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BUOYANCY ASSESSED WITH FLOATING TESTS AND UNDERWATER WEIGHING. A PILOT STUDY

PLOVNOST OCENJENA S TESTI PLOVNOSTI IN PODVODNIM TEHTANJEM. PILOTSKA RAZISKAVA

ABSTRACT

The aim of the present study was to compare the buoyancy assessed by floating tests with the buoyancy calculated using the variables measured during underwater weighing. We also aimed to evaluate the relationship between assessed buoyancy and body composition. Twenty-seven women (age: 20 ± 3 years, height: 1.66 ± 0.34 m, weight: 62 ± 7 kg; body mass index: 22 ± 2; vital capacity: 4.26 ± 0.47 l) and twenty-six men (age: 19 ± 2 years, height: 1.81 ± 6.76 m, weight: 79 ± 10 kg body mass index: 24 ± 3; vital capacity: 6.05 ± 0.7 l) volunteered to participate in the study. They performed floating tests, underwater weighing, pulmonary function measurement, and body composition procedure on the same day in random order with a 30-minute break. Floating testing consisted of one horizontal (HT) and two vertical tests with different arm positions, i.e., arms adducted to the body (VT1) or arms extended overhead (VT2). We assessed participants' buoyancy (B-HT, B-VT1, and B-VT2). In addition, we calculated participants' body volume and buoyancy (B-c) using variables measured during underwater weighing. Results showed that B-c was moderately correlated with B-VT1 (Spearman's $\rho = 0.51$; $p < 0.001$) and B-VT2 (Spearman's $\rho = 0.55$; $p < 0.001$), but not with B-HT. Multiple regression analysis showed that vital capacity and muscle mass had a positive and negative effect, respectively, on the scores of buoyancy assessed by vertical floating tests. In addition, the mass of the arms correlated negatively with the scores of buoyancy assessed by VT2 ($\beta = -6.26$; $p = 0.005$). According to the obtained results, we can conclude that both vertical floating tests i.e. with arms adducted to the body or arms extended overhead are suitable substitutes for underwater weighing to determine buoyancy, which is strongly related to vital capacity and lesser extent to muscle mass. Muscle mass is not a factor that can be changed immediately, while the amount of inspiration can be regulated. Therefore, the control of breathing and thus the reduction or increase of buoyancy is an important skill that novice swimmers should acquire as part of the learn-to-swim program.

Keywords: swimming beginners, learn-to swim, floating ability

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IZVLEČEK

Cilj raziskave je bil primerjati vrednosti plovnosti, ki so ocenjene s testi z vrednostmi, ki so izračunane iz podatkov podvodnega tehtanja. Želeli smo ugotoviti tudi učinek telesne sestave na plovnost. Sedemindvajset žensk (starost: 20 ± 3 leta, višina: 1,66 ± 0,34 m, teža: 62 ± 7 kg; indeks telesne mase: 22 ± 2; vitalna kapaciteta: 4,26 ± 0,47 l) in šestindvajset moških (starost: 19 ± 2 leti, višina: 1,81 ± 6,76 m, teža: 79 ± 10 kg indeks telesne mase: 24 ± 3; vitalna kapaciteta: 6,05 ± 0,7 l) je sodelovalo v raziskavi. V istem dnevu smo opravili teste plovnosti in meritve podvodnega tehtanja, vitalne kapacitete ter telesne sestave. Testiranje plovnosti je bilo sestavljeno iz testa v vodoravnem položaju (HT) in dveh testov v navpičnem položaju, pri katerih so bile roke bodisi priročeno (VT1), bodisi vzročeno (VT2). S temi testi smo ocenili plovnost preiskovancev (B-HT, B-VT1 in B-VT2). Poleg tega smo s podatki, izmerjenimi s podvodnim tehtanjem, izračunali tudi njihovo telesno prostornino in vzgon (B-c). Rezultati so pokazali, da je bil B-c zmerno povezan z B-VT1 (Spearmanov $\rho = 0{,}51$; $p < 0{,}001$) in B-VT2 (Spearmanov $\rho = 0{,}55$; $p < 0{,}001$), vendar ne z B-HT. Multipla regresijska je pokazala, da imata vitalna kapaciteta in mišična masa pozitiven oziroma negativen učinek na rezultate plovnosti, ocenjene s testoma v navpičnem položaju. Poleg tega je bila masa rok negativno povezana z rezultati plovnosti, ocenjenimi z VT2 ($\beta = -6{,}26$; $p = 0{,}005$). Glede na dobljene rezultate lahko sklepamo, da sta za ugotavljanje plovnosti oba testa v navpičnem položaju (priročeno in vzročeno) primerno nadomestilo testiranju s podvodnim tehtanjem. Plovnost je močno povezana z vitalno kapaciteto in v manjši meri z mišično maso. Mišična masa ni dejavnik, ki bi ga lahko hipno spreminjali, medtem ko količino vdiha lahko nadziramo. Zato je nadzor dihanja in s tem zmanjševanje ali povečanje plovnosti pomembna veščina, ki naj bi jo plavalni začetniki osvojili v okviru programa začetnega učenja plavanja.

Ključne besede: plavalni začetniki, učenje plavanja, sposobnost lebdenja na vodi

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INTRODUCTION

When our body is immersed in water, we experience weightlessness. The degree of weightlessness we experience varies depending on the part of the immersed body (Yanai, 2002). It is determined by the balance between the magnitudes of two opposing forces acting on the body, namely the buoyant force (F_b) and the weight of the body. When a body displaces enough water to create a F_b equal to or greater than the body's weight, the body experiences complete weightlessness and floats. This shows buoyancy, which is the tendency or ability of the body to stay afloat, often referred to as our floating ability (Llana-Belloch, LucasCuevas, Perez-Soriano, and Prigo Quesada, 2013). On the contrary, if the weight is greater than F_b, the body accelerates downward and sinks to the bottom. The F_b is calculated as follows (Halliday, Resnick, and Walker, 2011):

$$F_b = \rho \cdot g \cdot V$$

where F_b is the buoyant force in [N], ρ is the density of water in [kg.m^{-3}], g is the acceleration due to gravity in [m.s^{-2}], and V is the volume of the displaced body in the fluid [m^3]. With respect to the human body, the volume of the displaced body of liquid, and consequently F_b, depends largely on the volume of the lungs. On inhalation, V and hence F_b increase, while on exhalation they decrease. Indeed, most people float at maximal inhalation and sink after exhalation (Stallman 1997; Llana-Belloch, LucasCuevas, Perez-Soriano, and Prigo Quesada, 2013). In addition to lung volume, F_b of the human body also depends on its density, which is not homogeneous due to the different densities of the biological tissues that compose the human body (Clauser, McConville, and Young, 1969). While bone tissue is the most dense, with a density between 1400 kg/m^3 (cancellous or spongy bone) and 1800 kg/m^3 (cortical or compact bone), other tissues such as muscles, tendons, or ligaments are somewhat denser than water, with a density between 1020 kg/m^3 and 1050 kg/m^3. The only tissue that is less dense than water is adipose tissue with a density of 940-950 kg/m^3.

Overall, these data show that buoyancy or floating ability varies in different people due to differences in lung volume and body composition. Swimming instructors dealing with beginners, as well as coaches training competitive swimmers at various levels, should consider this natural fact. Beginners being less buoyant are likely to need more time to gain confidence, break contact with the bottom of the pool, and should perform more effective propulsive movements to stay on the surface alone than beginners having higher buoyancy. In addition, controlling buoyancy by manipulating lung volume is a fundamental skill that beginners should learn in the water. In fact, the acceptance of buoyancy is the turning point in initial learning (Stallman, Moran, Quan, and Langendorfer, 2017). In addition, buoyancy is an important ability for competitive swimmers. It can influence the swimmer's perceived drag, efficiency, and metabolic cost of swimming (Chatard, Collomp, Maglischo, and Maglischo, 1990; Chatard, Lavoie, and Lacour, 1990; McLean and Hinrichs, 1998; Zamparo, et al., 1996a). Therefore, it is not surprising that swimming instructors and coaches often use different tests to assess the hydrostatic profile of learners or swimmers. The swimmer's hydrostatic profile (F_b through measuring body volume (V_b)) can be measured using several validated techniques such as: underwater weighing (Yanai, 2004, Zamparo et al., 1996a) and measurement of water displacement (Katch, Hortobagyi, and Denahan, 1989). Underwater weighing is a method commonly used for body composition assessment (Behnke, Feen, and Welham, 1995), but it can also be used to indirectly measure buoyancy. In this method, a person is submerged in water while being weighed. The weight of the person in water is compared to their weight in air, and the difference is used to calculate his or her buoyancy. In addition, a swimmer's buoyancy can be measured by determining the amount of water they displace when submerged. We can do it by measuring the volume of water before and after the person enters the water (Katch, Hortobagyi, and Denahan, 1989). By using the weight of the swimmer to the volume of water displaced, swimmer's buoyancy can be estimated. However, these methods are expensive and require complex techniques to measure. For this reason, swimming instructors and coaches use various floating tests that are inexpensive and easy to perform and, therefore, are often used in learn-to-swim programs and in regular training of competitive swimmers (Kapus et al., 2002). Some of them (turtle and vertical float after maximum inhalation) have been used only to distinguish floaters from sinkers (Carter, 1973). However, in others (vertical and horizontal floating test), researchers used a scale to measure participants' floating ability (Stallman, 1971; Barbosa et al., 2012). We use two vertical and one horizontal floating tests in Slovenia (Kapus et al., 2002). In the vertical tests, the swimmer takes a deep breath and remains in a vertical position with different arm positions, i.e., arms adducted to the body or arms extended overhead in deep water. It is assumed that a greater proportion of the swimmer's surfaced body represents greater buoyancy (Barbosa et al., 2012; Kapus et al., 2002). In horizontal floating tests, the swimmer takes a deep breath and remains supine with arms extended overhead on the water surface. The swimmer slowly pulls the arms toward the body. It is assumed that the later the swimmer's legs begin to sink, the greater the buoyancy (Kapus et al., 2002). However, to our knowledge, there are no studies in the literature on the validity of the presented floating tests. Therefore, the aim of the present study was to compare the buoyancy assessed by floating tests with the buoyancy calculated using the variables measured during underwater weighing. We also aimed to evaluate the relationship between assessed buoyancy and body composition.

METHODS

Experimental approach to the problem

Participants performed floating tests, underwater weighing, pulmonary function measurement, and body composition procedure on the same day in random order with a 30-minute break.

Floating testing consisted of one horizontal (HT) and two vertical tests with different arm positions, i.e., arms adducted to the body (VT1) or arms extended overhead (VT2). We assessed participants' buoyancy (B-HT, B-VT1, and B-VT2). In addition, we calculated participants' V_b and buoyancy (B-c) using variables measured during underwater weighing. The floating tests and underwater weighing were performed in a heated pool. The water temperature, set at 31-32 °C, was noted with an accuracy of 0.1 °C and used to calculate water density. The pulmonary function measurement and body composition procedure took place under controlled environmental conditions in the laboratory (21°C, 40–60% RH, 970–980 mbar).

Participants

Twenty-seven women (age: 20 ± 3 years, height: 1.66 ± 0.34 m, weight: 62 ± 7 kg; body mass index: 22 ± 2; vital capacity (VC): 4.26 ± 0.47 l) and twenty-six men (age: 19 ± 2 years, height: 1.81 ± 6.76 m, weight: 79 ± 10 kg body mass index: 24 ± 3; VC: 6.05 ± 0.7 l) volunteered to participate in the study. None of the participants were smokers and none had respiratory disease. Participants were fully informed of the purpose and potential risks of the study before giving written informed consent to participate. The study was approved by the National Ethics Committee of the Republic of Slovenia.

Body Composition Procedure

Participant's body composition was measured by bioelectrical impedance using the InBody 720 (Biospace Co., Seoul, Korea). Before each measurement, participant' palms and soles were wiped with an electrolyte tissue. Then, participant stood on the InBody 720 scale with the soles of his or her feet in contact with the foot electrodes, and body weight was measured. Gender, age, and height (which were determined using a wall-mounted stadiometer [SECA 220; Seca, Ltd., Hamburg, Germany]) were manually entered into the device by the experimenter. The participant then grasped the handles, with the palm, fingers, and thumb of each hand in contact with the hand electrodes. Body composition analysis was initiated while the participant remained as immobile as possible. The 8-electrode InBody 720 system measured body composition on the entire body and on 5 segments (arms, legs, and trunk) by emitting multiple frequencies at 5, 50, 250, and 500 kHz from the 8-pole contact points. The scan time for the InBody 720 system was approximately 2 minutes per participant.

Pulmonary function

A pneumotachograph spirometer (Vicatest P2a, Mijnhardt, The Netherlands) was used for measurement VC. Pulmonary function measurements were performed according to the recommendations of the European Respiratory Society (Miller et al., 2005). Residual lung volume was estimated by multiplying the average VC by the constant 0.28 and 0.24 for women and men, respectively (Wilmore, 1969).

Floating tests

Vertical floating tests

Participant performed two vertical floating tests with different arm positions: VT1 and VT2. Participant took and hold a deep breath and remained in the vertical position without moving. When the participant had assumed a stable position, we assessed his or her buoyancy in relation to the water surface. In the VT1 test, if the water surface was near (Cazorla, 1993): a) the vertex (score 1); b) the forehead (score 2); c) the eyes (score 3); d) the nose (score 4); and e) the mouth (score 5). In the VT2 test, if the water surface was near (Kapus et al., 2002): a) the ends of the fingers (score 1); b) the wrists (score 2); c) the middle of the forearm (score 3); d) the elbows (score 4); and e) the middle of the upper arms (score 5). In both tests, buoyancy at immersion was scored as zero. If the water surface was midway between two anatomical landmarks, the higher one was selected. The vertical floating tests lasted approximately 30-60 seconds until the swimmer achieved stable position.

Horizontal floating test

The participant held deep breath and remained supine with arms extended overhead on the surface of the water (HT). Then the participant slowly pulled his or her arms toward the body. We assessed his or her buoyancy in relation to the moment the legs began to sink (Kapus et al., 2002): a) with arms extended overhead (score 1); b) with arms extended obliquely upward (score 2); c) with arms extended to the side (score 3); d) with arms extended obliquely downward (score 4); and e) with arms adducted to the body (score 5).

All floating tests were repeated three times. The highest score was used for further analysis.

Underwater weighing

The participant was weighed in his bathing suit before entering the pool. During underwater weighing, the participant sat on a submerged chair suspended from the hanging scale so that his entire body, except for his head, was underwater. After maximal exhalation, the participant submerged his head under water and after a stable position was reached, the value of the certified hanging scale (Salter Brecknell 235 10S, United Kingdom) was read. This procedure was repeated until three weights within 50 g were recorded. The highest value was used for further analysis.

Data analysis

Calculations

After underwater weighing, we calculated the B-c for each participant in several steps based on the loss of body weight during weighing underwater, water density, and VC (Williams, Anderson, and Currier, 1983).

First, we calculated the body volume at residual lung volume (V_{RLV}) using the loss of body weight during underwater weighing and corrected the density of water according to the water temperature at the time of weighing. In this experiment, the water density was 0.995 kg/L at a water temperature of 31° to 32°C. Therefore, we derived V_{RLV} from the following equation (Williams, Anderson, and Currier, 1984):

$$V_{RLV} = (W_{air} - W_{water})/(\text{water density})$$

where V_{RLV} is the body volume at residual lung volume, W_{air} is the weight measured on land, and W_{water} is the weight measured in water. Second, since the floating tests were performed at full lung capacity, the V_b was determined by the sum of V_{RLV} and VC. Third, we calculated F_b by multiplying the V_b by the water density. To do this, we used the following equation (Williams, Anderson, and Currier, 1984):

$$F_b = V_b \times \text{water density}$$

where F_b and V_b are the buoyant force and the body volume, respectively.

Finally, B-c was calculated for each participant by dividing body weight on land by F_b (Llana-Belloch, LucasCuevas, Perez-Soriano, and Prigo Quesada, 2013). A B-c higher than 1, i.e., Fb was greater than weight, meant that the participant was floating on the water surface. If B-c was 1, it meant that the participant remained at the same depth. When buoyancy was lower than 1, i.e., exerted a net downward force, the participant sank to the bottom of the pool.

Statistical analyses

The validity of the floating tests was determined by examining the Spearman correlations between the buoyancy assesed with floating tests (B-HT, B-VT1, and B-VT2) and the buoyancy calculated from the underwater weight measurement (B-c). In addition, we used the scores obtained in the floating tests, for which a significant correlation was confirmed, as the dependent (criterion) variable for further regression calculations. Two linear regression models were tested. VC and tissue masses were used as independent (predictor) variables in the first regression model. A separate model was created for VC and body segment masses to determine the relationship of the variables with their respective assesed buoyancy. A p value ≤ 0.05 was considered statistically significant. SPSS for Windows version 18.0 (SPSS Inc; Chicago, IL) was used for all analyses.

RESULTS

Descriptive statistics for body composition variables, buoyancy assessed by VT1, VT2, and HT, and calculated buoyancy from variables measured during underwater weighing are presented separately for female and male participants in Table 1.

Table 1. Measured and calculated variables presented for female and male participants.

	Female	Male
Fat Mass (kg)	12.70 (4.6)	8.13 (3.06)
Mineral Mass (kg)	3.46 (0.57)	4.59 (0.74)
Muscle Mass (kg)	27.61 (3.96)	40.54 (5.86)
Arms mass (kg)	5.12 (0.7)	8.45 (1.46)
Trunk mass (kg)	21.77 (2.15)	31.42 (4.15)
Legs mass (kg)	15.53 (2.05)	21.2 (2.9)
B-HT (score)	2 (2-2)	2.5 (1-2)
B-VT1 (score)	3 (2.5-3)	2.75 (2-4)
B-VT2 (score)	4 (3-4)	1.5 (0.75-4)
W_{air} (kg)	62.26 (7.46)	78.53 (10.33)
W_{water} (kg)	1.89 (0.63)	3.47 (1.16)
V_{RLV} (l)	60.36 (7.39)	75.04 (9.67)
VC (l)	4.26 (0.47)	6.05 (0.7)
V (l)	64.62 (7.69)	81.09 (10.1)
F_b (kg)	64.23 (7.64)	80.61 (10.04)
B-c	1.01 (0.01)	1.01 (0.01)

Note. Means are shown with standard deviations in parentheses for the majority of variables. Median scores from floating testing are shown with quartile range in parentheses. B-HT – buoyancy assessed by horizontal floating test; B-VT1 – buoyancy assessed by vertical floating tests with arms adducted to the body; B-VT2 – buoyancy assessed by vertical floating tests with arms extended overhead; Wair – body weight measured at dry land; Wwater - body weight when weighed underwater; VRLV –body volume at residual lung volume calculated with the loss of body weight when weighed underwater and corrected the density of the water; VC – vital capacity; V – body volume determined by the sum of the body volume at residual lung volume and vital capacity; Fb – buoyant force calculated by multiplying the body volume by the water density; B-c – calculated buoyancy by dividing body weight on land by the buoyant force.

We calculated a positive B-c for most participants (Table 1). The average lift was 1.98 kg (19.42 N) for women and 2.07 kg (20.3 N) for men. Twelve participants (4 women and 8 men) had a B-c lower than 1 and received scores between 0 and 2 on the floating tests. The results in Table 2 show that B-c was moderately correlated with B-VT1 ($r = 0.51$; $p < 0.001$) and B-VT2 ($r = 0.55$; $p < 0.001$), but not with B-HT. In addition, there was a strong correlation between B-VT1 and B-VT2 ($r = 0.81$; $p < 0.001$).

Table 2. Spearman's correlations (rho) between calculated buoyancy from variables measured at underwater weighing and buoyancy assessed by floating testing.

	B-c	B-HT	B-VT1	B-VT2
B-c	1.00	0.17	0.51**	0.55**
B-HT		1.00	0.4**	0.50**
B-VT1			1.00	0.81**
B-VT2				1.00

Note. ** - significant correlation between the variables ($p < 0.01$).

Based on the results in Table 2, B-VT1 and B-VT2 were used as dependent (criterion) variables for further regression calculations (Tables 3 and 4). We calculated two linear regression models. The first model included VC and tissue masses as predictor variables (Table 3).

Table 3. Analysis of the first linear regression model with B-VT1 and B-VT2 as criterion variables.

Criterion variable	Predictor variables	b	SE of b	β	t	p-value
B-VT1	VC	1.06	0.22	1.14	4.78	0.00
	Fat Mass	-0.03	0.03	-0.13	-1.04	0.30
	Mineral Mass	0.07	0.20	0.06	0.34	0.73
	Muscle Mass	-0.17	0.03	-1.39	-5.16	0.00
	R = 0.63; R^2 = 0.4; Adjusted R^2 = 0.35; F = 8.04; $p < 0.001$; St. Error of estimate: 0.8					
B-VT2	VC	1.08	0.30	0.82	3.60	0.00
	Fat Mass	0.02	0.04	0.07	0.58	0.57
	Mineral Mass	0.38	0.28	0.23	1.38	0.17
	Muscle Mass	-0.24	0.04	-1.40	-5.38	0.00
	R = 0.67; R^2 = 0.45; Adjusted R^2 = 0.4; F = 9.69; $p < 0.001$; St. Error of estimate: 1.09					

Note. B-VT1 – buoyancy assessed by vertical floating tests with arms adducted to the body; B-VT2 – buoyancy assessed by vertical floating tests with arms extended overhead; VC – vital capacity, R – coefficient of the multiple correlation; R2 – coefficient of the determination; β – standardized regression coefficient; b – unstandardized regression coefficient.

The linear regression model that included VC and tissue masses as predictor variables (Table 3) explained 35% and 40% of the variation in B-VT1 and B-VT2, respectively. VC had a positive ($\beta = 1.14$; $p < 0.001$ in VT1 and $\beta = 0.82$; $p < 0.001$ in VT2) and muscle mass had a negative ($\beta = -1.39$; $p < 0.001$ in VT1 and $\beta = -1.4$; $p < 0.001$ in VT2) effect on the scores of buoyancy assessed by vertical floating tests. The second linear regression model included VC and body segment masses as predictors (Table 4).

Table 4. Analysis of the second linear regression model with B-VT1 and B-VT2 as criterion variables.

Criterion variable	Predictor variables	b	SE of b	β	t	p-value
B-VT1	VC	1,04	0,22	1,12	4,65	0,00
	Arms mass	-2,47	1,62	-5,01	-1,52	0,13
	Trunk mass	0,76	0,62	4,46	1,23	0,23
	Legs mass	-0,20	0,12	-0,77	-1,62	0,11
	R = 0,64; R^2 = 0,41; Adjusted R^2 = 0,36; F = 8,41; p < 0,001; St. Error of estimate: 0,8					
B-VT2	VC	1.02	0.30	0.78	3.44	0.00
	Arms mass	-4.37	2.16	-6.26	-2.02	0.05
	Trunk mass	1.40	0.83	5.80	1.69	0.10
	Legs mass	-0.30	0.17	-0.80	-1.78	0.08
	R = 0.69; R^2 = 0.48; Adjusted R^2 = 0.43; F = 10.97; p < 0.001; St. Error of estimate: 1.06					

Note. B-VT1 – buoyancy assessed by vertical floating tests with arms adducted to the body; B-VT2 – buoyancy assessed by vertical floating tests with arms extended overhead; VC – vital capacity, R – coefficient of the multiple correlation; R2 – coefficient of the determination; β – standardized regression coefficient; b – unstandardized regression coefficient.

Table 4 showed that the second linear regression model explained 36% and 43% of the variation in B-VT1 and B-VT2, respectively. VC had the greatest influence on the scores of buoyancy assessed by vertical floating tests ($\beta = 1.12$; $p < 0.001$ for VT1 and $\beta = 0.78$; $p < 0.001$ for VT2). In addition, the mass of the arms correlated negatively with the scores of buoyancy assessed by VT2 ($\beta = -6.26$; $p = 0.05$).

DISCUSSION

The results of the present study showed that buoyancy assessed by both vertical floating tests i.e. with arms adducted to the body or arms extended overhead correlated with the buoyancy calculated using the variables measured during underwater weighing. This was not confirmed for the HT. Moreover, the scores of buoyancy obtained with the vertical floating tests were strongly related to VC (positive correlation) and to muscle mass (negative correlation) of the participants.

Descriptive statistics of the variables selected were within the range of values reported in the literature from similar group according to gender and chronological age (Psycharakis, and Yanai, 2018; Roberts, Kamel, Hedrick, McLean, and Sharp, 2003; Siders, Lukaski, and Bolonchuk, 1993). Therefore, we can concluded that both vertical floating tests are suitable substitutes for underwater weighing to distinguish the participants according to theirs buoyancy. However, the magnitude of the correlations between B-c and B-VT1 or B-VT2 was significant (Table 2), but only moderate, i.e., not sufficient to make clear what they really mean. Due to easy implementation, we suggest that these test can be used only for rough assessments of pupils' buoyancy. Stallman (1971) recommended that teachers screen all learners as early as possible using a floating test to identify poor floaters. Early identification, attention, and patience with learners with poor buoyancy can help them reach a skill level that will allow them to overcome buoyancy deficiencies very early. On the other hand, the implementation of vertical floating test for testing competitive swimmers is more questionable. Indeed, Barbarosa et al. (2012) showed that the vertical floating test with arms adducted to the body did not present any relationship with anthropometrical and biomechanical variables nor with the prone gliding test. Therefore, they concluded that this test was not appropriate techniques to assess the swimmers’ hydrostatic profile. Even more, Yanai (2008) argued against the suggestion that swimmers’ buoyancy or ability for static floating has significant influence on theirs swimming performances. He disagree with the widely accepted mechanism that a swimmer with less (static) buoyancy swims deeper, has more drag and must exert more effort to overcome the drag while swimming than a swimmer who floats higher in the water (Chatard, Bourgoin, Lacour, 1990). He suggested that faster swimmers use buoyancy more effectively to generate body roll. This reduces the waste of generated hydrodynamic forces in non-propulsive directions and maximises forward propulsion.

There are several reports in the literature describing that buoyancy is related to respiratory variables (e.g., lung volume, VC, residual volume, and tidal volume) (Zamparo et al., 1996b). For this reason, we included VC in both regression models, in which the buoyancy scores assessed with vertical floating tests were used as dependent (criterion) variables. In the first model, we considered VC and tissue masses as predictor variables. The results of the present study supported the above suggestion. The assessed scores of buoyancy were closely related to VC (positive correlation) and muscle mass (negative correlation) of the participants. However, the later results differed from the results of previous studies, in which a higher percentage of fat mass correlated with a higher B value (Zamparo et al., 1996b). The reason for this difference could be the selection of participants. In the present study, the students from the Faculty of sport participated. Therefore, we can assume that they were physically active in various sports on recreational or competitive level. They were homogeneous and heterogeneous in terms of fat and muscle mass, respectively. According to these results and from the perspective of learning to swim, we should emphasize that muscle mass is not a factor that can be changed immediately, while the amount of inspiration can be regulated. Therefore, the control of breathing and, consequently, the reduction or increase of buoyancy is an important skill that novice swimmers should acquire as part of the swimming learning program (Stallman, Moran, Quan, and Langendorfer, 2017). In the second model, we included VC and body segment mass as predictor variables. The assessed scores for buoyancy were closely related to VC (positive correlation) and to arm mass (negative correlation) for VT2 but not for VT1. This difference is related to the fact that participants extended their arms above their heads and thus out of the water for VT2, whereas they were adducted to the body for VT1.

Limitation of the study

The magnitude of the obtained correlations between the buoyancy assessed with floating tests and the buoyancy calculated from the underwater weight measurement does not allow to draw clear conclusions. The reason for this may lie in some limitations that should be addressed in future studies.

We calculated buoyancy using underwater weight measurements. However, these testing procedure was carried out in a manner for determining body composition (percent of body fat particularly), where participant fully exhaled during weighing (Williams, Anderson, and Currier, 1984). Therefore, our calculation of F_b was based on the sum of VRLV and VC, which can only be an approximation of real V_b. On the other hand, Stallman (1971) determined functional buoyancy as body density at full inspiration, uncorrected for residual lung volume. A replication of this study should use a spirometer connected to the valve and measure the participant's VC and V_b while weighing underwater at total lung volume (Stallman, 1971). Additional mass (usually 6.5 kg) should be added to ensure full immersion when the participant holds their breath at full inspiration (McLean, and Hinrichs, 1998).

Moreover, in the floating tests, we used the arbitrary unit scale to measure participants’ floating ability (Barbosa et al., 2012). Like any ordinal measure, the scale used describes a ranking rather than a relative magnitude or degree of difference between the items measured. It is possible to exist some significant limitations in using an ordinal scale to measure this physical phenomenon. Therefore, the ordinal scale should be replaced by an interval scale. This means that you measure the distance between the highest point of the head (in VT1) or the ends of the fingers (in VT2) and the water surface in centimetres and standardise these values with the head and arm length.

Several techniques for determining residual volume are described in the literature. Helium rinse oxygen rebreathing, nitrogen washout, volume expansion, and plethysmography are some of those used. However, all of these techniques require special equipment. Therefore, several researches have used estimates of residual lung volume as we did in the present study.

CONCLUSION

According to the obtained results, we can conclude that both vertical floating tests i.e. with arms adducted to the body or arms extended overhead are suitable substitutes for underwater weighing to determine buoyancy, which is strongly related to vital capacity and less to muscle mass. Muscle mass is not a factor that can be changed immediately, while the amount of inspiration can be regulated. Therefore, the control of breathing and thus the reduction or increase of buoyancy is an important skill that novice swimmers should acquire as part of the learn-to-swim program.

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The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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