Metabolic and cardiorespiratory response in swimmers during head-out immersion: A prosprective study

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Réponse métabolique et cardiorespiratoire chez les nageurs lors de l'immersion tête en dehors de l'eau : Etude prospective

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R É S U M É

Prérequis : Le sport représente un stress pour le corps humain. Plusieurs réponses métaboliques et cardiorespiratoires au sport sont connues. Cependant, peu d'éléments en sont connus concernant les nageurs et en particulier lors de l'immersion tête en dehors de l'eau.
But : Déterminer la réponse métabolique et cardiorespiratoire chez les nageurs lors de l'immersion tête en dehors de l'eau.
Méthodes: Nous avons comparé les besoins énergétiques ainsi que les modification cardiaques et ventilatoires chez 13 nageurs sains effectuant un exercice permanent durant 10 mn et ce ci à l'air par rapport à une immersion jusqu'aux hanches dans une eau à 26°C.
Résultats: La même charge de travail ergométrique a été réaliséeavec une consommation maximale d'oxygène de 3,9 ± 2,63 l/min à l'air versus 3,55 ± 2,48 l/min à l'eau (p=0,953). Les valeurs moyennes de ventilation minute, l'équivalent ventilatoire pour l'oxygène, l'équivalent ventilatoire pour le CO2, le débit expiratoire de pointe, le rapport d'échanges respiratoires et le rythme cardiaque; n'étaient pas différentes selon que l'exercice ait été réalisé à l'air ou dans l'eau. Cependant, le premier seuil ventilatoire était significativement plus élevé dans l'eau par rapport à sa valeur à l'air. La valeur moyenne du premier seuil ventilatoire était de 0,89 ± 0,23 l/min à l'air et de 1,08 ± 0,23 l/min lors de l'immersion dans l'eau; (p=0,016).
Conclusion: Ces résultats suggèrent qu'entrainer les nageurs en immersion (ceintures) pourrait améliorer leur capacité aérobie.

M o t s - c l é s

Adaptation, respiration, paramètres cardiaques, exercice dynamique, travail ergométrique, exercice, tête en dehors de l'eau, consommation maximale d'oxygène, paramètre ventilatoires.

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S U M M A R Y

Background: Sport represents a stress for the body. Many metabolic and cardiorespiratory changes are known during physical activity.However, litte is kwown in swimmers particularily during head-out immersion.
Aim: To determine the metabolic and cardiorespiratory response in swimmers during head-out immersion.
Methods: The energetic, cardiovascular function and ventilatory requirements of a 10 min steady state arm exercise performed by 13 healthy subjects in air and during immersion up to the hip in 26°C water were compared.
Results: The same ergometric work load was achieved with an average maximum oxygen uptake of 3.9 ± 2.63 l/min in air versus 3.55 ± 2.48 l/min in water (p=0.953). During exercise, the average values of minute ventilation, ventilation equivalent for oxygen, ventilation equivalent for CO2, peak expiratory flow, respiratory exchange ratio and heart rate were not different in water and in air. However, first ventilatory threshold was significantly higher in water than in air. The mean value of the first ventilatory threshold was 0.89 ± 0.23 l/min in air, and 1.08 ± 0.23 l/min in water immersion; (p=0.016).
Conclusion: These results suggest that training swimmers favoring immersion (weight belts) may improve their aerobic capacity.

K e y - w o r d s

Adaptation, breathing, cardiac variables, dynamic exercise, ergometric work, exercise, heat-out, maximum oxygen consumption, metabolism, sport, swimmer, ventilatory variables.

Recently, increased effort has been directed toward the study of man's physiologic response to work in water. Immersion exposes the body to new hydrostatic, viscous, inertial, and thermal conditions, and sometimes stimulates circulatory reflexes, that could alter cardiorespiratory responses to the exertion. The effects of these changes will vary with posture, workload, type of limb movement, mean intra-thoracic pressure, and water temperature and should be most evident in upright subjects exercising maximally in cold water [1]. Therefore, we find it mandatory to determine the changes caused by immersion. This paper reports a comparison of cardiorespiratory and metabolic responses between young swimmers exercising heavy loads in air at 18-24°C and others experimenting the same exercise but in water at 26°C.

PATIENTS AND METHODS

Thirteen healthy members of the Tunisian college of swimmers participated to this study (11 males and 2 females). All the swimmers' consents were obtained prior to the protocol. Physical characteristics of the subjects are detailed in table 1.

Table 1: Physical characteristics of the swimmers

Age (years)	19.2 ±2,66
Height (m)	1.71±0.07
Weight (kg)	67.61±10.3
Body mass index (%)	23.41

General set –up of the study

The subjects had to cycle with arms using an 'exergonic device' simulating a crawl arm-pulling. Each subject on air conducted an incremental graded cycle exercise. The beginning was with an initial rate of 20 cycles during the first minute. The cadence cycle was increased by 10 cycles every minute in the successive stages until a maximal test. The ambient air temperature of the room was kept between 18-24°C. The same protocol was conducted in water after 1 hour of rest. During immersion exercise, the subjects were in a circulating water tank (1.2 x 0.50 m). For submersion experiment, the water temperature was adjusted to 26°C. In water, the subjects were immersed up to the hip, the external surface of the chest and abdomen was not immersed. In both environments, when the subjects fell behind the cadence, or when their physiological responses did not increase in response to the higher cadence, they were strongly encouraged to complete at least another full minute. The work was stopped when the VO2 max plateau or the maximum HR were reached (220-age).

Measurements

Energetic variables: VO2 max, VO2 and VCO2; and spirometric variables: VE, PEF% and tidal volume (VT) were assessed by Metamax 3 B, a mobile ergospirometry system, connected to a facial mask. Assessment of metabolic and respiratory parameters were recorded every 3 seconds at rest (for 30 s), and during exercise in ambient air and in water immersion.

The device was calibrated before and after each test. RQ and respiratory oxygen equivalent (VE/VO2) were calculated from the data of oxygen and carbon dioxide measurements. HR monitoring was assessed by a polar. In both conditions, a plateau of VO2 max and HR with increasing workload were required. Two evaluators from 30-s-average respiratory data determined visually the VT1 and the second ventilation threshold VT2.

Statistical analysis

Data were analyzed using a series of dependent t-test. Statistical significance was established at the 95% confidence level ($p \leq 0.05$). Data are presented as mean SD.

RESULTS

The swimmers mean age was 19.2 years and the sex ratio 2/11 (2 females/11 males).The mean height was 67.61 ± 10.3 Kg and the mean weight 1.71 ± 0.07 m.

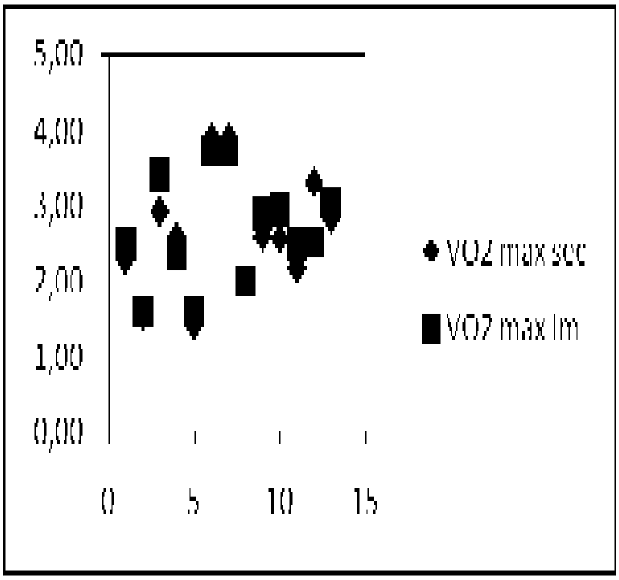
Ergometric Work

As expected, a similar ergometric workload was achieved during air and water exercises. In both air and water arm exercise, maximum work capacity was defined as being the work level above which the subject should not continue, because he reached the VO2 max or the maximum HR.

Maximum oxygen consumption (VO2 max)

During exercise in air, VO2 max reached a steady state at a mean value of 3.9± 2.63 l/min. During exercise in water, the mean value of VO2 max is 3.55± 2.48 l/min. The VO2 max was not significantly higher during water exercise than in air; p=0.953. Figure 1 shows that whatever conditions, the VO2 max in air and that in 26°C water are almost identical.

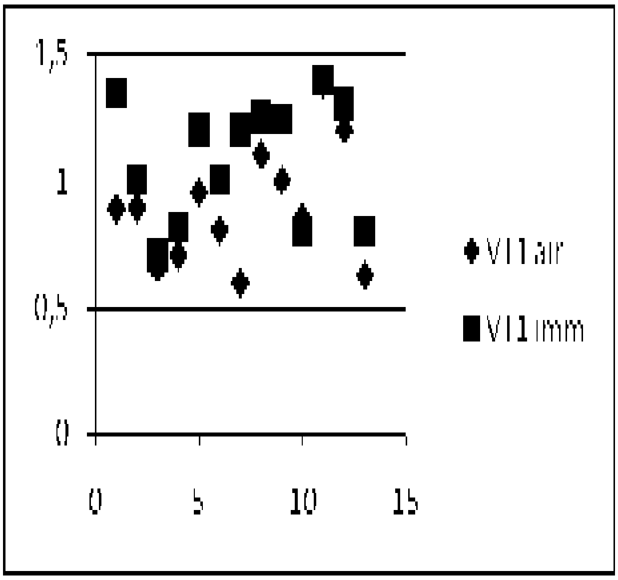
Figure 1 : VO2 max in air and in immersion



First ventilatory threshold VT1

The VT1 correlated to blood lactic acid level during exercise, was higher in water than in air. The mean value of VT1 was 0.89 ± 0.23 l/min in air, and 1.08 ± 0.23 l/min in water immersion (p=0.016). Fig. 2 shows that the VT1 was higher in water exercise than in air exercise.

Figure 2 : VT1 in air and in water



Second ventilatory threshold (VT2)

The VT2 correlated to the worsening of the metabolic acidosis. It remained unchanged during water exercise at 26°C (2.37 ± 0.5 l/min) and during air exercise (2.28 ± 0.53 l/min); p=0.463.

Ventilatory variables

The mean value of VE was 116.76 ± 76.5 l/min in air, and 117.31 ± 77.31 l/min in water immersion. VE was not significantly higher during water exercise than during air exercise (p=0.678). QR did not change either during air or water exercise. Its mean value was 0.94 ± 0.078 in air, and 0.92 ± 0.086 in water (p=0.173).The V Eq O2 assessed during water exercise (37.87 ± 28.96 l/O2 consumed) was not significantly lower than the one assessed during air exercise (41.85 ± 30.31 l/O2 consumed); p=0.260. The V Eq CO2 assessed during water exercise (31.78 ± 28.17 l/CO2 breathed) was not significantly lower than that assessed in air exercise (42.97 ± 29.71 l/CO2 breathed); p=0.314.Similarly, there was not any statistical difference of the PEF% between exercise in water and in air. The mean values were 6.14 ± 3.87 l/min and 5.79 ± 3.76 l/min respectively in water and in air (p=0.314).

Cardiac Variables

The VO2 values selected for the comparison of the HR were the VO2 max at each level of the arm work test in air and in water. During exercise, the maximal HR averaged 10 beats /min and was lower in water at 26°C than in air (163.25 ± 111.47 in water vs 173.26 ± 115.93 in air), but without statistical significance; p= 0.678.Various cardio respiratory responses are summarized in Table II. No significant difference was found between the means of VO2 max, VE, RQ, V Eq O2, V Eq CO2 and HR during exercise in water and those measured during exercise in air, except for the VT1 which was significantly greater during exercise in water than in air.

DISCUSSION

The physical characteristics of the swimmers in the present study (Table I) are in close agreement with these of the previously reported data concerning the trained college swimmers of international and Olympic caliber [2]. In this study, we have demonstrated that a duration of 6 min is sufficient for swimmers to achieve the same ergonomical workload in water and in air. These results are consistent with those reported by William who found a duration of 5 min [3]. However, Bréchat et al reported energetic and ventilatory requirements of a 30 min steady state cycling exercise [4].

Table 2: Summary of the results of the physiological responses during air exercise and during exercise water.

Characteristics	Air		Water		P
	Mean	SD	Mean	SD	
VO2 max (l/min)	3.9	2.63	3.55	2.48	0.953
VT1 (l/min)	0.89	0.23	1.08	0.23	0.016*
VT2 (l/min)	2.28	0.53	2.37	0.5	0.463
VE (l/min)	116.15	76.5	117.31	77.31	0.678
RQ	0.94	0.078	0.92	0.086	0.173
V Eq O2 (l/min)	41.85	30.31	37.87	28.96	0.260
V Eq CO2 (l/min)	42.97	29.71	31.78	28.17	0.314
PEF%	5.79	3.76	6.14	3.87	0.314
HR (beats/min)	173.26	115.93	163.25	111.47	0.678

**Significant difference*

At rest, water immersion up to the xiphoid, causes a rise in thoracic fluid content as demonstrated by the larger thoracic fluid conductivity [5]. This shift in plasma volume has been ascribed to the effect of hydrostatic pressure on the lower limbs and the abdomen [5]. In our study, we found that water level above the hip was sufficient enough to make the thoracic fluid vary. A water temperature between 29°C and 33°C is thought to be thermo neutral threshold during dynamic exercises [6]. In our study, the water temperature was 26°C and therefore is considered to be low. Lee et al [7] reported that water levels above the hip at 25°C cause depression of the internal temperature which is due to insufficient heat production offsetting heat loss even during light exercise.

VO2 max

The VO2 difference between water and air exercise remains not significant, consistent with the slight increase due to immersion as reported by other studies [8, 9, 10]. Magel et al [2] have found no significant difference between the mean maximum oxygen uptake during treadmill running (4.2 l/mn) and during tethered swimming (4.14 l/mn) The VO2 max in swimming was equivalent to that in running because of the interaction of the lower pulmonary ventilation and a higher oxygen extraction [2]. In this experiment, we have demonstrated that an increased oxygen store and /or an altered blood distribution to the weak active muscle don't cause a variation of the VO2 response to exercise in water and in air. However, some authors report that during exercise, the VO2 max could be increased by immersion [3, 4, 11]. In Shono's study, the VO2 max during swimming (3628 ± 228 ml/min) was significantly higher than that during running (3408 +/- 222 ml/min) [11]. William et al [3] reported that the increase of the VO2 during a sub maximum work in 25°C water compared to the corresponding values in air at 33°C, can probably be attributed to the shivering thermogenesis caused by the cool water, and possibly by a more effective convective heat transfer due to the moving water during exercise.

Nadel et al [12] reported that the increased VO2 max is necessary to support the shivering contractions superimposed upon the muscle contraction in a swimming exercise in a low water temperature (18°C). They also find that the convective heat loss during free swimming could be considerably greater than during stationary work in a water tank [12]. On the other hand, Igor et al [13] demonstrated that the increase in VO2 max during the first minute of immersion is partly due to the increased hydrostatic pressure causing a shift of venous blood towards the thoracic region, and a transient increase in the uptake of oxygen into the blood. Monpetit et al [14] highlighted another important factor. In their study, the swimming speed during maximal swimming effort was 10% higher when using the backward extrapolation (BE) method than when the conventional Douglas bag technique was used in the same subjects. The BE method is valid for measuring the VO2 peak in maximal swimming and allows the swimmer to use entirely his specifically trained musculature [14]. Conversely, other studies reported a decrease of VO2 max in immersion compared to that in air [15-17]. The VO2 max obtained by Yashuto et al (6) during deep water running was approximately 20% below that obtained in response to treadmill running. The lower VO2 max is believed to be due to a combination of cardiovascular responses to hydrostatic pressure and to the mechanical constraints imposed to the body when exercising against water resistance, and could also be attributed to limitations of limb movement due to the viscosity friction of water, which would reduce the amount of work done by working muscles. Bonen and co-workers [18] showed a significantly lower VO2 max in arm ergometry exercice (2.36 ± 0.24 l/min) compared to that observed in a swimming test ($P < 0.05$).

Differences between tethered swimming and arm ergometry VO2 max were important (14.7 ± 2.4%), despite the high correlation ($r = 0.97$) between these measurements. Predictions of a swimming VO2 max from the arm-ergometer data yielded to a considerable error (± 7.1% and ± 7.4%) [18].

First ventilatory threshold VT1

In the experiment we report, the VT1 correlated to blood lactic acid levels during exercise in water that was significantly higher than in air, reflecting the increased oxygen requirement in the cold. This may indicate an accumulation of more CO2 during exercise in water than in air and probably results in a higher alveolar PCO2. The excess of CO2 released from the bicarbonates is used to buffer acid metabolites produced during the exercise. Our results are in agreement with those of Reily and Svedenhag [19, 20].

Bréchat et al reported that plasma lactate levels rose significantly more (+122% versus +67%) when the same ergometric workload was achieved in water compared to a workload achieved in air [4]. The highest increases in ventilatory requirements during exercise were prompted by a larger production of carbon dioxide and lactate [4]. On the contrary, in the study reported by Yasuto et al, blood lactate levels reached in deep water running were lower than those reached in treadmill running. The restricted blood flow may be responsible for the lower blood lactate values exhibited at DWR VO2 max [6].

First ventilatory requirements during exercise

In the study we report, the ventilatory variables (VE, VT, FR, VC, RQ, PEF%, V Eq O2) ranked similarly in water and in air during the arm exercise. Our results show that there is no effect of water immersion or temperature on VE in relation to VO2 during exercise. The reduction of VT during work in water may be due to the effect of hydrostatic pressure, the position of the chest, and the involvement of the respiratory muscles in the arm stroke. This changing in the VT has also been reported by previous studies [3]. William et al [3], concluded that there was no effect of water immersion on VE during work. However, Bréchat et al. [3] observed an increase of the VE during the same work in air and immersion.

It appears that during immersion, the physical events causing the reduction of both VC and lung compliance might further extend the mechanical work of ventilation [3]. It can therefore be suspected that the large ventilatory work attested by high values of VE and TV, contributed to a higher VO2 in water than in air at similar ergometric workloads [3]. On the contrary, several studies reported a decrease of VE during work in immersion when compared to that in air [2, 8, 11, 15, 16].

Heart Rate

Alternation in cardiovascular dynamics is found to occur when the body is exposed to hydrostatic forces [6]. In the current study, the maximal HR remained unchanged in both environments. The HR was 10 beats/min lower in water than that in air, but this difference is not statistically significant. During exercise, the higher rate of blood flow through working muscles may act to reduce the effects of limb vasoconstriction even though the bradycardia response is still present. Our results are similar to those reported by many authors [2, 3, 8, 16, 21, 22]. William and co-workers [15] tried to explain the lower HR response to swimming compared with walking at similar levels of VO2. Several factors related to each activity must be considered such as the average of each performed activity, the position of the body and the active muscle mass involved in each exercise. This suggests that the decrease of the HR in swimming may be due to the facilitated venous return and to the greater cardiac filling which would result in a larger stroke volume and in a lowered HR at sub maximum and maximum work [15]. Craig and Dvorak [21] found an HR fall of 10 beats/min in water at 20°C compared to the HR in a warm water or in air. Therefore, due to its temperature, the swimming pool is a suitable environment of metabolic heat dissipation produced during an intense work.

Gilbert and al. [23] explain the bradycardia in immersion by the fact that the water temperature affects the relationship between HR and VO2 at waist depth, suggesting that water temperature can add a significant thermal load to the cardiovascular system. Yasuto et al. [6] explain the fact that the HR is low during a maximal effort in water immersion condition by the central shift in blood volume. In fact immersion results in a hydrostatic pressure gradient causing a facilitated central venous return and a greater preload and stroke volume. Other authors report that immersion causes a vagal dominance on the cardiac autonomic interaction, which is due to the central shift in blood volume and/or to the pressure of water on the trunk [24, 25].At heavier loads, resistance to the chest wall motion, altered conditions of body heat dissipation and, in upright subjects, of pooling abolition in dependent veins may alter cardio respiratory responses.

CONCLUSION

In this study we have demonstrated that immersion up to the hip at 26°C does not impair oxygen consumption or cardio-respiratory parameters during arm exercise. The active used musculature is not enough to vary the VO2 max, the VE and the HR in a situation in which not all the limbs are moving. However, we observed a significantly increase of the VT1 during exercise in immersion compared with that in air. Therefore, it is possible that an important exertion in water improves the aerobic capacity of the swimmers in this study.

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