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Inter-Limb Symmetry at Simultaneous and Alternated Arms Flexion by the Elbow during Water Fitness Sessions

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Abstract: The aim was to compare the inter-limb symmetry between alternated and simultaneous arms flexion during water fitness sessions. Twenty-three elderly women were recruited to perform flexion by the elbow with different mechanical strategies: (a) simultaneous and (b) alternated. An incremental protocol was used, with four music cadences, starting at 105 beats per minute up to 150. The peak force of dominant and non-dominant upper-limbs was retrieved. A symmetry index (SI, %) was also used to quantify coordination. There were significant variations in force produced by the dominant and non-dominant limbs in most of the cadences in the alternated or simultaneous actions. Differences with a medium effect between upper-limbs were shown when moving simultaneously indicating that an alternated movement can be a more proper strategy to work with. Despite that, both strategies seemed to be characterized by an asymmetric pattern (SI from 20 to 30%), requiring full attention from water fitness practitioners.

Keywords: water-based exercise; segmental action; coordination; asymmetries; older adults

1. Introduction

Popularity of water fitness programs has increased remarkably in the last years. It is reported as an effective way to enhance body posture and balance [1], rehab from musculoskeletal injuries [2], and improve the quality of life of special populations [3]. This means that body memory and structures may change by water exposure, giving the participants a more proper movement.

Water fitness practitioners use several exercises with variants and extensions within each session to work with and to reach the desired exertion. Walking, running, rocking, jumping, kicking, or scissors are the most used movements [4]. The addiction of different arm trajectories and strategies may increase the intensity of those movements or even increase complexity [5]. This has substantial importance when a specific part of the session is directed to build-up strength. It is known that human bodies are expected to be naturally asymmetrical when producing force. Here, the dominant body side starts to play an important role. This was already reported in simultaneous arms actions at higher cadences performing horizontal abduction and rocking horse [6]. However, it remains unclear if asymmetries between dominant and non-dominant limbs persist performing an alternated pattern or even if this kind of strategy is the most suitable.

Most water fitness sessions comprise of heterogeneous groups, being the elderly one of the main target groups. At this age, the central nervous system shows impairment in having a strong and accurate response to any required task [7]. As expected, the aging process leads to changes in motor control affecting bilateral coordination [8]. This implies experiencing changes in postural stability, balance, gait, and even in joint range of motion [9]. If asymmetric patterns persist at these ages, some deterioration can happen in the most sensitive joints, impairing, at the end, daily life actions. So, it is important to understand the kinetic behavior and coordination in different exercise modes at water fitness sessions. In simultaneous actions, the subjects need to disperse his/her attention for both upper limbs at the same time. Contrarily, during alternated tasks, the attention can be split in one time for each limb. In the end, this study is the first study to quantify in-water propulsive forces from the elderly at different mechanical strategies within the same exercise.

The aim of this study was threefold, to: (i) analyze and compare the force production during alternated and simultaneous upper-limbs flexion at various exercise intensities; (ii) analyze differences between dominant and non-dominant limbs during simultaneous and alternated elbow flexion, and (iii) quantify symmetry in both strategies. It was hypothesized that: (i) applied forces will increase with increasing cadence; (ii) dominant and non-dominant limbs would show different force outputs during the simultaneous action, but not for an alternated one; and (iii) both movements would be asymmetrical as seen in previous water tasks.

2. Materials and Methods

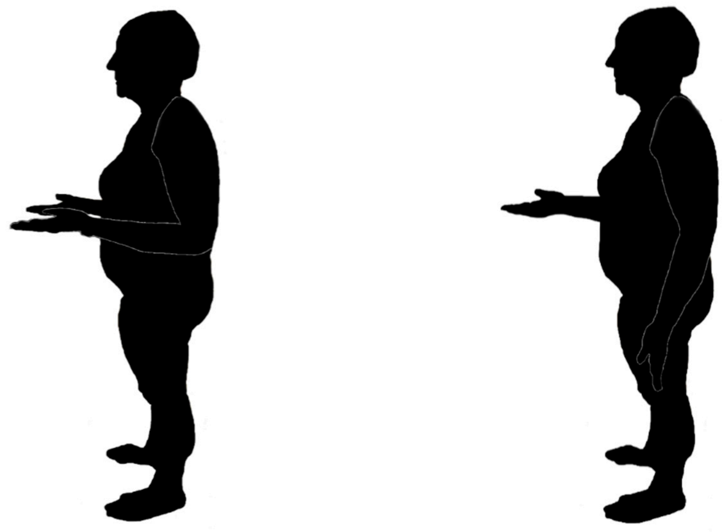
2.1. Participants

Twenty-three elderly women (age: 64.2 ± 7.2 years-old; body mass: 68.2 ± 9.3 kg; height: 158 ± 0.07 cm; and body mass index: 27.3 ± 2.9 kg/m^2) participated in this study. The inclusion criteria were defined as follows: (i) being more than 60 years-old; (ii) being physical active with at least one year of participating in water fitness sessions; and (iii) not showing a clinic report of any kind of injury in the past six months. An informed consent document dissecting all the experimental procedures was signed by the participants. All procedures were approved by the Institutional Ethics Committee showing agreement with the Helsinki Declaration concerning studies using human subjects.

2.2. Experimental Procedures

This study presents a randomized crossover design. The experiment was held in a 25 m indoor pool having 12.5 m width and maximal depth of 1.80 m. The water temperature was set at 29.5 °C. To avoid fatigue issues, women were randomly chosen to perform each water fitness exercise in separate days as following (Figure 1): (a) simultaneous upper-limbs flexion and (b) alternated upper-limbs flexion. A 3 min warm-up for each exercise preceded by stationary running at low amplitude and intensity (mean heart rate less than 100 bpm) was considered. The level of the water surface was set near the xiphoid process, as previously described [10].

Both selected exercise patterns are prescribed on a regular basis in water fitness programs. Each exercise was performed over an incremental protocol, with four music cadences, starting at 105 beats per min (b·min^{-1}) and increasing every 30 s by 15 b·min^{-1}, up to 150 b·min^{-1}. The music cadence was controlled by a metronome (Korg, MA-30, Tokyo, Japan) plugged-in to a sound system. Both exercises were performed at "water tempo" allowing the synchronization with the specific movement [11]. This means that each arm flexion (simultaneously or alternated) was done during two consecutive music beats. Verbal and visual cues were given to participants during the protocol. The test ended when the participant decreased the range of motion, failed to maintain the desired cadence, or completed the 30 s trial.



(**A**) (**B**)

Figure 1. The simultaneous (**A**) and alternated (**B**) upper limb flexion during the in-water upright position.

2.3. Measures

The force output was assessed by a differential pressure system [12]. The system (Aquanex, Swimming Technology Research, Inc., Florida, FL, USA) has two independent pressure sensors for data acquisition. Each sensor was positioned between the phalanges of the middle and ring fingers of both right and left hands. Measurements were made of: (i) the normal peak force of the dominant upper limb (PF_D, in *N*) and (ii) the normal peak force of the non-dominant upper limb ($PF_{ND,}$ in *N*). Data was exported using a signal-processor (AcqKnowledge v.3.7.3, Biopac Systems, Santa Barbara, CA, USA) with a 5 Hz cut-off low-pass 4th order Butterworth filter upon residual analysis. Based on adaptation purposes, the first cycle (showing a positive and negative peak) was not considered for further analysis. The symmetry index (**SI**, %) was used as a coordination measure and was estimated as proposed by Robinson et al. [13]:

$$\mathbf{SI}\ (\%) = \frac{2(\mathbf{x_d} - \mathbf{x_{nd}})}{(\mathbf{x_d} + \mathbf{x_{nd}})} \times 100 \quad (1)$$

where: $\mathbf{x_d}$ represents the force produced by dominant upper-limb and $\mathbf{x_{nd}}$ represents the force produced by the non-dominant upper-limb.

2.4. Statistical Procedures

An exploratory data analysis was performed to check potential outliers. The normality of the distributions was confirmed using the Shapiro–Wilk test ($p > 0.05$). Data were expressed as mean and standard deviation (SD). Repeated-measures ANOVA followed-up by the Bonferroni post-hoc test was used to verify differences in the force production between music cadences. A Student's *t*-test was conducted to compare peak force production between dominant and non-dominant upper limbs. The symmetry data was characterized as: perfect symmetry, if **SI** = 0%; symmetric motion, if 0% > **SI** < 10%; and, asymmetric motion, if **SI** ≥ 10%. The Cohen's d [14] was used as an effect size measure and interpreted as the following: (i) small effect (0.20 ≤ d < 0.50); (ii) moderate effect (0.50 ≥ d < 0.80); and (iii) large effect (d ≥ 0.80). The level of statistical significance was always set at $p \leq 0.05$.

3. Results

Figure 2 depicts the comparison between music cadences for PF_D and PF_{ND} according to the two mechanical strategies. There were significant variations when comparing PF_D at cadence 105–135

(p = <0.01, ES = 0.87), 105–150 (p = <0.01, ES = 1.59), 120–135 (p = <0.01, ES = 0.62), 120–150 (p = <0.01, ES = 1.48), and 135–150 b·min^{-1} (p = <0.01, ES = 0.73) during the simultaneous strategy. Meanwhile, no differences were observed for cadence 105–120 b·min^{-1}. The PF_{ND} showed differences for the overall incremental protocol of music cadences (105–120: p = <0.01, ES = 0.63; 105–135: p = <0.01, ES = 1.27; 105–150, p = <0.01, ES = 1.69; 120–135: p = <0.01, ES = 0.63; 120–150, p = <0.01, ES = 1.15; 135–150, p = <0.01, ES = 0.61).

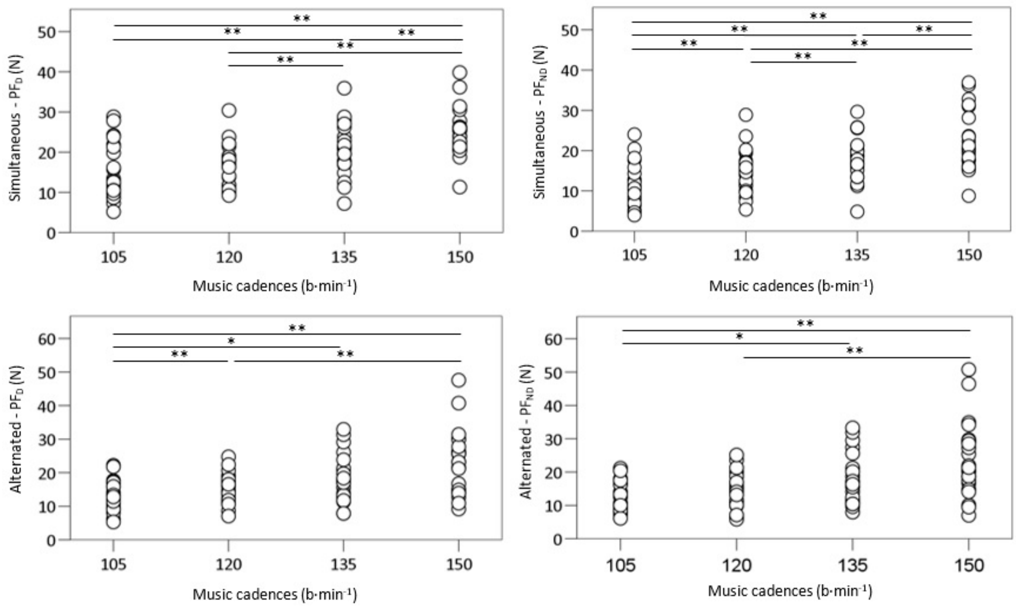


Figure 2. Comparison of music cadences according to the PF_D and PF_{ND} and for the two strategies (N = 23). * $p \leq 0.05$; ** $p \leq 0.01$.

The alternated strategy elicited differences for both upper-limbs between 105 and 135 (PF_D: p = 0.04, ES = 0.89; PF_{ND}: p = 0.05; ES = 0.92), 105 and 150 (PF_D: p = <0.01, ES = 1.36; PF_{ND}: p = <0.01; ES = 0.09), and 120 and 150 b·min^{-1} (PF_D: p = <0.01, ES = 1.08; PF_{ND}: p = <0.01; ES = 1.10). The PF_D also demonstrated differences between 105 and 120 b·min^{-1} (p = <0.01, ES = 0.49). No differences were found at 120–135 and 135–150 b·min^{-1} for PF_D and PF_{ND}.

The comparison between upper-limbs at the same mechanical strategy and music cadence is shown in Table 1. Significant differences were found between PF_D and PF_{ND} for overall music cadences with a medium ES (105 − 0.59; 120 − 0.46; 135 − 0.40; 150 − 0.43) during the simultaneous strategy. No differences were found for the alternated strategy.

Table 1. Descriptive statistic (mean ± SD) of peak force production between upper-limbs at the same music cadence (n = 23).

Strategies	Variables	Music Cadence (b·min^{-1})							
		105	p	120	p	135	p	150	p
Simultaneous	PF_D (N)	14.87 ± 6.81	<0.01	17.06 ± 4.82	<0.01	20.53 ± 6.24	0.01	24.97 ± 5.84	0.01
	PF_{ND} (N)	11.38 ± 5.28		14.77 ± 5.43		18.22 ± 5.49		22.16 ± 7.32	
Alternated	PF_D (N)	13.18 ± 4.50	0.12	15.33 ± 4.35	0.24	18.43 ± 6.92	0.44	23.21 ± 9.38	0.72
	PF_{ND} (N)	12.03 ± 4.30		14.33 ± 5.17		17.66 ± 7.55		23.76 ± 10.93	

b·min^{-1}, beats per minute; n, number of subjects; N, Newton; PF_D, peak force for dominant upper-limb; PF_{ND}, peak force for the non-dominant upper-limb.

Table 2 presents the symmetry index (**SI**) for both strategies. Values were above 10% (cut-off value) for the simultaneous and alternated strategies during the overall incremental protocol. No differences were found between strategies at the same music cadence.

Table 2. Descriptive statistic (mean ± SD) for the symmetry index (**SI**; n = 23).

Music Cadence (b·min^{-1})	Variable	Simultaneous	Alternated	p
		Mean ± SD	Mean ± SD	
105	**SI** (%)	30.45 ± 18.26	23.03 ± 15.27	0.11
120	**SI** (%)	21.25 ± 16.37	23.18 ± 15.85	0.68
135	**SI** (%)	20.86 ± 12.38	21.35 ± 21.48	0.97
150	**SI** (%)	20.20 ± 13.78	28.07 ± 23.08	0.17

b·min^{-1}, beats per minute; %, percentage; n, number of subjects; **SI**, symmetry index.

4. Discussion

The aim of this study was to compare the kinetic behavior between alternated and simultaneous arms flexion by the elbow at different music cadences. There were differences in the force produced by the dominant and non-dominant limbs in most cadences at alternated or simultaneous actions. Differences with a medium effect were seen between limbs (dominant vs. non-dominant) when moving simultaneously. Despite that, both in-water mechanical strategies seemed to be characterized by an asymmetric pattern in this cohort of subjects.

The understanding of movement strategies in several exercise modes is critical for fitness professionals to plan their programs. This is even more important in older adults as they experience several changes in motor control that affect their movement quality and coordination [8]. In this sense, the understanding of the most effective exercises or variants is a must to reduce hypothetical long-term injuries and/or to build-up strength for this cohort.

The forces applied during arms flexion by the elbow in this study were around 11–25 N. This is far from what was seen (from 26 to 48 N) in young adults while performing horizontal arms adduction [6]. Although exercises were not the same, the alterations in muscle function through aging is an underlying reason that affects force control and may explain the diversity found in force outputs. This is crucial to consider when conducting water-based programs with heterogeneous demographics. Indeed, in the present study, the elderlies showed different values between most of the cadences in both simultaneous and alternated strategies. Increasing cadence imposes a higher movement frequency and, as a consequence, an increased drag force due to an increased turbulent flow surrounding the body [15]. As such, the force production to overcome drag is expected to increase as well. This is a common trend already shown in humans, at least for vertical aquatic motion [6]. Even at cadences such as 150 b·min^{-1}, these older women were able to increase force production. Although water professionals may find several cadences to work with (from 105 to 150), it still remains unanswered which strategy is the most suitable to maintain the best possible coordination for this population in that specific part of the session.

The comparison between upper-limbs at the same mechanical strategy and music cadence showed differences just while acting simultaneously. A more demanding cognitive processing can explain this while moving the upper limbs simultaneously than alternated. During the alternated strategy the participants could focus entirely on a single-arm movement maintaining integrity through space and time. In contrast, the simultaneous action required a task-specific control of the spatial and temporal characteristics of the movements with both hands. This coordinative pattern seems to be strictly dependent both the amplitude and direction of the movement [16]. Here, both sides of the body should act precisely to have the same kinematic expression, which is extremely difficult to maintain because of the one side dominance. The dominant limb output can increase variability, showing different angular adjustments in comparison to the opposite limb. This kind of response in terms of variability in simultaneous actions is even greater from the elderly than younger subjects [17]. It was already shown that older adults are more variable than other age cohorts on tasks that demand the simultaneous control of more than one effector such as the case of using both feet [18].

Nevertheless, it is important to highlight that the participation from the elderly in some kind of coordinative-working sessions may help in reducing variability in coordination. Elderly women engaged in rhythm-based programs proved to be more successful in inter-limb coordination than sedentary ones [19]. This is something positive that water-based programs can add to this cohort of subjects. In addition, a more harmonious inter-limb symmetry may lead to a clear reduction of injury predisposition. So, we might consider that the alternated arms flexion can be a more proper strategy that water fitness professionals can use to build strength in that specific part of the sessions.

Regarding the symmetry index, there were no differences between strategies, and both proved to be asymmetrical. This was an expected behavior, as most of the water movements, such as arm stroke [20], leg kicking [21], or even vertical horizontal adduction [6] showed to be asymmetrical. This is not so obvious in other types of movements done, at least, on dry-land. Land-based movements such as gait [22] or jumping [23] can easily demonstrate more symmetrical patterns. The fluid density can be one reason underlying this issue. Water is denser than air, which, most of the time, can be a useful resource for training and exercise [24]. Although the biological effects of immersion in water may be beneficial in certain exercise contexts, it can also be challenging when the movement is performed by an older population. If the coordination and balance during daily-basis tasks are affected at these ages [25], it is expected that in-water movements will be more challenging as well. Accordingly, water fitness professionals should pay major attention and give constant verbal cues even if they opt by using an alternate arm flexion during some parts of the sessions in order to build-up strength.

5. Conclusions

Our findings show that increasing music cadence led to higher force production during in-water upper-limb flexions by the elbow. The differences between dominant and non-dominant limbs were seen mainly flexing the arms simultaneously. This shows that an alternated movement could be a more proper strategy to work. Despite that, both mechanical strategies were classified as asymmetric when practiced by older women, requiring full attention from water fitness professionals. These findings will help water fitness professionals understand how different motor strategies affect force production and how they should plan their daily sessions. Some practical implications should be considered: (i) prescribe, when possible, exercises with alternated patterns, but always encouraging the elderly to keep their attention in both sides of the body while exercising and (ii) use music cadences near to 135 $b \cdot min^{-1}$ to work with, because it seems to promote fewer asymmetries.

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