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Protective Effects of the Launch/Entry Suit (LES) and the Liquid Cooling Garment (LCG) During Re-entry and Landing After Spaceflight.

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Abstract:

Heart rate and arterial pressure were measured during shuttle re-entry, landing and initial standing in crewmembers with and without inflated anti-g suits and with and without liquid cooling garments (LCG). Preflight, three measurements were obtained seated, then standing. Prior to and during re-entry, arterial pressure and heart rate were measured every five minutes until wheels stop (WS). Then crewmembers initiated three seated and three standing measurements. In subjects without inflated anti-g suits, SBP and DBP were significantly lower during preflight standing (P = 0.006; P = 0.001 respectively) and at touchdown (TD) (P = 0.001; P = 0.003 respectively); standing SBP was significantly lower after WS. Non-LCG users developed significantly higher heart rates during re-entry (P = 0.029, maxG; P = 0.05, TD; P = 0.02, post-WS seated; P = 0.01, post-WS standing) than LCG users. Our data suggest that the anti-g suit is effective, but the combined anti-g suit with LCG is more effective.

Keywords: antigravity suit, arterial pressure, heart rate, liquid cooling garment

Introduction:

Many cardiovascular changes associated with space flight, including decreased orthostatic tolerance (2, 3, 5, 6), exercise capacity (4), blood volume (2, 9, 20), adrenergic responsiveness (6, 21) and carotid baroreceptor-cardiac reflex responses (5, 7) have been reported. These changes reduce the ability of the cardiovascular system to oppose gravitational forces upon return to Earth. Because of these changes, crewmembers are very susceptible to orthostatic hypotension during re-entry and landing. There are two operational countermeasures which have been developed to protect crewmembers during this time: the anti-gravity suit and the liquid cooling garment. Until now there has been no systematic investigation of the cardiovascular responses to re-entry into Earth's atmosphere or of the efficacy of these countermeasures.

Since the Challenger accident all crewmembers have been required to wear a protective suit during launch and entry; either the Launch/Entry Suit (LES), which is a partial pressure suit; or its successor the Advanced Crew Escape Suit (ACES), which is a full pressure suit. Both contain the same anti-G suit within, which consists of a series of inflatable bladders on the legs and abdomen. The suits were designed to protect crewmembers against loss in cabin pressure, contaminated atmosphere, temperature extremes in case of a potential bail out and gravity forces during re-entry. Unfortunately, the LES added a heat stress to the crewmembers. Attempts were made to alleviate this by use of an in-suit fan that circulated cabin air across the upper torso of the crewmember, but this was ineffective because the fan actually warmed the circulated air significantly (17). Cewmembers reported extreme discomfort from the heat and the increased thermal load was thought to contribute to the increased incidence of orthostatic intolerance following resumption of Shuttle flights after the Challenger accident. (14). Because of this problem, in 1994 a liquid cooling garment or LCG was added to reduce the heat load. The LCG is a two-piece form-fitting garment that covers the entire body and circulates chilled water (thermoelectrically cooled using Shuttle power) through a network of small vinyl tubing sewn into the fabric.

The purpose of this study was evaluate the effects of both the antigravity suit and the liquid cooling garment on heart rate and arterial pressure responses during re-entry, landing and initial standing. We studied thirty-two astronauts who flew on twenty-two flights (lasting from 4 to 16 days). We found that astronauts who inflated their anti-gravity suits had better protection of arterial pressure during re-entry and landing. In addition, of those who inflated their anti-g suits, those who also wore the liquid cooling garment exhibited significantly lower heart rates. These data suggest that both devices used simultaneously provide the best cardiovascular protection during the hazardous period when astronauts return to Earth

Methods:

This test protocol was approved by the JSC Institutional Review Board (IRB). Informed consent was obtained from each subject prior to his or her participation in the study. Thirty-two Shuttle astronauts (26 males & 6 females) aged 41.4 ± 0.84 years were included in this analysis. Astronauts participated on flights lasting from 4 to 16 days. Most subjects participated in some form of exercise during flight and most followed the standard fluid load protocol (oral isotonic saline at a rate of 15 ml/kg) prior to their return to earth. Subjects were studied 10 days prior to launch and again on landing day.

Before flight, subjects were trained to instrument themselves with an entry monitoring assembly device (modified Accutracker II ABP monitor, Suntech Medical Instruments, Raleigh, NC) that recorded non-invasive arterial pressure, and the electrocardiogram (ECG). Arterial pressure was measured by ausculative sphygmomanometry using a standard blood pressure cuff, three leads, and a microphone to detect Korotkoff sounds (K-sounds). This device also provided a display for the operator with indications of errors in the form of a test code for each reading. A set of three mutually perpendicular one-axis accelerometers (x, y and z) accelerometers was worn on the outside of the suit to document body posture. An analog data tape recorder (modified HR-40G, TEAC America, Montebello, CA) acquired cuff pressure, ECG, K-sounds and torso and body posture for later analysis. Preflight baseline data were acquired when the subjects donned the recording instruments and then were fully suited. Crewmembers were asked whether or not they intended to inflate their anti-g suits for re-entry. If so, preflight data collection was performed with the anti-g suit inflated to the expected pressure level. If not, it was performed with the anti-g suit not inflated. Three measurements of systolic blood pressure (SBP), diastolic blood pressure (DBP) and heart rate (HR) were obtained while subjects were seated, then immediately again while they were standing.

On landing day, a microphone was also attached to the TEAC recorder so that the crewmember could annotate different positional and flight information. The equipment was set to take arterial pressure and heart rate every five minutes beginning at the time of the de-orbit maneuver (annotated as "time of ignition", abbreviated as TIG), through the period of maximum g-loading ("max-G") during atmospheric deceleration, until the vehicle landed ("touched down" or TD) and rolled to a stop. As soon after wheels stop as possible, the crewmember collected three seated and then three standing arterial pressure and heart rate measurements. Data points used for analyses were preflight seated, preflight standing, TIG, max-G, touch down (TD), seated post-wheels stop and standing post-wheels stop.

Analysis & Statistics:

Two separate investigators manually verified all arterial pressures after crewpersons returned from orbit. Heart rates were calculated from the ECG for each pressure measurement.

Subjects first were separated into two groups based upon whether the anti-g suit was inflated or not inflated. Second, of those with inflated anti-g suits, a subset was chosen to compare those who wore and those who did not wear the liquid cooling garment. Data are presented as means ± SE. All data were tested for normalcy and equal variance (11). Differences within groups were analyzed using 2-way repeated measures analysis of variance. The Tukey test was performed to document differences in variables when there was a significant main effect. Comparisons were considered significant if $P \leq 0.05$.

Results:

Figure 1 illustrates the effect of the antigravity suit on heart rate and arterial pressure preflight, during each phase of re-entry, and after wheels stop. Preflight, seated heart rate and blood pressure were not different between groups with and without the anti-g suit inflated ($P = 0.24$, SBP; $P = 0.17$, DBP; and $P = 0.33$, HR respectively). However, during preflight standing, both systolic and diastolic pressures were significantly lower in subjects without the anti-g suit inflated (P = 0.006, SBP; and, P = 0.001 DBP) while heart rate remained similar (P = 0.69). This protection was also evident on landing day. Both heart rate and arterial pressure remained similar between those with and without inflated anti-g suits at TIG (P = 0.22, SBP; P = 0.88, DBP; and P = 0.22, HR). They were also similar during the period of max-G (P = 0.66, SBP; P = 0.32, DBP; and P = 0.68, HR). However, at touch down, differences appeared. Both systolic and diastolic pressures were significantly lower in those who did not inflate the anti-g suit (P = 0.001, SBP; and P = 0.003, DBP). Throughout this period, heart rate was not significantly different between groups (P = 0.68). After wheels stop, pressures and heart rate were not different seated but upon initial standing, systolic pressure was significantly higher in the group using inflated suits (P = 0.13, seated SBP; P = 0.24, seated DBP; P = 0.22, seated HR; P = 0.06, standing SBP; P = 0.51, standing DBP; P = 0.73, standing HR).

Figure 2 depicts the effect of the liquid cooling garment on heart rate and arterial pressure during each phase of re-entry and postflight. All subjects included in this analysis had their anti-g suits inflated. No differences in either systolic or diastolic pressure were found between the two groups during re-entry (P = 0.97, SBP at TIG; P = 0.46, DBP at TIG; P = 0.23, SBP at maxG; P = 0.64, DBP at maxG; P = 0.59, SBP at TD; P = 0.74, DBP at TD; P = 0.06, SBP seated; P = 0.58, DBP seated; P = 0.38, SBP standing; and P = 0.64, DBP standing). Heart rate was not different between groups at TIG (P = 0.36), but the non-LCG users developed significantly higher heart rates than the users as re-entry progressed (P = 0.03 at maxG; P = 0.05 at TD; P = 0.02, post-wheels stop seated; and, P = 0.01, post-wheels stop standing). The non-LCG group had significant increases in arterial pressure (P =0.001, SBP; P = 0.001, DBP) and HR (P = 0.02) at max-G.

Discussion:

This is the first study to systematically document arterial pressure and heart rate responses during re-entry to Earth's atmosphere following spaceflight. It also is the first to document the efficacy of the antigravity suit and the liquid cooling garment. Our data suggest that, while the anti-g suit itself offers some cardiovascular protection, the combined use of the anti-g suit with the liquid cooling garment offers superior protection.

Effect of the anti-g suit

By the time astronauts are ready to return to Earth there have been several cardiovascular adaptations to the microgravity environment, which leave them ill prepared for gravity. Two changes that have a major impact on the circulation are dehydration and autonomic dysfunction (2, 6, 9, 20, 21). Despite routine attempts to partially restore plasma volume through ingestion of an oral isotonic saline solution before re-entry (3) virtually all astronauts have about a 9% reduction of plasma volume on landing day (2, 9, 20). In addition, some astronauts have inappropriately low increases in sympathetic activity during orthostatic stress (6, 21). While neither of these presents a hemodynamic problem during weightlessness, their effects are significant with the re-onset of gravitational forces, when the reduced vascular volume and low sympathetic responsiveness can translate into less venous return and low cardiac output. The anti-g suit increases venous return by compression of capacitance vessels. Studies using a similar device, the medical anti-shock trouser (MAST) have shown that suit inflation increases left ventricular end diastolic volume and stroke volume for up to 90 minutes (8, 12, 19), and increases inferior vena caval and forearm blood flow (12, 19) without changing cardiac contractility (8). Centrifugation protocols designed to mimic

Shuttle re-entry G-profiles, showed that the anti-g suit afforded cardiovascular protection. (10). The data from the present study demonstrate that inflation of the anti-g suit also protects arterial pressure during actual re-entry and landing (Fig 1).

Effect of the liquid cooling garment

Although the anti-G suit within the LES provided mechanical support, it could not alleviate the heat stress imposed by the suit. Therefore the liquid cooling garment was developed. The present data demonstrate that, among those who used the anti-g suit, heart rate was significantly lower in those who also wore the LCG (Fig. 2). This difference became more pronounced as the orbiter heated up after entering the atmosphere, suggesting that the cooling garment protected the subjects from heat stress. This is not unexpected, since studies using heat perfused suits have shown increases in heart rate and cardiac output and decreases in blood pressure, peripheral resistance, stroke volume, and hepatic blood flow (16).

During re-entry the orbiter cabin air can become very hot, despite pre-cooling before re-entry. Core temperatures can increase a half a degree Celsius when astronauts are fully suited (15). This is enough to cause a shunting of blood to cutaneous vascular beds, and concomitant increases in heart rate (1). This heat stress impacts crewmembers' performance and contributes to postflight orthostatic and exercise intolerances. Other studies have shown that, when subjects are exposed to heated environments, use of cooling garments lowers heart rate, core temperature and skin blood flow, and lengthens exercise time (13). In addition, skin and rectal temperatures, and heart rate are maintained at baseline levels and sweat production is reduced (18, 22). The liquid cooling garment was added as an operational countermeasure as a result of these problems with heat stress. These data indicate that it is successful.

Summary:

In summary, we found that astronauts who utilize their antigravity suit maintain arterial pressure above those who do not, during re-entry and landing. In addition, we found that the liquid cooling garment relieves heat stress, as indicated by the lower heart rates in subjects who wore the LCG. Thus, the combination of the two devices is recommended.

Limitations:

Due to the difficulty in obtaining these types of data, the sample sizes are smaller than we would like them to be. The levels of significance would most likely be greater with additional subjects.

References:

1. Abraham, P., Leftheriotis, G., Desvaux, B., Saumet, M., and Saumet, J. L. Diameter and Blood Velocity Changes in the Saphenous Vein During Thermal Stress. *Eur.J Appl.Physiol Occup.Physiol* 1994;69(4):305-8.

2. Buckey, J. C., Jr., Lane, L. D., Levine, B. D., Watenpaugh, D. E., Wright, S. J., Moore, W. E., Gaffney, F. A., and Blomqvist, C. G. Orthostatic Intolerance After Spaceflight. *J Appl.Physiol* 1996;81(1):7-18.

3. Bungo, M. W., Charles, J. B., and Johnson, P. C., Jr. Cardiovascular Deconditioning During Space Flight and the Use of Saline As a Countermeasure to Orthostatic Intolerance. *Aviat.Space Environ.Med* 1985;56(10):985-90.

4. Bungo, M. W. and Johnson, P. C., Jr. Cardiovascular Examinations and Observations of Deconditioning During the Space Shuttle Orbital Flight Test Program. *Aviat.Space Environ.Med* 1983;54:1001-4.

5. Fritsch-Yelle, J. M., Charles, J. B., Jones, M. M., Beightol, L. A., and Eckberg, D. L. Spaceflight Alters Autonomic Regulation of Arterial Pressure in Humans. *J Appl.Physiol* 1994;77(4):1776-83.

6. Fritsch-Yelle, J. M., Whitson, P. A., Bondar, R. L., and Brown, T. E. Subnormal Norepinephrine Release Relates to Presyncope in Astronauts After Spaceflight. *J Appl.Physiol* 1996;81(5):2134-41.

7. Fritsch, J. M., Charles, J. B., Bennett, B. S., Jones, M. M., and Eckberg, D. L. Short-Duration Spaceflight Impairs Human Carotid Baroreceptor- Cardiac Reflex Responses. *J Appl.Physiol* 1992;73(2):664-71.

8. Geelen, G., Arbeille, P., Saumet, J. L., Cottet-Emard, J. M., Patat, F., and Vincent, M. Hemodynamic and Hormonal Effects of Prolonged Anti-G Suit Inflation in Humans. *J Appl.Physiol* 1992;72(3):977-84.

9. Johnson, P. C.; Driscoll, T. B.; Leblanc, A. D. Blood volume changes. Johnston, R. S. and Dietlein, L. F. Biomedical Results from Skylab. Washington, DC: NASA; 1977. pp.235-41.

10. Krutz, R. W., Jr., Sawin, C. F., Stegmann, B. J., and Burton, R. R. Preinflation Before Acceleration on Tolerance to Simulated Space Shuttle Reentry G Profiles in Dehydrated Subjects. *J Clin.Pharmacol.* 1994;34(5):480-3.

11. Lilliefors, H. W. On the Kolmogorov-Smirnov Test for Normality With Mean and Variance Unknown. *J.Am.Stst.Assoc.* 1967;62:399-402.

12. Mannering, D., Bennett, E. D., Mehta, N., and Davis, A. L. Application of the Medical Anti-Shock Trouser (MAST) Increases Cardiac Output and Tissue Perfusion in Simulated, Mild Hypovolaemia. *Intensive Care Med* 1986;12(3):143-6.

13. McLellan, T. M., Frim, J., and Bell, D. G. Efficacy of Air and Liquid Cooling During Light and Heavy Exercise While Wearing NBC Clothing. *Aviat.Space Environ.Med* 1999;70(8):802-11.

14. Nicogossian, A., Pool, S., and Sawin, C. Status and Efficacy of Countermeasures to Physiological Deconditioning From Space Flight. *Acta Astronaut.* 1995;36(7):393-8.

15. Pawelczyk, J. A.; Rimmer, D. W. Cold Stimulation to Improve Orthostatic Tolerance. Bioastronautics Investigators Workshop; 1-17-2001; 2001.

16. Rowell, L. B., Brengelmann, G. L., Blackmon, J. R., and Murray, J. A. Redistribution of Blood Flow During Sustained High Skin Temperature in Resting Man. *J Appl.Physiol* 1970;28(4):415-20.

17. Sawin, C. F., Baker, E., and Black, F. O. Medical Investigations and Resulting Countermeasures in Support of 16- Day Space Shuttle Missions. *J Gravit Physiol* 1998;5(2):1-12.

18. Shvartz, E. and Benor, D. Total Body Cooling in Warm Environments. *J Appl.Physiol* 1971;31(1):24-7.

19. Terai, C., Oryuh, T., Kimura, S., Mizuno, K., Okada, Y., and Mimura, K. The Autotransfusion Effect of External Leg Counterpressure in Simulated Mild *Hypovolemia.* J Trauma 1991;31(8):1165-8.

20. Waters, W. W., Ziegler, M. G., and Meck, J. V. Post-Spaceflight Orthostatic Hypotension Occurs Mostly in Women and Is Predicted by Low Vascular Resistance. *J Appl.Physiol* 2002;92:586-94.

21. Whitson, P. A., Charles, J. B., Williams, W. J., and Cintròn, N. M. Changes in Sympathoadrenal Response to Standing in Humans After Spaceflight. *J Appl.Physiol* 1995;79(2):428-33.

22. Xu, X., Hexamer, M., and Werner, J. Multi-Loop Control of Liquid Cooling Garment Systems. *Ergonomics* 1999;42(2):282-98.

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Figure Legends:

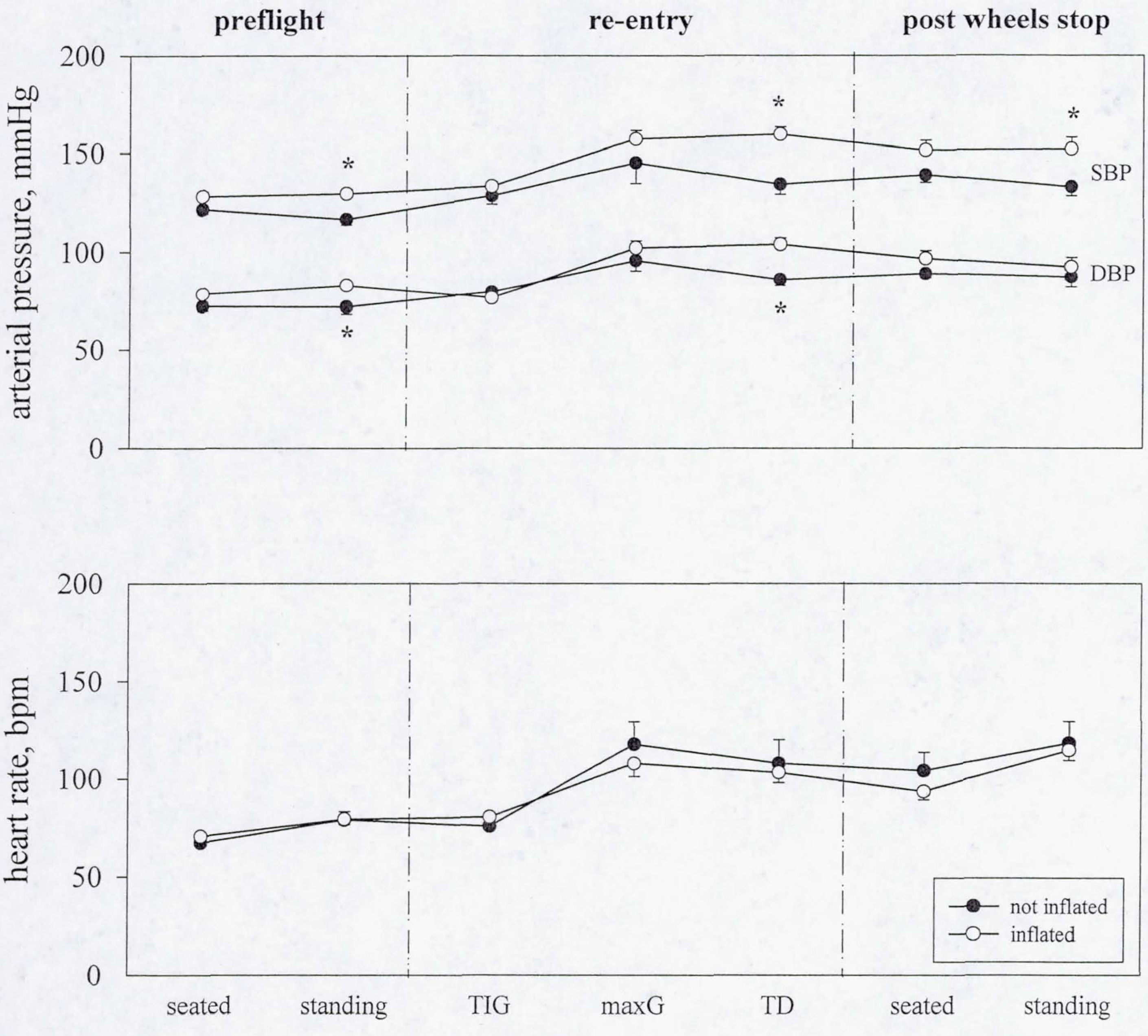
Figure 1. Heart rate and arterial pressure preflight, during each phase of re-entry, and after wheels stop in subjects with anti-g suits inflated (○, n = 24) and not-inflated (●, n = 8). TIG is the time of rocket ignition, max-G is the period of maximum gravity, and TD is orbiter touchdown. Values represent means ± SE.

*$p \leq 0.05$ when comparing subjects with inflated anti-g suits to those using no inflation.

Figure 2. Heart rate and arterial pressure during each phase of re-entry and after wheels stop in subjects with (○, n = 3) and without (●, n = 8) the liquid cooling garment or LCG. All subjects included in this analysis were tested with anti-g suits inflated. TIG is the time of rocket ignition, max-G is the period of maximum gravity, and TD is orbiter touchdown. Values represent means ± SE.

*$p \leq 0.05$ when comparing subjects using the LCG to those not using the LCG.

**$p \leq 0.05$ when comparing TIG to maxG within the same group.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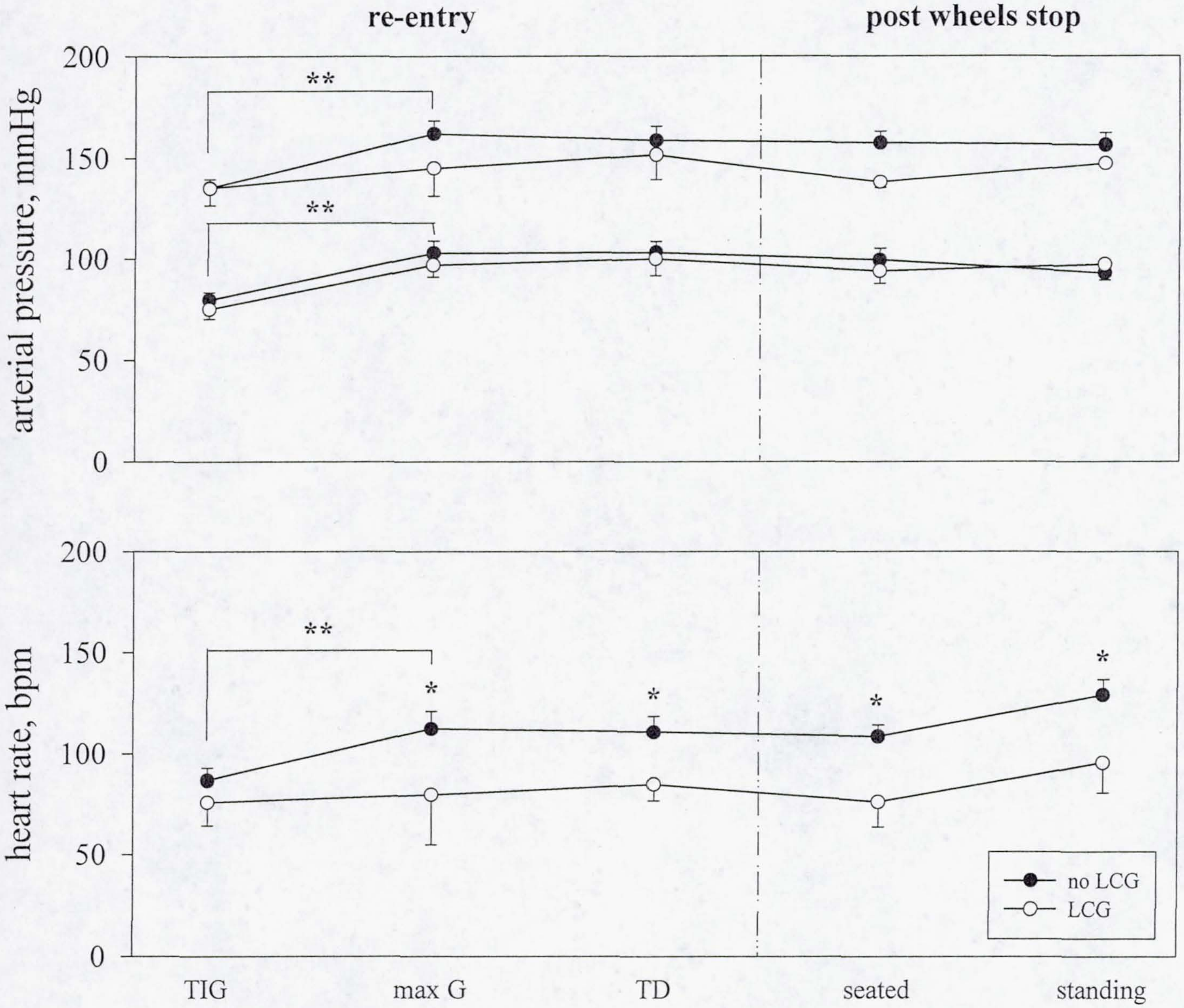

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