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# Plasma Volume Changes During Submaximal Swimming

R. G. McMurray

Human Performance Laboratory, University of North Carolina, Chapel Hill, NC 27514, USA

**Summary.** The hemodynamic and diuretic responses of six swimmers were evaluated during 35 min of resting immersion, free swimming, and land bicycle ergometry at approximately 70% exercise specific maximal oxygen uptake. Venous blood, sampled at 0, 5, 10, 15, 25, and 35 min of each trial, was analyzed for hemoglobin, hematocrit, and total plasma protein concentration. Urine output was also measured. Resting immersion resulted in a significant ($p < 0.05$) hemodilution (plasma volume = $+2.5 \pm 1.5\%$) during the first 25 min and a return towards resting levels at the termination. During swimming exercise, plasma volume decreased by $-15.9 \pm 1.3\%$ ($p < 0.01$). A similar $-17.0 \pm 1.3\%$ decrease was also evident during cycle ergometry. Urine output averaged $3.1 \pm 0.9$ ml · min$^{-1}$ during resting immersion, significantly greater than either swimming ($1.0 \pm 0.1$ ml · min$^{-1}$) or cycling ($0.4 \pm 0.2$ ml · min$^{-1}$). Total plasma protein concentration increased less during cycling compared to swimming ($p < 0.05$) and was unchanged ($p > 0.05$) during resting immersion. It was concluded that the hemodynamic and renal responses to immersion are suppressed during swimming. It was also apparent that, despite possible differences in hemodynamics, plasma shift during exercise may be similar on land and in the water. It appears that the amount of plasma lost from the intravascular space during exercise may be independent of the muscle mass involved, but related to a combination of the ratio of active to total mass for each individual and body position.

**Key words:** Swimming – Immersion – Plasma volume shifts – Diuresis – Exercise

## Introduction

Previous investigations have indicated that exercise will cause fluid shifts within the body (Lundvall et al. 1972; Senay et al. 1980, Wilkerson et al. 1977).

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*Offprint requests to:* R. G. McMurray (address see above)

Furthermore, Miles and associates (personal communications) noted that during exercise the amount of plasma lost from the intravascular space is independent of the muscle mass involved but directly related to the relative intensity of the exercise. The question then remains as to whether these responses would occur when the exercise occurs in the water.

Immersion in water upsets the normal hemodynamic equilibrium associated with a land environment, by minimizing the gravitational effects on the capillary hydrostatic pressure (McCally 1965). Also, the effect of water pressure against the skin decreases superficial vascular transmural pressure (pressure inside the vessel minus the outside pressure), thus causing hemodilution during the initial phase of immersion (Khosla and DuBois 1979; Epstein 1978). As immersion continues (> $^1/_2$ h) a reflex renal diuresis occurs and hemoconcentration prevails (Boening et al. 1972; McCally 1965; Vogt and Johnson 1965). Presently, it is unknown what plasma volume shifts would occur when exercise is super-imposed on immersion. Therefore, the following investigation was undertaken to evaluate the plasma volume response during swimming exercise and to compare the response to that obtained during resting immersion as well as land exercise of similar intensity.

## Materials and Methods

Six trained swimmers were selected as subjects. All were within normal limits of weight for their respective height and age (age = 28.3 ± 3.4 years; height = 182.9 ± 5.1 cm; weight = 77.0 ± 3.4 kg). They were all informed of the nature, purpose and risks of the investigation. Each subject was screened prior to participation by a 12-lead electrocardiogram and medical history.

Each subject completed five trials: a tethered swim maximal capacity test, a bicycle ergometry maximal test, a 35 min swim at approximately 70% of maximal capacity, a 35 min cycle ergometry test at 70% of maximal capacity, and a 35 min immersion rest trial. The maximal capacity testing occurred 4 to 7 days prior to the submaximal trials.

The tethered swim maximal test utilized a discontinuous protocol with three minute work stages separated by three minute rest intervals. Weight was added at each stage, dependent upon the heart rate of the previous stage, until the subject could no longer support the weight. The bicycle ergometry maximal capacity test was completed utilizing the protocol of Taguchi et al. (1971). During both maximal capacity tests oxygen uptake ($\dot{V}_{O_2}$) was measured the last minute of each stage and the last minute of exercise. The $\dot{V}_{O_2}$ was calculated from measurements of ventilation (gasometer), fractions of expired oxygen (Beckman E-2 oxygen analyzer), and carbon dioxide (Beckman LB-2 $CO_2$ analyzer). Heart rates were obtained by carotid palpation at the end of each work stage. Couldry et al. (1982) have found this method to be as accurate as ECG as long as the same investigator completes all measurements. From the maximal test results, a 70% $\dot{V}_{O_2}$ max workload was obtained for use during the submaximal trials.

The submaximal and resting immersion trials followed the same general protocol and occurred on separate days. The subject reported to the lab 4 h post-absorptive and began a 30 min supine rest. During the rest a 20 gauge catheter was inserted into a forearm vein. After 30 min a supine resting blood sample was obtained. The subject then completely emptied his bladder and moved to either the pool, immersion tank, or bicycle ergometer to begin the 35 min trial. During the resting immersion trial, the subject simply assumed a semi-prone position immersed in 35.0 ± 0.5° C water to the level of the neck (the body was supported). Three milliliter blood samples were obtained from a forearm vein at 5, 10, 15, 25, and 35 min of rest. All blood samples were obtained using a three syringe technique in which the first syringe clears the catheter, the second syringe is the sample, and the third syringe contains 3 ml of heparinized saline to keep the catheter patent. This technique takes

**Table 1.** Mean (± SD) physical characteristics and maximal oxygen uptake ($\dot{V}_{O_2}$ max) data of the six male subjects

| | Age (years) | Height (cm) | Weight (kg) | Bicycle | | Swimming | |
|---|---|---|---|---|---|---|---|
| | | | | $\dot{V}_{O_2}$ max[a] | Heart rate max[b] | $\dot{V}_{O_2}$ max[a] | Heart rate max[b] |
| Mean | 28.3 | 182.9 | 77.0 | 4.18 | 189 | 4.11 | 178 |
| SD | 11.6 | 5.1 | 7.5 | 0.42 | 7 | 0.38 | 11 |

[a] $\dot{V}_{O_2}$ max in $l \cdot min^{-1}$
[b] Heart rate in beats $\cdot min^{-1}$

approximately 1 min from the cessation of activity to resuming exercise. At the end of 35 min the subject was removed from the water and completely emptied his bladder into a graduated cylinder so that urine output could be measured.

The swimming trials involved swimming lengths of the pool for 35 min. Free swimming was chosen over tethered swimming because the subjects could use a more normal stroke and breathing pattern. All subjects practiced swimming at the appropriate pace prior to the actual trial. Maintenance of the appropriate pace (70% $\dot{V}_{O_2}$ max) was monitored from heart rates obtained by carotid palpation at the blood sampling intervals. After the first 5 min of exercise none of the subjects deviated from the pace by more than 5%. At 5, 10, 15, 25, and 35 min of swimming the subject stopped and remained in a semi-prone immersed position while a 3-ml blood sample was obtained from a forearm vein. At the end of swimming the subjects urine output was measured.

The bicycle submaximal trials always occurred after the submaximal swimming so that similar relative exercise intensities could be obtained. As with the swimming trials, exercise intensity was based on the 70% $\dot{V}_{O_2}$ max heart rate with the heart rate being monitored minute by minute. The subject pedalled for 35 min with blood sampling occurring at 5, 10, 15, 25, and 35 min of exercise. Urine output was again measured at the end of exercise.

All blood samples were analyzed for hemoglobin, hematocrit, and total plasma protein concentration. Hematocrit was determined in triplicate by the microhematocrit method and corrected for trapped plasma (Hct × 0.961). Hemoglobin was also determined in triplicate using the cyanmethemoglobin method. Mean corpuscular hemoglobin concentration (MCHC) was calculated from the hematocrit and hemoglobin values. Total plasma protein concentration was measured by refractometry. Percentage change in blood cell, and plasma volumes were calculated according to the method of Dill and Costill (1974). Changes in plasma water were computed by the formula of Eisenman et al. (1936). All submaximal exercise and resting data was compared by two-way analysis of variance and a Tukey HSD aposteriori test applied when significance was found ($p < 0.05$).

## Results

The presentation of the results will concentrate primarily on comparisons of the responses that occurred during the 35 min submaximal bicycle and swimming trials, and 35 min of immersion rest. The maximal capacity tests were used only to determine the submaximal exercise intensities (see Table 1).

The intensity of exercise for the submaximal cycling and swimming was similar (Fig. 1). During free swimming the subjects exercised at an average of 71% $\dot{V}_{O_2}$ max. Exercise started at 60.8% of maximum and finished at approximately 75% of $\dot{V}_{O_2}$ max. Cycle exercise followed the same protocol as

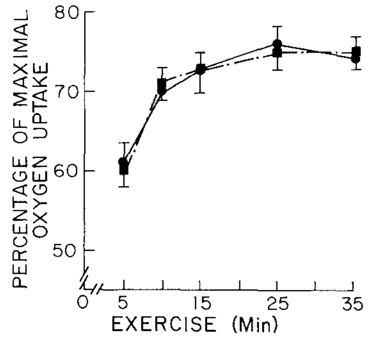

**Fig. 1.** Exercise intensity (% $\dot{V}_{O_2}$ max) based on heart rate during the 35 min of submaximal swimming (●) and cycling (■) (Mean ± SEM)

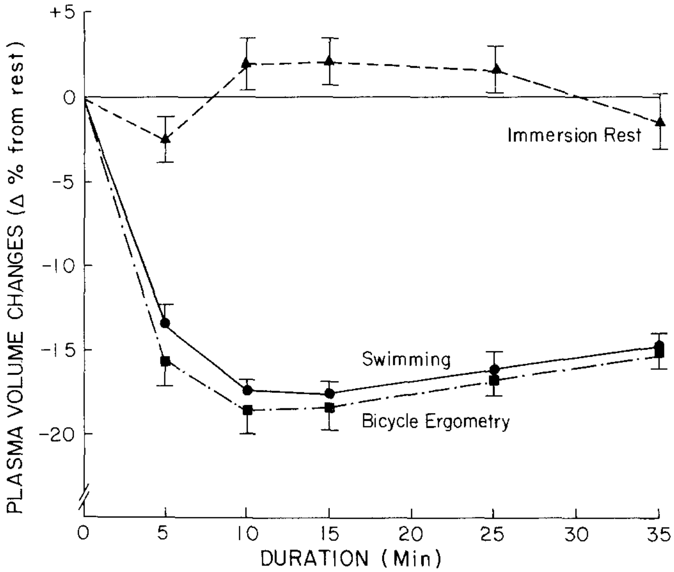

**Fig. 2.** Changes in plasma volume from supine rest during 35 min of swimming (●) and cycling (■) at similar relative work intensities, and 35 min of immersion rest (▲) (Mean ± SEM)

during swimming starting at 60.0% of maximum and terminating at 75% $\dot{V}_{O_2}$ max.

The mean (± SEM) hematocrit, hemaglobin, and total plasma protein concentrations during the three conditions are presented in Table 2. Thirty-five minutes of immersion rest produced mixed hemodynamic results (Fig. 2). Hemoconcentration was evident for the first 5 min (plasma volume = $-2.5 \pm 1.3\%$; $p < 0.05$), followed by a dilution for the next 20 min (plasma volume = $+2.0 \pm 1.3\%$; $p < 0.05$, and a slight but non-significant ($p > 0.05$) concentration at the end (plasma volume = $-1.5 \pm 1.6\%$). No significant changes ($p > 0.05$) in red cell volume or MCHC was noted throughout the duration of rest. The changes in blood volume and total plasma protein concentration were accounted for by changes in plasma volume.

**Table 2.** Hematocrit, hemoglobin, and total plasma protein concentrations during 35 min of swimming (swim) and cycling (cycle) at approximately 70% $\dot{V}_{O_2}$ max, and 35 min of semi-prone immersion rest (IR)

| Time (min) | Hematocrit (%) | | | Hemoglobin (g · 100 $ml^{-1}$) | | | Total plasma protein (g · 100 $ml^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | IR | Swim | Cycle | IR | Swim | Cycle | IR | Swim | Cycle |
| 0 | 40.7 ± 0.6 | 42.4 ± 0.8 | 40.3 ± 0.5 | 12.9 ± 0.4 | 13.7 ± 0.6 | 13.2 ± 0.5 | 6.8 ± 0.2 | 6.9 ± 0.1 | 6.7 ± 0.2 |
| 5 | 41.3 ± 0.8 | 45.9 ± 0.8 | 44.9 ± 0.4 | 13.1 ± 0.4 | 14.8 ± 0.7 | 14.4 ± 0.6 | 7.1 ± 0.3 | 7.6 ± 0.2 | 7.3 ± 0.1 |
| 10 | 40.4 ± 0.6 | 47.7 ± 0.6 | 46.3 ± 0.4 | 12.7 ± 0.4 | 15.0 ± 0.6 | 14.4 ± 0.4 | 6.7 ± 0.3 | 7.8 ± 0.1 | 7.4 ± 0.2 |
| 15 | 40.4 ± 0.5 | 47.8 ± 0.6 | 46.2 ± 0.6 | 12.7 ± 0.4 | 15.1 ± 0.7 | 14.6 ± 0.5 | 6.7 ± 0.3 | 7.9 ± 0.2 | 7.5 ± 0.2 |
| 25 | 40.4 ± 0.6 | 47.2 ± 0.6 | 45.6 ± 0.6 | 12.7 ± 0.5 | 15.0 ± 0.7 | 14.5 ± 0.6 | 6.8 ± 0.2 | 7.9 ± 0.2 | 7.4 ± 0.2 |
| 35 | 41.2 ± 0.7 | 46.1 ± 0.8 | 44.4 ± 0.7 | 13.0 ± 0.6 | 15.0 ± 0.9 | 14.5 ± 0.7 | 7.0 ± 0.3 | 7.8 ± 0.3 | 7.4 ± 0.3 |

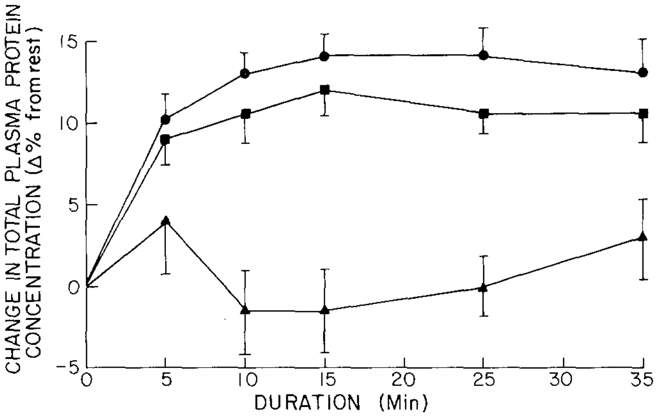

**Fig. 3.** Changes in total plasma protein concentration during 35 min of immersion rest (▲) and 35 min of swimming (●) and cycling (■) at similar intensities (Mean ± SEM)

Swimming and cycling at similar intensities produced significant ($p < 0.01$) hemoconcentration throughout the duration of exercise (Fig. 2). The hemoconcentration was maximized in 10 min of exercise and no further significant changes were noted. No significant differences in blood or plasma volumes were noted when comparing the two exercise modes ($p > 0.05$). No significant alteration in red cell volume or MCHC occurred ($p > 0.05$) and the entire reduction in blood volume could be accounted for by the decrease in plasma volume (for either swimming or cycling). Compared to supine rest both exercise bouts significantly increased total plasma protein concentration (Fig. 3), but swimming resulted in a significantly greater ($p < 0.05$) change in total plasma protein concentration than cycling. A small, but significant ($p < 0.05$) loss of plasma water was also noted during cycling when compared to swimming (−0.20 $g \cdot 100$ ml plasma$^{-1}$).

Urine output averaged 3.1 ± 0.8 ml $\cdot$ min$^{-1}$ during immersion rest. Swimming exercise significantly reduced the output to 1.0 ± 0.1 ml $\cdot$ min$^{-1}$ ($p < 0.05$). Urine output was still further reduced to 0.4 ± 0.2 ml $\cdot$ min$^{-1}$ during cycle ergometry ($p < 0.05$).

## Discussion

The intent of this investigation was to examine changes in plasma volume that occur at rest during immersion and during free swimming, and to determine if these changes are similar to land exercise of the same intensity. Khosla and DuBois (1979) have demonstrated that the initial phase of resting immersion results in hemodilution. McCally (1964) has also noted a decrease in hematocrit during the first half-hour of immersion. In general, our resting results would agree. The initial hemoconcentration at the fifth minute is believed to be a result of our subjects moving from the supine resting position to the upright position to empty his bladder and enter the immersion tank. Hagan et al. (1978, 1980) have demonstrated that a hemoconcentration does occur in 5 min after moving from the supine to the upright posture or during exertion. Therefore, if our subjects had remained in the supine resting position during this transitional period, no concentration may have been evident. The ensuing hemodilution of immersion has been previously explained to be a result of the water pressure on the skin increasing the capillary resistance to flow and reducing the venous pressure (Khosla and DuBois 1979). Such a change would decrease capillary filtration and enhance end-capillary or venular reabsorption of fluid (Von Diringshofen 1948; Davis and DuBois 1977). The absence of gravity may decrease the intra-capillary pressure further increasing the transmural pressure differential and allow for greater influx of fluids (Dill et al. 1930). The hemoconcentration towards the end of resting immersion is probably a result of the reflex diuresis prevailing (Epstein 1978; Khosla and DuBois 1979; McCally 1965). The urine output data suggests diuresis but it is impossible to determine the onset because urine output was just measured for the entire 35-min period.

Swimming exercise resulted in hemoconcentration. Since all blood sampling occurred with the subject in the horizontal position, the changes in plasma volume were not related to posture but to the exercise. The hemoconcentration during swimming is contrary to the hemodilution found during the initial phase of immersion rest. Previous research has indicated that blood pressure increases during swimming exercise (Holmer 1974). The increased pressure would cause an increased capillary pressure which may have been sufficient to reverse the transmural pressure differential that occurred during immersion rest. Thus, fluids would be forced from the capillary beds. Also, swimming would involve a great deal of active muscle mass which would increase the effective capillary surface area available for filtration (Kjellmer 1965). It is possible that swimming exercise may increase the osmotically active components of the muscular tissue thus creating an environment more favorable to the efflux of fluids. Lundvall et al. (1972) have demonstrated a 22 mOsm/kg $H_2O$ increase during bicycle ergometry of similar intensity to our swimming exercise. Senay (1972, 1979) has also noted a hyperosmotic response during exercise. Since we did not measure osmolality the above is speculation.

Bicycle ergometry on land resulted in a hemoconcentration similar to swimming exercise of the same intensity. Since the subject's reference blood sample was obtained in the supine position and work was completed in the upright position, a portion of the plasma volume loss must be attributed to postural change. Hagan et al. (1980) have noted a 15.7% reduction in plasma volume during cycling at 69% $V_{O2}$ max, using a supine resting reference. They further attributed approximately 14% of the 15.7% plasma volume loss to posture. Thus, it is possible that during cycle ergometry, only a small amount of plasma volume change was directly due to exercise. Therefore, the hemoconcentration during upright cycling was a combined result of hydrostatic capillary pressure (related to gravity), increased mean capillary pressure forcing fluid from an increased active vascular bed, and an increase in osmotically active particles (Hagan et al. 1980; Smith et al. 1976; Lundvall et al. 1972; respectively).

The similarity of hemoconcentration when comparing swimming and cycling is quite intreging when one considers the differences in body position during exercise and the lack of effect of gravity during swimming. The similarities of hemoconcentration suggest that several factors may be responsible for the plasma efflux: gravity, capillary pressure related to blood pressure, effective capillary surface area, and osmotically active particles. Therefore, when comparing swimming and cycling, the sum total of the four factors must be the same in order to have similar plasma volume changes. Since swimming does not have the gravitational effects of upright cycle ergometry, changes in the other three factors must have occurred. A greater mean blood pressure would cause capillary pressure to rise thus enhancing plasma efflux (Smith et al. 1976). Holmer (1974) has noted that mean blood pressure is significantly greater during swimming (arm work) when compared to running (leg work). Also, Astrand et al. (1965) has demonstrated that blood pressure is greater in arm work verses leg work. Hence, during swimming a greater mean blood pressure (than during cycling) would contribute to the plasma efflux. Kjellmer (1965) has noted that the effective capillary surface area available for filtration within the active muscle is important in causing the plasma flux. When one considers that the total active muscle mass of swimming is probably greater than cycling, a second possible mechanism responsible for the hemoconcentration becomes evident. Presently little is known concerning osmotic changes during swimming therefore speculation comparing osmotic changes during swimming and cycling cannot be made.

A net loss of plasma protein was evident during both the swimming and cycling trials. The amount of total protein lost was calculated based on the measured protein concentration and that predicted by the change in plasma volume (Senay 1972). In all cases, the loss of protein was less ($p < 0.05$) during swimming than during cycling; $-0.2\ \mathrm{g} \cdot 100\ \mathrm{ml}^{-1}$ vs $-0.7\ \mathrm{g} \cdot 100\ \mathrm{ml}^{-1}$, respectively. The loss of protein has been previously reported for land exercise (Van Beaumont et al. 1972; Senay et al. 1972, 1980), but this is the first evidence of a similar occurrance during swimming exercise. Circulating total plasma protein levels are a result of both the efflux out of the vessel and the amount being returned to circulation. Senay (1972) has discussed the importance of the lymphatic system in returning protein to the vascular system. Kjellmer (1965) has stated that the massaging action of the contracting muscles increases lymph flow from the area of activity thus moving protein into the vascular volume that was previously in the interstitium. Swimming involves a greater active muscle mass than cycling, thus the lymphatic vascular pump may have been more active, returning a greater amount of protein to the vascular system than during cycling. Also the greater hydrostatic pressure of immersion may force centralization of lymph from the more superficial extravascular space: similar to its effect on blood (Epstein 1978). This is somewhat supported by the resting immersion data which indicates a small increase in total plasma protein ($+0.12\ \mathrm{g} \cdot 100\ \mathrm{ml}^{-1}$) during resting immersion. Our resting immersion data is supported by the results of Khosla and DuBois (1979). Therefore, immersion maybe an important factor in the kinetics of plasma protein balance. When compared to swimming, the greater loss of plasma protein during cycling correlates with the fact that plasma water content was reduced to a greater extent during cycling. Also, as can be seen in Fig. 2, the loss of plasma volume during swimming was always slightly less (but not significantly different) than during cycling, thus a greater plasma water content would be expected during swimming. This is conjecture as conclusions concerning protein shifts based on changes in plasma volume and total plasma protein concentrations may be tenuous (Senay and Christensen 1965; Senay 1972).

Plasma volume shifts were similar for both modes of exercise, yet the hypothesized mechanisms are somewhat different. This suggests that during exercise the maximum efflux is limited, regardless of the mechanism or mechanisms involved. Hagan et al. (1980) have suggested such a phenomenon for bicycle ergometry on land. They noted that the effect of gravity on hemoconcentration in the upright position was similar to the combined effects of exercise and posture in the low-sit position. They suggested that the combined effects of gravity and exercise, regardless of which dominates, are balanced by the interstitial fluid pressure and total tissue pressure thus stabilizing fluid transudation to maintain an adequate plasma volume. Our results would support this hypothesis and further suggest that, with the exception of gravity, the same mechanisms exist during both land and swimming exercise.

In conclusion, the results suggest that changes in plasma volume and the resulting hemoconcentration during swimming are similar to land exercise at the same relative intensity when the reference blood sample for both is obtained in the horizontal position. It appears that even with the limited effect of gravity during swimming, the increase in capillary pressure, capillary surface area for exchange, and osmolarity is sufficient to mediate the plasma volume change. It is also evident that the acute hemodilution and/or diuretic effects of immersion are substantially suppressed during swimming exercise.

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