HUMAN CARDIORESPIRATORY RESPONSES TO RESTING WATER IMMERSION TO THE NECK WITH CHANGING BODY POSITIONS

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ABSTRACT

The aim of the study was to elucidate combined effects of water immersion (WI) and changing body positions on human cardiorespiratory (CR) function in regular swimming pool conditions. Twelve young healthy volunteers (6 females, 6 males) adopted a series of eight 4-min resting body positions on dry land and during WI. CR and gas exchange parameters were measured breath-by-breath by a telemetric portable gas analyzer (K4 b^2, Cosmed®, Italy). An integrated telemetric monitor (Polar® Vantage, Finland) was used for the measurement of heart rate (HR) simultaneously. WI had significant effect on CR and metabolic function so that redistribution of blood volumes occurred towards central circulation. Coolness of water was noticed to increase resting metabolic rate considerably. We conclude that constant hydrostatic pressure with immersion blunted the cardiac variations with body positions in regular swimming pool conditions.
Key words: Water Immersion, Body Position, Cardiorespiratory Function

INTRODUCTION

Human cardiorespiratory function (CR) is best balanced to upright body position in on-land activities. Various body positions and environmental factors, however, modify that balance frequently. Entering water is a dramatic experience to a human body. During upright water immersion (WI) hydrostatic pressure is exerted on the thoracic cavity and abdominal area creating an imbalance between the air pressure in the alveolar spaces and greater pressure on the thorax (Epstein 1981). Consequently, a redistribution of blood volume (cephalad shift) occurs towards central circulation (Arborelius et al. 1972). The cardiac output, stroke volume and blood volume in central circulation have been found to increase during WI in thermo neutral water (Arborelius et al. 1972, Epstein et al. 1981; _ramek et al. 2000). _ramek et al. (2000) observed that entering water itself had no effect on oxygen consumption (VO_2), however, in contrast to thermo neutral condition (32 ºC), 1-hour sitting in 20 ºC and 14 ºC water increased VO_2 by 93% and 350% in the two conditions, respectively. Choukroun and Varene (1990) demonstrated that there is a close relationship between water temperature and hydrostatic pressure effecting VO_2 so that the effects of temperature overrule the effects of hydrostatic pressure when immersed to cold water. On the other hand, total WI has been used to simulate space flight conditions where the effects of changing body positions disappear due to weightlessness (McArdle et al. 2001). In microgravity, however, blood and fluid volumes shift upward into the thoraco-cephalic regions due to loss of hydrostatic gradient (Leach et al. 1996). Breath-by-breath (BxB) gas analysis in WI has been applied to study the CR response to free swimming during immediate recovery period (Rodríguez 1999, 2000), however, focusing on the consequences of physical activity rather than the effects of WI itself. Despite numerous research designs though, the theory around the consequences of WI on CR, in connection with changing body positions in regular swimming pool conditions, is still full of beliefs and misconceptions. To elucidate the combined influence of body position and WI during rest, this study compared the effects of lying, sitting, and standing on CR function and gas exchange between dry land and WI in a standard swimming pool.

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METHODS

Twelve volunteers (table 1) aged 19-24 years, 6 males and 6 females, adopted a series of resting body positions both on dry land and during water immersion (head out of the water) in a standard swimming pool. The subjects were instructed to change their body position at 4-min intervals, an assistant removing the measurement equipment during the experiments. The sequence of eight events (4 min each) was: sitting (SID), standing (STD), lying (LYD), and standing (STD) in dry-land; standing (STW), lying (LYW) and standing (STW) in water, and standing (STD) in dry-land. Air and water temperatures were 25.5 ºC and 26.9 ºC, respectively. Immediately after the experiments the subjects were asked to report with a questionnaire (table 3) about their sensations of coldness and/or warmness.

Table 1. Physical characteristics of the subjects. Values are mean (SD).

	Age (y)	Height (m)	Weight (kg)	BMI ($kg \cdot m^{-2}$)	Body Area m^2
Females	22.0	1.64	55.3	20.6	1.55
(n = 6)	(1.2)	(0.04)	(4.5)	(1.0)	(0.10)
Males	23.8	1.79	72.2	22.5	1.85
(n = 6)	(1.1)	(0.05)	(5.5)	(1.0)	0.10)
All subjects	22.9	1.72	63.8	21.5	1.70
(n = 12)	(1.5)	(0.09)	(10.0)	(1.3)	(0.19)

CR and metabolic parameters were monitored using a BxB telemetric portable gas analyzer (K4 b^2, Cosmed®, Italy). An integrated telemetric monitor (Polar® Vantage, Finland) was used for the measurement of heart rate (HR) simultaneously. BxB data was first screened for artifacts. Thereafter the data was averaged every 10 seconds for both BxB noise reduction and to enable statistical handling of the data. Differences among variables in the various experimental conditions were tested by one way repeated measures ANOVA (or Friedman RM ANOVA on ranks), after testing for normality (Kolmogorov-Smirnov test). Post-hoc paired multiple comparison tests (Student-Newman-Keul method) were used thereafter.

RESULTS

Figures 1-5 show the CR and metabolic responses to the change in body position and WI. Significant reactions were noticed as a consequence to the physical activity when changing the body positions, and the reaction was especially large when entering water in all measured parameters. HR response (fig. 1) was more pronounced in dry-land conditions than in the water. Oxygen pulse (fig. 2), which reflects the stroke volume, increased significantly between STD and LYD conditions and during the entire WI. Pulmonary ventilation (VE) (fig. 3), VO_2 (fig. 4), and energy expenditure (EE) (fig. 5) demonstrated only modest reaction to the change in body position in dry land but increased significantly during WI. Table 2 shows that during the last part of each 4-min event, separated from the active change in body position, the whole body resting metabolism was lower in standing as compared to lying, but the CR function appeared to be less efficient when standing (higher HR response, equal ventilatory work for a lower VO_2 and lower ventilatory efficiency). However, HR stayed at lower level during STD immediately after the WI. Oxygen pulse started to decrease immediately after the WI but stayed higher in STD as compared to STD preceding the WI. During WI, body position did not influence resting metabolism or CR responses, thus simulating effects of weightlessness. Table 3 shows that the subjects reported only moderate cold sensations (−0.8 up to −1.8) during WI while in dry land the sensations were mainly neutral (+0.5). Noticeable shivering was observed with some of the leanest male subjects during the LYW and the second STW. Only non-significant gender specific differences were found in all measured parameters.

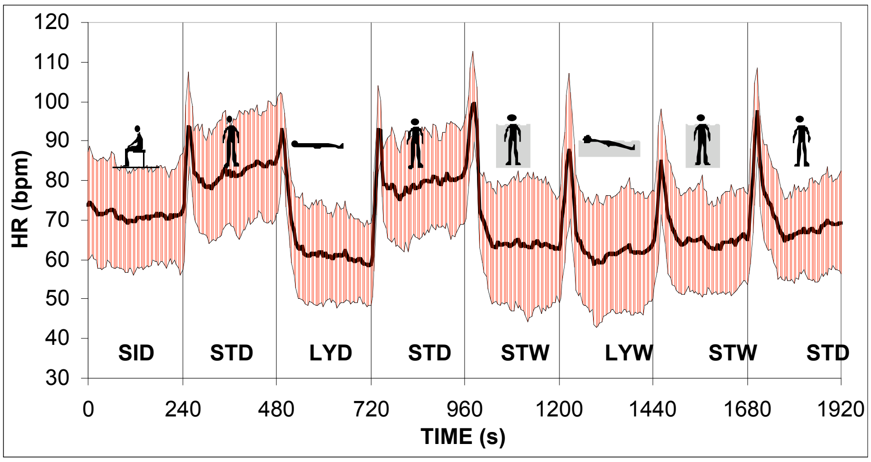

Figure 1. Heart rate during the experiments in dry land and in water [Mean (SD)].

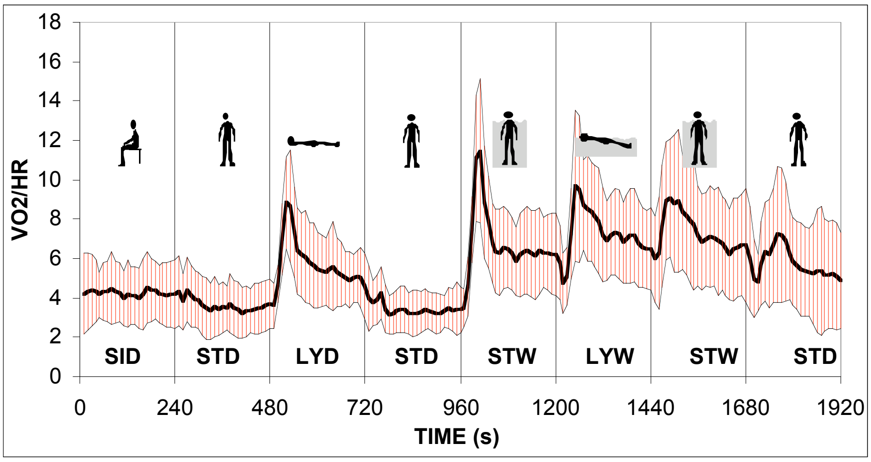

Figure 2. Oxygen pulse during the experiments in dry land and in water [Mean (SD)].

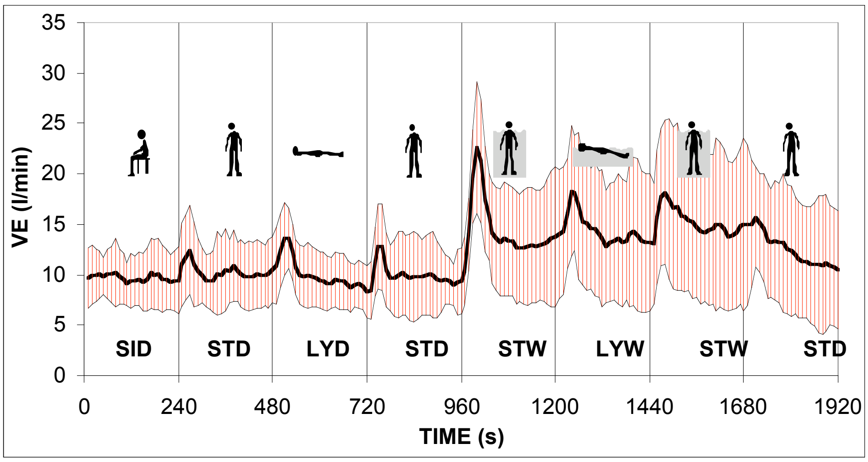

Figure 3. Pulmonary ventilation during the experiments in dry land and in water [Mean (SD)].

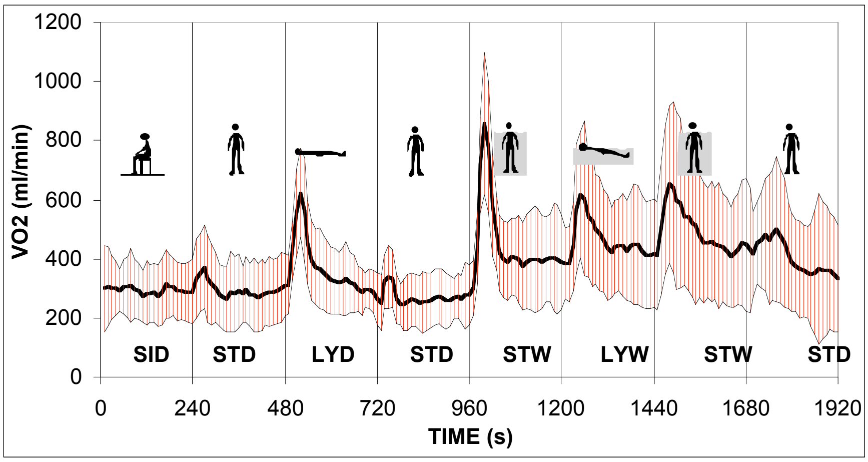

Figure 4. Oxygen consumption during the experiments in dry land and in water [Mean (SD)].

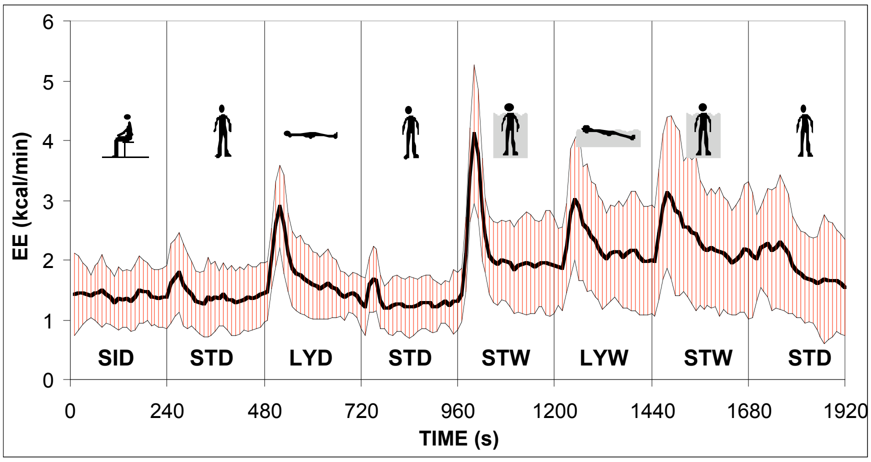

Figure 5. Energy expenditure during the experiments in dry land and in water [Mean (SD)].

Table 2. Effects of body position on selected resting cardiorespiratory and metabolic parameters during water immersion (W) as compared to dry-land (D) conditions. [Mean (SD)].

Body position	*Parameter*	*Dry-land (D)*	*Water (W)*	*D-W diff. (p)*	*Parameter*	*Dry-land (D)*	*Water (W)*	*L-W diff. (p)*
Lying	Oxygen uptake ($mL \cdot min^{-1}$)	310 (92)	439 (184)	< .05	Pulmonary ventilation ($L \cdot min^{-1}$)	9.1 (2.5)	13.5 (6.6)	< .05
Sitting		292 (104)	□	□		9.7 (3.2)	□	
Standing		281 (115)**	395 (167)	< .05		10.0 (3.3)	13.0 (5.8)	< .05
Lying	Heart rate ($beats \cdot min^{-1}$)	61 (12)	62 (16)	ns	Ventilatory equivalent for O_2 (V_E/VO_2)	27 (5)	28 (7)	ns
Sitting		71 (12)*	□	□		30 (3)	□	□
Standing		83 (14)**	64 (17)	< .05		33 (5)*	31 (9)	< .05

* Different from the sitting position; ** Different from the lying position; $p < .05$

Table 3. Self-reported cold and warm sensations of the subjects during the course of the experiments. Scale from 3 (very warm) through 0 (neutral) to –3 (very cold). [Mean (SD)].

	Females	Males	All
Sitting, dry	0.5 (0.8)	0.3 (0.5)	0.4 (0.7)
Standing, dry	0.5 (0.8)	0.3 (0.5)	0.4 (0.7)
Lying, dry	0.3 (0.5)	0.3 (0.5)	0.3 (0.5)
Standing, dry	0.3 (0.5)	0.3 (0.5)	0.3 (0.5)
Standing, water	−1.2 (0.4)	−1.2 (0.8)	−1.2 (0.6)
Lying, water	−1.0 (0.9)	−1.8 (0.8)	−1.4 (0.9)
Standing, water	−0.8 (0.8)	−1.5 (1.2)	−1.2 (1.0)
Standing, dry	−0.5 (1.0)	−0.5 (0.5)	−0.5 (0.8)

DISCUSSION

The present data demonstrated that the strategy to properly regulate cardiac output in different body positions was affected by WI. The major findings refer to the fact that there might be counter balanced effects from different mechanisms regulating the CR function during immersion and changing body position. Although the HR response when lying in water was essentially the same as in dry land, the standing position during WI did not show tachycardia, as was the case on land. WI itself decreased HR and increased oxygen pulse presumably due to hydrostatic pressure around abdominal area and thorax. The CR function was thus regulated towards central circulation, supporting previous literature (Arborelius et al. 1972, Epstein et al. 1981). Larsen et al. (1994) also reported significant decrease in HR during thermo neutral WI. Park et al. (1999) suggested that WI at 30 ºC provides an additional increase in cardiac preload leading to an increase in the stroke volume compared to that of the thermo neutral WI at 34-35ºC. Furthermore, _ramek et al. (2000) suggested that WI at thermo neutral temperatures would stimulate mainly baroreceptors leading to bradycardia and decreased vascular resistance, approximating that WI might actually strengthen the influence of the parasympathetic nervous system. Previously Miwa et al. (1997) came into similar conclusion when studying the blood pressure and HR variability during WI. The present data stood well in-line with these suggestions, while HR was lower and oxygen pulse higher during the STD immediately after the WI. The reaction was clear even within the short 4-min period of time used by this study and the chosen sequence of activities was considered not to have affected on the results.

The effects of coolness of water (26.9 ºC) in the present data were most evident. Even though only a few of the leanest males experienced noticeable shivering in water we observed that both VO_2 and EE were significantly increased during WI. _ramek et al. (2000) observed that when water temperatures of 32 ºC and 20 ºC were compared there was a 93% elevation in VO_2 due to coolness of water. The present data showed that entering the water at 26.9 ºC, which is a typical temperature in swimming pools, increased both VO_2 and EE by nearly 40%. This is an important observation to those who frequently visit swimming pools for both recreation and physical activity in order to maintain their energy balance. One may thus expend additional energy considerably just by staying in water and along with some water activities the high EE may become a prominent feature of visiting swimming pools.

As shown by the present data the resting metabolism during WI was larger as compared to land conditions. This is probably not only due to increased heating of the body but also due to parallel activation of thermo regulation mechanisms and inspiratory musculature. Respiratory function seemed more efficient, particularly in the standing position (see table 2). It seems evident that while standing in the water the hydrostatic pressure, by squeezing the abdominal area and thorax cavity with concomitant help of air in the lungs and dead spaces buoying the torso upwards, enables a better emptying of the lungs. Simultaneously the water compression overloads the inspiratory muscles when inhaling, with a natural effect of increasing VO_2. These assumptions support Robertson et al. (1978) suggesting that during WI there is a significant amount of gas trapping due to breathing at low lung volumes and the central shift of blood flow. The increase in V_E observed during WI could then be explained by 1) the increased pulmonary dead space and lower ventilatory efficiency, and 2) the increased intrathoracic blood volume, which, in turn, would increase bronchial blood flow and cause a relative bronchial obstruction.

WI seemed not to have gender specific effects on CR system as was also demonstrated by Watenbaugh et al. (2000) observing that long lasting thermo neutral WI to the neck increased left atrial diameter similarly in both women (28%) and men (25%). The present data showed that all CR responses were similar between males and females and the only slight differences were noted in the feeling of coldness while some of the leanest males experienced shivering during WI. We conclude that constant hydrostatic pressure with immersion blunted the cardiac variations with body positions. Further research should clarify differential regulatory mechanisms adapting human CR function to WI in regular swimming pool conditions.

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