“Push-Pull Effect”

Aircrew Risk Awareness

Lt. Col (Dr.) Jeff “Bags” Woolford, MD, MPH, MBA

RAMS/USAF and NATO STO HFM-309 Technical Course

Garmisch-Partenkirchen, Germany

19 March 2019 @ 1400

Disclosure Information

I have no financial relationships to disclose.

I will not discuss off-label use and/or investigational use.

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- Anatomy
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- Push-Pull Effect Studies
- Current Preventive Measures
- Future Preventive Measures
- Questions?

http://afthunderbirds.com/site/media-downloads/

Lt. Col (Dr.) Jeff "Bags" Woolford

EDUCATION

1995	Bachelor of Science in Professional Aeronautics, Embry-Riddle Aeronautical University, Daytona Beach, FL
2002	Squadron Officer School (Residence), Air University, Maxwell Air Force Base, AL
2004	White House Emergency Actions Course, White House Military Office, Washington, DC
2005	Bachelor of Science in Biology, University of Maryland – Baltimore County, Baltimore, MD
2008	Doctor of Medicine, Uniformed Services University, National Naval Medical Center, Bethesda, MD
2010	Air Command and Staff College (Correspondence), Air University, Maxwell Air Force Base, AL
2014	Master of Public Health from the Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD
2016	Master of Business Administration from the Cary Business School, Johns Hopkins University, Baltimore, MD
2017	Air War College (Correspondence), Air University, Maxwell Air Force Base, AL

ASSIGNMENTS

08/1989 – 09/1989	Student, Basic Military Training, Lackland AFB, TX
09/1989 – 11/1989	Student, Apprentice Tactical Aircraft Maintenance (F-16), Sheppard AFB, TX
11/1989 – 01/1990	Student, Aircraft Maintenance Specialist (F-16 Crew Chief), Shaw AFB, SC
01/1990 – 03/1992	Aircraft Mechanic (F-16C), Ramstein AB, Germany
03/1992 – 12/1992	Aircraft Mechanic (F-16C), Mountain Home AFB, ID
01/1993 – 03/1997	Aircraft Mechanic (A-10A), Warfield ANGB, MD
03/1997 – 05/1997	Student, Academy of Military Science, McGhee-Tyson ANGB, TN
05/1997 – 07/1998	Student, Specialized Undergraduate Pilot Training, Laughlin AFB, TX
08/1998 – 09/1998	Student, Introduction to Fighter Fundamentals Course, Columbus AFB, MS
09/1998 – 03/1999	Student, A-10 Pilot Initial Qualification Course, Davis-Monthan AFB, AZ
03/1999 – 08/2004	A-10A Aircraft Commander, Warfield ANGB, MD
08/2004 – 09/2008	Medical Student, Uniformed Services University, Bethesda, MD
09/2008 – 10/2009	Transitional Intern, Wilford Hall Medical Center, Lackland AFB, TX
11/2009 – 11/2010	Flight Surgeon / Squadron Medical Element, Osan AB, Korea
11/2010 – 05/2013	A-10C Pilot-Physician / Squadron Medical Element, Spangdahlem AB, Germany
05/2013 – 07/2014	Student, Johns Hopkins University, Baltimore, MD
07/2014 – 07/2016	Resident of Aerospace Medicine, Wright-Patterson AFB, OH
07/2016 – Present	USAF-RAF Exchange Officer/Pilot-Physician, MoD Boscombe Down, United Kingdom

http://theaircache.com/2012/08/04/a-10-thunderbolt-ii/

Photo Credit: David Turnbull / Release Authorization: Kevin Taylor

Public Release Information

- Inverted flight duration ≈22 seconds @ ≤ -2G
- Range from -2.06G to +8.56G = Δ 10.62G

THUNDERBIRDS PILOT LOST CONSCIOUSNESS IN HIGH-G MANEUVER

Thunderbirds pilot Maj. Stephen Del Bagno temporarily lost consciousness during a high G-force maneuver and was incapacitated right before a fatal crash April 4.

The Air Force investigation into ccident at the Nevada Test and Training Range, near Nellis Air Force Base, said Del Bagno was practicing an aerial maneuver called the High Bomb Burst Rejoin, and flew inverted for about 22 seconds at about 5,500 to 5,700 feet above ground level, where he experienced up to negative two G-forces.

Del Bagno then started a descending half-loop maneuver called the Split-S, reaching a maximum of 8.56 Gs after five seconds, the report said. The extreme G-forces caused him to lose consciousness for five seconds. About a second before hitting the ground, he recovered somewhat and started trying to recover his F-16CM, but it was too late. He did not try to eject.

The accident investigation board found that the "push-pull effect" of quickly going from -2.06 Gs — or twice the equivalent of standing on one's head — to 8.56 Gs dramatically lessened his tolerance to G-forces, and substantially contributed to the crash. Those conditions also lessened the effectiveness of his anti-G force straining maneuver.

Del Bagno, whose call sign was "Cajun," was an experienced F-35 pilot, whose love of flying, enthusiasm and excitement for his first season with the Thunderbirds was apparent to all. In a January video documenting the moment he and other newly minted Thunderbirds received their iconic red flight helmets, Del Bagno called it "a fantastic day."

The Thunderbirds, the U.S. Air Force Air Demonstration Squadron, suspended performances for six weeks after Del Bagno's loss.

The report said Del Bagno was known as "an 'inspirational' leader who was always positive and put others before himself."

"The merger between his positive personality and pilot skills made him a 'perfect fit for the Thunderbirds' mission to recruit, retain and inspire," the report said. "A member of his squadron summed up [Del Bagno] as 'just a beautiful human being.'"

Del Bagno appeared in good spirits before the flight, the report said, and was current and qualified to fly. He had a reputation for exceptional physical fitness and had carried out many high-G maneuvers successfully in the weeks prior to the mishap.

But the report said that physical fitness does not protect against the physiological effects of negative-Gs.

Losey, Stephen. "Thunderbird Pilot Lost Consciousness in a High-G Maneuver." *Air Force Times* (Vienna), October 29, 2018, Vol. 79, Issue 20 ed., On the Radar sec.

Operational Relevance?

- “Push-Pull” Maneuvers were associated with:

  - 31.3% of G-LOC events in the Royal Air Force

  - 29.0% of G-LOC events in the United States Air Force

Liu, Yang, Li-Fan Zhang, Hong-Bing Lu, Guo-Peng Zhang, and Huang-Sheng Pu. "Mathematical modeling of the push-pull effect for various acceleration profiles and countermeasures." *Aviation, space, and environmental medicine* 80, no. 9 (2009): 781-789.

Frequency of the "Push-Pull Effect" in U.S. Air Force Fighter Operations Study

The purpose of this study was to determine the frequency of maneuvers found to cause the push-pull effect in U.S. Air Force fighter aircraft.

Michaud, Vincent J., Terence J. Lyons, and Christopher M. Hansen. "Frequency of the "push-pull effect" in US Air Force fighter operations." *Aviation, space, and environmental medicine* 69, no. 11 (1998): 1083-1086.

Frequency of the "Push-Pull Effect" in U.S. Air Force Fighter Operations Study

TABLE II. PERCENTAGE OF ENGAGEMENTS WITH PUSH-PULL EFFECT MANEUVERS BY TYPE OF SORTIE, PILOT STATUS, AND AIRCRAFT TYPE.

Sortie Type	Pilot Status	F-16	F-15	Aircraft Combined (%)
BFM	Student	11/30 (37%)	7/43 (16%)	25
BFM	Instructor	3/28 (11%)	5/35 (14%)	13
ACM	Student	18/42 (43%)	16/24 (67%)	51
ACM	Instructor	12/32 (38%)	5/8 (63%)	43
Aircraft totals		44/132 (33%)	33/110 (30%)	32

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Frequency of the "Push-Pull Effect" in U.S. Air Force Fighter Operations Results

- Push-Pull Effect maneuvers were found with an overall average of 32%, ranging from 11% to 67% depending on the nature of the training mission.
- The Push-Pull Effect maneuvers observed contained segments of less than +1Gz, ranging on average from 0.00Gz to +0.5Gz for an average of 3.5 to 5.0 seconds.

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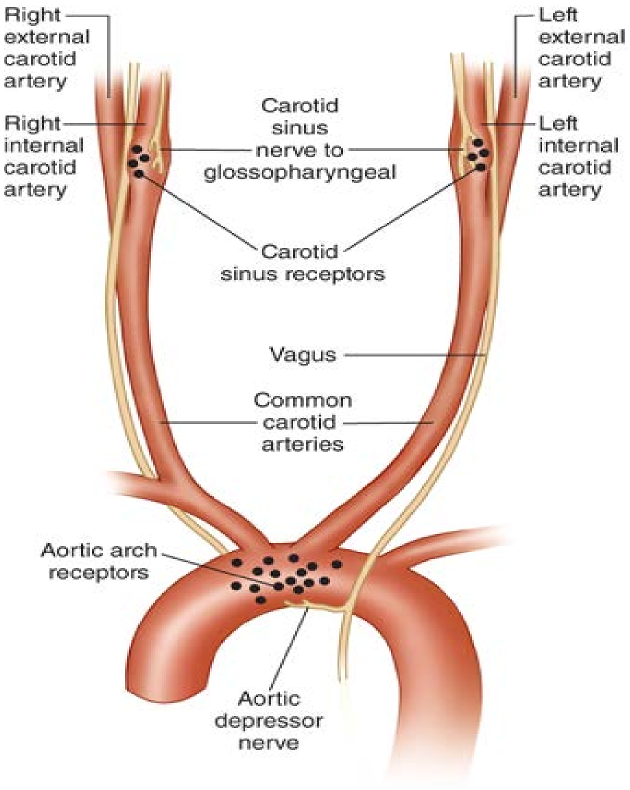
- The Push-Pull Effect maneuvers observed contained segments of less than +1Gz, ranging on average from 0.00Gz to +0.5Gz for an average of 3.5 to 5.0 seconds.

- CONCLUSION: Data from 240 HUD tapes containing over 240 air combat training engagements from F-15 and F-16 aircraft reveal that push-pull maneuvers are most frequently, unintentionally, performed when entering the merge head-on, when "re-entering the fight", and when executing an offensive role.

Michaud, Vincent J., Terence J. Lyons, and Christopher M. Hansen. "Frequency of the "push-pull effect" in US Air Force fighter operations." *Aviation, space, and environmental medicine* 69, no. 11 (1998): 1083-1086.

Anatomy



Barrett, Kim E., Susan M. Barman, Scott Boitano, Heddwen L. Brooks, Michael Weitz, Brian Patrick Kearns, and William F. Ganong. *Ganongs Review of Medical Physiology*. 25th ed. New York: McGraw Hill Education, 2016.

Medical Formulas

$$CO = SV \bullet HR$$

Cardiac Output = Stroke Volume x Heart Rate

$$MAP = \frac{(SBP - DBP)}{3} + DBP$$

Mean Arterial Pressure = 1/3 (Systolic BP – Diastolic BP) + Diastolic BP

$$CPP = MAP - ICP$$

Cerebral Perfusion Pressure = Mean Arterial Pressure – Intracranial Pressure

The "Push-Pull Effect" Study

The purpose of this study was to prove or refute previous authors' suggestions that tolerance to $+G_z$ is reduced when preceded by $0G_z$ or $-G_z$.

Banks, R. D., J. D. Grissett, G. T. Turnipseed, P. L. Saunders, and A. H. Rupert. "The" push-pull effect"." *Aviation, space, and environmental medicine* 65, no. 8 (1994): 699-704.

Systolic Blood Pressure vs. +2.25 G_z

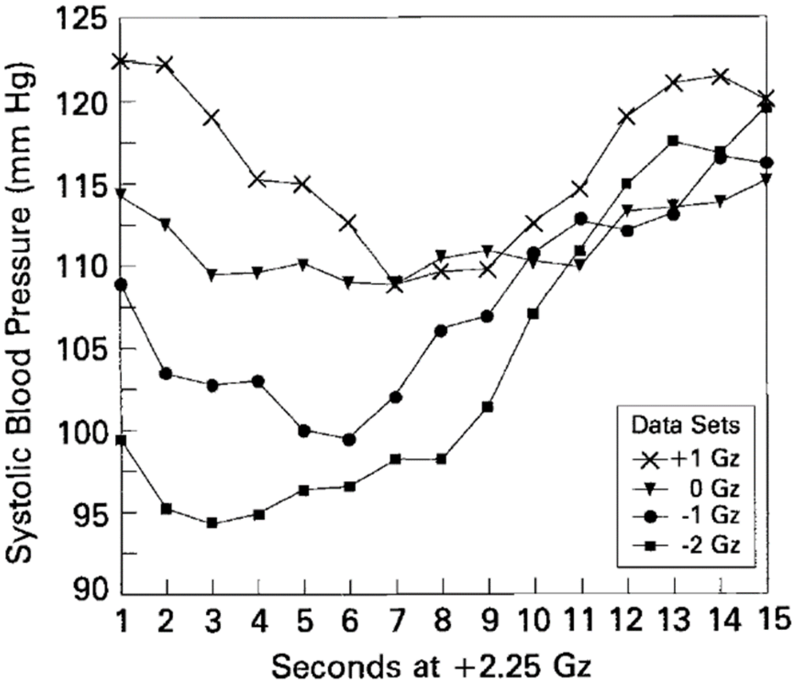


Fig. 3. Mean values of systolic blood pressure (BP_s) vs. seconds at +2.25 G_z exposure.

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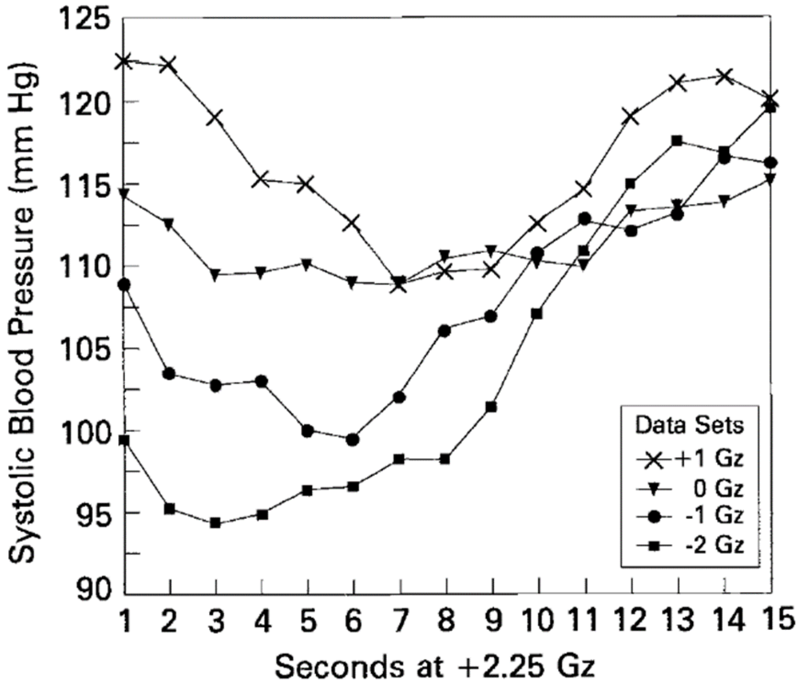

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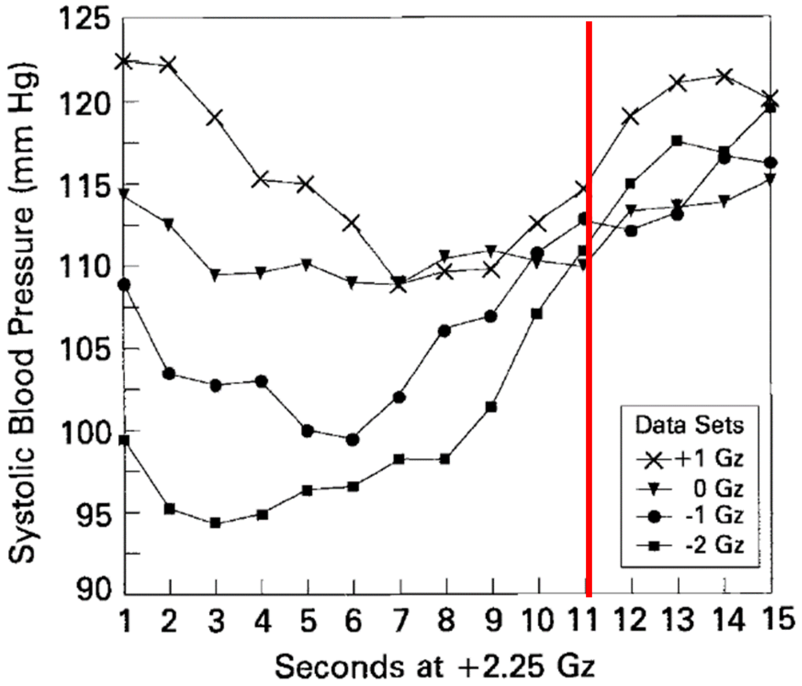

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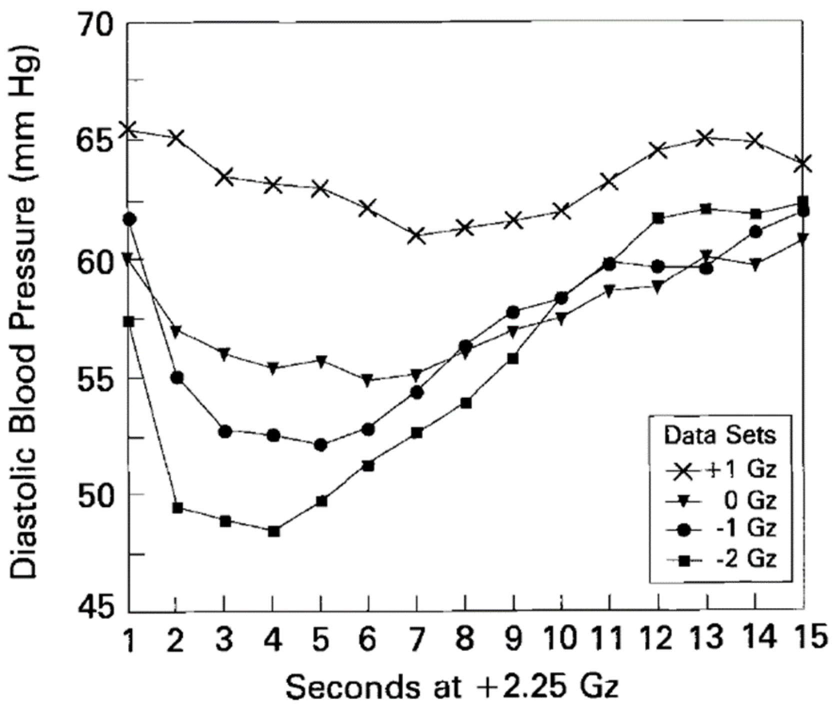

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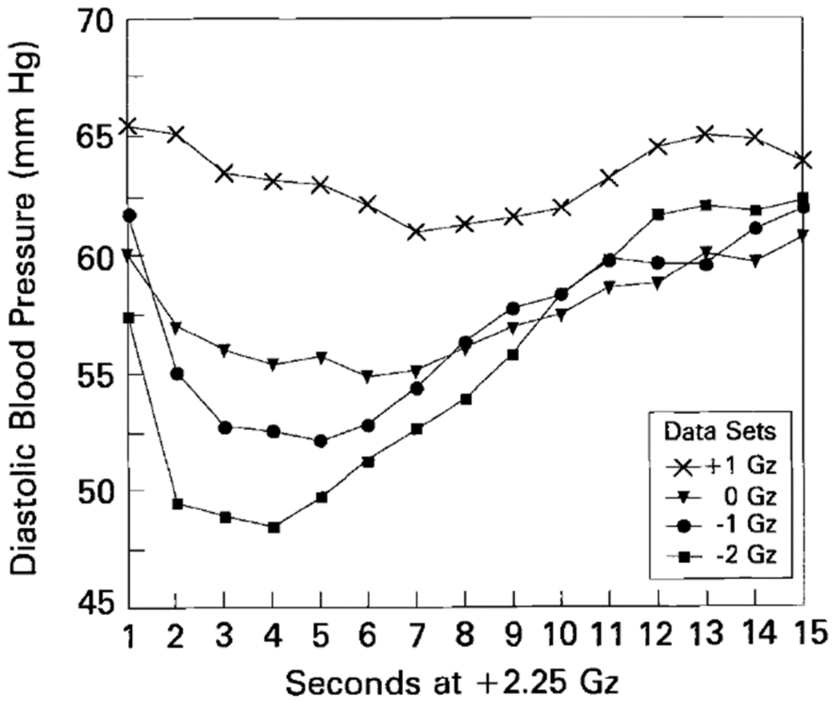

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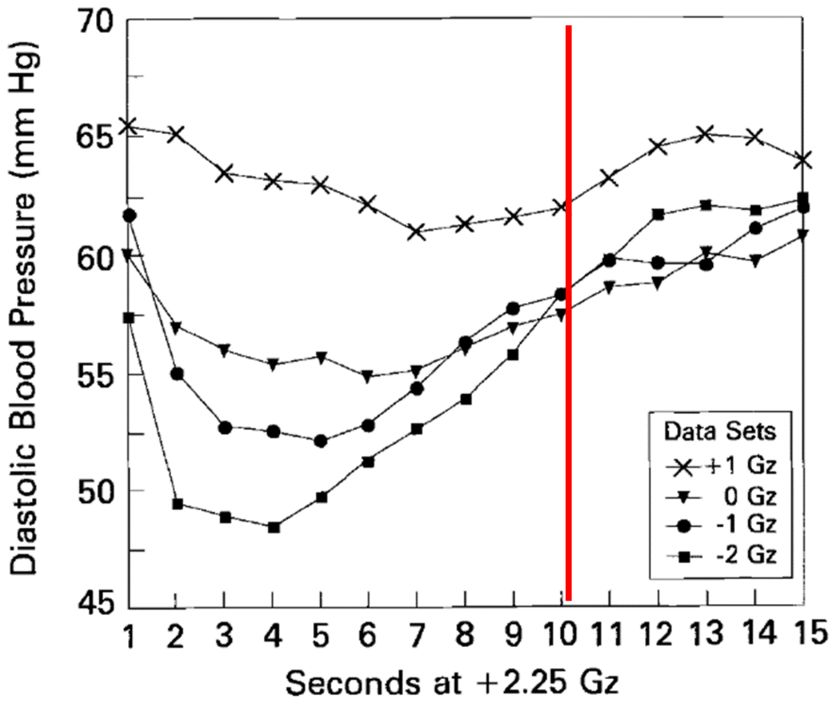

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Mean Pulse Pressure vs. +2.25 G_z

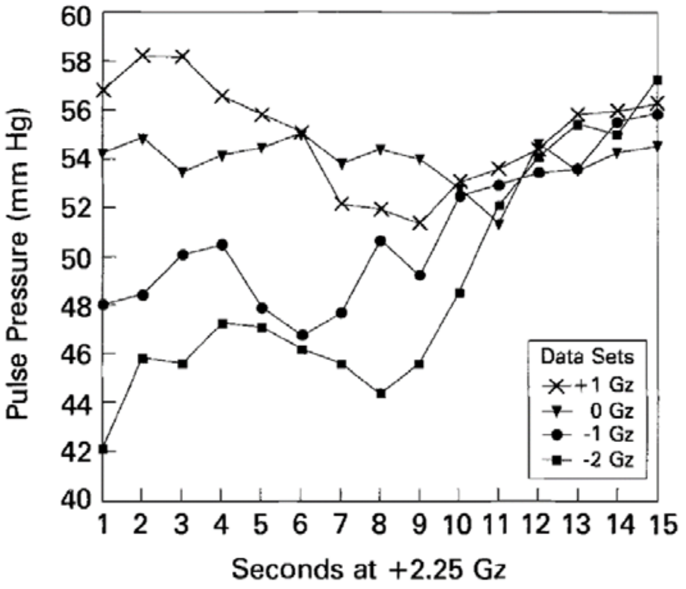

Fig. 5. Mean values of pulse pressure (PP) vs. seconds at +2.25 Gz exposure.

TABLE II. ANALYSIS (*t*-TEST) OF BPs DURING 15 S EXPOSURE TO +2.25 Gz WHEN SUBDIVIDED INTO 5-S INTERVALS, FOR ALL CONDITIONS OF PRECEDING Gz EXPOSURE.

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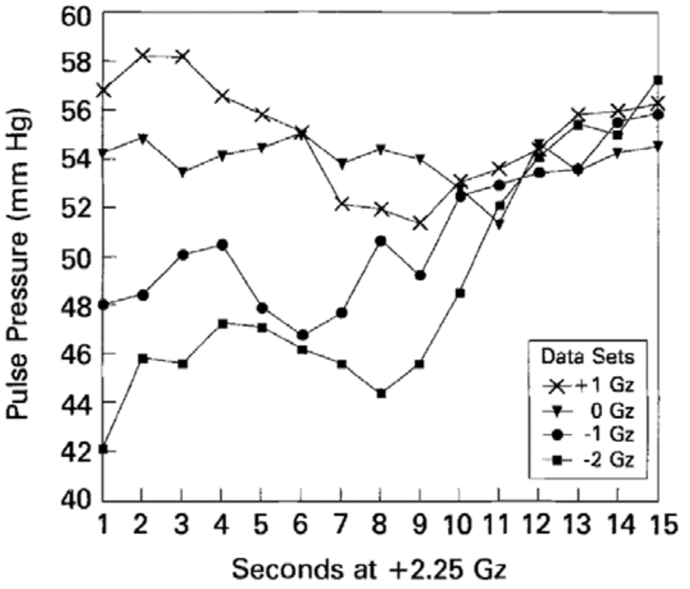

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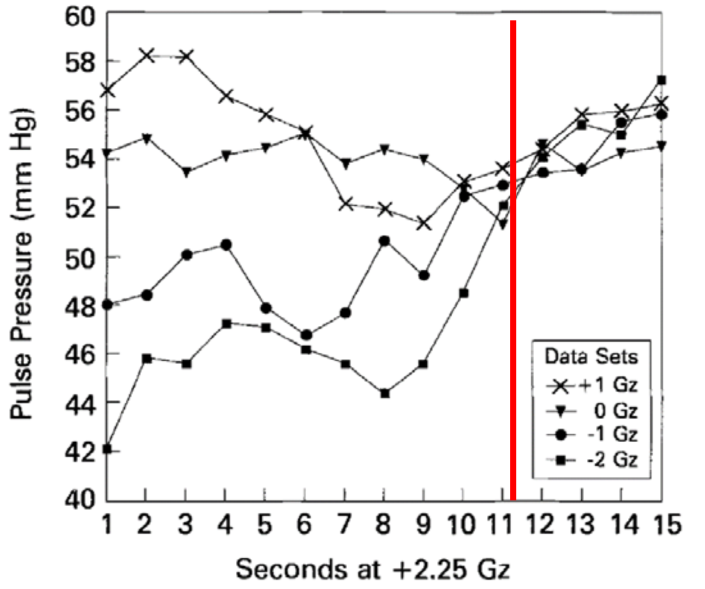

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The "Push-Pull Effect" Results

- The minimum blood pressure was progressively lower during the 15 second period as the pre-exposure experimental conditions became more negative (+1, 0, –1, and $–2G_z$).
- Episodes of peripheral vision loss increased as the preceding $–G_z$ became more negative.

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- Episodes of peripheral vision loss increased as the preceding $–G_z$ became more negative.

- CONCLUSION: Blood pressure during exposure to $+G_z$ was significantly affected by the preceding 10 second exposure to $–G_z$, and is indicative of reduced $+G_z$ tolerance.

Banks, R. D., J. D. Grissett, G. T. Turnipseed, P. L. Saunders, and A. H. Rupert. "The" push-pull effect"." *Aviation, space, and environmental medicine* 65, no. 8 (1994): 699-704.

The Effect of Varying Time at –G_z on Subsequent +G_z Physiological Tolerance (Push-Pull Effect) Study

The purpose of this experiment was to observe the effect of varying time duration at –G_z on the push-pull effect.

Banks, Robert D., J. D. Grissett, P. L. Saunders, and A. J. Mateczun. "The effect of varying time at-Gz on subsequent+ Gz physiological tolerance (push-pull effect)." *Aviation, space, and environmental medicine* 66, no. 8 (1995): 723-727.

Systolic Blood Pressure vs. Time at +2.25 G_z

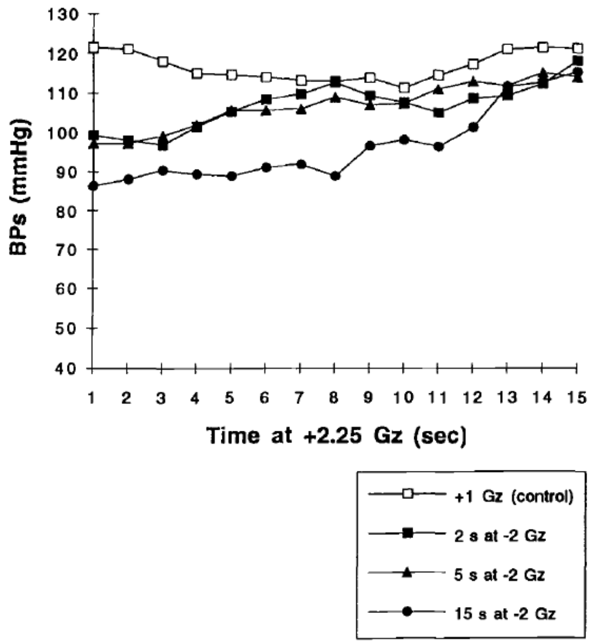

Fig. 2. Mean values of systolic blood pressure (BPs) vs time at +2.25 Gz exposure for +1 Gz control (0 s at −2 Gz), and 2, 5, and 15 s at −2 Gz.

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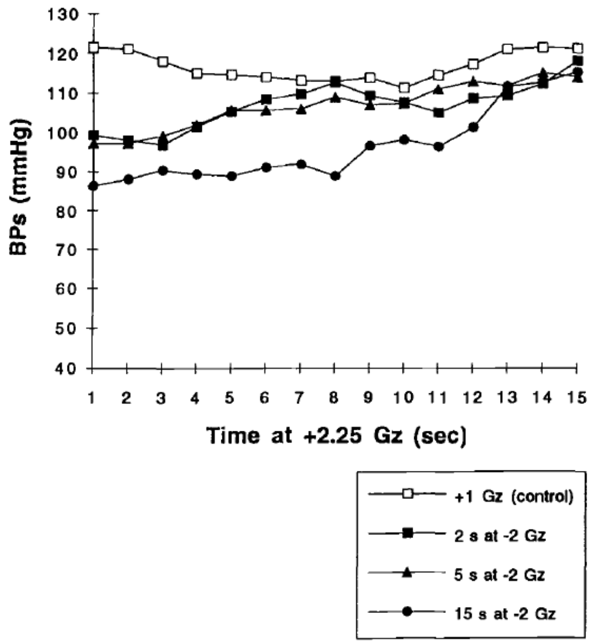

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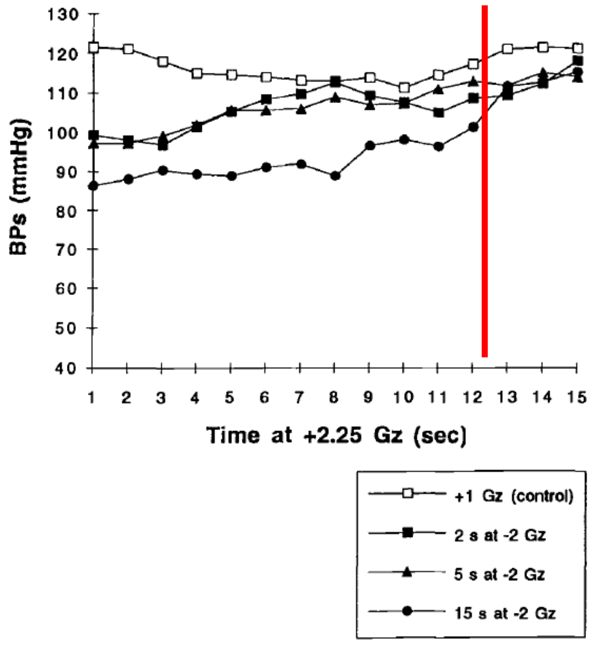

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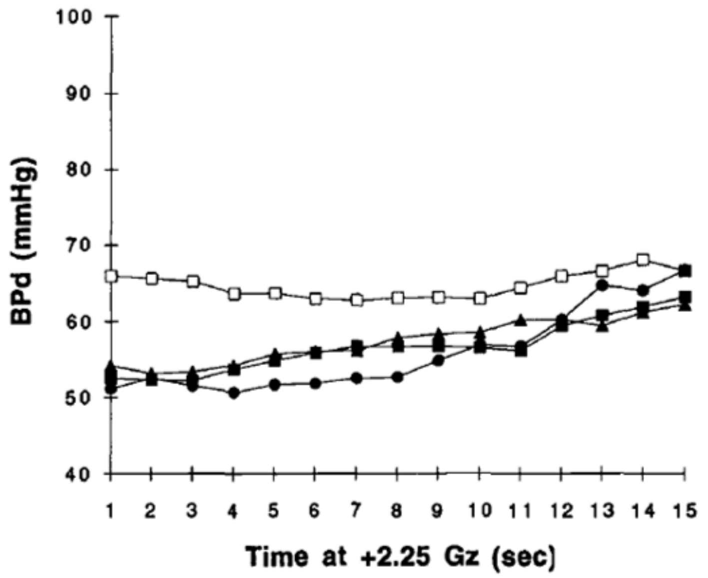
Diastolic Blood Pressure vs. Time at +2.25 G_z

TIME AT $-G_z$ & PUSH-PULL EFFECT—BANKS ET AL



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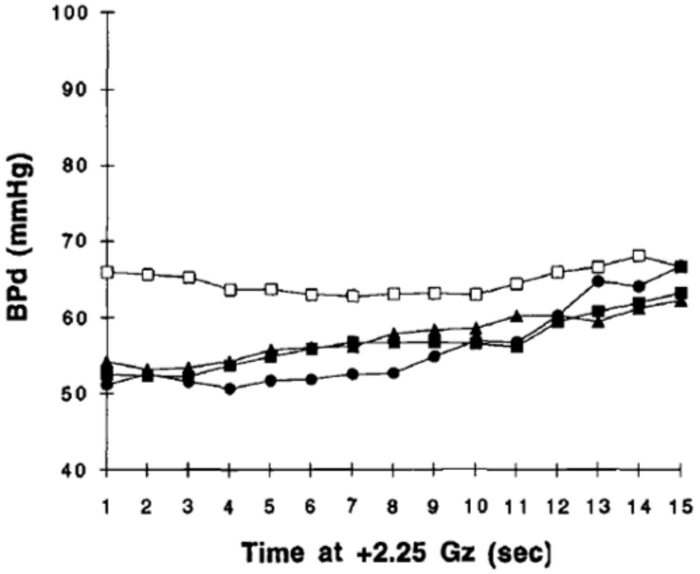
Diastolic Blood Pressure vs. Time at +2.25 G_z

TIME AT $-G_z$ & PUSH-PULL EFFECT—BANKS ET AL



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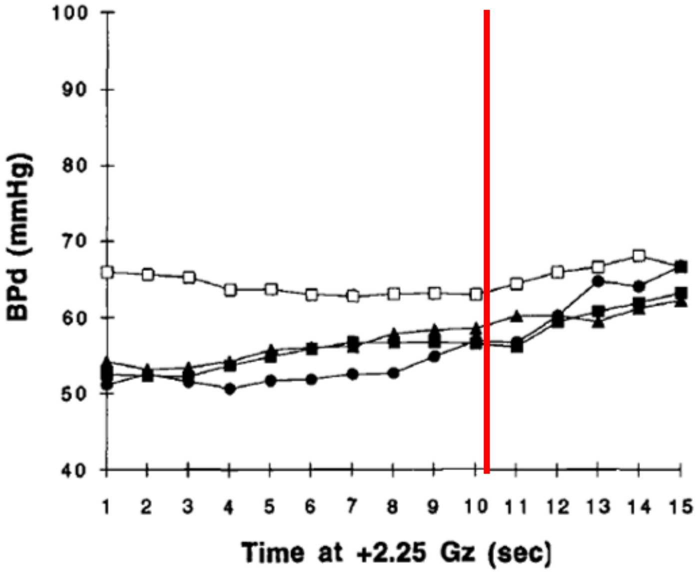
Diastolic Blood Pressure vs. Time at +2.25 G_z

TIME AT −Gz & PUSH-PULL EFFECT—BANKS ET AL



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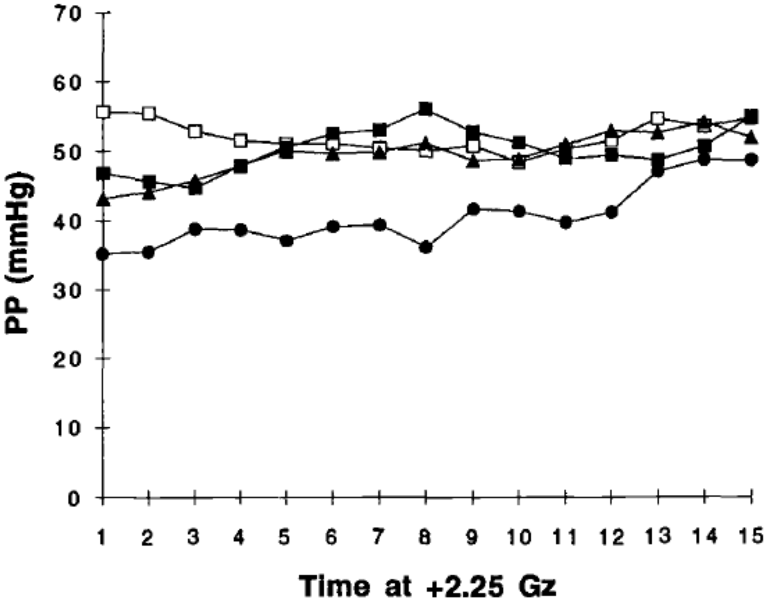
Pulse Pressure vs. Time at +2.25 G_z



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Pulse Pressure vs. Time at +2.25 G_z

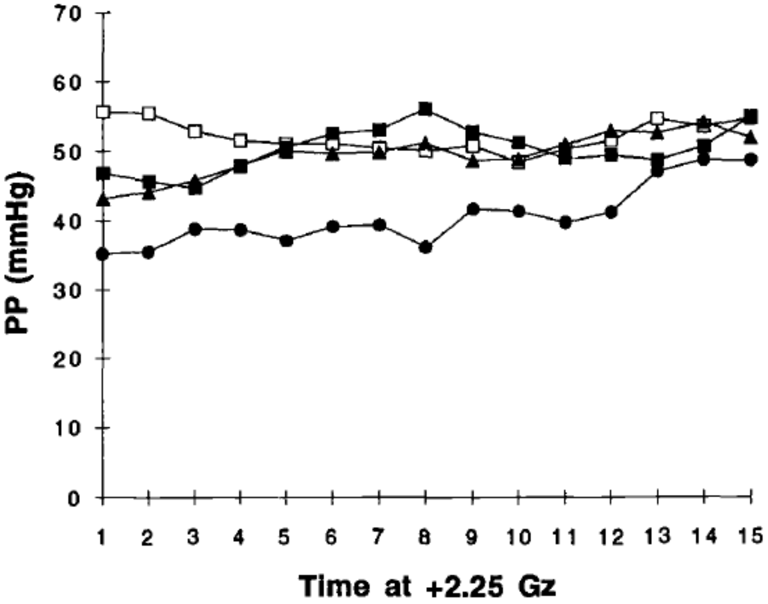

Fig. 4. Mean values of pulse pressure (PP) vs time at +2.25 Gz exposure for +1 Gz control (0 s at −2 Gz), and 2, 5, and 15 s at −2 Gz. (Legend as in Fig. 2.)

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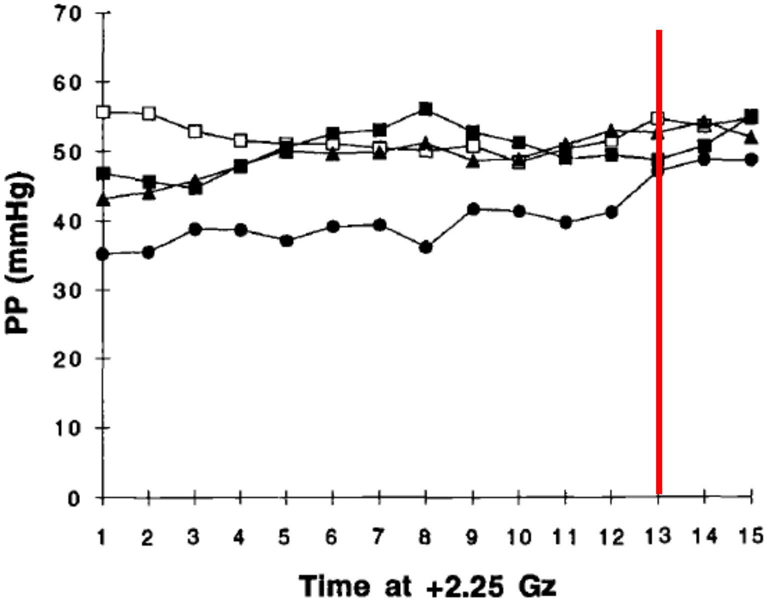

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The Effect of Varying Time at –G_z on Subsequent +G_z Physiological Tolerance (Push-Pull Effect) Results

- Mean blood pressure was significantly reduced when the +2.25G_z exposures were preceded by –2G_z.
- Following 15 seconds of –2G_z, mean blood pressure decreased more and was slower to recover than for 2 and 5 seconds of –2G_z.

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- Following 15 seconds of –2G_z, mean blood pressure decreased more and was slower to recover than for 2 and 5 seconds of –2G_z.

- CONCLUSION: During relaxed conditions, the push-pull effect is augmented by increasing duration of the preceding –G_z.

Banks, Robert D., J. D. Grissett, P. L. Saunders, and A. J. Mateczun. "The effect of varying time at-Gz on subsequent+ Gz physiological tolerance (push-pull effect)." *Aviation, space, and environmental medicine* 66, no. 8 (1995): 723-727.

Extrapolation?

The "Push-Pull Effect" Study

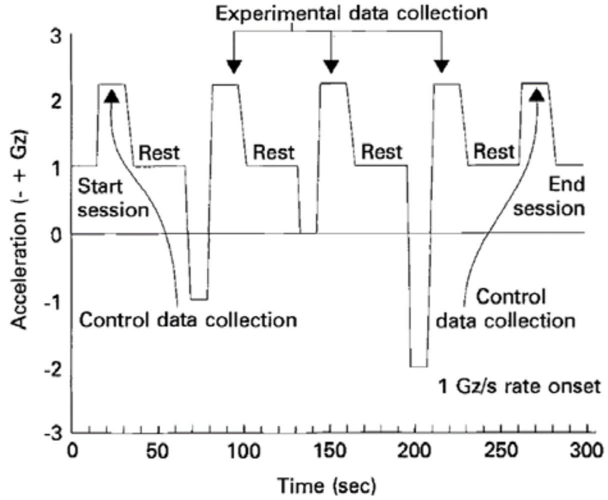
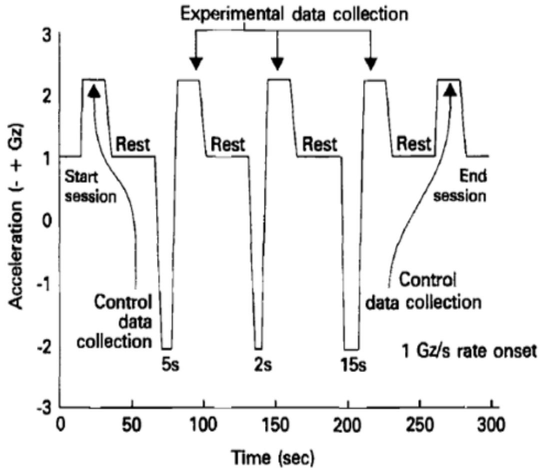


Fig. 2. Typical Gz exposure profile for one session showing 2 control and 3 experimental segments, each separated by a 30-s rest period at +1 Gz. BP data were collected at 15-s periods of exposure to +2.25 Gz for each condition, as indicated.

The Effect of Varying Time at –G_z on Subsequent +G_z Physiological Tolerance (Push-Pull Effect) Study

TIME AT –Gz & PUSH-PULL EFFECT—BANKS ET AL.



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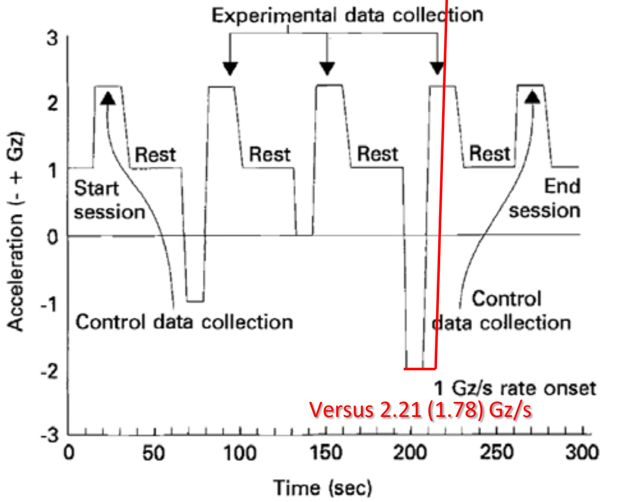
Limited Release Information

The "Push-Pull Effect" Study



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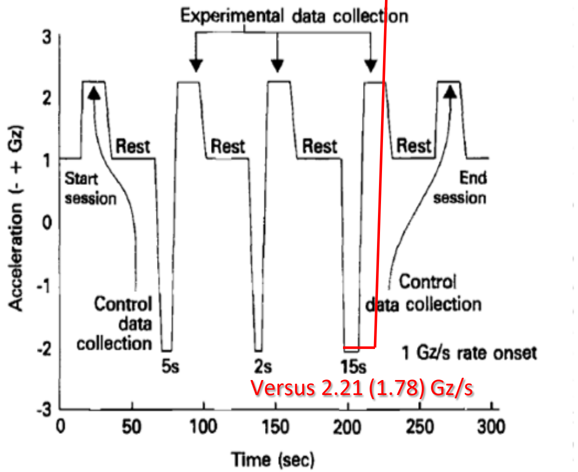

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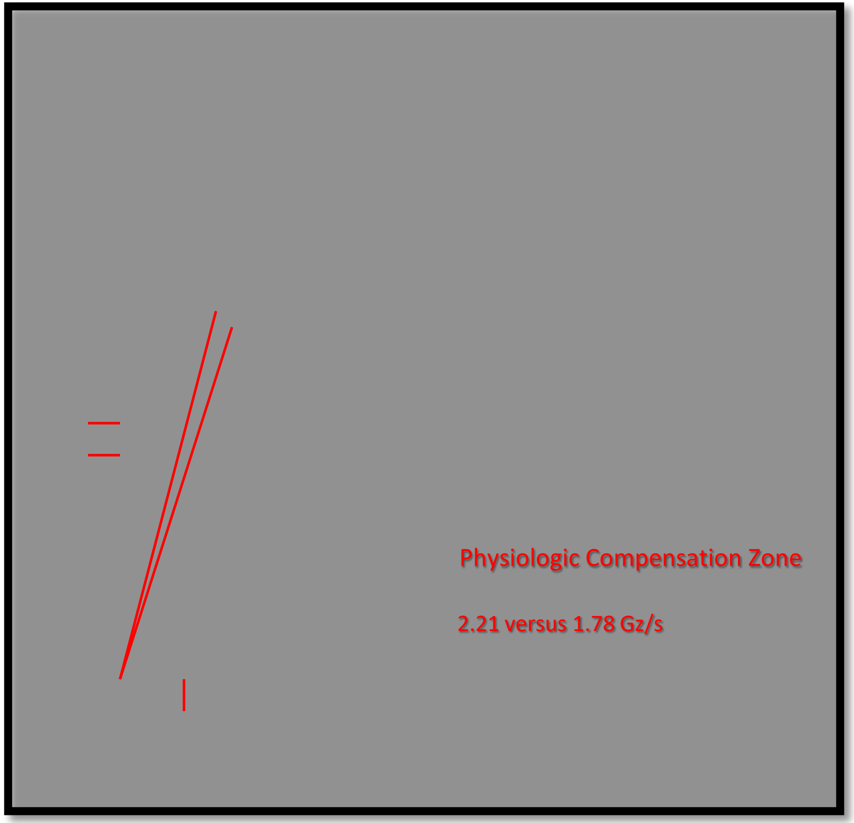
“Stoll Curve” G-Tolerance vs. Acceleration Rates

Stoll, Alice M. "Human tolerance to positive G as determined by the physiological end points." *Aviat Med* 27 (1956): 356-367.

Limited Release Information



Stoll, Alice M. "Human tolerance to positive G as determined by the physiological end points." *Aviat Med* 27 (1956): 356-367.

Blood Pressure and Heart Rate Responses to Sudden Changes of Gravity During Exercise Study

The purpose of this study was to propose an experimental model, involving sudden gravitational stress superimposed on dynamic exercise, that would provide new information regarding the efficiency of circulatory control (or lack thereof) to maintain blood pressure and blood perfusion under conditions of increased metabolic requirements.

Linnarsson, D., C. J. Sundberg, B. Tedner, Y. Haruna, J. M. Karemaker, G. Antonutto, and P. E. Di Prampero. "Blood pressure and heart rate responses to sudden changes of gravity during exercise." *American Journal of Physiology-Heart and Circulatory Physiology* 270, no. 6 (1996): H2132-H2142.

Blood Pressure and Heart Rate Responses to Sudden Changes of Gravity During Exercise Study

H2136 BAROREFLEX CONTROL OF HEART RATE DURING EXERCISE

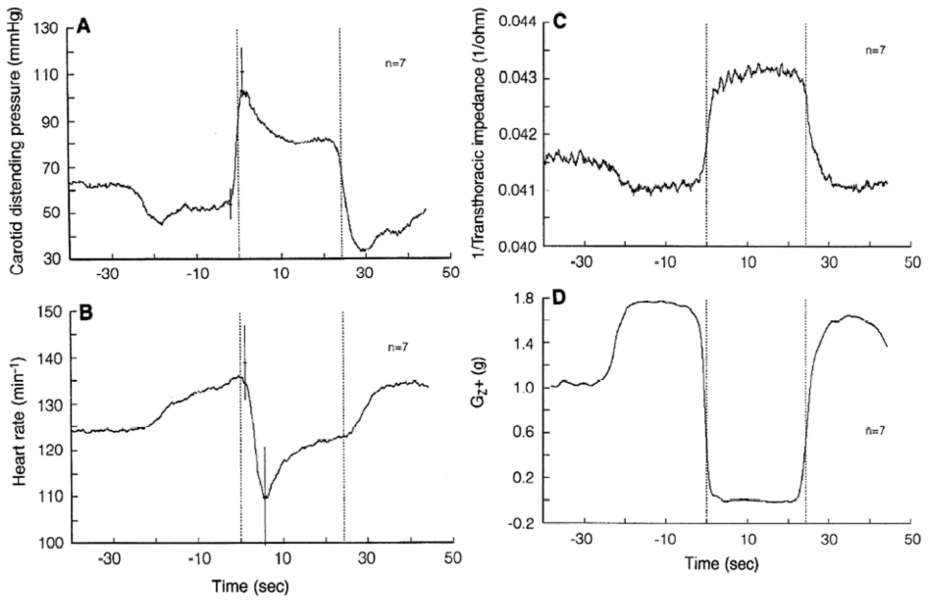


Fig. 3. Ensemble mean time courses of cardiovascular variables in upright exercising subjects (80–90 W) during transient weightlessness in parabolic flight. *A*: CDP; *B*: HR; *C*: 1/TTI; *D*: gravity in head-to-foot direction (G_{z+}). Vertical broken lines indicate instant of 0.5 G_{z+}. For further explanations, see Fig. 2.

Linnarsson, D., C. J. Sundberg, B. Tedner, Y. Haruna, J. M. Karemaker, G. Antonutto, and P. E. Di Prampero. "Blood pressure and heart rate responses to sudden changes of gravity during exercise." *American Journal of Physiology-Heart and Circulatory Physiology* 270, no. 6 (1996): H2132-H2142.

Blood Pressure and Heart Rate Responses to Sudden Changes of Gravity During Exercise Results

- Heart rate responses are described as a function of carotid distending pressure and the inverse of transthoracic impedance after a time delay of 2.3 to 3.0 seconds.
- Time constants of 0.34 to 0.35 seconds for decreasing heart rate.
- Time constants of 2.9 to 4.6 seconds for increasing heart rate.
- The carotid-cardiac baroreflex … accounts for 85 to 95% of the initial heart rate responses to sudden changes of gravity.

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- The carotid-cardiac baroreflex … accounts for 85 to 95% of the initial heart rate responses to sudden changes of gravity.

- CONCLUSION: Heart rate increases occur much more slowly than heart rate decreases.

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Role of Autonomic Nervous System in Push-Pull Gravitational Stress in Anesthetized Rats Study

The purpose of this study was to investigate the integrative response of the autonomic nervous system by studying responses to gravitational stress before and after autonomic function was inhibited by hexamethonium in 10 isoflourane-anesthetized … Sprague-Dawley rats.

Hakeman, Amy L., and Don D. Sheriff. "Role of the autonomic nervous system in push-pull gravitational stress in anesthetized rats." *Journal of Applied Physiology* 94, no. 2 (2003): 709-715.

Role of Autonomic Nervous System in Push-Pull Gravitational Stress in Anesthetized Rats Study

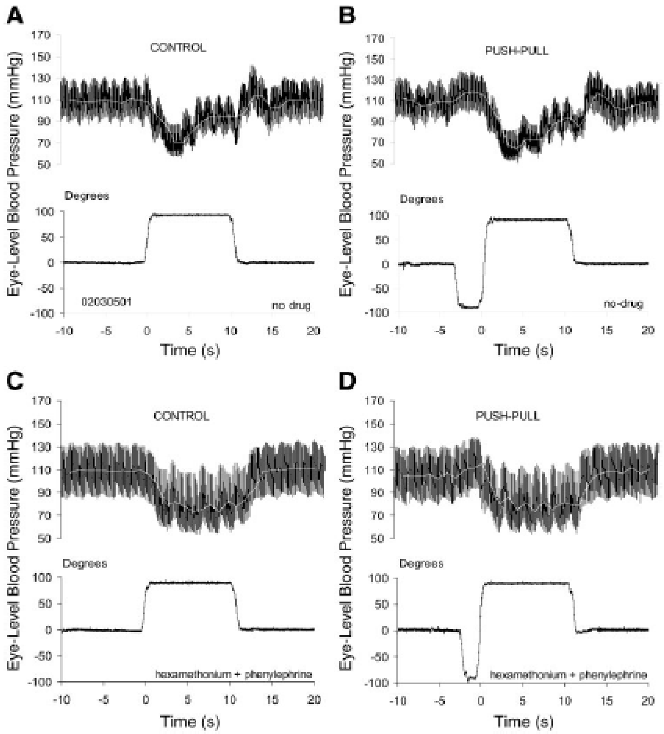

Fig. 3. Response of eye-level blood pressure to intact control $+G_z$ gravitational stress (*A*), intact push-pull gravitational stress (*B*), control $+G_z$ gravitational stress during phenylephrine infusion after hexamethonium (*C*), and push-pull gravitational stress during phenylephrine infusion after hexamethonium (*D*). *Top traces* depict eye-level blood pressure, and *bottom traces* depict tilt angle.

Hakeman, Amy L., and Don D. Sheriff. "Role of the autonomic nervous system in push-pull gravitational stress in anesthetized rats." *Journal of Applied Physiology* 94, no. 2 (2003): 709-715.

Role of Autonomic Nervous System in Push-Pull Gravitational Stress in Anesthetized Rats Results

- The push-pull effect is abolished when autonomic ganglionic neurotransmission is inhibited.
- Substantially lowering or raising baseline arterial blood pressure also abolished the push-pull effect, probably by disrupting baroreflex function .

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- CONCLUSION: Intact autonomic function and a normal baseline arterial pressure are needed for expression of the push-pull effect in anesthetized rats subject to tilting.

Hakeman, Amy L., and Don D. Sheriff. "Role of the autonomic nervous system in push-pull gravitational stress in anesthetized rats." *Journal of Applied Physiology* 94, no. 2 (2003): 709-715.

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Hypotensive Effect of Push-Pull Gravitational Stress Occurs after Autonomic Blockade Study

The purpose of this study was to test the hypothesis that non-autonomic mechanisms can cause a push-pull effect, by using eye-level blood pressure as a measure of G tolerance.

Sheriff, Don D. "Hypotensive effect of push-pull gravitational stress occurs after autonomic blockade." *Journal of Applied Physiology* 95, no. 1 (2003): 167-171.

Hypotensive Effect of Push-Pull Gravitational Stress Occurs after Autonomic Blockade Study

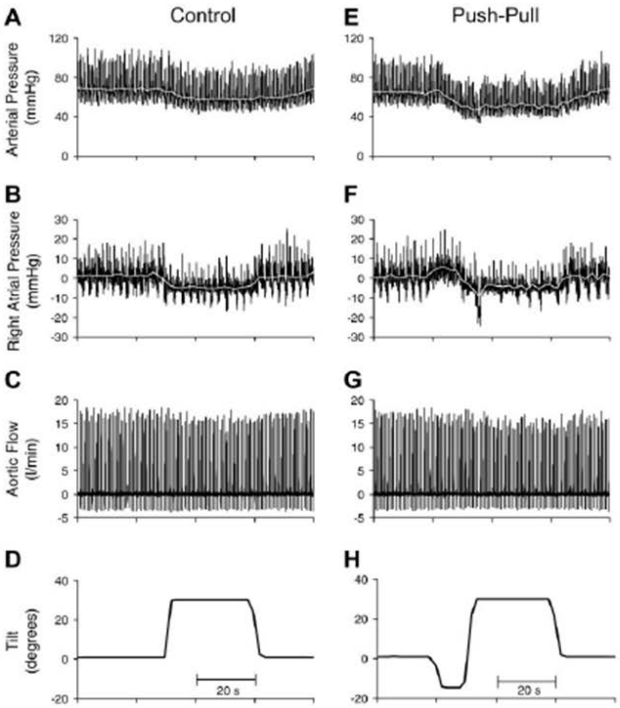
NONAUTONOMIC PUSH-PULL EFFECT 169

Fig. 2. Cardiovascular responses to control and push-pull gravitational stress in a conscious dog. *A–D*: responses to 30 s of 30° head-up gravitational stress (control). *E–H*: responses to 30 s of 30° head-up tilt gravitational stress immediately preceded by 10 s of −15° head-down tilt (push-pull). Head-down tilt raises arterial and right atrial pressures. Head-up tilt decreases arterial and right atrial pressures and aortic flow. Heart-level arterial pressure falls further during push-pull head up tilt (*E*) than during control head-up tilt (*A*). White lines in *A*, *B*, *E*, and *F* depict mean values. Data are from a sedated, atrioventricular-blocked dog paced at 75 beats/min after autonomic blockade with hexamethonium.

Sheriff, Don D. "Hypotensive effect of push-pull gravitational stress occurs after autonomic blockade." *Journal of Applied Physiology* 95, no. 1 (2003): 167-171.

Hypotensive Effect of Push-Pull Gravitational Stress Occurs after Autonomic Blockade Results

- A push-pull effect attributable to peripheral vascular factors occurs in conscious dogs after autonomic blockade.
- In addition to the autonomic factors, the non-autonomic factors appear to contribute importantly to the push-pull effect in relatively large species such as dogs and humans.

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- In addition to the autonomic factors, the non-autonomic factors appear to contribute importantly to the push-pull effect in relatively large species such as dogs and humans.

- CONCLUSION: A push-pull effect attributable to at total rise in vascular conductance occurs when autonomic function is inhibited.

Sheriff, Don D. "Hypotensive effect of push-pull gravitational stress occurs after autonomic blockade." *Journal of Applied Physiology* 95, no. 1 (2003): 167-171.

Enhanced Parasympathetic Tone Signal Cascade

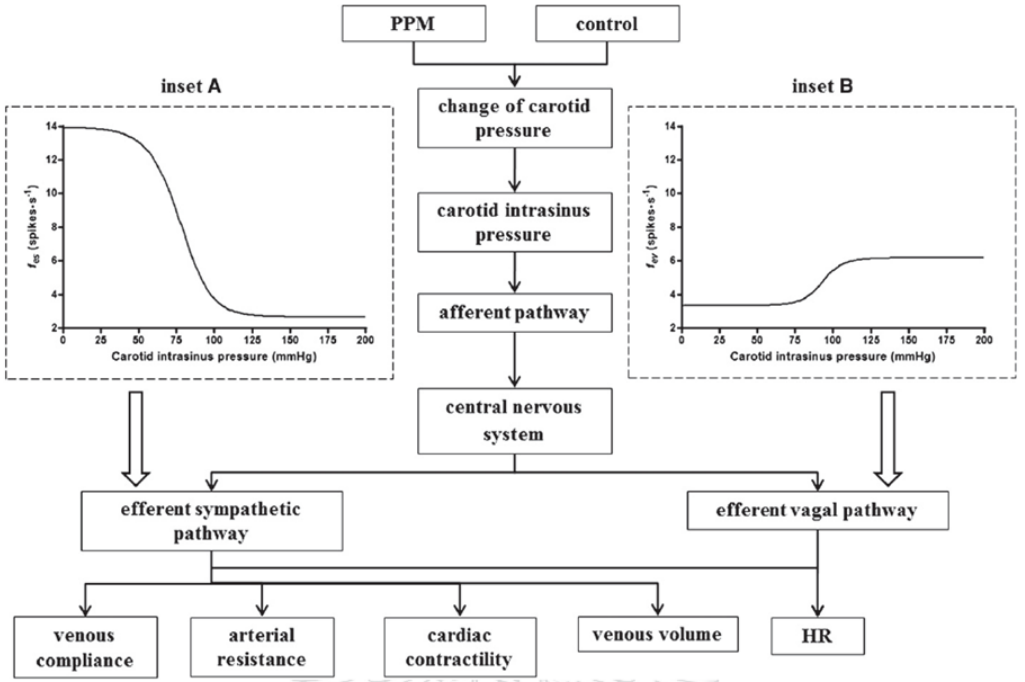

Fig. 1. Block diagram of the submodel of the carotid baroreflex. Inset A) relationship between carotid intrasinus pressure and sympathetic efferent activity; inset B) relationship between carotid intrasinus pressure and vagal efferent activity.

Liu, Yang, Li-Fan Zhang, Kang-Li Zhang, and Hong-Bing Lu. "Role of carotid baroreflex and sympathetic responses in the push-pull effect: a simulation study." *Aviation, space, and environmental medicine* 83, no. 9 (2012): 841-849.

Tachycardic Heart Rate @ +6G Centrifuge

Centrifuge Training. Performed by Jeffrey Woolford. United States: 711th Human Performance Wing, Brooks Air Force Base, Texas, 2005. VHS.

“Bunt Bradycardia” Study Discussion

Increased parasympathetic nervous-system activity results in bradycardia, peripheral vasodilation and decreased cardiac contractility. Because the demands of +G stress require increased cardiac output through increased heartrate and stroke volume, as well as increased vasoconstriction, a pilot may be physiologically biased against full +G acceleration tolerance following –G stress.

Banks, Robert D., and Gary Gray. "" Bunt bradycardia": two cases of slowing of heart rate inflight during negative Gz." *Aviation, space, and environmental medicine* 65, no. 4 (1994): 330-331.

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$$CO = SV \bullet HR$$

∴ HR must ↑ to meet demand …

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HR Effect of MAP

$$MAP \simeq DP + 0.01 \times \exp(4.14 - 40.74/HR)(SP - DP)$$

$\therefore$ When HR↑ then MAP↓

Moran, Daniel, Yoram Epstein, Gad Keren, Arie Laor, Jack Sherez, and Yair Shapiro. "Calculation of mean arterial pressure during exercise as a function of heart rate." *Applied Human Science* 14, no. 6 (1995): 293-295.

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$$CPP = MAP - ICP$$

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∴ When CPP↓ = **G-LOC Risk**↑

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Current Preventive Measures

- Understanding the Push-Pull Risk
  - "Bunt Bradycardia"

- Properly fit Aircrew Flight Equipment (ATAGS)

- Precisely-timed Anti-G Straining Maneuver (AGSM)
  - "Hot Mic"
  - Critical HUD tape review

- Avoid food, drinks, medications, and/or supplement that increase heart rate or lower mean arterial pressure.

Future Preventive Measures

"The effects of physical conditioning on G-tolerance are not well established [and] it may be difficult to suggest to aircrew that convincing data exist to support the notion that any specific exercise program is known to favorably influence any element of their G-tolerance."

Bateman, William A., Ira Jacobs, and Fred Buick. "Physical conditioning to enhance+ Gz tolerance: issues and current understanding." *Aviation, space, and environmental medicine* 77, no. 6 (2006): 573-580.

Royal Air Force Push-Pull Training Maneuver

Starting at 400 KIAS at 10K AGL, roll to 100° AOB (left or right) and perform an outside turn holding -1.0G for 5 seconds duration, followed by an immediate transition to +7G sliceback in the same plane at a rate of +10G per second, holding the targeted +7.0G until symptoms become apparent to the student, signs are obvious to the instructor, or 15 seconds elapse, whichever occurs first. Repeat as necessary to achieve parameters routinely experienced during mission.

Photo Credit: David Turnbull / Release Authorization: Kevin Taylor

Future Preventive Measures

- PPM Centrifuge Profiles
- “Predictive” G-suit
- “Integrated” G-Suit

BRADYCARDIA DURING NEGATIVE-Gz—BANKS

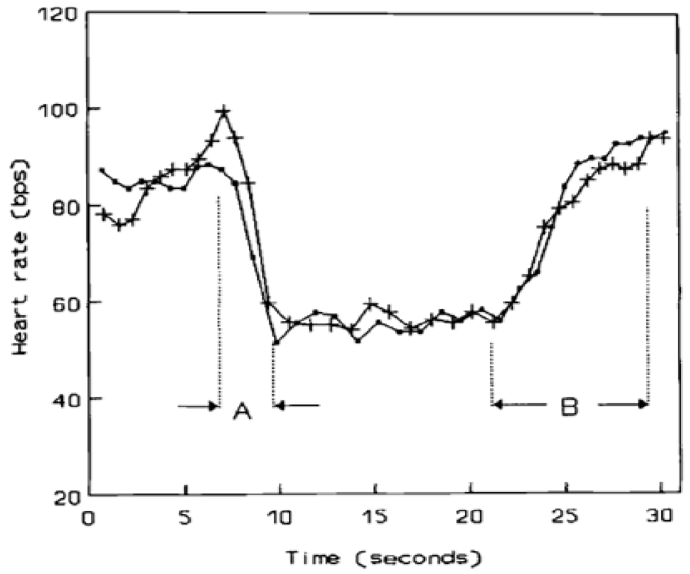

Fig. 1. Heart rate vs. time during 15 s at −1 Gz for two pilots: (•) Pilot one; (+) Pilot two. “A” denotes the approximate time interval of cardio-deceleration. “B” denotes cardio-acceleration on return to +1 Gz.

Banks, Robert D., and Gary Gray. "" Bunt bradycardia": two cases of slowing of heart rate inflight during negative Gz." *Aviation, space, and environmental medicine* 65, no. 4 (1994): 330-331.

Summary

- Introduction
- Public Release Information
- Anatomy
- Medical Formulas
- Push-Pull Effect Studies
- Current Preventive Measures
- Future Preventive Measures
- Questions?

Photo Credit: Ryan Brown / Release Authorization: Kevin Taylor

Questions?

Photo Credit: Ryan Brown / Release Authorization: Kevin Taylor