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Research article

The influence of musical cadence into aquatic jumping jacks kinematics

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Abstract

The aim of this study was to analyze the relationships between the head-out aquatic exercise "Jumping jacks" kinematics and the musical cadence in healthy and fit subjects. Five young women, with at least one year of experience conducting head-out aquatic programs 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 (120 b·min^{-1}, 135 b·min^{-1}, 150 b·min^{-1}, 165 b·min^{-1} and 180 b·min^{-1}) with 16 full cycles of the "Jumping jacks" exercise. Data processing and calculation of upper limbs' (i.e. hands), lower limbs' (i.e. feet) and center of mass' 2D linear velocity and displacement were computed with the software *Ariel Performance Analysis System* and applying the 2D-*DLT* algorithm. Subjects decreased the cycle period during the incremental protocol. Significant and negative relationships with the musical cadence were verified for the center of mass and upper limbs vertical displacement. On the other hand, for the lower limbs lateral velocity, a significant and positive relationship was observed. It is concluded that expert and fit subjects increase the lower limb's velocity to maintain the range of motion, while the upper limb's displacement is reduced to coupe the music cadence.

Key words: Aquatic jumping exercises, simultaneously actions, music rhythm, range of motion, segmental velocity.

Introduction

In recent years head-out aquatic exercises have gained popularity, due to its benefits for health purposes. Such types of aquatic programs are becoming a major component to, e.g.: (i) reduce overweight (Gappmaier et al., 2006); (ii) improve the elderly people balance (Suomi and Koceja, 2000); (iii) enhance performance of elite athletes (Robinson et al., 2004) or; (iv) improving the physical fitness of healthy subjects (Colado, 2004).

Since head-out aquatic classes are most of the time full with dozens of subjects, instructors have a greater challenge to maintain all of them synchronized. Instructors use massively the music tempo for such purpose. Added to that, music's melody and tempo are a way to motivate subjects, achieving a given intensity of exertion (Kinder and See, 1992). Technical literature reports as being the most appropriate musical cadence to achieve aerobic target zone, for head-out aquatic exercise sessions, those ranging from 125 to 150 b·min^{-1} (AEA, 2008) or 130 to 150 b·min^{-1} (Kinder and See, 1992). Barbosa et al. (2010a) suggested that healthy and physically active subjects are able to perform basic head-out aquatic exercises within a 136-158 b·min^{-1} music cadence range.

Basic head-out aquatic exercises are categorized in six main groups (Sanders, 2000): (i) walking; (ii) running; (iii) rocking; (iv) kicking; (v) jumping and; (vi) scissors. Despite the differences in the way that each group is performed, the walking, running, rocking and kicking present an alternating segmental action. Similar biomechanical strategies (including the kinematical ones) were reported for such main groups when increasing the exercise intensity and/or the musical cadence. In order to reduce the water resistance, a greater knee joint flexion was used to reduce the lower limbs' surface area, as the velocity increased for walking/running tasks (Alberton et al., 2011; Kato et al., 2001). In addition, it was verified that the transition velocity from walking to running in the aquatic environment happened at 1.67 m·s^{-1} (Kato et al., 2001). While assessing the "Rocking horse" (Oliveira et al., 2010) and the "Side kick" (Oliveira et al., 2011) kinematics, when increasing the musical cadence, expert and healthy subjects increased the segmental velocity, to avoid a decrease in the segmental range of motion. Nevertheless, from the six main groups for basic head-out aquatic exercises there is a lack of data regarding the jumping ones. Indeed, jumping is one of the drills most often performed in head-out aquatic exercise sessions. From a coordination point of view it is one of the simplest exercises as the segmental action is made simultaneously by the four limbs. "Jumping jacks" are quite popular as well conducting head-out aquatic exercise for some specific populations with a given coordination handicap (e.g., new subjects in the program, elderly, subjects with some specific neuromuscular or cardiovascular conditions). Plus, the buoyancy reduces the effect of weight bearing on skeletal joints and reduces compressive joint forces (Raffaelli et al., 2010). So, for subjects with overweight and/or orthopedic disabilities it is easier to perform such type of basic exercises in the aquatic environment. To the best of our knowledge there is no research attempting to understand the relationship between musical cadence and water jumping exercise kinematical response.

Thus, the purpose of this study was to analyze the relationships between the head-out aquatic exercise "Jumping jacks" kinematics and the musical cadence in healthy and fit subjects. With that aim we had the intent to increase the knowledge about biomechanics concerning aquatic locomotion and skills. A second goal was to give

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some practical information for head-out aquatic instructors in order to manipulate the exercise response according with music cadence for training purposes. It was hypothesized that increasing musical cadence will decrease the cycle period and, therefore the segmental range of motion.

Methods

Subjects

Five young women, non-pregnant, clinically healthy and physically active, holding a graduation degree in Sports Sciences and with at least one year of experience conducting head-out aquatic programs, volunteered to participate in this study. Subjects reported no previous history of orthopedic or muscle-skeletal injuries in the previous six months. Table 1 presents the subjects' main characteristics. 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. Women were informed of the experimental risks and signed an informed consent document before the investigation.

Table 1. Mains characteristics of the female instructors studied.

Variables	Mean (±SD)	Min-Max
Age (years)	23.7 (.5)	23-24
Height (m)	1.64 (.07)	1.58-1.74
Body Mass (kg)	57.4 (4.8)	52-65
Body Mass Index (kg.m^{-2})	22.2 (2.6)	20-27
Aquatic fitness classes conducted (min.wk^{-1})	260 (88)	180-420

Procedures

Each subject performed a basic head-out aquatic exercise entitled "Jumping jacks". The "Jumping jacks" consists of a jumping exercise divided in two hops. During the first hop the subject makes an abduction of both arms and legs simultaneously in the frontal plane. During the second hop the subject makes an adduction of the previously referred segments, returning to the original and neutral position. The exercise was initiated with the water surface at the xiphoid process level. Arms were always fully immersed, meaning that arm's abduction is made up to the xiphoid process horizontal level and then adducted. 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 (Kinder and See, 1992) that was already reported in some scientific papers as well (Barbosa et al., 2010a; Kato et al., 2001).

The protocol consisted of five sets of 16 full repetitions of the "Jumping jacks" exercise, at the "water tempo", immersed to the xiphoid process (i.e., breast). The bouts intensities were 80%, 90%, 100%, 110% and 120% of the cadence reported by Barbosa et al. (2010a) to achieve a 4 mmol·l^{-1} of blood lactate, representing 120 b·min^{-1}, 135 b·min^{-1}, 150 b·min^{-1}, 165 b·min^{-1} and 180 b·min^{-1}, respectively. The musical cadence was electronically controlled by a metronome (Korg, MA-30, Tokyo, Japan) connected to a sound system. A metronome was used to avoid the influence of the music's melody in the subject's performance. All women were familiarized with the concept of ''water tempo'' and followed the music metric throughout the test. At each two musical beats women made the four segments abduction followed by its adduction. Whenever necessary, the evaluators gave verbal and/or visual cues for subjects follow the appropriate exercise cadence and accomplish the number of repetitions asked. All subjects completed the protocol's five bouts. So, an overall of 25 bouts were assessed. The water temperature was 30ºC and the relative humidity was 75%.

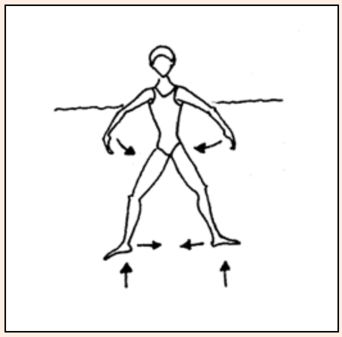

Figure 1. The basic head-out aquatic exercise "Jumping jacks".

Data collection

The protocol was videotaped independently in frontal 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 surface as reported elsewhere (Oliveira et al., 2010; 2011). 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 sampling rate of 50 [Hz]. Zatsiorsky's model adapted by de Leva (1996) was used dividing the trunk in two articulated segments and including an overall number of nineteen body landmarks to be digitized in each frame. To create a single biomechanical model of a dual media movement, as described previously (Barbosa et al., 2010b), the independent digitalization from both cameras was reconstructed with the help of a calibration object (1.50 x 0.85 m; 6 control points) and a 2D-DLT algorithm (Abdel-Aziz and Karara 1971). For the analysis of the curve of the center of mass kinematics, a filter with a cut-off frequency of 5 [Hz] was used, as suggested by Winter (1990). For the segmental kinematics a cut-off frequency of 9 [Hz] was used, near to the value proposed by Winter (1990). A double-passage filtering for the signal processing was performed. It was assessed (Oliveira et al., 2011): (i) the cycle period; (ii) the 2D (vertical and lateral components) linear variation of the position from selected anatomical landmark and segments (center of mass, hands and feet) and; (iii) the 2D (vertical and lateral components) velocity of the same anatomical landmark and segments (i.e., center of mass, hands and feet).

Statistical analysis

The normality and homogeneity assumptions were

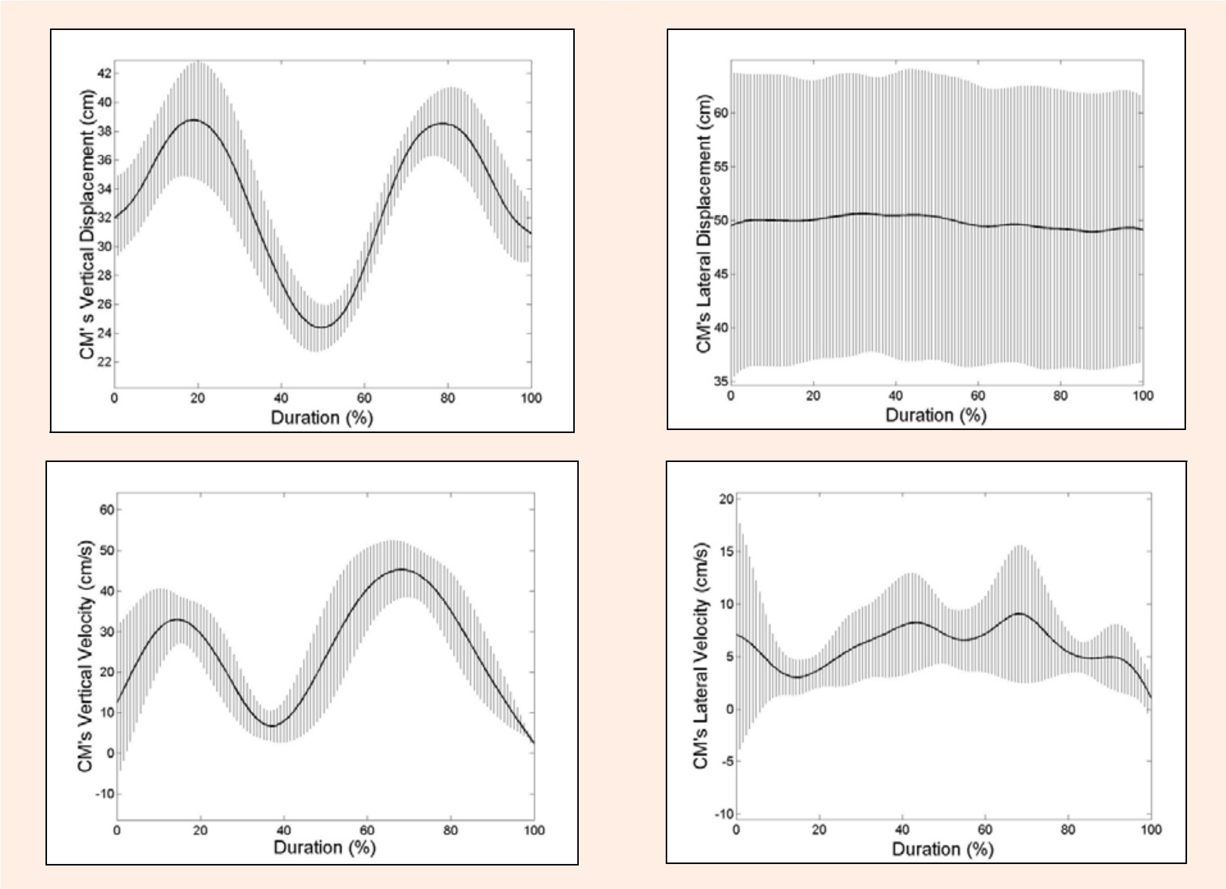

Figure 2. **Mean plus one standard deviation intra-cyclic variation of the center of mass kinematics from all subjects performing the second bout at 135 b·min^{-1}.**

checked respectively with the Shapiro-Wilk and Levene tests. For qualitative assessment, mean intra-cyclic curves normalized to time for 2D center 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 good-of-fit adjustment and the lowest standard error of the estimation was adopted. All relationships presented a better adjustment when linear regressions were computed. So, linear regression models were used to describe the relationships between musical cadence and kinematical variables (2D displacements and 2D velocities), as well as its coefficients of determination. As rule of thumb, for qualitative and effect size assessments, it was defined that the relationship was: (i) very weak if $R^2 < 0.04$; weak if $0.04 \le R^2 < 0.16$; moderate if $0.16 \le R^2 < 0.49$; high if $0.49 \le R^2 < 0.81$ and; very high of $0.81 \le R^2 < 1.0$. The level of statistical significance was set at $p \le 0.05$.

Results

Centre of mass qualitative assessment

Figure 2 presents a qualitative analysis from the center of mass kinematics during the second bout at 135 b·min^{-1}. For qualitative assessment it was performed the mean plus one standard deviation intra-cyclic variation of the center of mass' lateral displacement, vertical displacement, lateral velocity and vertical velocity from all women performing the second bout at 135 b·min^{-1}. The center of mass' vertical displacement and vertical velocity presented a two-peak kinetics profile. On the other hand, the center of mass' lateral displacement was characterized by a single-peak or parabolic profile. The center of mass' lateral velocity had a multi-peak profile but quite smooth (i.e., with very low range of displacement and velocity).

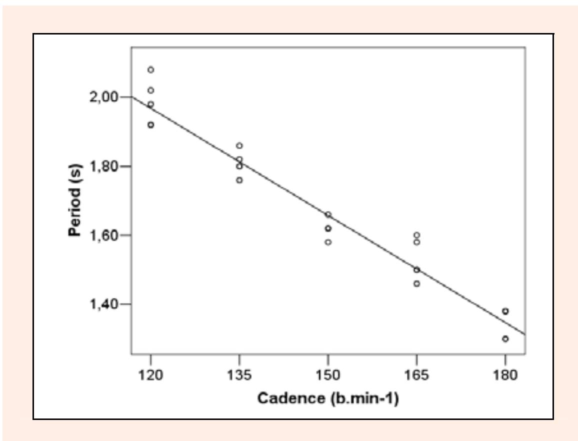

Figure 3. **Simple scattergram for the relationship between the cycle period and the musical cadence.**

Cycle period

Figure 3 reports the simple scattergram from the cycle

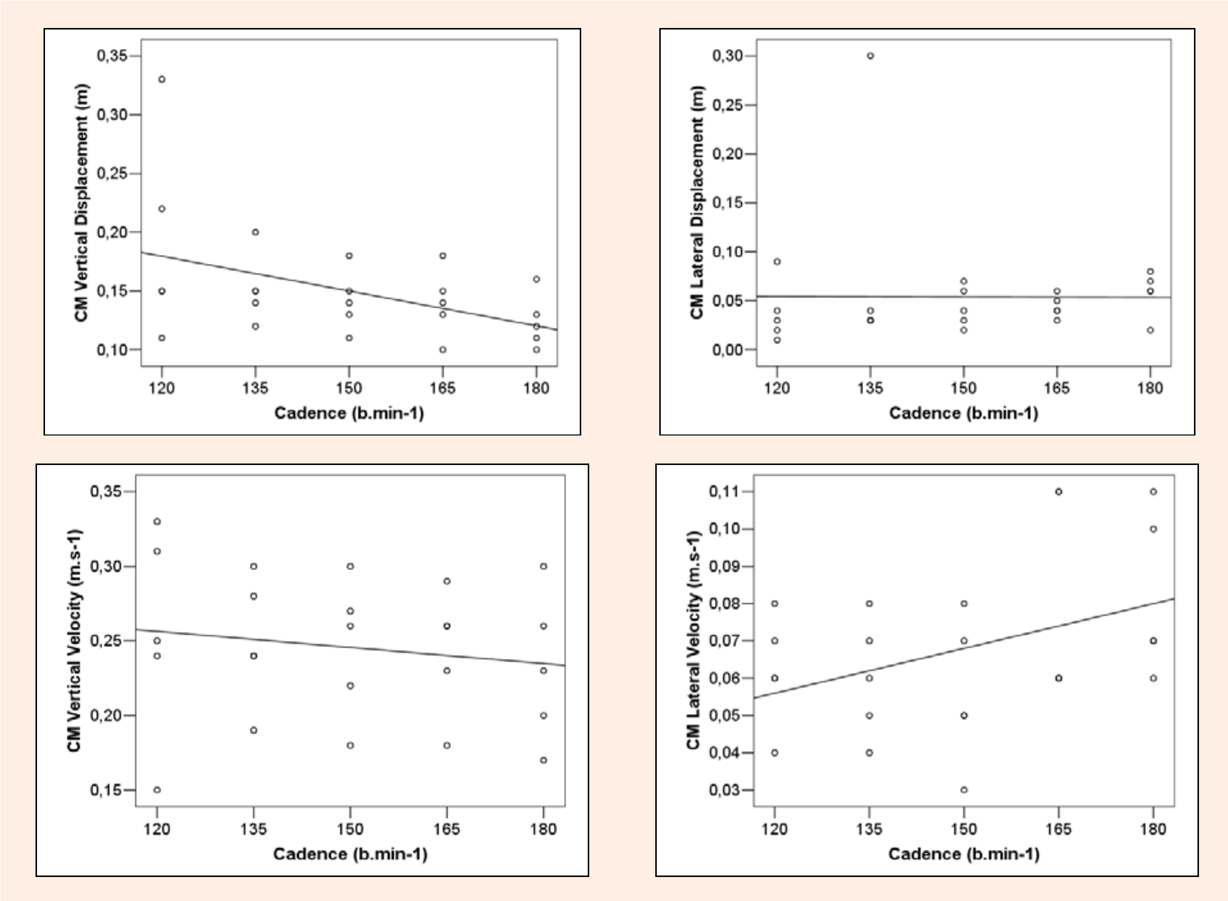

Figure 4. Simple scattergram from center of mass' kinematics according to the musical cadence imposed.

period according to the musical cadence imposed. There was a significant, negative and very high relationship between both variables ($R^2 = 0.95$; $P < 0.01$).

Centre of mass kinematics

Figure 4 presents the simple scattergram for the relationship between the center of mass kinematics and the musical cadence imposed. There was a negative and moderate relationship between center of mass displacements and the cadence imposed, with significant ($R^2 = 0.20$; $p = 0.03$) and non-significant ($R^2 < 0.04$; $p = 0.98$) meaning for the vertical and lateral displacements, respectively. Increasing cadence imposed non-significant differences in the center of mass vertical ($R^2 < 0.04$; $p = 0.44$) and lateral ($R^2 = 0.07$; $p = 0.12$) velocities.

Upper limbs' kinematics

Figures 5 and 6 present the simple scattergram from right and left hands kinematics according to the musical cadence, respectively. There was a non-significant relationship between the right hand lateral displacement and the cadence imposed ($R^2 < 0.04$; $p = 0.87$). Meanwhile, the vertical displacement presented a significant relationship ($R^2 = 0.27$; $p < 0.01$). Both vertical and lateral velocities presented non-significant relashionships when increasing the candence ($R^2 = 0.11$; $p = 0.11$ e $R^2 < 0.04$; $p = 0.78$, respectively). For the left hand a non-significant relationship was verified for the lateral displacement ($R^2 < 0.04$; $p = 0.78$). The vertical displacement presented a significant relationship with the cadence imposed ($R^2 = 0.22$; $p = 0.02$). The left hand lateral velocity presented significant relationships ($R^2 = 0.36$; $p < 0.01$) with the cadence. The same phenomena was not verified for the vertical velocity ($R^2 = 0.11$; $p = 0.11$).

Lower limbs' kinematics

Figures 7 and 8 present the simple scattergram from right and left foot kinematics according to the musical cadence, respectively. There were no relationships between the right foot vertical and lateral displacements and the cadence imposed ($R^2 = 0.07$; $p = 0.12$ and $R^2 < 0.04$; $p = 0.74$, respectively). For the right foot vertical velocity, there was a positive and non-significant relationship with the increasing cadence ($R^2 < 0.04$; $p = 0.86$). However, increasing cadence imposed significant relationships with the right foot lateral velocity ($R^2 = 0.17$; $p = 0.04$). For the left foot, no significant relationships were verified between vertical and lateral displacements and the cadence imposed ($R^2 < 0.04$; $p = 0.31$ and $R^2 < 0.04$; $p = 0.51$, respectively). The vertical velocity presented no significant relationships with the increasing cadence ($R^2 < 0.04$; $p = 0.92$). Nevertheless, increasing cadence imposed positive, moderate and significant relationships between the left foot lateral velocity and the cadence ($R^2 = 0.37$; $p < 0.01$).

Discussion

The purpose of this study was to analyze the relationships between the head-out aquatic exercise "Jumping jacks"

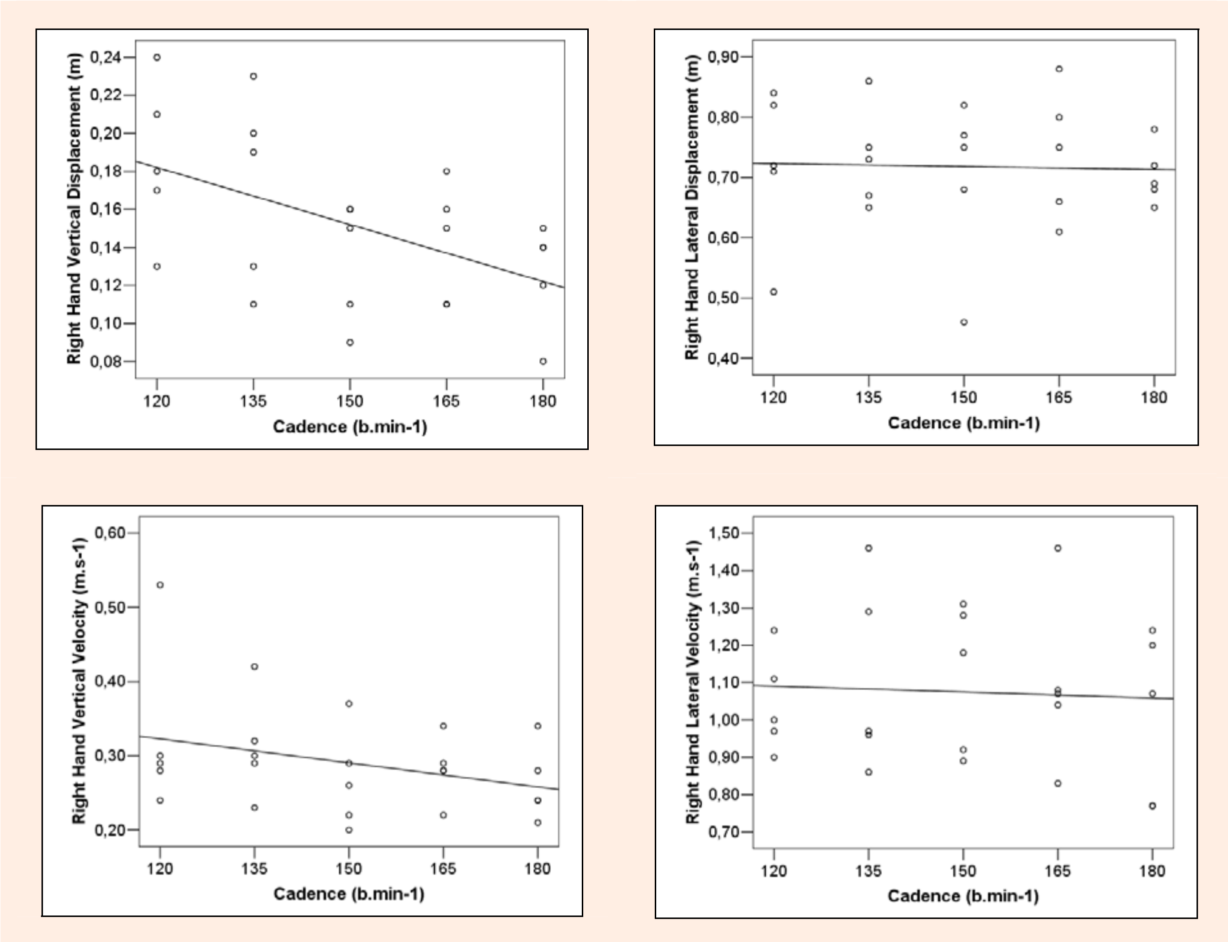

Figure 5. Simple scattergram from right hand's kinematics according to the musical cadence imposed.

kinematics' and the music cadence. Increasing the musical cadence, expert and fit subjects increase the lateral velocity of lower segments (i.e. feet) to maintain the range of motion. For the centre of mass and upper segments (i.e. hands) the vertical displacement is reduced to maintain the musical cadence.

It has been argued that musical cadences between 125-150 b·min^{-1} and 130-150 b·min^{-1} are the most suitable to maintain the full range of motion when exercising head-out aquatic exercises (Kinder and See, 1992; AEA, 2008). However, for Barbosa et al. (2010a), expert subjects with high fitness levels, are able to follow properly musical cadences, up to 150 b·min^{-1}, practicing this kind of aquatic programs. To the best of our knowledge, only a few number of kinematical studies aimed to understand the subject's behavior performing basic exercises up to their maximal intensity controlled by the musical cadence (Oliveira et al., 2010; 2011). However, those papers dedicated their attention to alternated limb actions. So, it seems not to exist any research about the kinematical response practicing exercises that perform simultaneous limb actions, as happens with "Jumping Jacks".

Centre of mass qualitative assessment

From a qualitative point of view, the center of mass vertical displacement and velocity presented a two-peak kinetics profile. Because "Jumping jacks" is a vertical jump exercise, both hoping actions imposed rise and fall movements, representing the upper and lower bounds of the centre of mass' curves. The center of mass reduced values of lateral displacement and velocity were characterized by a single-peak and multi peak kinetics profile, respectively. Requiring simultaneous actions from both sides of the trunk, the lateral displacement and velocity are much reduced during the vertical jump. So, the jumping and fall points are similar. The lower values presented for both variables were due to the micro imbalances induced by weight and impulsion force during the suspension phase, leading to a slight unstable balance while performing the exercise. Similar trend is verified for the "Side kick" with higher values for both lateral displacement and velocity components (Oliveira et al., 2011). The kicking action and the upper segmental moment (e.g. hands) impose a trunk lateral flexion and therefore a higher lateral displacement and velocity when kicking to the side (Oliveira et al., 2011).

Cycle period

It was hypothesized that increasing cadence would impose a decrease in the cycle period. The subjects decreased the cycle period during the incremental protocol. Cycle period is considered as being (Oliveira et al., 2010):

$$P = \sum_{i=1}^{n} t_i \quad (1)$$

Where P is the cycle period (in s) and t is the duration (in s) of each phase, being the exercise composed by i partial phases.

The duration of each phase can be computed as:

$$t_i = \frac{d_i}{v_i} \quad (2)$$

Where t_i is the duration of each partial phase of the exercise (in s), d_i is the segment displacement (in m) during the partial phase and v_i is the segment velocity (in $m \cdot s^{-1}$) during the partial phase.

The less time spent to perform the exercise is explained by the kinematical strategies adopted. For the upper segments, subjects decreased d_i and maintained the v_i. On the other hand, for the lower segments, the v_i was increased to keep the d_i when increasing the cadence. Similar trend for increased velocity strategy was observed for expert and fit subjects while performing kicking (Oliveira et al., 2011) and rocking (Oliveira et al., 2010) exercises. Authors suggested that the data reported in previous studies was related to the sample subject's profile. They were expert and fit subjects (i.e. head-out aquatic exercise instructors) that were aware from the need to maintain at all time a full range of motion performing basic exercises, independently from the cadence imposed (Oliveira et al., 2010; Oliveira et al., 2011). Thus similar explanation can be taken into account for this study.

Centre of mass kinematics

There were no significant relationships between center of mass lateral displacement and velocity. Jumping jacks is a basic exercise that requires a simultaneously action of the four limbs. Because the jumping and fall points are quite similar, it is difficult to obtain significant changes in the lateral components of any kinematical variable selected. So, the slight lateral changes observed during the suspension phase were due to the movement characteristics. In a vertical point of view, there was a significant and negative relationship between vertical displacement and cadence, while the velocity remained stable. The velocity represents a unique combination of displacement and the time spent to cover that specific distance. As the cycle period decreases at higher cadences (Oliveira et al., 2010; 2011), there is less choice of combine the vertical velocity and displacement. Moreover, when jumping on water, body is submitted to the buoyancy and drag forces (Rafaelli et al., 2010). To increase the center of mass vertical velocity, subjects needed to produce higher mechanical impulse to jump. However, the jumping range will be higher and, as a consequence, the buoyancy and drag effect will impose more time to return to the neutral position. Taking into account that the center of mass vertical velocity remained stable, the only kinematical strategy was reducing the jumping range throughout the incremental protocol.

Upper limbs' kinematics

For the hands, only the vertical displacement presented a significant and negative relationship with the music cadence. The remaining variables were not related to the musical cadence. For land-based movements, the fluid(air) presents a constant resistance in all anatomical

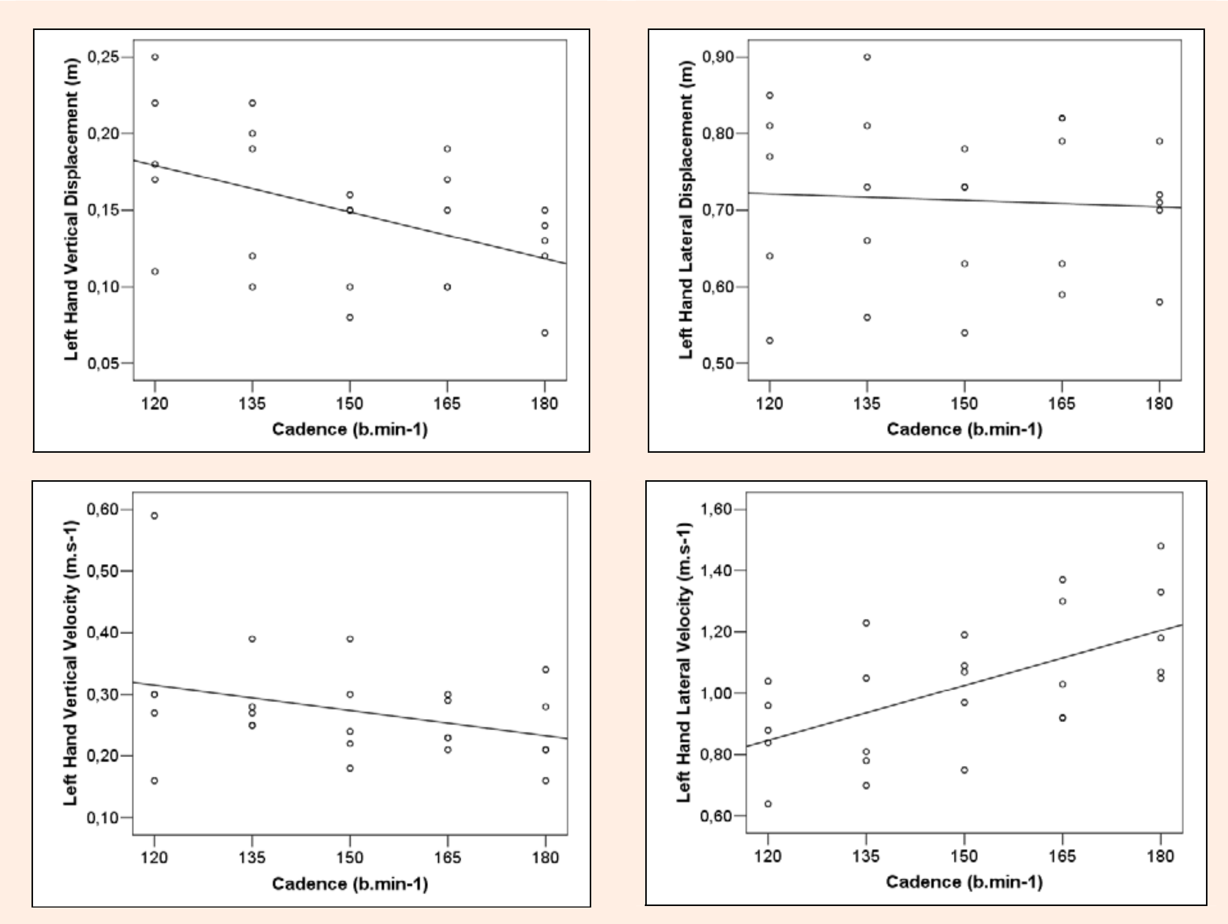

Figure 6. Simple scattergram from left hand's kinematics according to the musical cadence imposed.

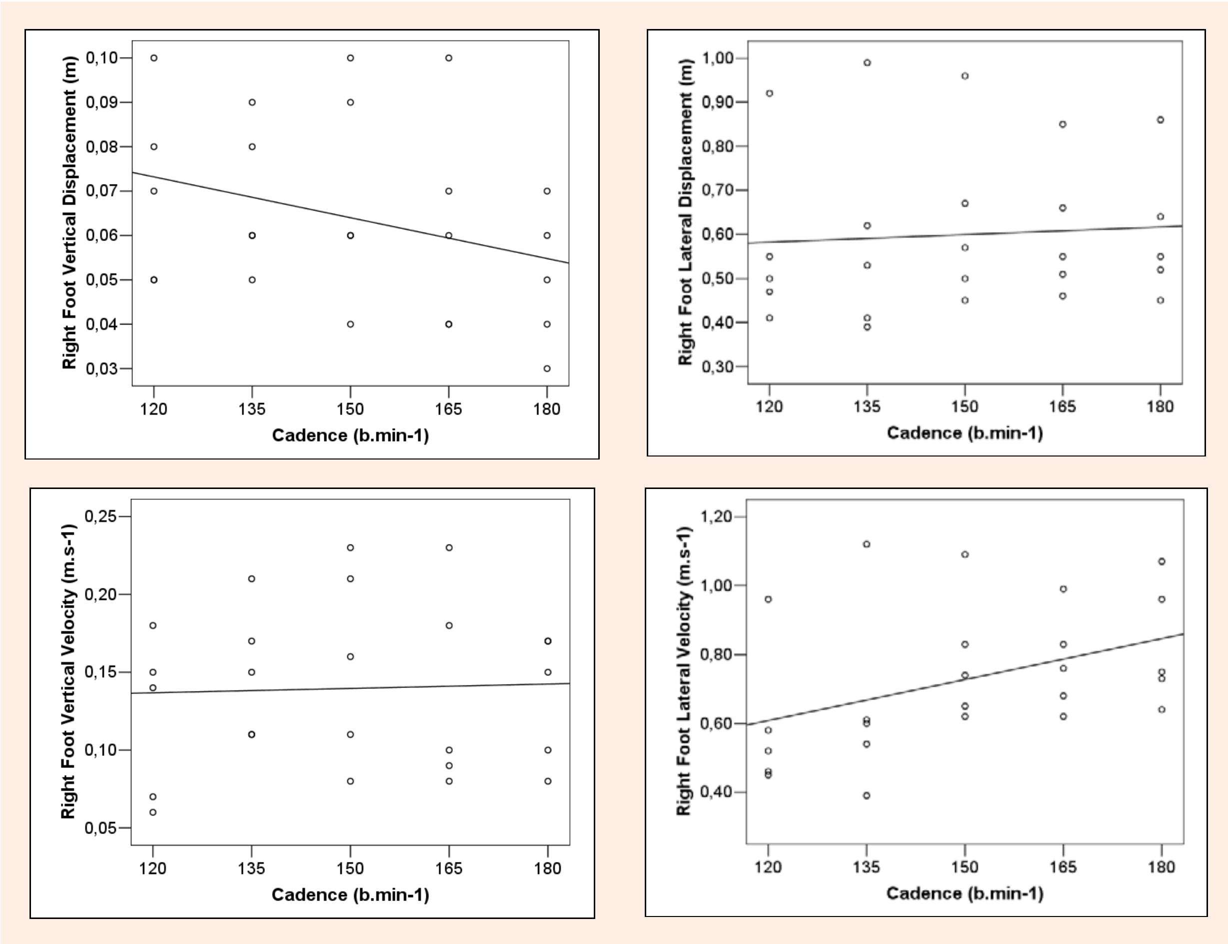

Figure 7. **Simple scattergram from right foot's kinematics according to the musical cadence imposed.**

reference planes. In the aquatic environment, a greater effort is necessary to move the body due to the higher density and viscosity of this fluid, generating an increased drag force (Alberton et al., 2011). In addition, the increasing cadence imposes a higher movement frequency and velocity. As velocity increases subjects are submitted to an increased drag force as well, and a higher metabolic power is required to overcome such external force (Barbosa et al., 2009). Previous studies showed for alternating exercises that expert and fit subjects were able to increase their upper limbs velocity maintaining the range of motion at higher cadences (Oliveira et al., 2010; 2011). However, in those alternating exercises a lower upper limbs range of action was observed when compared to Jumping jacks upper limbs drills. Despite the abduction action being assisted by buoyancy, acting upward, the opposite effect is observed for the adduction action. As the cycle period was reduced during the incremental protocol, there was a single combination of the upper limbs vertical velocity and displacement. So, aiming not to reach fatigue soon, the kinematical strategy adopted was to maintain the upper limbs segmental velocity and to decrease their range to follow the music cadence.

For instance, if with increased cadence the CM and upper limbs vertical displacements were reduced, we can expect an increase in power output with musical cadence. Power output was not measured in this study, although speculations can be made that the relationship with the cadence will be non-linear. At least one study reported neuromuscular evidences during stationary running (Alberton et al., 2011). Although the increase execution at submaximal cadences not corresponded to an increase in the neuromuscular response, significant increases were seen between submaximal cadences and the maximal velocity (Alberton et al., 2011). In this sense is possible to exist a critical cadence to maximize power output maintaining the full segmental range of motion while performing this type of exercises.

Lower limbs' kinematics

Most of the variables (i.e., vertical and lateral displacements and vertical velocity) presented no significant relationships with the increasing cadence. Significant data was only observed for the foot lateral velocity. Due to some anatomic characteristics, it is known that the upper limbs range of motion is higher when compared to the lower ones. Using frontal plane as reference, the arms (i.e., abduction/adduction) are able to reach a higher range than the legs. This difference between upper and lower limbs is even more notorious considering the simultaneously action of the four limbs. From a qualitative point of view, it is expected a movement with vertical focus for the upper limbs and a lateral focus for the lower ones. As a consequence, the drag force imposed to the lower segments is lower than for upper ones. For this reason, when increasing the music cadence it was possible to increase the lower limbs segmental velocity to maintain the range of motion. Similar trend was reported as well for some of

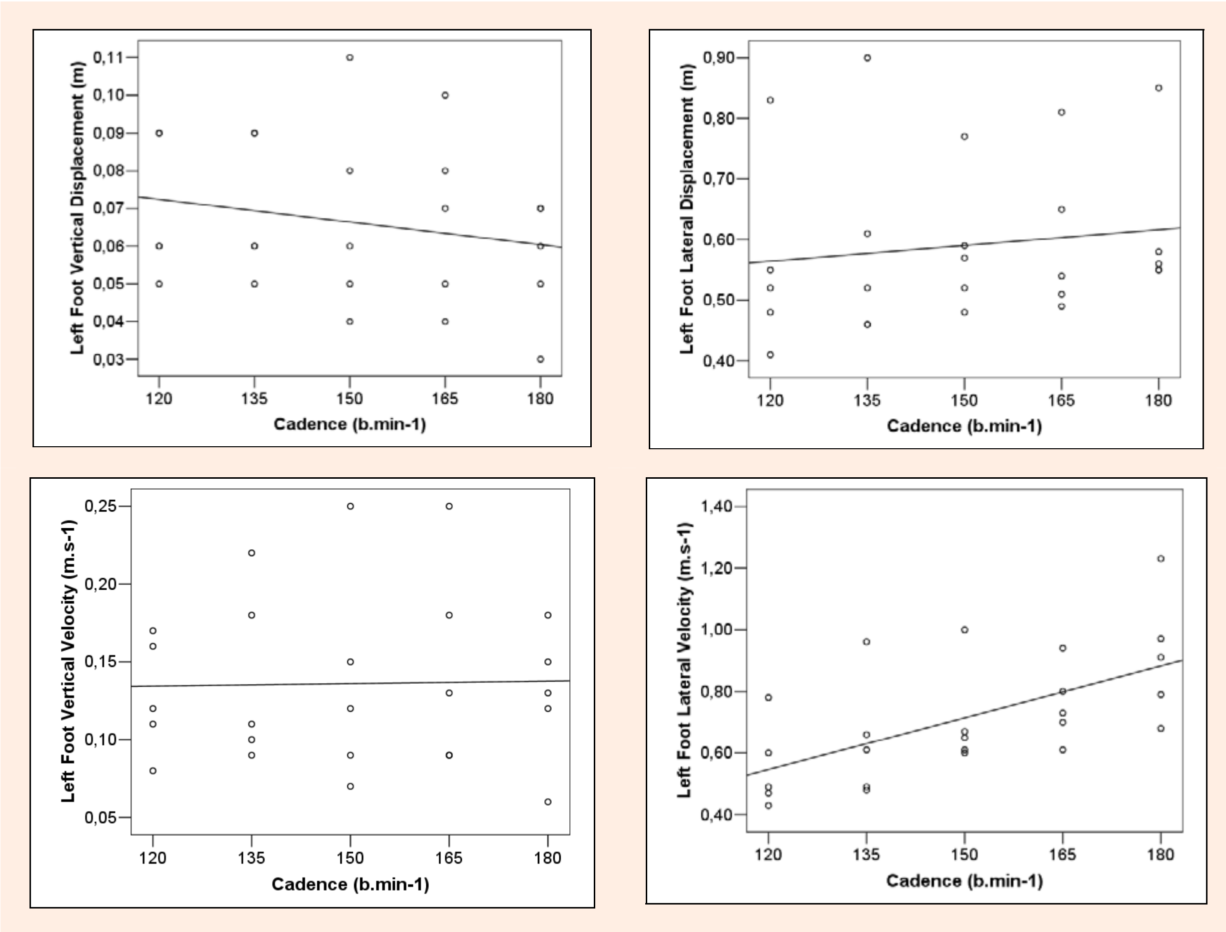

Figure 8. Simple scattergram from left foot's kinematics according to the musical cadence imposed.

the head-out basic exercise main groups such as: (i) Walking (e.g., Kato et al., 2001); (ii) running (e.g., Alberton et al., 2011); (iii) kicking (e.g., Oliveira et al., 2011) and; (iv) rocking (e.g., Oliveira et al., 2010) during incremental protocols.

Some limitations should be addressed: (i) the reduced sample size (and therefore the statistical power); (ii) the high fitness level of the sample group (so, data is only representative of the kinematical strategies employed by this kind of subjects) and; (iii) it was analyzed a basic jumping exercise (i.e., performing the same limb action with the four segments simultaneously and in the same anatomical reference plane) that might not be representative of other more challenging jumps from the inter-limb synchronization point of view.

Conclusion

As a conclusion, performing the "Jumping jacks" exercise, expert and fit subjects increased the lower limb's velocity to maintain the range of motion. At the same time, the upper limb's displacement is reduced to coupe the music cadence. It appears that, for exercise drills with simultaneous limb actions, expert and fit subjects have a similar kinematical response that is used for alternated limb actions (e.g., walking, running, kicking or rocking). Head-out aquatic exercise instructors should be aware of the possible kinematical responses throughout increasing cadences, manipulating it according to the movement focus aiming to maximize the power output. Future research should focus on the relationships between increasing cadence and power output in order to determine the critical cadence intervals for power enhancement.

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Key points

- While performing the Jumping Jacks, expert and fit subjects increase their lower limbs segmental velocity to maintain the range of motion.
- The upper limbs displacement is reduced to maintain the music cadence.
- Expert and fit subjects present similar response for alternating or simultaneously head-out aquatic exercises when increasing the music cadence.

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