"Glycerol-induced Hyperhydration"

by

Marvin L. Riedesel, Timothy P. Lyons and M. Colleen McNamara
Department of Biology
University of New Mexico
Albuquerque, New Mexico
87109

Maintenance of euhydration is essential for maximum work performance. Environments which induce hypohydration reduce plasma volume and cardiovascular performance progressively declines as does work capacity (Fortney et al., 1981). Hyperhydration prior to exposure to dehydrating environments appears to be a potential countermeasure to the debilitating effects of hypohydration. The extravascular fluid space, being the largest fluid compartment in the body, is the most logical space by which significant hyperhydration can be accomplished. Volume and osmotic receptors in the vascular space result in physiological responses which counteract hyperhydration.

Our hypothesis is that glycerol-induced hyperhydration (GIH) can accomplish extravascular fluid expansion because of the high solubility of glycerol in lipid and aqueous media. A hypertonic solution of glycerol is rapidly absorbed from the gastrointestinal tract, results in mild increases in plasma osmolality and is distributed to 65% of the body mass (Lin, 1977). A large volume of water ingested within minutes after glycerol intake results in increased total body water because of the osmotic action and distribution of the glycerol (Riedesel et al. 1987). The resulting expanded extravascular fluid space can act as a reservoir to maintain plasma volume during exposure to dehydrating environments. We have conducted experiments to be presented later which demonstrate advantages of GIH for subjects exercising in a hot environment (Lyons et al. 1990). The fluid shifts associated with exposure to microgravity result in increased urine production and is another example of an environment which induces hypohydration. Our goal is

to demonstrate that GIH will facilitate maintenance of euhydration and cardiovascular performance during space flight and upon return to a 1 g environment.

The experimental protocol for the GIH experiments involved the subjects checking into the hospital at 1900 h and drinking one liter of water at 2000 h to ensure euhydration. No food or water after midnight and at 0715 h a catheter was placed in a cubital vein. At 0730 subjects drank glycerol, 1 g/kg, in orange juice, 3.4 ml/kg. In the first study subjects drank 1.5 liter of 0.1% NaCl during the next two hours and 300 ml of 0.1% NaCl during the third hour. The control run involved the same protocol including the same volume of fluid intake except without glycerol either 48 h prior to or after the experimental run.

The glycerol intake markedly decreased the urine volumes (Figure 1). Another experiment with the same protocol involved 1.5, 1.0 and 0.5 g/kg glycerol intake. The serum glycerol values varied with the glycerol dosages (Figure 2). The 0.5 g/kg dosage did not result in significant changes in water retention. The amount of water retained after 4 h was similar for the 1.0 and 1.5 g/kg glycerol dosages. Therefore subsequent studies have involved the 1.0 g/kg dosage. Apparently the rates of glycerol catabolism and excretion are dose dependent such that the 1.5 g/kg doesn't result in a greater water retention than the 1.0 g/kg. The mean volume of water retained after 4 h has been 10.2 ml/kg (S.E. = 0.5) when subjects ingested 1 g/kg glycerol and drank 1.5 to 1.8 liter of water within 1 to 3 h of time zero. It is also of interest to note that whereas the retention of water was for 4 h the increased plasma osmolality following the glycerol intake had returned to control values within 2 h (Figure 3). This indicates that glycerol and water have moved from the plasma to the intracellular space and the water retained is intracellular.

The next study asked the question, does the GIH provide an advantage for subjects exercising in the heat? The subjects were heat acclimated prior to participation. At 48-h or longer intervals the 6 men and 2 women participated in random order in three separate 4.5-h

experiments. Each experiment included a 1.5-h bout of exercise at 60% of maximum oxygen consumption in a moderate dry heat (42° C). One experiment involved limited fluid intake (5.4 ml/kg) which was similar to ad libitum fluid intake in pilot studies under similar conditions. The other two experiments involved ingesting a large volume of fluid in an attempt to hyperhydrate the subjects prior to the exercise. One attempt at hyperhydration involved ingestion of glycerol (1 g/kg) in orange juice plus a large volume of water (21.4 ml/kg) at time zero plus additional glycerol (0.1g/kg) in orange juice at hourly intervals after the first two hours. The subjects drank 50 ml of water at hourly intervals after the second hour (Table 1). The second involved drinking the same volume of water and orange juice (Table 1).

Table 1. Fluid Ingestion Regimens

	Large Fluid Intake		Limited Fluid Intake
	Glycerol	No Glycerol	
Time Zero	1 g GLY/kg in 3.3 ml/kg OJ	3.3 ml/kg OJ	3.3 ml/kg OJ
Within 1 h	21.4 ml/kg of water	21.4 ml/kg of water	
Each hour after 2 h	0.1 g GLY/kg in 0.1 ml/kg OJ plus 50 ml water	0.1 ml/kg OJ plus 50 ml water	50 ml water
Total Fluid intake in 4 h	28.4 ml/kg	28.4 ml/kg	5.4 ml/kg

GLY = glycerol, OJ = orange juice.

The mean accumulated sweat output for the 90 min of exercise was 1450 ± 160 ml with the glycerol ingestion compared to 1130 ml ± 100 ml following just the large volume of water ($P < 0.05$) (Figure 4). During the 60- to 90-min interval of exercise in the heat, the glycerol ingestion resulted in a mean sweat output of 700 ± 90 ml and the large volume of water without glycerol at time zero resulted in a mean volume of 470 ml ± 40 ml ($P < 0.01$). This difference amounted to a 33% increase in sweat following the pre-exercise GIH.

After 30 min of exercise, the mean rectal temperature was lower ($P < 0.05$) following glycerol ingestion when compared to the other two fluid regimens. The limited fluid intake and large volume of water at time zero resulted in similar mean rectal temperatures during the 90 min of exercise (Figure 5).

The next experiment was designed to determine whether or not we could extend the GIH to 48 h. This experiment involved 7 male subjects and once again at time zero they ingested a large volume of fluid (21.4 ml/kg) either with or without glycerol, 1 g/kg. On both the control and glycerol intake days, the total water plus orange juice intake over the 48-h period was 50.8 ml/kg. On days they ingested glycerol, the glycerol intake was 1 g/kg at 0700 h, 0.10 g/kg at 0800 h, 0.303 g/kg at 1000 h and 1100 h, and 0.379 g/kg at 1400 h and 1600 h. Previous studies and pilot experiments had indicated that these rates of water and glycerol intake would provide GIH for 48 h. The fluid intake and urine volumes are presented in figure 6.

Our current studies involve cardiovascular responses to lower body negative pressure (LBNP) prior to and after bedrest with and without GIH. Prior to bedrest subjects undergo a maximum oxygen consumption test (VO_2max), underwater weighing to determine percent body fat and three pre-syncope LBNP tests. The 4 male subjects had VO_2max values greater than 40 ml O_2/kg/min and less than 20% body fat. The LBNP box involved a seal with a kayak skirt at the

waist and a foot rest rather than a bicycle saddle for support of the subject. During the LBNP tests the electrocardiogram was recorded continuously and the arterial blood pressures were recorded manually at 1-min intervals. The reproducibility of the LBNP responses is illustrated in figure 7.

The standard LBNP test conducted on days -1, 4, 5, 6, & 7 of the bedrest involved 5 min at each level of negative pressure, -10, -20, -30, -40, -50, and -60 mm Hg. Glycerol and fluid intake was administered on days 5 and 6 of the bedrest as described above for the 48-h GIH. The heart rate, systolic and diastolic blood pressure were analyzed by analysis of multiple variance and the Dunnett's test for multiple comparison of treatments.

Subjects had less tolerance for LBNP on bedrest day 4 when compared to pre-bedrest (day -1), ($p < 0.05$). The heart rate and blood pressure responses on bedrest days 4, 5, 6, and 7 were similar ($p > 0.05$). The GIH on days 5 and 6 did not improve cardiovascular responses to the standard LBNP test. This may have been expected because the standard LBNP test is only of 30 min duration. In the heat stress experiment described in the previous paragraphs, the increased sweating after GIH was greater during the 30 to 60-min and 60 to 90-min intervals than during the 0 to 30-min interval of heat stress.

Experiments for the immediate future will involve bedrest, a "soak" procedure (2-h exposure to cycling LBNP, 1 min to -60 and 1 min to zero LBNP). The "soak" procedure will be conducted 1.5 h after the GIH on day 5 of the bedrest. Pre-syncope LBNP will be conducted on days -1, 4, 5, and 6 of the bedrest. These experiments will also include monitoring of cranial blood flow by the transcranial doppler technique during all LBNP tests.

Additional future studies will include measurements of 14-C tagged glycerol and tritiated water in the laboratory rat after GIH to determine the distribution of glycerol and water among various body fluid compartments. We are also interested in testing the extent to which we can

increase the amount of hyperhydration by changing the timing and dosages of glycerol and water intake.

REFERENCES

Fortney, S.M., E.R. Nadel, C.B. Wenger and J.R. Bove. 1981. Effect of blood volume on sweating rate and body fluids in exercising humans. J. Appl. Physiol. 51:1594-1600.

Lin, E.C. 1977. Glycerol utilization and its regulation in mammals. Annu. Rev. Biochem. 46:765-795.

Lyons, P.T., M.L. Riedesel, L.E. Meuli, and T.W. Chick. 1990. Effects of glycerol-induced hyperhydration prior to exercise in the heat on sweating and core temperature. Med. Sci. Sports Exerc. 22:477-483.

Riedesel, M.L., D.L. Allen, G.T. Peake, and K. Al-Qattan. 1987. Hyperhydration with glycerol solutions. J. Appl. Physiol. 63:2262-2268.

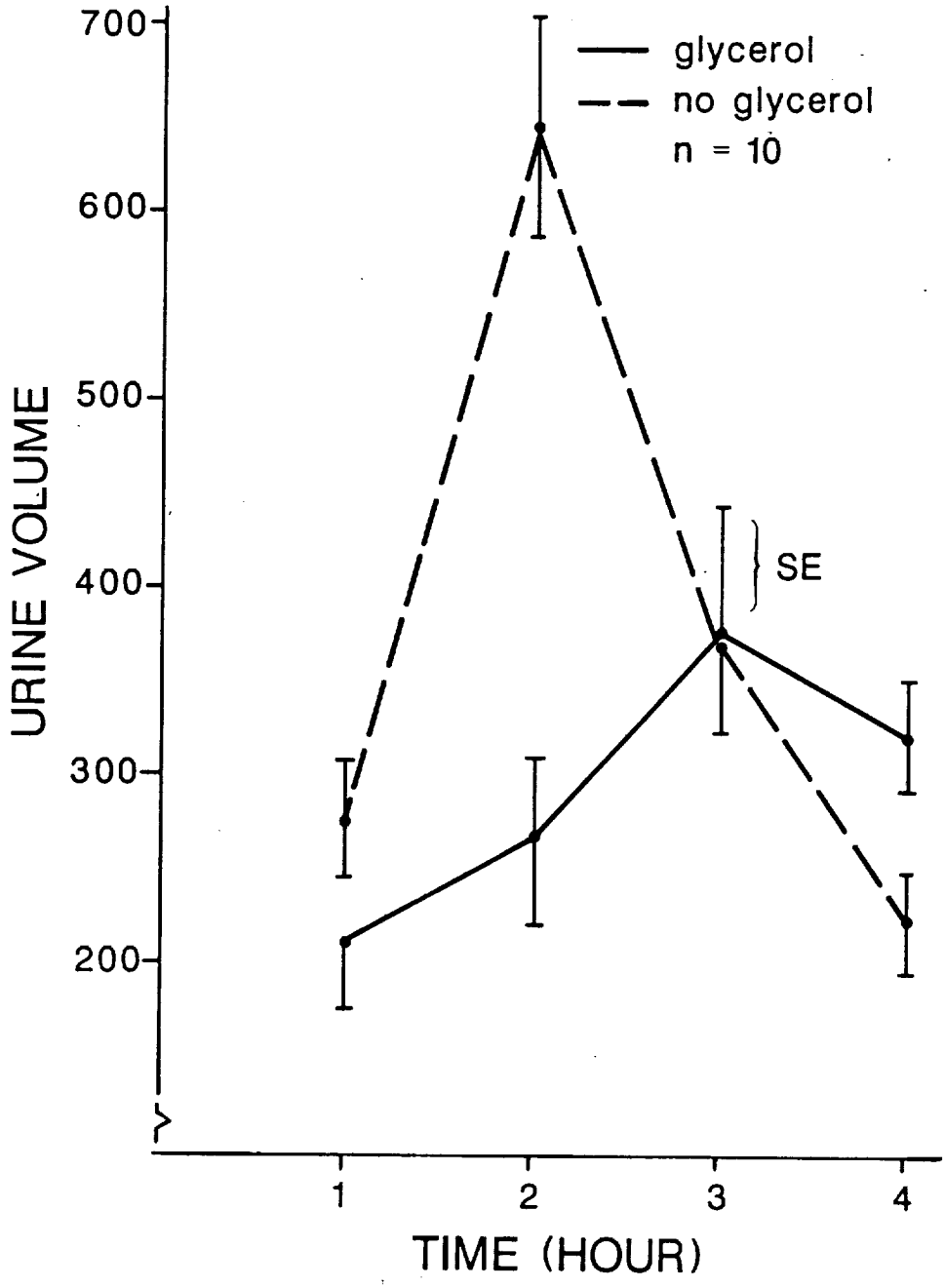

Figure 1. Mean volume of urine voided at each hour (ingestion of 0.1% NaCl, 21.4 ml/kg, during first two hours and 300 ml during third hour).

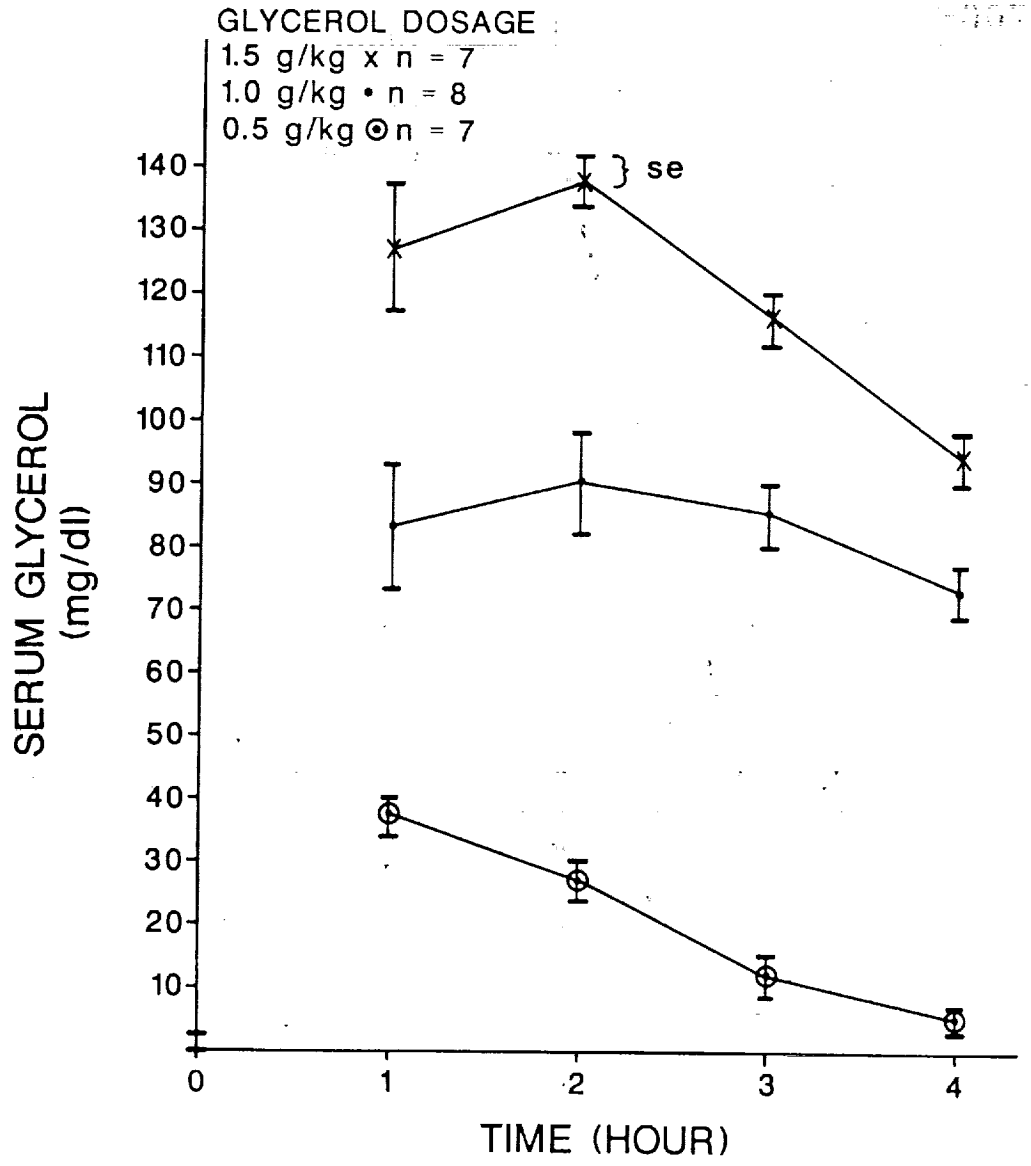

Figure 2. Serum glycerol after glycerol ingestion (ingestion of 0.1% NaCl, 21.4 ml/kg, during first 40 min.).

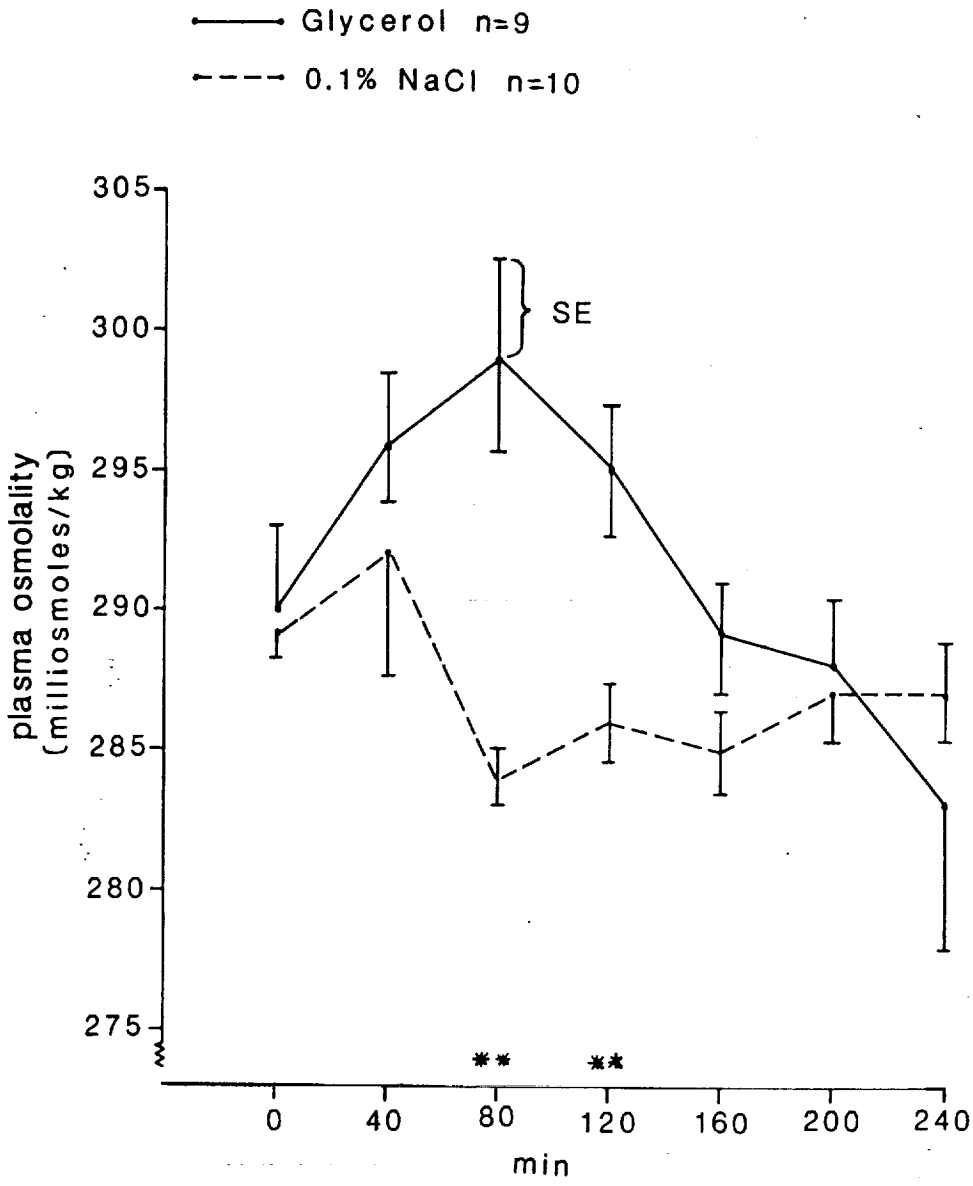

Figure 3. Plasma Osmolality (same fluid ingestion as Figure 2).

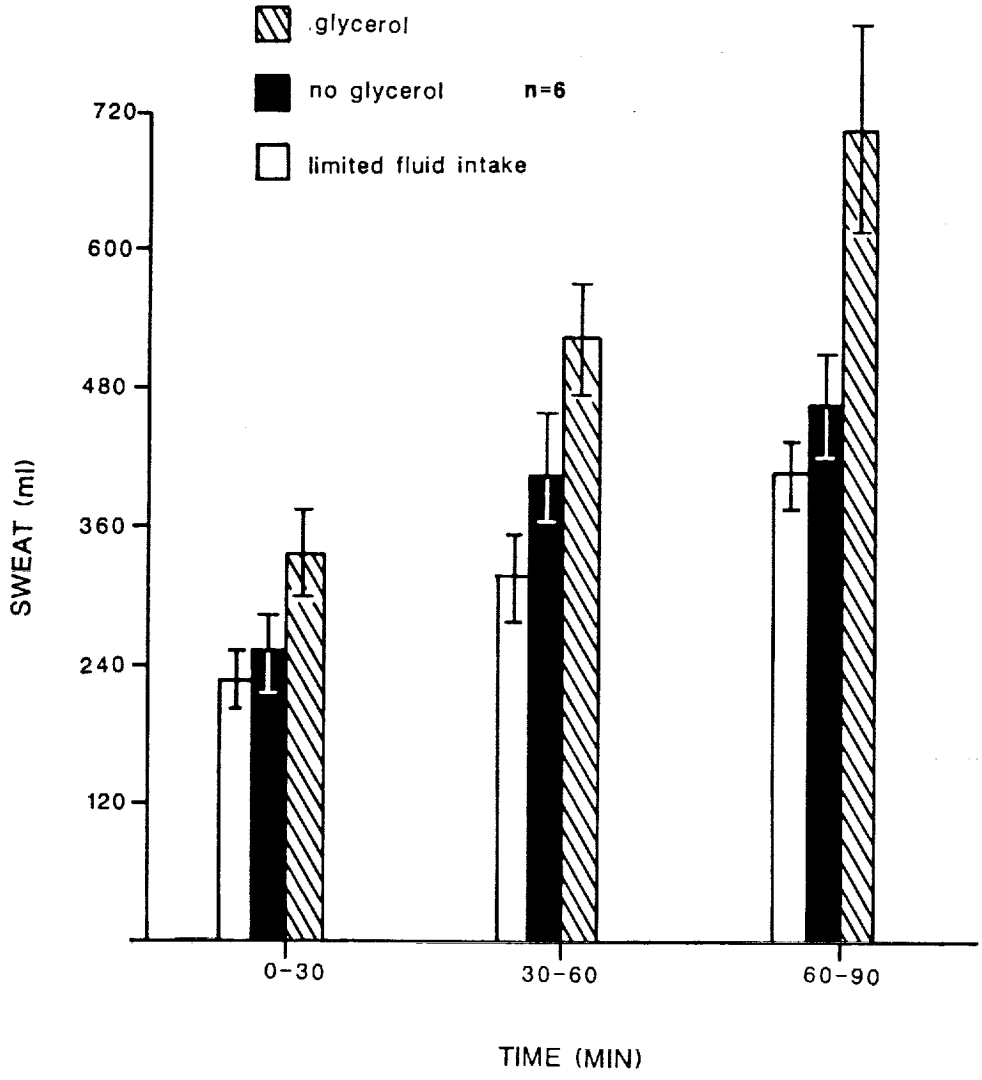

Figure 4. Mean sweat output for six subjects at 30-min. intervals during moderate exercise (60% VO_2max) in the heat (42°C, 100 m/min. air velocity, 25% relative humidity). Significance between glycerol and other two fluid regimens at 30-60 min. ($p < 0.05$) and 60-90 min. ($p < 0.01$). Fluid regimen same as Table 1.

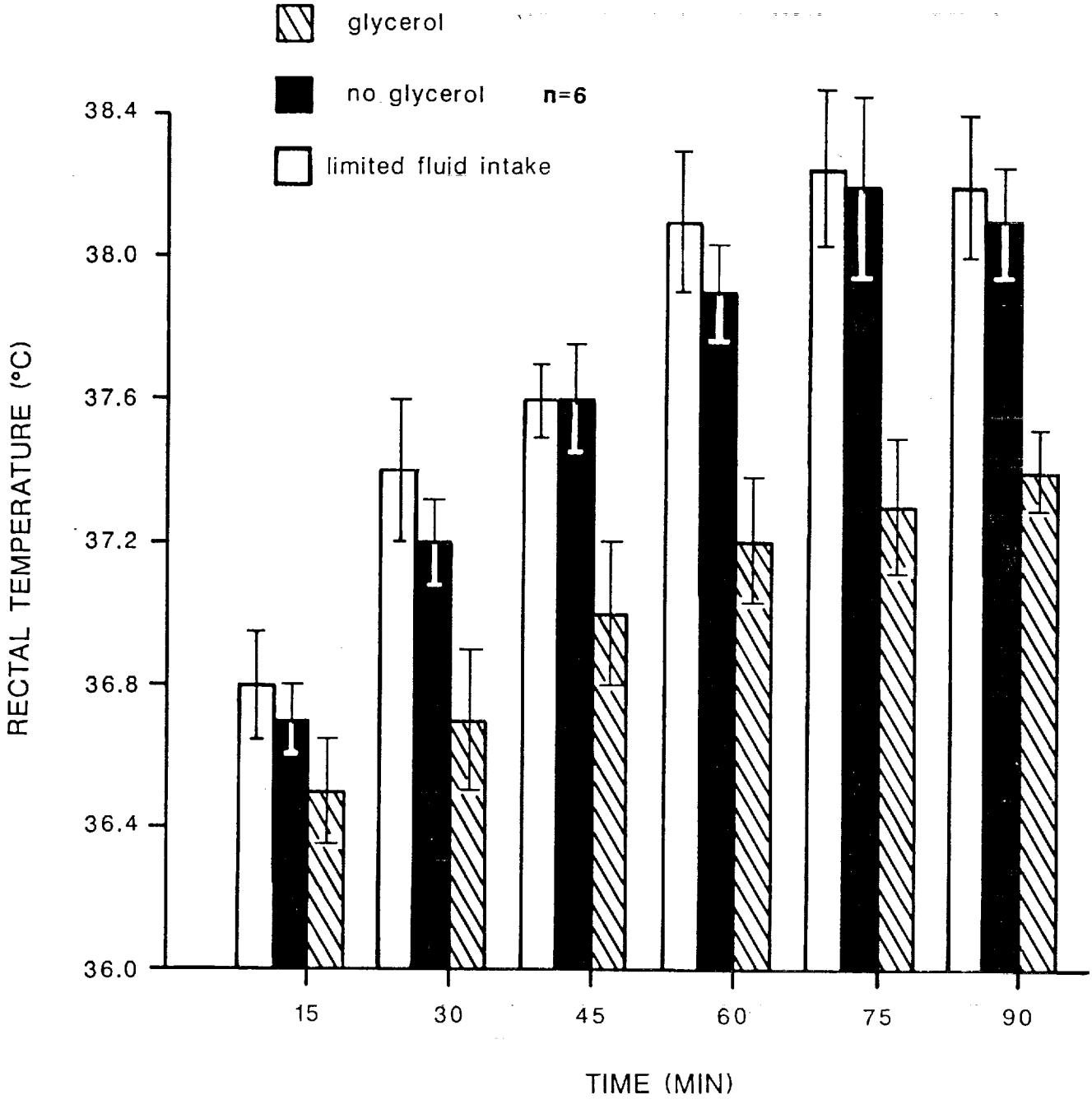

Figure 5. Mean rectal temperature at 15-min. intervals during moderate exercise (60% VO_2max) in the heat (42°C, 100 m/min. air velocity, 25% relative humidity). Significance between glycerol and other two fluid regimens after 15-min. interval ($p < 0.01$). Fluid regimen same as Table 1.

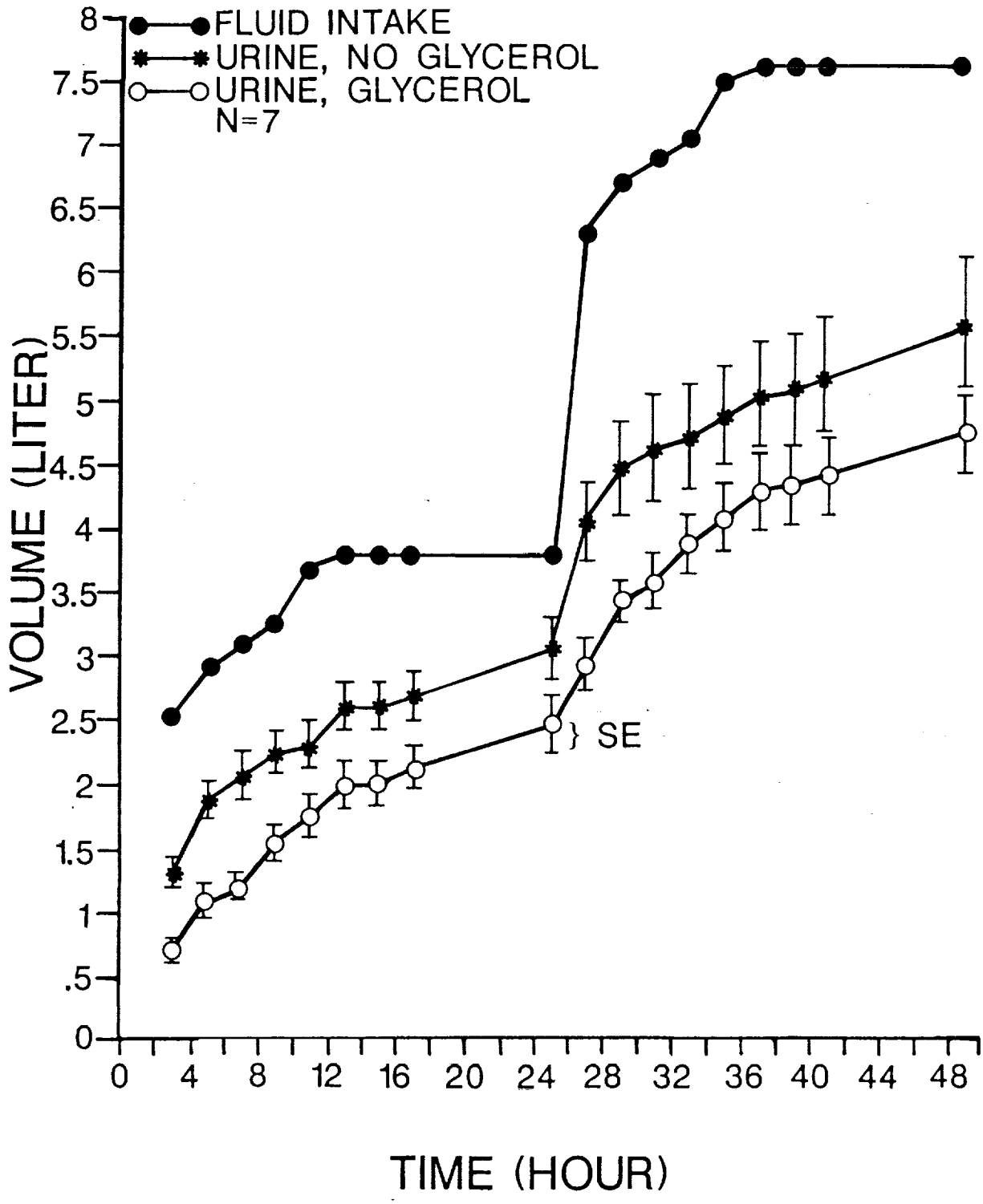

Figure 6. Accumulated fluid intake and urine output with and without glycerol. Significance in urine output between glycerol and no glycerol was $p < 0.05$ at each hour.

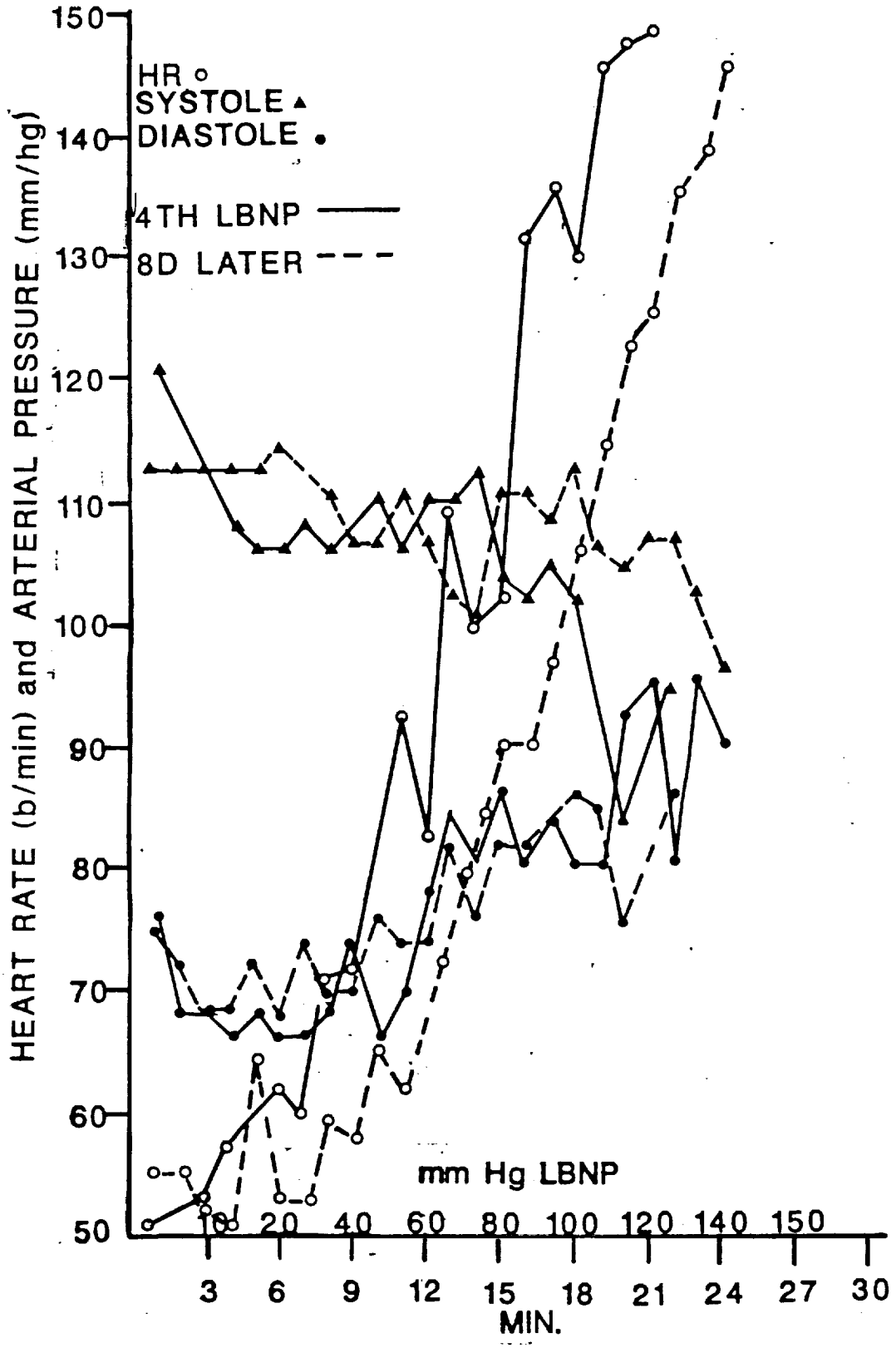

Figure 7. Heart rate and blood pressure responses to lower body negative pressure for a given subject at the same time of day on separate days.