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Understanding the Effect of Age on Force Production and Symmetry during Water Exercises: Differences between Young Adults and Older Women

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Abstract: Participants from across the age span participate in water fitness sessions. This challenges instructors to create proper exercise prescriptions. The aim of this study was to understand the effect of age on force production and symmetry during water exercises. Twenty-six women were categorized into two groups: (i) young adult (n = 13; 23.61 ± 1.15 years) and (ii) older (n = 13; 67.38 ± 3.48 years). Women performed a horizontal upper limbs adduction during an incremental protocol comprising four music cadences increased every 30 s (105, 120, 135, and 150 b·min^{-1}). A differential pressure system composed of two sensors was used to measure the in-water force and to estimate the symmetry index. Young adults showed higher in-water forces (43–67 N) when compared with their older counterparts (31–55 N). No differences were observed between groups for the symmetry index. The cadences of 105–120 and 120–135 lead to different in-water force of the dominant limb in both groups, while the force of the non-dominant limb showed mix-findings. In conclusion, water fitness instructors should be aware that the same music cadence may trigger different kinetic behaviors in different ages, but without impairing symmetry when exercising at 120–135 b·min^{-1}.

Keywords: biomechanics; pressure sensors; asymmetries; cadence; head-out aquatic exercises

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Citation: Santos, C.C.; Soares, S.; Costa, M.J. Understanding the Effect of Age on Force Production and Symmetry during Water Exercises: Differences between Young Adults and Older Women. *Appl. Sci.* **2023**, *13*, 7904. https://doi.org/10.3390/app13137904

Academic Editors: Dana Badau, Adela Badau and Philip X. Fuchs

Received: 13 May 2023
Revised: 3 July 2023
Accepted: 4 July 2023
Published: 5 July 2023

1. Introduction

Water fitness programs have become one of the most popular physical activities within the health primary and tertiary prevention systems mainly due to their benefits for health, such as reducing weight [1] or improving older peoples' balance [2]. The water proprieties arise as being accountable for the popularity achieved in this type of physical activity [3]. The reduced effect of body weight (weight-bearing) due to buoyancy and multidirectional load linked to the drag force acts favorably in adherence to this type of program [4,5]. These often include muscular conditioning as some part of the sessions aiming to improve participants' strength and conditioning, as well as, to help in the rehabilitation from an injury episode [6]. Those programs are widely chosen by participants of different age groups, gender, fitness levels, and/or health conditions. Although attendance prevails in older women, water exercise also promotes several health-related benefits in young adults and middle-aged participants, e.g., [7,8].

Water fitness exercises are commonly reported as "head-out aquatic exercises" and can be coupled into six main groups [9] with distinct variants (i.e., number of limbs, added material) being employed for the session diversification. Within this, music cadence is essential to achieve the desired level of exertion and to obtain synchronization with a specific movement [10]. Acute physiological and biomechanical responses derived from increases in music cadence have become widely reported in the water fitness literature [4,11]. Within the biomechanics domain, the effect of music cadence in movement kinematics has taken most of the attention, and just a small amount of research has been directed to movement kinetics. The previous literature has reported that an increase in music cadence led to an increase in segmental velocity [12] and therefore in drag force [4]. The same behavior seems to occur with the in-water forces, as an increase in music cadence promotes a consequential increase in the in-water force of the upper limbs during basic water exercises [13,14]. Still, a paucity of information remains about in-water forces, mostly when searching for a comparison between different groups.

The available literature has given special attention to particular target groups (e.g., older women), but most water fitness sessions are heterogeneous. Men and women of different ages, fitness levels, or social backgrounds can be found in a single session. At least from a sex comparison point of view, young adult men showed higher in-water forces when compared with women from the same age range [15]. However, it remains unclear if participants from the same sex, but with different ages, show different in-water kinetic behaviors. At least in the physiological domain, different acute responses should be expected while performing a basic water exercise. Bartolomeu et al. [16] found that an increase in effort seemed to trigger different physiological responses in young and older women, with the lower values being detected for the older group. It is well known that the aging process is associated with a decline in muscle mass and therefore in strength [17] and with changes in motor control affecting coordination [18]. Older women seem not able to reach symmetric motion while exercising at different music cadences [19], but young adults tend to be more symmetric at the cadence of 135 b·min^{-1} [13] while performing horizontal adduction of upper limbs. So, understanding kinetic behavior in a broad range of ages (young vs. older) and through a larger spectrum of music cadences could help water fitness instructors design and plan programs according to the target groups, even if they belong to the same class or are part of the same session.

The aim of this study was to understand the effect of age on force production and symmetry during the horizontal adduction performed at different music cadences. A comparison according to upper limbs and different music cadences was also run. It was hypothesized that young women would show higher in-water forces and older women would be more likely to show asymmetries while exercising. The music cadence will influence the kinetic behavior of both groups.

2. Materials and Methods

2.1. Participants

Twenty-six healthy women, thirteen young adults (23.61 ± 1.15 years; 61.72 ± 7.94 kg of body mass; 161.36 ± 6.51 cm of height; 23.15 ± 3.12 kg/m^2 of body mass index) and thirteen older women (67.38 ± 3.48 years; 72.30 ± 11.03 kg of body mass; 158.82 ± 4.55 cm of height; 27.23 ± 2.10 kg/m^2 of body mass index), enrolled in the same regular water fitness program volunteered to participate in the present study. Initial recruitment was based on voluntary enrollment available to all classes of the fitness center, but only the class with sufficient young and adult women was considered to participate in this study.

Women were categorized into two groups based on chronological age: young adults women aged ≤30 years; and older women aged ≥65 years. All participants were clinically healthy with at least one year of experience in water fitness programs. They were excluded if they had not attended two water fitness sessions per week since the water program started, if they were unable to perform the protocol, or if in the past six months (from the beginning of the study) they were diagnosed with an injury, condition, or syndrome of a given nature. All women were informed of the benefits and experimental risks prior to signing the informed consent. All procedures were in accordance with the Declaration of Helsinki with respect to human research.

2.2. Anthropometric Data Collection

Several anthropometric measures were retrieved with all women using their normal swimming suits. The body mass and stature were measured by a single person. Body mass was measured to the nearest 0.1 kg using a portable scale (TANITA, BC-730, Amsterdam, The Netherlands). Women stepped on the scale barefoot wearing only a regular swimsuit and cap. The stature was measured to the nearest 0.1 cm using a portable stadiometer (Seca, 242, Hamburg, Germany). Women stayed in an orthostatic position (i.s., standard anatomical position) with their heels, back, and head against the wall, while their feet remained flat on the floor. The stadiometer headpiece was carried to the top of the head, and the measurement was taken during an extensive inhale. The body mass index was calculated as the ratio of body mass by the squared height (in kg/m^2). Women's hand dominance was obtained by self-report.

2.3. In-Water Protocol

Women were instructed to refrain from intense exercise, and data collection was performed at the same time of the day to avoid systematic bias. They were also instructed to maintain their normal nutritional routines, avoiding caffeine intake.

The in-water protocol was held in a 12.5 m indoor pool with a water temperature set at 29.5 °C and relative humidity at 55%. A 3 min warm-up (performed at low amplitude and impact) was prescribed by a certified water fitness professional including several basic water exercises. After that women were instructed to perform a horizontal adduction of the upper limbs during an incremental protocol of music cadences. The exercise is characterized by maintaining a full extension of the upper limbs with both hands positioned at a 90° angle considering the water surface. The lower limbs remain fixed to the ground with a scissor position and with the trunk in a static position. A more detailed informative description of the water fitness exercise was presented by Santos et al. [13]. As the selected exercise is prescribed on a daily basis, familiarization was not required. So, women were instructed to maintain the level of water surface near of xiphoid process [20]. Since participants presented different heights, the water surface boundary for each participant was modified and controlled by the water depth of the pool and confirmed with visual inspection by the same certified professional.

The incremental protocol comprised four music cadences (105, 120, 135, and 150 b·min^{-1}) increased by 15 b·min^{-1} every 30 s. Each cadence was conducted at "water tempo", meaning that in every two musical beats, women made their two upper-limbs' abduction. All women were familiarized with the exercise and the concept of "water tempo" and followed the music metric throughout the test. The music cadence was controlled by a metronome (Korg, MA-30, Tokyo, Japan) plugged into a sound system. The metronome was used to avoid the influence of the music's melody in the women's exercise. The amplitude of the movement was checked by visual inspection, and the test ended when participants failed to maintain the music cadence synchronized with the movement or when they reached 30 s of exercise duration. Despite this, the certified water fitness professional remained on the pool deck giving intermittent verbal and visual feedback during every cadence.

2.4. In-Water Data Collection

The in-water behavior was interpreted on the basis of kinetic or symmetry domains. In-water force was measured during the incremental protocol using a reliable [21] differential pressure system composed of two hand sensors (Type A, Swimming Technology Research, Richmond, VA, USA). Inside each sensor, there is a diaphragm that flexes which is sensed as an electrical signal that is proportional to the difference in the two pressures. Each sensor measures the pressure component acting perpendicular to it. Both sensors were positioned between the third and fourth metacarpals (Figure 1). It has been assumed that this place is a good proxy of the application of pressure vector on the hand. This system measures pressure differences between the palmar and dorsal surfaces of both hands, and therefore the resultant hand force (in Newtons, N) is derived from the product of the differential pressures and the hand surface area (in cm^2). The hand surface area of dominant and non-dominant limbs was measured by digital photogrammetry. Women were instructed to place each hand on a flat surface (i.e., scanning machine) with a 2D calibration frame (3 × 3 cm), and from there all images were converted into PFD files and exported to a specific on-screen digitizer (Universal Desktop Ruler, v3.8, AVPSoft, Pittsburgh, PA, USA). The sensor's cable was placed on each woman with shoulder/arm elastic straps and connected to a two-channel A/D converter plugged into a laptop with the Aquanex software (v.4.1, Model DU2, Swimming Technology Research, Richmond, VA, USA). The system was calibrated as reported elsewhere [21], and the data were acquired with a sampling frequency of 100 Hz.

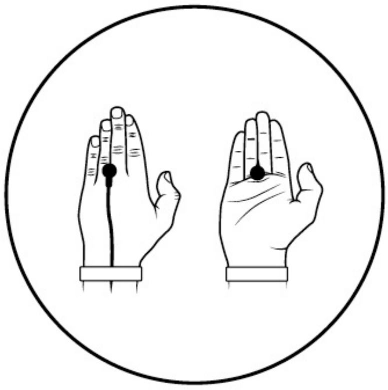

Figure 1. The differential pressure system (Aquanex System) used to measure in-water force.

Data were imported into a signal-processing software (AcqKnowledge v.3.7.3, Biopac Systems, Santa Barbara, CA, USA), and the signal was smoothed with a 5 Hz cutoff low-pass fourth-order Butterworth filter. The resultant peak force (F_{PEAK}, N) of the dominant (D) and non-dominant (ND) upper limb was defined as the maximum value obtained from the underwater force–time curves of the horizontal adduction. However, the first positive and negative peaks (one cycle) were discarded to avoid bias. In the case of symmetry, a Symmetry Index (SyI, %) was estimated as proposed by Robinson, Herzog, and Nigg [22]. The calculation gathers the force produced by the dominant and by the non-dominant upper limbs. The symmetry data were interpreted as if SyI = 0%, perfect symmetry; if 0% > SyI < 10%, symmetric motion; if SyI $\geq$ 10%, asymmetric motion.

2.5. Statistical Analysis

The sample size required was computed beforehand (GPower, v.3.1.9, University of Kiel, Kiel, Germany). Exploratory data analysis was used to identify potential outliers. The Shapiro–Wilk and Levene's tests were computed to assess the samples' normality and homogeneity, respectively. The mean and one standard deviation (M $\pm$ 1 SD) were computed as descriptive statistics for all variables. Since normality was found, an unpaired *t*-test with 95% confidence interval (CI) was used to compare differences between groups (i.e., young adults vs. older women) in all variables. Cohen d [23] was selected as an effect size (ES) measure and interpreted as small if $|d| < 0.5$, moderate if $0.5 > |d| < 0.8$, and large if $|d| \geq 0.8$. All statistical analyses were performed using the SPSS software (version 27, IBM, Chicago, IL, USA), and the significance was set at $p \leq 0.05$.

3. Results

Figure 2 depicts a typical underwater force–time curve during horizontal adduction of upper limbs. A single peak profile is shown for the horizontal adduction, with the peak force value happening nearest 60% of the adduction phase. Moreover, using visual inspection, the peak force value clearly differs between the young and the older women group during the horizontal adduction phase.

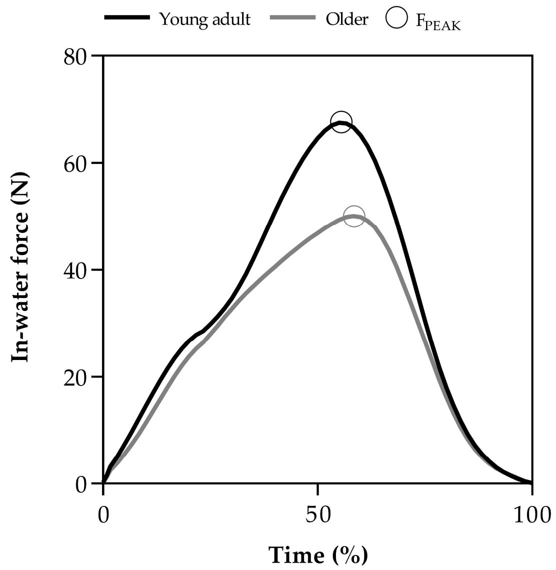

Figure 2. Example of the underwater force–time curve between young adult women (black line) and older women (gray line) during the horizontal adduction. F_{PEAK}, resultant peak force.

The kinetics and symmetry comparison between young adults and older women are shown in Table 1. Moderate to large effects were found for the in-water force variables throughout the incremental protocol of music cadences. Young adults depict higher in-water forces when compared with their older counterparts. However, no differences were observed for SyI (just presenting small to moderate effects).

Table 1. Descriptive statistics and comparison of age groups in force production and symmetry.

Music Cadence	Variable	Age Group		Mean Difference(95 CI)	*p*	ES
		Young Adult	Older			
105 b·min^{-1}	F_{PEAK} D (N)	44.14 ± 7.19	35.82 ± 8.01	8.32 (2.16 to 14.48)	0.010	1.09
	F_{PEAK} ND (N)	43.40 ± 8.04	31.37 ± 8.59	12.04 (5.30 to 18.77)	0.001	1.45
	SyI (%)	10.77 ± 7.58	15.75 ± 12.75	−4.98 (13.47 to 3.51)	0.238	0.47
120 b·min^{-1}	F_{PEAK} D (N)	50.10 ± 6.59	42.53 ± 8.62	7.33 (1.20 to 13.47)	0.021	0.99
	F_{PEAK} ND (N)	48.22 ± 8.47	41.48 ± 9.52	7.51 (0.40 to 14.62)	0.039	0.75
	SyI (%)	10.66 ± 8.84	13.58 ± 9.41	−2.92 (−10.32 to 4.47)	0.422	0.32
135 b·min^{-1}	F_{PEAK} D (N)	55.83 ± 9.42	49.85 ± 6.50	8.44 (2.77 to 14.11)	0.005	0.74
	F_{PEAK} ND (N)	56.18 ± 9.58	46.05 ± 9.71	11.44 (4.40 to 18.49)	0.003	1.05
	SyI (%)	10.24 ± 5.95	13.46 ± 15.52	−3.22 (−13.03 to 6.58)	0.495	0.27
150 b·min^{-1}	F_{PEAK} D	63.36 ± 10.04	55.47 ± 9.13	8.35 (0.75 to 15.96)	0.033	0.82
	F_{PEAK} ND	67.05 ± 13.84	49.75 ± 9.98	17.30 (7.53 to 27.06)	0.001	1.43
	SyI (%)	11.74 ± 5.73	17.47 ± 12.27	−5.73 (−13.65 to 2.20)	0.146	0.60

%, percentage; b·min^{-1}, beats per minute; D, dominant upper limb; ES, effect size; FPEAK, resultant peak force; ND, non-dominant upper limb; N, Newton.

Figure 3 shows the comparison of music cadences and upper limbs throughout the incremental protocol according to each age group. Differences were found between cadence 105–120 and 120–135 b·min^{-1} in the force of the dominant limb for young adult women (Panel A) and older women (Panel B). The F_{PEAK} of non-dominant limb was different between all music cadences for young adult women, while it remained similar in older women (except between cadences 105 and 120 b·min^{-1}). Despite this, the overall trend was to increase F_{PEAK} from a slower to faster music cadence. No differences were found between the dominant and non-dominant limbs at the same cadence in the young adult group. However, the F_{PEAK} of older women differs according to limbs at the cadence of 105 and 150 b·min^{-1}.

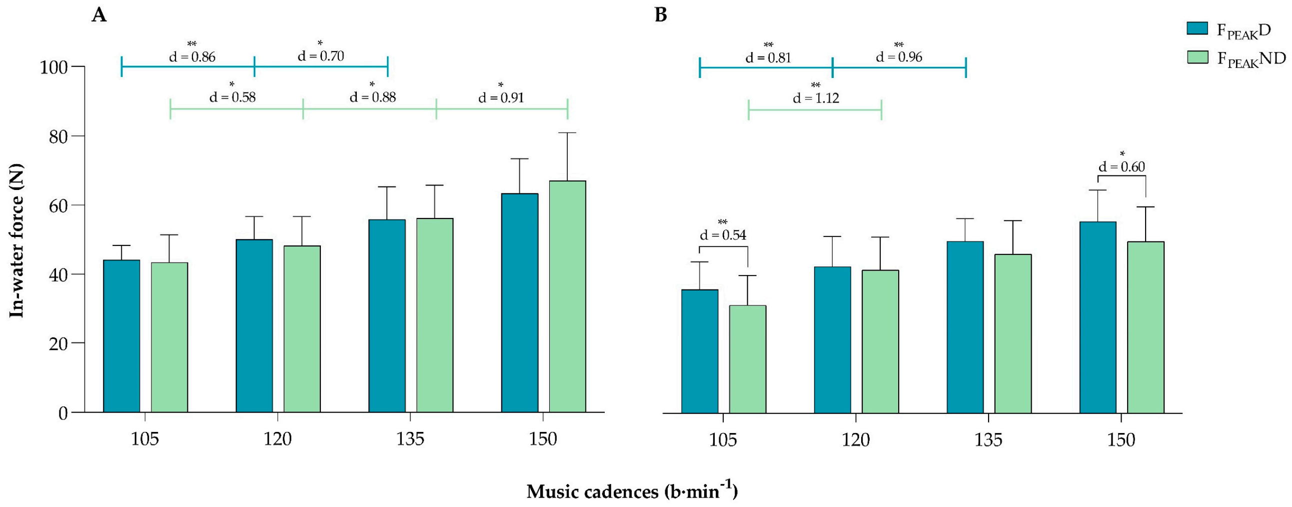

Figure 3. Comparison of music cadences and limbs according to young adult (Panel (**A**)) and older women (Panel (**B**)). Blue bars represent the resultant peak force (F_{PEAK}) of the dominant upper limb (D), while green bars represent the non-dominant upper limb (ND). *, $p \leq 0.05$; **, $p \leq 0.01$.

4. Discussion

The aim of this study was to understand the effect of age on force production and symmetry according to upper limbs and different music cadences. Young adults and older women showed different kinetic behavior when performing horizontal adduction at different music cadences, but symmetry was similar between both. The cadences of 105–120 and 120–135 b·min$_{-1}$ lead to the different in-water force of the dominant limb in young adults and older women, while the force of the non-dominant limb showed mix-findings.

Young adult women applied around 43–67 N of force while older women applied around 31–55 N during the incremental protocol of music cadences. The previous literature has reported slightly lower values than those found in the present study. For instance, Santos et al. [16] found that older women applied around 31 N at the cadence of 150 b·min^{-1} while performing horizontal adduction of upper limbs. Despite this, Santos et al. [10] found that young adult participants (men and women) were able to apply around 50 N at the same cadence, but only the dominant limb was reported. Prins et al. [24] noted in a clinical population values near 45 and 60 N for the right and left hand, respectively, during horizontal arm adduction at maximum velocity. Although arms act as a fundamental lever, the hand and finger positions may influence kinetic behavior. As seen previously, a higher drag force can be reached when hands are positioned perpendicular to the flow [25] and when fingers adopt a small spread [26]. Even though intermittent verbal and visual feedback was given, the kinematic behavior was not controlled for further analysis. So, one can be argued that the perception of correct body segmental alignment and orientation (i.e., the expertise level of the participants) could influence the kinematics and, therefore, the kinetic behavior. Another explanation from diverse results may be related to data computation and analysis when considering the hand surface area. So, this should be kept in mind when comparing data in further studies.

The motion patterns in the water have been analyzed over the years in different basic exercises, e.g., [12], with different strategies while using the limb (e.g., alternating vs. simultaneous) [14] and adding resistive or fluctuating material, e.g., [27]. Nonetheless, water fitness instructors face heterogeneous groups in their daily water fitness sessions. So, providing proper knowledge about acute responses, namely from a kinetic point and according to the age of participants, could help them to design a proper program to achieve the desired level of exertion for all. To the best of our knowledge, this is the first study to provide data about kinetic behavior according to different age groups. As expected, young adult women were able to apply a greater amount of force than their older counterparts. Differences were around 7–8 N for the dominant limb and ranged between 8 and 17 N for the non-dominant limb. It is well-documented that the aging process leads to a natural loss of muscle mass with an increase in body fat [17]. This happens mostly above 60 years old accompanied by a decline in the neuromuscular system [28]. So, the ability to generate force tends to rapidly decline within advancing age when compared with maximum strength [29]. Due to the atrophy of type II muscle fibers [30], physiological responses (i.e., blood lactate) also tend to be lower in such cohort [16]. Thus, instructors should give special attention to the effect of age as different behaviors can arise within the same water fitness session. Our hypothesis was only partially confirmed, as both groups were similar in the symmetry index throughout all music cadences.

An increase in segmental velocity imposed by higher music cadences [12] will lead to an increase in resistance while performing water fitness exercises [4]. For land-based movements, the fluid (air) presents a constant resistance in all anatomical 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. So, a greater force will be needed to overcome such resistance imposed by the water mostly at a higher movement frequency. This trend was shown in the present study as an effect of music cadence was observed in the resultant peak force. That is, the higher the music cadence, the more force was necessary. However, this behavior seems more evident in young adult women for both upper limbs. While assessing 27 older women, Santos et al. [19] found that an incremental protocol imposes different kinetic behaviors for all music cadences. However, it should be noted that authors used women of $\geq$60 years old. Another study, but with young adult men and women, also reported increases in force through an incremental protocol [13]. So, this trend should be expected and seems not an age-related behavior.

Another key issue is the muscle imbalances that can elapse from asymmetric actions which can increase susceptibility to a chronic injury. The persistence in asymmetric patterns that came when analyzing both sides of the body can deteriorate the current status of a given joint impairing, in some cases, daily life activities. Although no differences were found between upper limbs in the young group, the cadences of 105 and 150 $b \cdot min^{-1}$ demonstrated a limb effect in the older group. These results seem to be in agreement with the values observed in the symmetry index. Bodies are expected to be asymmetrical by nature, but with advancing age coordination decreases [18]. It seems that older women are not comfortable exercising at lower or higher cadences than young adult women, where the motion pattern may require different muscle coordination and activation than they are used to. Indeed, this trend to find a more asymmetric motion at very lower and higher cadences corroborate previous literature [15,19]. This means that the cadences ranging from 120 to 135 $b \cdot min^{-1}$ may be most suitable to maintain symmetry in older populations and even can be the best strategy to work with heterogeneous groups. In fact, it has been argued that musical cadences between 125 and 150 $b \cdot min^{-1}$ are the most suitable to maintain the full range of motion when exercising water fitness exercises. However, for Barbosa et al. [31], expert subjects with high fitness levels are able to follow proper musical cadences, up to 150 $b \cdot min^{-1}$. This is in agreement with our study, since symmetry in young adults was not compromised at higher music cadences. So, at some point, instructors can go further than the 135 $b \cdot min^{-1}$ if their class is mostly composed of young adults.

Some limitations of the present research can be pointed out: (i) not including a kinematic analysis to control the range of motion and (ii) not using a larger spectrum of music cadences. The kinetic behavior in the aquatic environment remains a challenging topic to be studied. Although kinetic responses were already tested according to the age of the participants, future approaches should rely on chronic adaptations through these various cadences or consider different water fitness exercises. More studies with men participants are welcome to understand the kinetic behavior with sex as a factor. A biophysical approach (i.e., physiological accompanied by a biomechanical assessment) should also be a point of interest in the future.

5. Conclusions

It can be concluded that young adult women are able to deliver higher in-water forces than older women when performing horizontal adduction at the same music cadence. Symmetry seems not to be an issue that can distinguish behaviors between groups. Still, the water fitness instructors should be aware that the use of mid-range cadences (120–135 b·min^{-1}) might be the most suitable strategy to implement in water fitness sessions with heterogeneous groups. At the different stages of the annual plan and considering the degree of heterogeneity of their classes, the water fitness professionals can direct the focus of the exercise prescription for strength development or coordination work type (on the basis of symmetry) by choosing the proper cadences to work with.

Author Contributions: Conceptualization, C.C.S. and M.J.C.; methodology; C.C.S. and M.J.C.; formal analysis, C.C.S.; investigation, C.C.S. and S.S.; writing—original draft preparation, C.C.S.; writing—review and editing, S.S. and M.J.C.; funding acquisition, M.J.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Portuguese Foundation for Science and Technology (FCT) under the project UIDB04045/2020.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the local Ethics Committee.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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