AUTHORS:
Maria Graça [1, 2, 3]
Márcio Borgonovo-Santos [1]
Pedro Fonseca [1]
Joaquim Alvarelhão [3]
Ricardo J Fernandes [1, 4]
Andrea Ribeiro [1, 5]
Daniel Daly [5]
João Paulo Vilas-Boas [1, 4]

[1] Porto Biomechanics Laboratory (LABIOMEP-UP), University of Porto, Portugal.
[2] CIAFEL, Faculty of Sport, University of Porto, Portugal.
[3] School of Health Sciences, University of Aveiro, Portugal.
[4] CIFI2D, Faculty of Sport, University of Porto, Portugal.
[5] School of Health, Fernando Pessoa University, Porto, Portugal.
[6] Department of Movement Sciences, KU Leuven, Belgium.
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Shoulder's abduction rehabilitation movements in deep-water: A dual-media biomechanical analysis.

KEYWORDS:
Aquatic exercises. Rehabilitation.
Upper limb abduction. Dual media.

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ABSTRACT

Physiotherapists often use deep-water exercises, combining movements under and above water. The purpose of this study was to examine the range of motion, peak velocity, phase duration and smoothness coefficient in dual-media shoulder abduction performed in deep water with different buoyancy aids and compare dominant and non-dominant upper limbs. Ten healthy right-handed and experienced participants (five men and five women, age 30.1 ± 9.4 years, BMI 21.8 ± 2.8), performed the upper limb abduction movements at maximum speed in three conditions: no aided buoyancy, pool noodle and buoyancy belt. Biomechanical components at the upper limb endpoint (third finger) were determined using a movement capture system (Qualisys, Gothenburg, Sweden). Gender interaction was not significant for any variable. Comparing dominant and non-dominant upper limbs, the results showed differences in the underwater phase for the range of motion (without buoyancy aid t = -0.60; pool noodle t = 0.10; buoyancy belt t = -2,18), in phase duration (without buoyancy aid t = 0.42; pool noodle t = -0.75; buoyancy belt t = 0.15) and in the smoothness coefficient (without buoyancy aid t = 1.89), similar to the transition phase. When comparing the fluctuation conditions for each upper limb, the results show differences in above water phase in peak velocity with no aided buoyancy vs. the buoyancy aid, buoyancy belt (non-dominant limb, t = 0.04) and in the transitional phase for range of motion for no buoyancy aid vs. the buoyancy aid, buoyancy belt in both upper limbs (dominant limb, t = 2.08; non-dominant limb, t = 2.40) and phase time in the non-dominant limb (t = -0.04). In sum, the range of motion and peak velocity indicate the buoyancy belt as the best option for shoulder abduction with optimal symmetry between dominant and non--dominant upper limbs for the different phases of dual media in sessions performed in deep water.

CORRESPONDING AUTHOR: Maria Graça.
Health Superior School of University of Aveiro 3800 Aveiro, Portugal.
telephone: 0351 918 791 779 email: maria.graca@ua.pt

Movimentos de reabilitação de abdução do ombro em águas profundas: Uma análise biomecânica de duplo meio

RESUMO

Os fisioterapeutas costumam prescrever exercícios em águas profundas, combinando movimentos abaixo e acima da superfície da água. O objetivo do presente estudo foi examinar a amplitude de movimento, pico da velocidade máxima, duração das fases e o coeficiente de suavidade durante a abdução do ombro realizada em águas profundas, utilizando diferentes meios de flutuação em função da lateralidade. Dez participantes saudáveis, destros e experientes na água (cinco homens e cinco mulheres, idade 30.1 ± 9.4 anos, IMC 21.8 ± 2.8) realizaram os movimentos de abdução do membro superior em velocidade máxima em três condições: sem auxílio à flutuabilidade, com "esparguete" de piscina e com cinto de flutuação. A cinemática 3D da extremidade distal do membro superior (terceiro dedo) foi determinada usando um sistema de captura de movimento de duplo meio (Qualisys, Gothenburg, Sweden). A interação do sexo não foi significativa para nenhuma variável. Comparando membro superior dominante com não dominante, os resultados mostraram diferenças na fase subaquática para a amplitude de movimento (sem auxiliar de flutuação t = -0.60; "esparguete" de piscina t = 0.10; cinto de flutuação t = -2.18), no tempo de duração da fase (sem auxiliar de flutuação t = 0.42; "esparguete" de piscina t = -0.75; cinto de flutuação t = 0.15) e no coeficiente de suavidade (sem auxiliar de flutuação t= 1.89), à semelhança da fase de transição. A comparação entre as condições de flutuação para cada membro superior, os resultados apresentam diferenças na fase aérea no pico da velocidade para as condições de sem auxiliar de flutuação vs. cinto de flutuação (membro não dominante, t = 0.04) e na fase transitória para amplitude de movimento para as condições com "esparguete" de piscina vs. cinto de flutuação em ambos os membros superiores (membro dominante, t = 2.08; membro não dominante, t = 2.40) e tempo de fase no membro não dominante (t = -0.04). Em suma, a amplitude de movimento e o pico da velocidade indicam o cinto de flutuação como melhor opção na abdução do ombro entre o membro superior dominante e não dominante para as diferentes fases do duplo meio em águas profundas.

PALAVRAS-CHAVE:
Exercícios aquáticos. Reabilitação.
Abdução do membro superior. Duplo meio.

INTRODUCTION

Physiotherapists and other health related professionals often use aquatic therapeutic exercises for rehabilitation purposes, some of which are conducted in deep-water. In this specific condition, participants are not supported by the pool floor and use a pool noodle or buoyancy belt as an added buoyancy solution. Although buoyancy aids permit upper limb movements with shoulder girdle and trunk stability (McCreesh, Purtill, Donnelly, & Lewis, 2017), more information is required to validate these treatment strategies for better rehabilitation and health prevention programs. In fact, regarding upper limbs impairment (e.g., rotator cuff injuries), kinematic analyses have provided valid data for improving movement patterns in daily life activities and functional recovery on dry land (Dunn et al., 2008; Edwards, Ebert, Littlewood, Ackland, & Wang, 2017; Vidt et al., 2016).

In aquatic physiotherapy, development of trunk strength can begin only after some head control and other body functions recover (Alikhajeh, Hosseini, & Moghaddam, 2012; Lambeck & Gamper, 2011). A person with 0.97 body density reaches floating equilibrium when 97% of his volume is submerged, so the body has to make the necessary adjustments to match gravity forces with buoyancy forces to obtain equilibrium. Maintaining balance in water requires the use of trunk muscle motor control to assure vertically alignment of the centre of body mass with the centre of body buoyancy.

If there is an asymmetric distribution of submerged body volume, hydrostatic torque influences "safe equilibrium" (Becker, 2009; Becker & Cole, 2010). When buoyancy devices are used, the symmetry can be artificially disturbed or assisted. When the rehabilitation movements are carried out in a dual media, we have a speed restriction due to the hydrodynamic resistive force and the aerodynamic drag, which is negligible above the water due to the relatively low speed of the movements controlled by the pain and deficit of muscular activity (Cuesta-Vargas, Buchan, & Arroyo-Morales, 2014).

On dry land, smoothness is an important variable to better understand movement quality and to develop clinical reasoning for sensorimotor control. Through examining movement smoothness, we can access the patient's overall control capacity and track and quantify recovery (Balasubramanian, Melendez-Calderon, & Burdet, 2012). The movement smoothness coefficient usually increases with motor control improvement, so it is normally considered an important recovery marker (Hogan & Sternad, 2009). This coefficient can be quantified using the spectral arc-length metric, a sensitive measure for assessing motor recovery in neurological diseases and motor learning in persons with impairments. In determining upper limb movement smoothness, the hand's third fingertip velocity can be used to obtain a measure independent from temporal scaling and retains good sensitivity and reliability (Balasubramanian, Melendez-Calderon, Roby-Brami, & Burdet, 2015).

To better understand how buoyancy aids influence shoulder abduction exercises in continuous movements under and above the water surface, the present study analyzed the range of motion (ROM), peak velocity, movement duration and the smoothness coefficient in a healthy sample. Results for the group and each individual were examined comparing under and above water phases on dominant and non-dominant limbs. Comparisons were made between three conditions of exercise: (a) without aided buoyancy, and (b) seated in a pool noodle, and (c) wearing a buoyancy belt. The most effective buoyancy device should provide more smoothness, increasing upper limbs symmetry and sufficient ROM and peak velocity. Further, we examined a "transitional movement phase" between under and above water movement, examining the changes in velocity. This critical "transition" on the water-air interface should improve the understanding of aquatic rehabilitation exercise complexities in patients with a shoulder injury.

MATERIAL AND METHODS

PARTICIPANTS

Ten (five females and five males) healthy volunteers participated in this study. The female and male participants respectively were: age 32.60 (± 13.45) vs. 27.60 (± 1.52) yrs., height, 1.68 (± 0.04) vs. 1.82 (± 0.04) m, body mass 58.20 (± 2.28) vs. 76.60 (± 14.40) kg and BMI 20.72 (± 1.63) vs. 22.92 (± 3.49). Since no statistical differences were detected between gender, data were pooled and analyzed as a single group. All participants were right-handed, experience in the water environment and had no previous history of shoulder injury. All provided written informed consent, in accordance with the Helsinki Declaration and the Oviedo Convention. The Ethics Committee Sports Faculty of the University of Porto approved this study under protocol number 28.2018.

PROCEDURES

Participants completed an upper limb dominance questionnaire, and anthropometric measures were recorded. Data collection was performed in the middle of a 25m long and 1.90m deep indoor swimming pool. The movements examined included abduction of both shoulders simultaneously in three conditions submerged to the neck: the first with no aided buoyancy, the second seated in a pool noodle and the third wearing a buoyancy belt at waist level. Data acquisitions only started after a researcher verified that subjects were performing the movement correctly at their maximum speed. Three-dimensional kinematical data was registered by tracking 48 reflective markers positioned in a full-body configuration for a more extensive study. The present study used only the ten upper limb and four trunk markers (FIGURE 1).

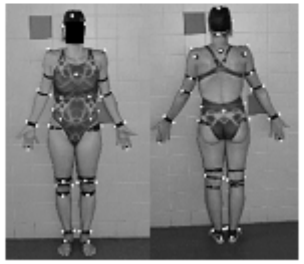


FIGURE 1. Reflective body markers setup model with 48 body markers.

A dual-media motion capture system (Qualisys, Gothenburg, Sweden), comprised of eight underwater cameras and 12 land cameras operating at a sampling frequency of 100 Hz, was used. Cameras were positioned around the subject's active zone (FIGURE 2). Ten repetitions of each movement were collected at the maximum speed for each condition and subject. The fastest repetition with complete data per condition was chosen for subsequent analysis.

FIGURE 2. Cameras setup for dual-media motion capture and space calibration.

Shoulder abduction was studied based on Kapandji's (2007) concepts (FIGURE 3), on the frontal plane, with upper limbs moving away from the trunk in vertical elevation. This lateral flexion can have a potential ROM of 180 degrees (Kapandji, 2007).

FIGURE 3. Shoulder abduction based on Kapandji's concepts *Start angle (S); **Final angle (F); ROM = F-S.

DATA COLLECTION

The collected data were first pre-processed through the Qualisys Track Manager 2.9 (Qualisys AB, Sweden) software, regarding marker labelling and trajectory gap filling. Next, the best performance of each condition was chosen to guarantee the quality of trajectory and minimize errors. The variables of interest for shoulder abduction included the velocity magnitude, peak velocity and smoothness coefficient for dominant and non-dominant upper limbs, without aided buoyancy, with a pool noodle and buoyancy belt. The upper limb endpoint (fingertip) was used as a referential to calculate the velocity magnitude. Consistent with the International Society of Biomechanics recommendations describing thoracohumeral motion, joint angle kinematic calculations were decomposed in X–Y–Z on the frontal plane, corresponding to the elevation plane, using the axis defined from anatomical landmarks (Wu et al., 2005). Maximum and minimum angles were calculated for each of the three conditions, total ROM, and under and above water phases. The ROM was calculated by subtracting the minimum angle from the maximum one (FIGURE 4).

FIGURE 4. Motion analysis in dual-media through the Qualisys Track Manager 2.9.

All data were exported to a TSV file. The velocity magnitude (EQUATION 1) was used to calculate the adapted smoothness coefficient of spectral arc-length (EQUATION 2) and characterized the complete ROM's velocity pattern, explicitly comparing the phases performed above and underwater and in transitory dual media. The magnitude of velocity (V), threshold ($\hat{V}$) and upper bound of velocity magnitude (V_c^{max}), were used to calculate the coefficient of smoothness (V_c) using the spectral arc-length algorithm (EQUATION 2) (Sivakumar Balasubramanian et al., 2015).

$$V = sqrt\ (Vx^2 + Vx^2)$$

EQUATION 1

$$V_c \triangleq \min\{V_c^{max}, \min\{V, \hat{V}(r) < \bar{V}\ \forall\ r > V\}\}$$

EQUATION 2

Messier and Kalaska (1999) found that using the fingertip is a reliable procedure to calculate the smoothness coefficient. Based on this, we characterized the dual-media shoulder abduction movement through the magnitude of velocity taken from the upper limb endpoint (third fingertip) to determine the smoothness coefficient. After, we studied the velocity magnitude (*V*) values related to the time and kinematic trajectory of the shoulder abduction movement we identified five points graphically: the starting point (P1), the point where the variation of values seemed unstable (P2), the point of velocity change related with movement at the water surface (P3), the point of highest velocity (P4) and, finally, the stoppage of the movement (P5) (FIGURE 5).

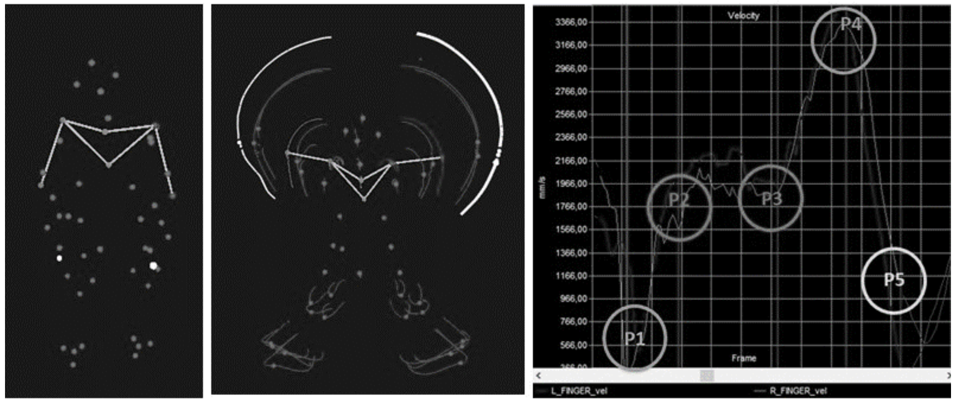


FIGURE 5. Reference points of the shoulder abduction used to track the velocity magnitude and the points of interests on the velocity x time curve.

Then, we defined four distinct phases: (a) an underwater phase with lower velocity (Uw Ph 1) between P1 and P2; (b) a second underwater phase (Uw Ph 2) between P2 and P3, where velocity variation should show the poorest coefficient of smoothness; (c) start of the above water phase (Aw Ph 1), between P3 and P4, with high velocity and no intermittencies, and (d) an above water phase (Aw Ph 2), between P4 and P5, where the decrease of velocity was related with the end of motion. Then, we looked at the transition phase (Uw Ph 2 + Aw Ph 1) where the velocity magnitude has the bigger variation (FIGURE 6).

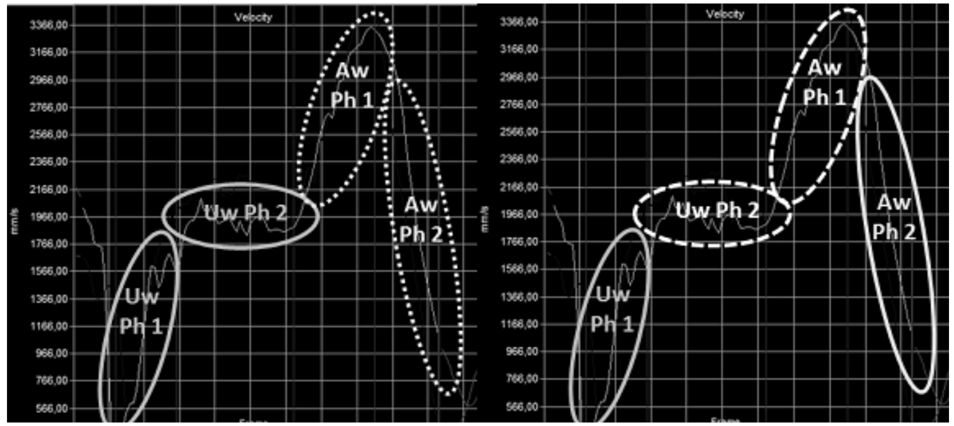


FIGURE 6. The velocity magnitude curve for shoulder abduction in dual-media. On the left, the underwater phase composed of a first under water phase (Uw Ph1) with increasing speed, a second under water phase (Uw Ph2) maintaining speed, then the above water phase, with a first above water (Aw Ph1) increasing to the peak velocity and the second above water phase (Aw Ph2) decreasing to the minimum speed. On right, the defined transition water phase composed by the second of underwater phase and the first above water phase, where the bigger changing occurs.

STATISTIC

Data analysis was conducted with the statistic software SPSS version 24.0 (SPSS Inc., Chicago, IL, USA). The normality of data distribution was screened in scatter plots and formal test (Shapiro-Wilk test) separately for male and female participants and merged groups. We chose to work with merged groups because gender differences were not significant for our study variables. T-tests were used for the comparison of the variables means, normally distributed. The data were reported as mean standard deviation (SD), differences of means ± SD and the statistical significance level of $p < .05$.

RESULTS

In table 1, mean and *SD* values were given for all outcome measures. Looking at the total ROM, we found the largest ROM when using the buoyancy belt and the smallest without buoyancy. In general, the above water phase showed greater ROM, and the peak velocities were higher above water, except for pool noodle dominant arm which showed the same peak velocity. Values for peak velocity varied between 1.9 m/s (underwater) and 3.1 m/s (above-water). The highest peak velocity was found in the non-dominant buoyancy belt condition above water. The movement duration for all phases were steady for all dominances and conditions with minimum asymmetries between dominant and non-dominant limbs, but the larger values were in the underwater phase (0.6s).

The smoothness coefficient values for shoulder abduction ranged between -1.6 λ/s and -1.8 λ/s for above-water and between -1.8 λ/s and -2.0 λ/s for underwater. The smoothness coefficients were lower in the underwater phase with the lower value in the non-dominant for buoyancy belt condition. The above water phase showed a higher smoothness coefficient on the non-dominant limb with no aided buoyancy. For the transition phase, results showed mean smoothness values of -1.6 λ/s and the time spent was also similar to the underwater phase.

Comparison between dominant and non-dominant upper limb results showed several significant differences for all ROM in the underwater phase with no aided buoyancy (t= -0.60); pool noodle (t = -1.42); buoyancy belt (t = 0.27) and in the transitory phase with no aided buoyancy (t = -0.58); pool noodle (t = -2.18) and buoyancy belt (t = 0.72). For the peak velocity, results showed differences underwater with pool noodle (t = 0.09) and in the transitory phase with buoyancy belt (t = -1.46). For the time spent results showed differences between dominant and non-dominant upper limb, in all floating conditions and in all phases. Importantly, the smoothness coefficient results showed differences in the underwater phase with no aided buoyancy (t = 1.89), in the transitory phase with pool noodle (t = 1.61) and in the above-water phase with the buoyancy belt (t = 1.39) (TABLE 2).

When comparing buoyancy conditions, in the above water phase only peak velocity showed differences in dominant upper limb for no aided vs. buoyancy belt. In the transitory phase results for ROM showed differences in the dominant limb between pool noodle vs. buoyancy belt, and for all non-dominant upper limb conditions, and for phase time between pool noodle vs. buoyancy belt for the non-dominant limb (TABLE 3).

Table 4 shows that the mean ROM for the underwater phase was lower than for the above water phase for all buoyancy conditions. Percentage wise similarity was strongest between dominant and non-dominant upper limb for buoyancy belt. Time spend under water was larger in all buoyancy conditions with the lower ROM. For pool noodle the percentage of spend time and ROM were larger than in the other conditions. Therefore, ROM was larger and more time was spent in the underwater phase.

TABLE 1. *Mean* and *SD* in each condition per phase and indication of normality.

		TOTAL	UNDERWATER PHASE				ABOVE WATER PHASE				TRANSITORY WATER PHASE			
FLOATING CONDITIONS /DOMINANCE		ROM (°)	ROM (°)	PEAKV (M/S)	TIME (S)	SM_CF (Λ/S)	ROM (°)	PEAKV (M/S)	TIME (S)	SM_CF (Λ/S)	ROM (°)	PEAKV (M/S)	TIME (S)	SM_CF(Λ/S)
No aided Dominant	Mean (*SD*)	128.5 (27.6)	49.0(20.7)	1.9(0.4)	0.6(0.1)	-1.9(0.2)	71.7(20.6)	2.1(0.9)	0.5(0.1)	-1.7(0.3)	75.8(29.9)	2.3(0.5)	0.5(0.2)	-2.10(0.2)
	p	-	-	-	-	-	-	-	.03	-	-	-	-	-
No aided Dominant	Mean (*SD*)	126.2 (23.6)	51.4(21.7)	2.0(0.5)	0.6(0.1)	-1.9(0.2)	71.3(18.6)	2.7(0.8)	0.5(0.1)	-1.6(0.4)	90.7(21.6)	2.6(0.3)	0.5(0.3)	-2.0(0.4)
	p	--	-	-	-	-	-	-	-	-	-	-	-	-
Pool noodle Dominant	Mean (*SD*)	135.5 (21.8)	61.1(18.0)	2.2(0.6)	0.6(0.1)	-1.9(0.2)	76.2(15.7)	2.2(0.8)	0.4(0.1)	-1.7(0.3)	79.2(29.9)	2.5(0.4)	0.6(0.3)	-1.7(0.7)
	p	-	.03	.02	-	-	-	-	-	-	-	-	-	-
Pool noodle Dominant	Mean (*SD*)	139.9 (14.5)	66.0(19.9)	2.2(0.5)	0.6(0.1)	-1.9(0.2)	77.0(12.6)	2.5(0.6)	0.4(0.1)	-1.7(0.1)	72.8(17.7)	2.6(0.5)	0.5(0.2)	-1.9(0.7)
	p	-	-	-	-	-	-	-	-	-	-	-	-	-
Buoyancy belt Dominant	Mean (*SD*)	141.6 (22.6)	50.8(11.4)	1.9(0.3)	0.5(0.1)	-1.8(0.3)	84.4(13.8)	2.8(0.5)	0.4(0.1)	-1.7(0.2)	83.4(20.7)	2.4(0.5)	0.6(0.3)	-2.0(0.1)
	p	-	-	-	-	-	-	-	-	-	-	-	-	-
Buoyancy belt Dominant	Mean (*SD*)	133.6 (12.8)	49.2(16.4)	2.0(0.8)	0.5(0.1)	-2.0(0.2)	83.5(15.0)	3.1(0.5)	0.4(0.1)	-1.8(0.2)	79.9(15.9)	2.8(0.5)	0.5(0.2)	-2.1(0.1)
	p	-	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 2. Comparison of measures of dominant vs. non-dominant upper limb for buoyancy condition (means difference, *SD*, *t*-value and significance).

		UNDERWATER PHASE				ABOVE WATER PHASE				TRANSITORY WATER PHASE			
BUOYANCY CONDITIONS		ROM (°)	PEAKV (M/S)	TIME (S)	SM_CF (Λ/S)	ROM (°)	PEAKV (M/S)	TIME (S)	SM_CF (Λ/S)	ROM (°)	PEAKV (M/S)	TIME (S)	SM_CF(Λ/S)
Pool noodle	Mean (*SD*)	-2.68 (13.06)	-0.2 (0.3)	0.01(0.06)	0.05(0.08)	0.57(16.89)	-0.7(1.3)	-0.03(0.05)	-0.06(0.48)	-2.10(11.43)	-0.2(0.4)	0.04(0.11)	-0.08(0.39)
	t-test	-0.62	-1.21	0.42	1.89	0.10	-1.25	-1.62	-0.40	-0,58	-1,28	-1,13	-0.65
	p	.01	-	.00	.00	-	-	.00	-	.00	-	.00	-
Pool noodle	Mean (*SD*)	-5.38(7.39)	0.0(0.3)	-0.01(0.03)	0.06(0.20)	-0.88(12.58)	-0.3(0.8)	0.01(0.03)	0.09(0.33)	-7.30(15.41)	-0.0(0.4)	0.11(0.09)	0.17(0.33)
	t-test	-2.18	0.09	-0.75	0.87	-0.21	-0.83	0.75	0.81	-1.42	-0.26	3.70	1.61
	p	.01	.02	.00	-	-	-	.00	-	.02	-	.00	.00
Buoyancy belt	Mean (*SD*)	1.21(11.19)	0.09(0.6)	0.04(0.14)	0.22(0.37)	0.66(16.74)	-0.3(0.6)	0.02(0.14)	0.09(0.04)	-3.70(16.34)	0.2(0.3)	-0.03(0.08)	0.04(0.13)
	t-test	0.27	-0.34	0.15	1.81	-0.12	-1.42	-0.15	1.39	0.72	-1.46	-0.98	1.00
	p	.03	-	.01	-	-	-	.01	.00	.03	.02	.00	-

TABLE 3. Comparison of measures between buoyancy condition for each upper limb (means difference, *SD*, *t*-value and significance).

		UNDERWATER PHASE				ABOVE WATER PHASE				TRANSITORY WATER PHASE			
FLOATING CONDITIONS		ROM (°)	PEAKV (M/S)	TIME (S)	SM_CF (Λ/S)	ROM (°)	PEAKV (M/S)	TIME (S)	SM_CF (Λ/S)	ROM (°)	PEAKV (M/S)	TIME (S)	SM_CF(Λ/S)
No aided vs. pool noodle for dominant	Mean (*SD*)	-6.39(27.61)	-0.3(0.9)	-0.03(0.19)	0.02(0.23)	-1.15(23.35)	-0.2(90.88)	0.05(0.17)	-0.01(0.25)	-7.66(24.27)	-0.3(0.7)	-0.04(0.29)	-0.37(0.73)
	t-test	-0.69	-0.93	-0.47	0.21	-0.15	-0.50	0.85	-0.15	-0.95	-1.08	-0.44	-1.66
	p	-	-	-	-	-	-	-	-	-	-	-	-
No aided vs. buoyancy belt for dominant	Mean (*SD*)	-1.20(-27.95)	-0.0(0.5)	0.04(0.16)	-0.09(0.45)	-9.80(24.10)	-0.7(0.5)	-0.02(0.15)	0.05(0.33)	-1.80(26.08)	-0.4(0.5)	0.09(0.19)	-0.05(0.15)
	t-test	0.13	-0.37	0.99	-0.60	-1.09	-3.84	-0.71	0.50	-0.22	-1.97	1.59	-1.05
	p	-	-	-	-	-	0.01	-	-	-	-	-	-
Pool noodle vs. buoyancy belt for dominant	Mean (*SD*)	7.58(15.66)	0.3(0.5)	0.08(0.15)	-0.11(0.33)	-7.93(13.74)	-0.5(0.8)	-0.08(0.15)	0.07(0.28)	10.65(15.41)	-0.1(0.6)	0.14(0.27)	0.32(0.78)
	t-test	1.45	1.34	1.70	-0.97	-1.73	-1.70	-1.70	0.70	2.08	-0.44	1.55	1.30
	p	-	-	-	-	-	-	-	-	.04	-	-	-
No aided vs. pool noodle for non dominant	Mean (*SD*)	-9.09(31.08)	-0.2(0.8)	-0.05(0.22)	0.02(0.25)	2.60(22.61)	0.2(0.6)	0.08(0.17)	0.14(0.38)	-11.57(17.13)	-0.1(0.3)	0.11(0.29)	-0.12(0.77)
	t-test	-0.98	-0.53	-0.63	0.25	-0.35	0.83	1.43	1.11	-2.03	-1.11	1.15	-0-49
	p	-	-	-	-	-	-	-	-	.01	-	-	-
No aided vs. buoyancy belt for non dominant	Mean (*SD*)	4.93(22.68)	-0.0(0.7)	0.03(0.17)	0.08(0.21)	-10.32(28.88)	-0.4(0.8)	0.00(0.13)	0.16(0.36)	-3.40(20.09)	-0.3(0.4)	0.11(0.23)	0.07(0.47)
	t-test	0.75	-0.02	0.64	1.12	-1.07	-1.29	-0.05	1.35	-0.54	-2.51	1.49	0.47
	p	-	-	-	-	-	-	-	-	.01	-	-	-
Pool noodle vs. buoyancy belt for non dominant	Mean (*SD*)	14.01(22.72)	0.2(0.8)	0.09(0.15)	0.06(0.28)	-7.71(18.29)	-0.6(0.8)	-0.09(0.15)	0.02(0.20)	10.78(13.48)	-0.2(0.5)	0.00(0.18)	0.19(0.66)
	t-test	1.85	0.49	1.87	0.63	-1.07	-1,96	-1.87	0.32	2.40	-1.22	0.04	0.91
	p	-	-	-	-	-	-	-	-	.01	-	.02	-

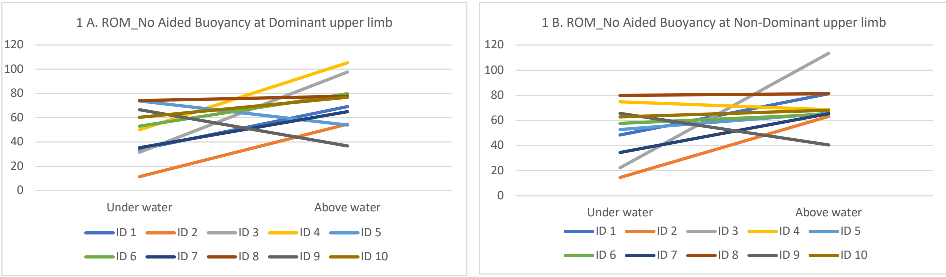
TABLE 4. ROM and time per phase with in addition the total ROM and the total time for each condition (no aid buoyancy, noodle and buoyancy belt; dominant and non-dominant).

		DOMINANT UPPER LIMB			NO DOMINANT UPPER LIMB				
BUOYANCY CONDITIONS		NO AIDED BELT	POOL NOODLE	BUOYANCY BELT	NO AIDED BELT	POOL NOODLE	BUOYANCY BELT	MEAN	SD
ROM	under water phase	49	61,1	50,8	51,4	66	49,2	54,6	7,2
	above water phaset	71,7	76,2	84,4	71,3	77	83,5	77,4	5,6
	TOTAL	120,7	137,3	135,2	122,7	143	132,7	131,9	8,6
% ROM	under water phase	40,8	44,5	37,6	41,9	46,2	37,1	41,4	3,6
	above water phaset	59,7	55,5	62,4	58,1	53,8	62,9	58,7	3,7
	TOTAL	100	100	100	100	100	100	100,0	0,0
Time	under water phase	0,6	0,6	0,5	0,6	0,6	0,5	0,6	0,1
	above water phaset	0,5	0,4	0,4	0,5	0,4	0,4	0,4	0,1
	TOTAL	1,1	1	0,9	1,1	1	0,9	1,0	0,1
%Time	under water phase	54,5	60	55,6	54,5	60	55,6	56,7	2,6
	above water phaset	45,5	40	44,4	45,5	40	44,4	43,3	2,6
	TOTAL	100	100	100	100	100	100	100,0	1,0

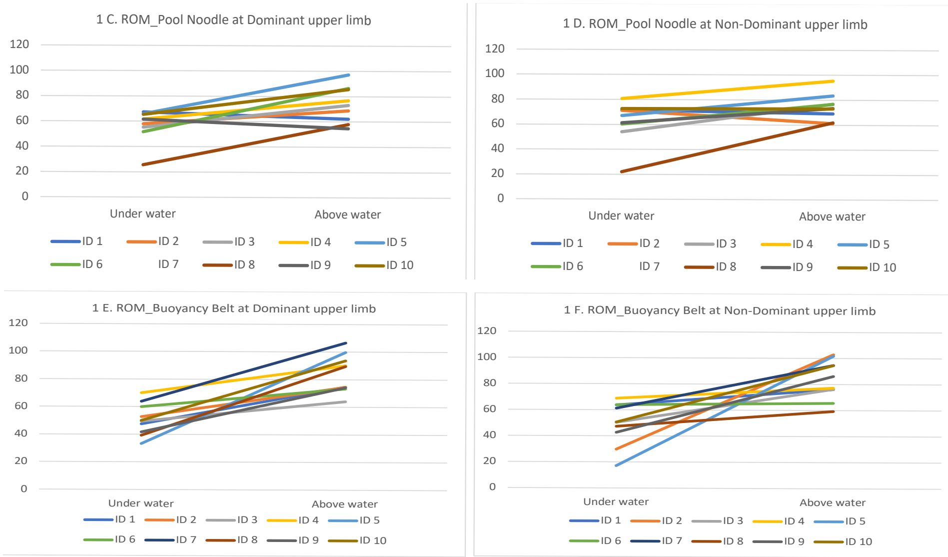
Table 5 presents descriptive characteristics for each individual to examine the individual relationship between under and above water ROM in shoulder abduction dual media. The great challenge is to understand the diversity of individual movement patterns. Looking at the figures 1A-1F, the trend of each individual between under and above water showed a tendency of similarity (comparable trend) when using buoyancy devices. In contrast, figures 1A and 1B showed the diversity between individuals in ROM between under and above water with no aided buoyancy in deep water, particularly the extremely small ROMs underwater stand out. Further of mention is the ROM above water with no aided buoyancy showing low values and variability in the trends between individual. Examining the buoyancy device results, there was a clear tendency toward greater ROM above water using the buoyancy belt (FIGURES 1C-1F).

TABLE 5. Descriptive characteristics of the sample.

GROUP	GENDER	AGE	HEIGHT	WEIGHT	LATERALITY	BMI
A1	F	20	1,66	56	D	20.32
A2	M	28	1,81	78	D	23.81
A3	F	50	1,62	61	D	23.24
A4	M	25	1,85	87	D	25.42
A5	M	28	1,75	54	D	17.63
A6	F	25	1,73	56	D	18.71
A7	M	29	1,82	71	D	21.43
A8	F	44	1,67	58	D	20.8
A9	M	28	1,85	90	D	26,3
A10	F	24	1,71	60	D	20.52



FIGURES 1 A-B. Individual relationship between under and above water ROM in shoulder abduction dual media.



FIGURES 1 C-F. Individual relationship between under and above water ROM in shoulder abduction dual media.

DISCUSSION

The current study examined upper limb abduction in dual media through two phases: above water and underwater. In a deeper analysis, this study also defined a transitory phase based on the changes in velocity magnitude. ROM, peak velocity magnitude, phase duration and smoothness coefficient were examined in the three phases to better understanding clinical reasoning in aquatic physiotherapy for specific shoulder abduction rehabilitation exercises in deep water.

We look for the outcomes for irreparable massive rotator cuff tears, there is no consensus on treatment, because of the lack of high-quality comparative studies to guide treatment recommendations (Kovacevic et al., 2020). Researchers need to define the minimum clinically important difference for various massive rotator cuff tear treatment strategies. The choice of objective outcomes can improve the interpretation of motion change associated with the patient's perception (Maria et al., 2018). Physical therapy, compared to surgery, is associated with a lower improvement in perceived functional outcomes. However, aquatic physical therapy can be better understood if we study the different shoulder injuries with combined biomechanics outcomes and compare the different outcomes to aquatic therapy exercises (Phadke, Camargo, & Ludewig, 2009; Robert-Lachaine, Allard, Gobout, & Begon, 2015; Struyf et al., 2014).

Looking for biomechanical measurements for shoulder rehabilitation in the systematic review of Richardson et al (Richardson et al., 2020), electromyography showed that integrating the kinetic chains during shoulder rehabilitation may increase scapular muscle recruitment, which can produce lower trapezius muscle ratios and reduce the demands on the rotator cuff. This motion pattern can be facilitated by the aquatic movement, as our study showed disturbance in the peak velocity and smoothness coefficient. The smoothness coefficient and muscular activity are important markers of movement analysis for clinician/therapist planning and evaluation of the recovery on land (Hogan & Sternad, 2009; Mercer & Masumoto, 2009).

Several studies showed procedures for rotator cuff study. For instance, a study in young competitive swimmers suggested that a competitive swim season can increase muscular imbalances in the shoulder rotators, mainly because of increased levels of internal rotation strength and endurance, which are proportionally larger than their antagonists (Batalha, Raimundo, Tomas-Carus, Barbosa, & Silva, 2013). The literature shows that shoulder abduction uses combined activity of supraspinatus, biceps brachii, infraspinatus, upper trapezius and lower trapezius with differents functions between stabilizing and affecting the upper limb movement. We believe that the type of floating device influences the normal activity of muscles and respectively the optimal performance.

So, this study focused on use of buoyancy equipment to improve performance of the shoulder abduction in dual media. We looked at the influence of the pool noodle versus the buoyancy belt, using the no aided buoyancy as a control. Because of the larger range of motion (percentage) in the underwater phase, the lower peak velocity, with the better smoothness coefficient in the transition phase and no relevant phase time difference, we would suggest the buoyancy belt as the best floating device for improving recovery efficiency using exercises for shoulder in dual media. The buoyancy belt also seems to be the device that best influences trunk stability, allowing the best activity of shoulder muscles and respectively large ROM.

The ROM results suggests less ROM in the underwater phase related to the water resistance and because the movement is limited by the bigger turbulence in the pelvic area. Above water, the hands can touch above the head. However, comparing the dominant and non-dominant upper limb movements, movement symmetry in deep-water exercises can be difficult to achieve. The different muscle activity, ability and body mass can explain the results of the comparison between floating conditions. The underwater and transitory phases meet water resistance so the ROM was less, even with the buoyancy devices. When looking for movement stability, using the buoyancy aid was a better option, as shown by the smoothness results provided.

The peak velocity showed values between 1.9 m/s for underwater and 3.1 m/s for above-water, respectively. These results showed differences between dominant and non-dominant upper limbs with a buoyancy belt in all phases, suggesting more asymmetry and difficulty when using this floating equipment. Comparing high peak velocity values for the different floating conditions at the above water phase, it suggested a strategy for maintaining balance with the higher values of peak velocity at buoyancy belt condition, which can be related to upper trunk support near the shoulder. This helps to overcome the suddenly reduced water resistance at transition, resulting in a larger ROM and higher peak of velocity above water. When we look at transitory phase smoothness coefficient, we found the lowest smoothness, which can be related with larger turbulence on the surface where hands appeared to be in water and shoulder range of motion around the 90°.

The phase time results showed differences between dominant and non-dominant upper limbs in all phases. Results also pointed out differences for non-dominant upper limb between pool noodle and buoyancy belt. For the smoothness coefficient, the results are compatible with the spectral arc-length scores previously obtained on dryland for a point-to-point reaching tasks: around -1.6 (Balasubramanian et al., 2015). This is particularly true for the above-water phase (ranging between -1.6 and -1.8). Lower smoothness values (ranging between -1.8 and -2.0) were observed for the underwater phase, which might be explained by the disturbing effect of the drag resistance imposed by the water.

Smoothness coefficient showed no differences between dominant and non-dominant upper limbs or between floating conditions in any phases, suggesting a good motor control during the exercises. A higher peak velocity above water compensates imbalance, considering the differences between ROM, peak velocity and smoothness coefficient under and above water. This finding suggests that the approach used may discriminate between compromised and healthy limbs or subjects (Balasubramanian et al., 2015; Hogan & Sternad, 2009).

Furthermore, if we focused on rotator cuff injury recovery, the evidence of aquatic intervention studies provides no objective motion outcomes (Brady, Redfern, MacDougal, & Williams, 2008; Hultenheim-Klintberg, Gunnarsson, Svantesson, Styf, & Karlsson, 2009), but are usually based on patients perceptions and clinical examinations as is mentioned in a systematic review for treatment of irreparable massive rotator cuff tears (Kovacevic et al., 2020). So, significant opportunities exist for multi-center research groups to embark on high-quality comparative clinical studies to improve our understanding and management of massive rotator cuff tears (McCreesh et al., 2017; Phadke et al., 2009; Vidt et al., 2016).

The study of the three phases of dual media leads to better understanding of motion, but further research needs to be done to make the link with the kinetic chain and the correct doses of exercises, as previous systematic reviews showed there is lack of evidence for conservative physical therapy (Malliaras et al., 2020; Sangwan, Green, & Taylor, 2015). Even the specific pain outcomes of shoulders disability for daily life activities need more research, as well as the efficacy of muscle reeducation (Hayes, Ginn, Walton, Szomor, & Murrell, 2004; Lewis, 2016) to better understand the muscular activity related with pain level in water comparing with land.

We know that aquatic therapy has strategies for shoulder pain patient's relief, through the immersion effects, the buoyancy influence on muscle activity and the patient's expectation of aquatic therapeutic exercise (Burmaster, Eckenrode, & Stiebel, 2016). Our study discussed ROM, peak velocity, phase duration and smoothness in deep water movements, but we don't know what happens in shallow water pools. Patients' recovery passes through different levels or needs. More studies should develop this rational.

CONCLUSIONS

Symmetry between dominant and non-dominant upper limbs regarding different floating conditions during shoulder abduction were examined through ROM, peak velocity, phases time duration and smoothness coefficient. We concluded that when performing shoulder abduction in dual-media the use of the pool noodle limits the ROM, by the lower body support, seeming to offer poorer motor control due to the noodle's placement in the direction of the movement promoting an asymmetric ROM, larger peak velocity and smoothness coefficient for all phases compared to other floating conditions. Further, the pool noodle's placement seems to stimulate some adaptations to compensate the peak velocity between dominant and non-dominant upper limb.

For rehabilitation goals, physiotherapist look for symmetry between upper limbs and good stability for core balance, which can be achieved by the buoyancy belt when performing shoulder abduction in dual-media, as it could be related with findings for ROM and smoothness coefficient for dominant and non-dominant upper limb in the different phases. This suggests the buoyancy belt as the best equipment to perform abduction movements with less impact on shoulder stability.

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