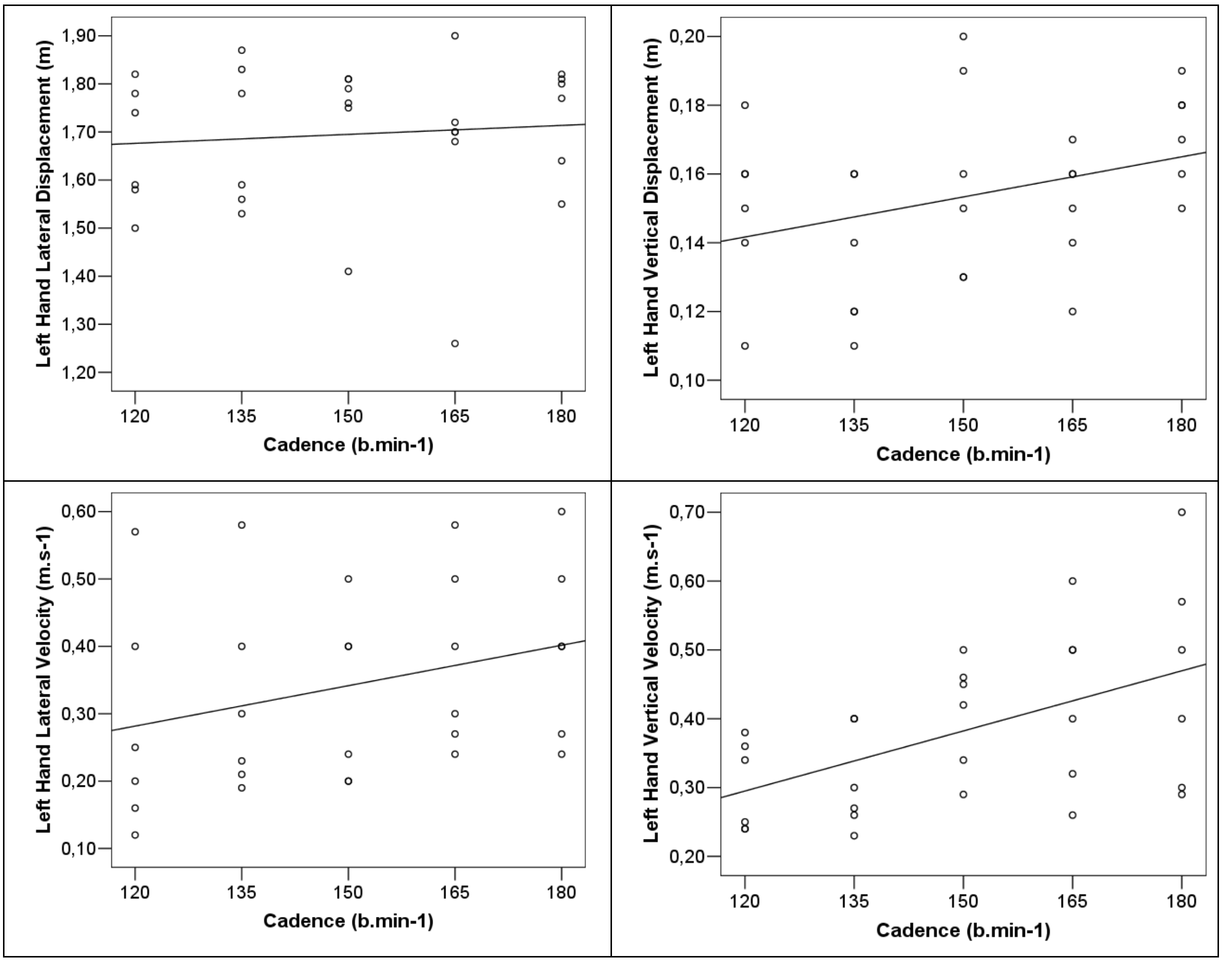

Figure 6: Simple scattergram from the left hand's kinematics according to the musical cadence imposed

Figures 7 and 8 are simple scattergrams from the right- and left foot kinematics according to the musical cadence There were no relationships between the right foot lateral and vertical displacements and the cadence imposed (R^2=0.03; P=0.35; retrospective power=0.00 and R^2=0.04; P=0.30; retrospective power=0.00, respectively). For the right foot lateral velocity, there was a positive and non-significant relationship with the increasing cadence (R^2=0.08; P=0.13; retrospective power=0.00). However, increasing cadence imposed significant and moderate relationships with the right foot vertical velocity (R^2=0.35; P<0.01; retrospective power=1.00). There were none relationships between the left foot lateral and vertical displacements and the cadence imposed (R^2=0.00; P=0.94; retrospective power=0.00 and R^2=0.06; P=0.21; retrospective power=0.00, respectively). For the left foot lateral velocity, there was a positive and non-significant relationship with the increasing cadence (R^2=0.10; P=0.08; retrospective power=0.00). Nevertheless, increasing cadence imposed positive, moderate and significant relationships between the left foot vertical velocity and the cadence (R^2=0.36; P<0.01; retrospective power=1.00).

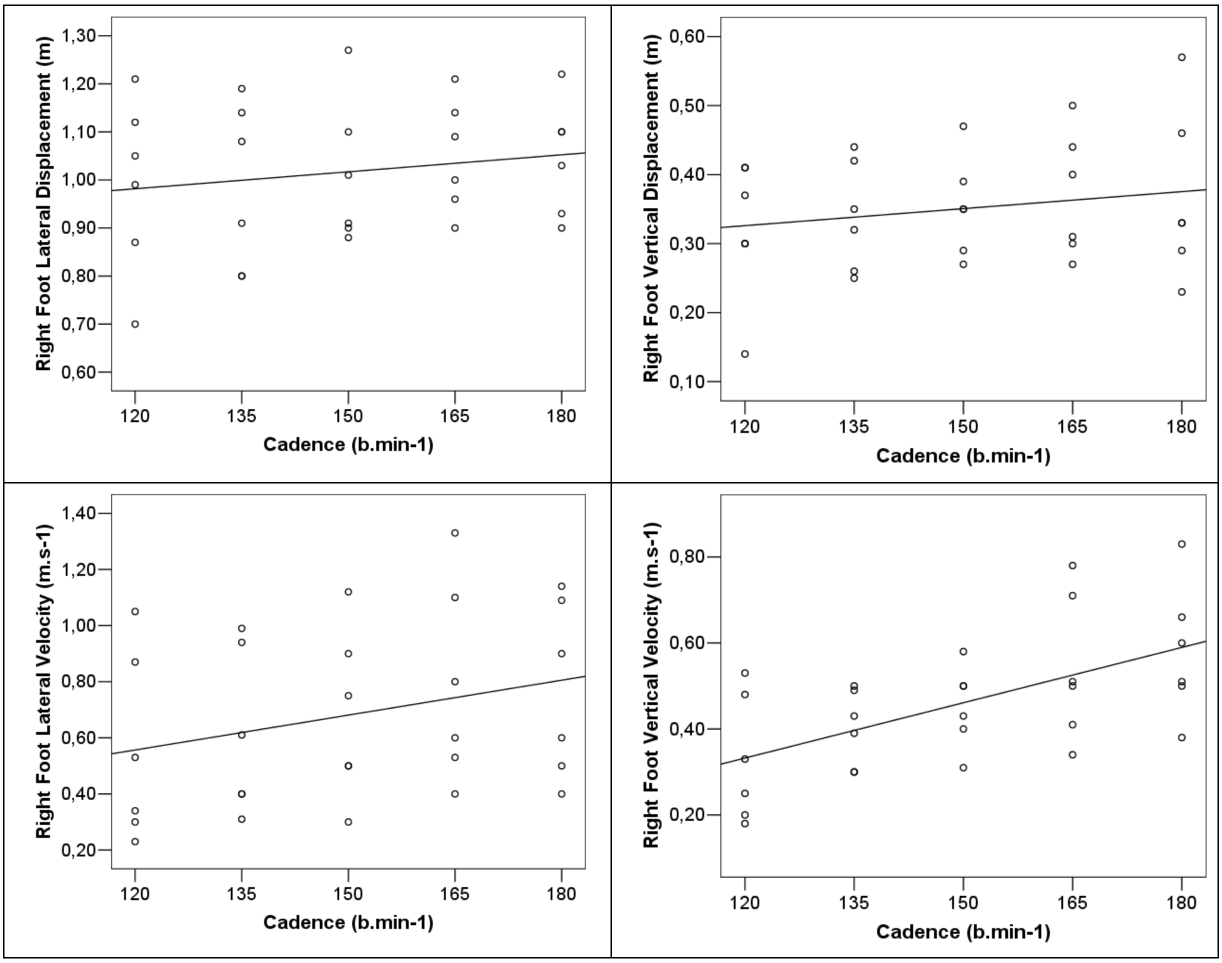

Figure 7: Simple scattergram from right foot's kinematics according to the musical cadence imposed

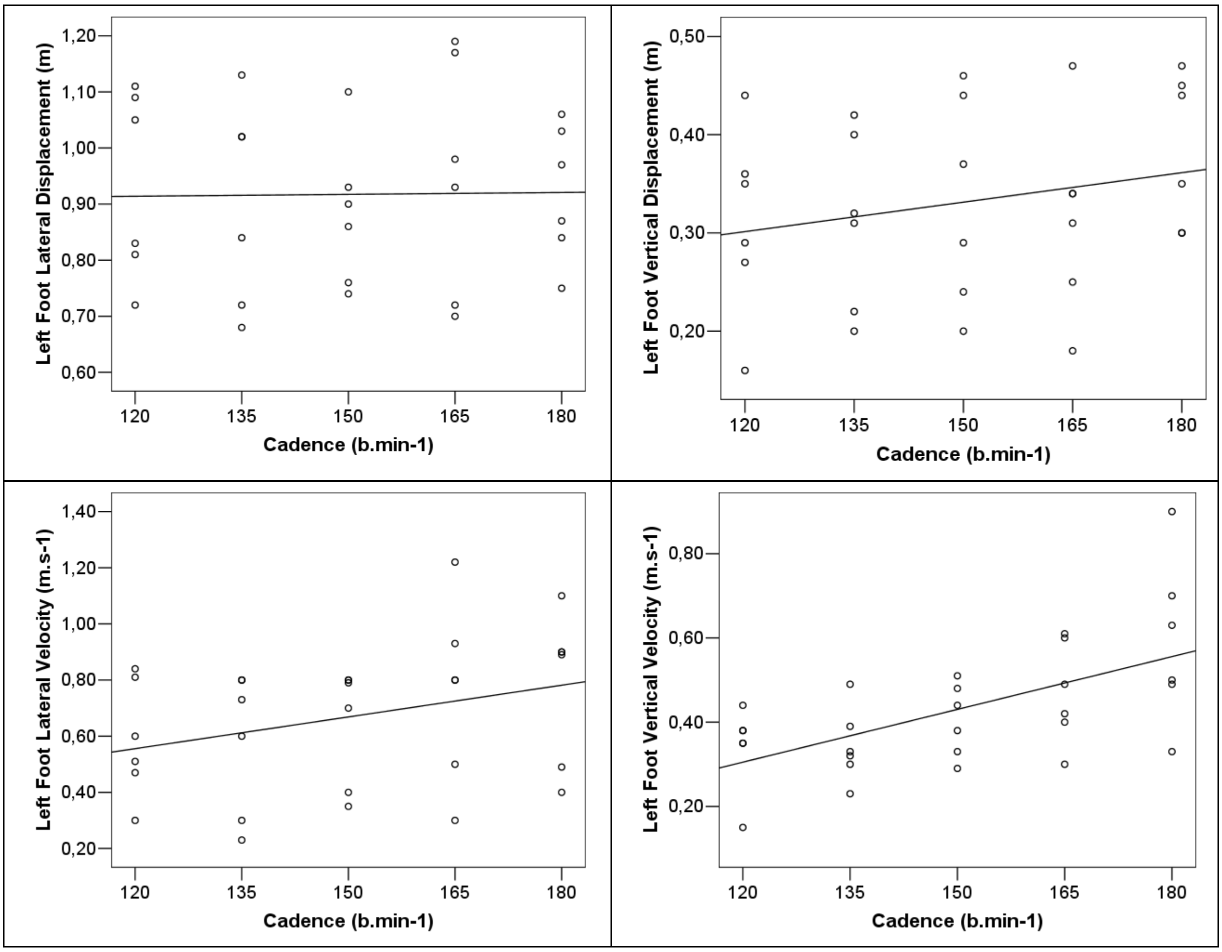

Figure 8: Simple scattergram from left foot's kinematics according to the musical cadence imposed

Discussion

The purpose of this study was to analyze the relationships between the aerobic head-out aquatic exercise "Side Kick" kinematics and the musical cadence. Main data suggest that expert and fit subjects increase segmental velocity with increased musical cadence, avoiding the decrease of the segmental range of motion.

Technical literature suggests that music cadences between 125-150b.min^{-1} [2] and 130-150b.min^{-1} [21] are the most suitable for head-out aquatic exercises. Within this musical cadence it is argued that the movement range of motion can be maintained[2,21]. However, from a physiological point-of-view, a recent paper[3] verified that. at least for expert and fit subjects, the musical cadence should range between 136 and 158b.min^{-1}. In such research it was considered that guidelines set out by organisations such as the ACSM and AEA are appropriate but can be slightly modified for aquatic activities to provide a more accurate exercise prescription for healthy and physically active subjects. In addition, it was suggested that new investigations should be developed to determine the musical cadence with greater accuracy. Another study regarding the physiological response to different cadences, including alternate side kicking, reported that several energetic, cardiorespiratory and psycho-physiological parameters increased with increasing cadences (110-120b.min^{-1} vs. 120-130b.min^{-1} vs. 130-140b.min^{-1})[20]. In this regard, little has been known until now about the relationships between musical cadence and the exercise kinematics.

From a qualitative point-of-view, the centre of mass lateral displacement is presented by means of a single-modal or parabolic profile. The kicking action will impose a trunk lateral flexion and therefore a lateral displacement when kicking to the side. The lateral velocity component has a multi-peak profile. In all swimming strokes, multi-peak intra-cyclic variation curves for the centre of mass displacement is well described[23]. Thus when performing head-out aquatic exercises, lateral body movement is also applied to propulsive and drag forces, imposing multi-peak profile curves as happens in competitive swimming. The centre of mass vertical displacement and vertical velocity are characterized by a bi-modal profile. Side Kick is a hopping movement from one leg to the other. As a consequence the centre of mass will rise and fall at each hopping action. Indeed, this anatomical landmark displacement is similar to the one reported for the gait cycle[14] but with a higher range of values.

A very high relationship between the cycle period and the musical cadence was verified. There was a decrease in the time variable throughout the incremental protocol. Indeed, 83% of the cycle period behaviour was explained by the music metrics. There were non-significant relationships between the displacement variables (e.g. right hand, left hand, right foot and left foot) and the musical cadence. The only exception was the centre of mass lateral and vertical displacements. On the other hand, most of the velocity variables (e.g. centre of mass lateral velocity and the vertical velocities of the left hand, right foot and left foot) were moderate, positive and significantly related to the musical cadence.

Similar data was found in the only paper published about the relationship between musical cadence and a basic head-out aquatic exercise kinematics. In this paper, the “Rocking Horse” kinematics and its relationship with musical cadence was assessed[11]. It was also reported that there was a decrease in the cycle period throughout the incremental protocol. Moreover, the relationships between lateral or vertical displacements and music cadence were not significant, and increased cadence imposed increased segmental and centre of mass velocities[10].

When increasing music cadence, the decrease of each partial duration of the exercise period can be related to: (i) the decrease in the limb’s range of the motion and the maintenance of *segmental velocity* or; (ii) the maintenance of the limb’s range of motion and the increase in the segmental velocity or; (iii) the reduction of the limb’s range of the motion and increased of the segmental velocity. In the introduction section it was hypothesized that increasing cadence would impose a decrease of the limb’s range of motion. At least technical literature suggests it[2,21], although there is little empirical data. However, from the three possible biomechanical responses, subjects included in this sample decreased the partial duration of each exercise phase through an increase of the segmental velocity. This same phenomenon was already verified in the single empirical data about this kind of relationship in head-out aquatic exercises[11].

For Kruel et al.[17], expert subjects with high fitness levels, are able to use musical cadences up to 180b.min^{-1} while practising head-out aquatic exercises. Such subjects seem to be able to keep the full range of motion, by increasing segmental velocity[17]. Thus it can be suggested that data reported in the present paper is related to the sample subject’s profile. Samples reported in this paper consisted of: (i) expert subjects, i.e. head-out aquatic exercise instructors that were aware of the need to maintain at all times a full range of motion performing basic exercises, independently from the cadence imposed and; (ii) very active subjects that were not only aware of the technical tips, but were also physically fit, allowing them to maintain a range of motion at different musical cadences. In this way, it can be speculated that, if other types of subjects were included in the sample (e.g. ordinary head-out aquatic class members instead of instructors), major findings could be a decrease in the segmental range of motion and the maintenance of segmental velocity. However, no empirical data have reported such relationships in this kind of subject cohort. The development of research based on the same method design reported in this paper but with subjects from other backgrounds should be a priority in the near future.

Conclusions

In conclusion, segmental velocity increases with increasing cadence, reducing the cycle period and maintaining the segmental displacements. Expert and fit subjects are able to maintain the full range of motion, even when the exercise cadence is modified. However, it is unclear if this occurs in non-expert and/or subjects with lower fitness levels. Therefore head-out aquatic exercise instructors should be aware of the possible range of motion decrease throughout increasing cadences, and avoid it manipulating (i.e. increasing) the segmental velocity.

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