NECK INJURY CRITERIA DEVELOPMENT FOR USE IN SYSTEM LEVEL EJECTION TESTING; CHARACTERIZATION OF ATD TO HUMAN RESPONSE CORRELATION UNDER GY ACCELERATIVE INPUT

Stephen J. Satava II, Jeffrey C. Parr, Michael E. Miller, and Chris Perry

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Introduction

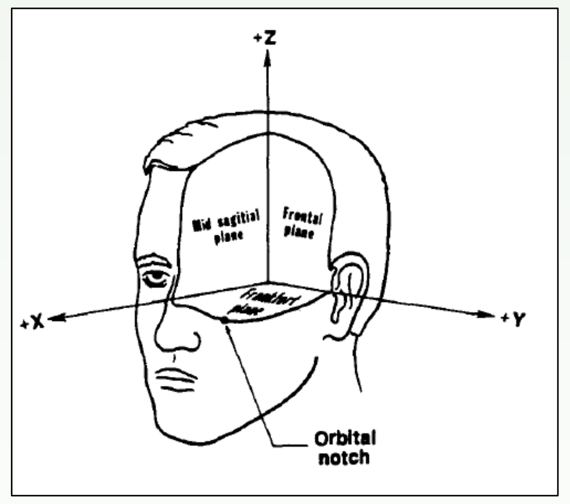
Increased injury risk during ejection due to the increasing mass of modern Helmet Mounted Displays (HMDs) drove Parr et al. to define new neck injury criteria that would reduce subjective interpretation of ejection system test results and provide early input to HMD and escape system design [1, 2, 3]. As a direct result of the work done by Parr et al., the Multi Axial Neck Injury Criteria (MANIC) Gx, Gy, and Gz calculations and limits were developed and adopted by MIL-HDBK-516 to define neck safety criteria for new and modified USAF aircraft ejection systems. The associated MANIC(Gx, Gy, Gz) human risk curves provide clear guidance for implementation of MANIC responses with the Air Force Life Cycle Management Center's (AFLCMC) requirement for ejection systems to maintain risk of Abbreviated Injury Scale (AIS) 2+ injury below 5% [3].

Extensive costs and safety limitations associated with human and Post Mortem Human Subject (PMHS) testing drives the use Anthropomorphic Test Devices (ATDs). Although biofidelity is sought, differences remain in the human and ATD neck responses during Gx, Gy, and Gz acceleration [4, 5, 6]. These differences necessitate a transfer function between human and ATD MANIC responses to allow ATD testing to more precisely influence early system evaluation and comparison to AFLCMC risk requirements.

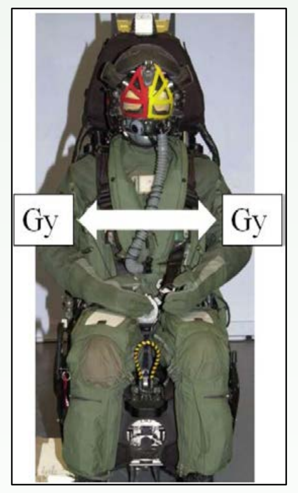
The MANIC structure provides a unit-less, quantitative criteria for ejection system evaluation utilizing the six primary neck loads (Fx, Fy, Fz, Mx, My, and Mz) and critical values (Fxcrit, Fycrit, Fzcrit, Mxcrit, Mycrit, Mzcrit) [3]. Limitations in available upper neck response and injury data forced Parr to truncate the MANIC equation in each acceleration axis [1, 2, 3]. The Six Factor (SF) MANIC(Gy) equation is simply the full MANIC (without truncation) applied to Gy acceleration responses.

$$MANIC(Gy) = \sqrt{\left(\frac{Fx}{Fxcrit}\right)^2 + \left(\frac{Fy}{Fycrit}\right)^2 + \left(\frac{Fz}{Fzcrit}\right)^2 + \left(\frac{My}{Mycrit}\right)^2 + \left(\frac{Mz}{Mzcrit}\right)^2} \quad [3]$$

$$SF\ MANIC(Gy) = \sqrt{\left(\frac{Fx}{Fxcrit}\right)^2 + \left(\frac{Fy}{Fycrit}\right)^2 + \left(\frac{Fz}{Fzcrit}\right)^2 + \left(\frac{Mx}{Mxcrit}\right)^2 + \left(\frac{My}{Mycrit}\right)^2 + \left(\frac{Mz}{Mzcrit}\right)^2}$$



Anatomical Coordinate System [7]

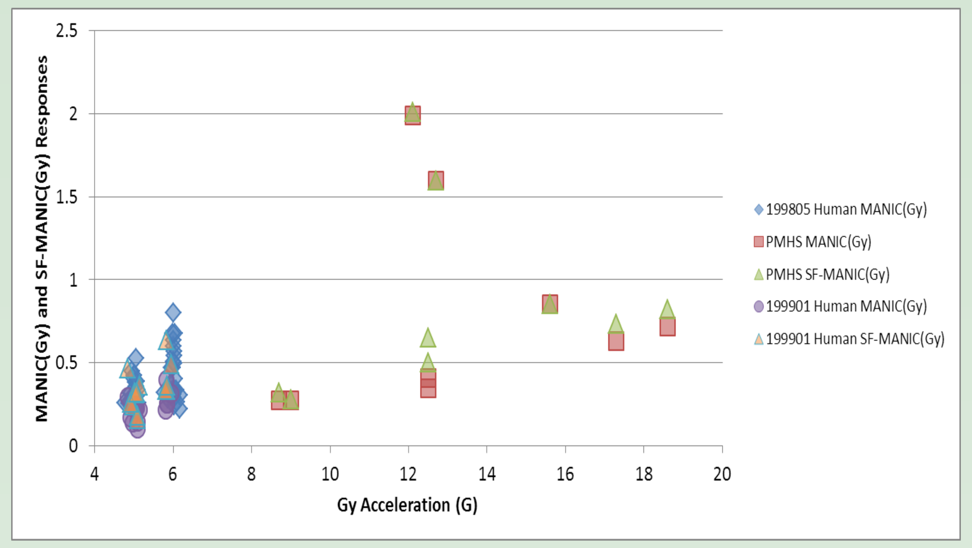


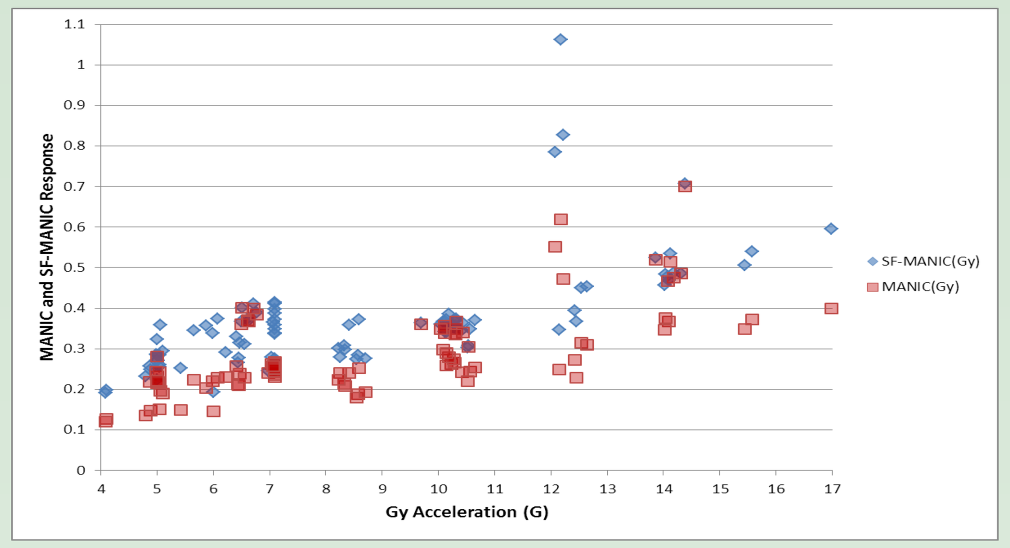
Gy Acceleration Axis [1]

Objectives

- Determine appropriate MANIC(Gy) response for ATDs
  - Is Mx (side bending) significant in the ATD neck response
  - Is Six Factor (SF) MANIC required for ATD evaluation
- Quantify delta between ATD and human MANIC(Gy) response
- Define MANIC(Gy) transfer function
  - Develop injury criteria that is appropriate for ATD testing

MANIC(Gy) Calculation and Mx Significance





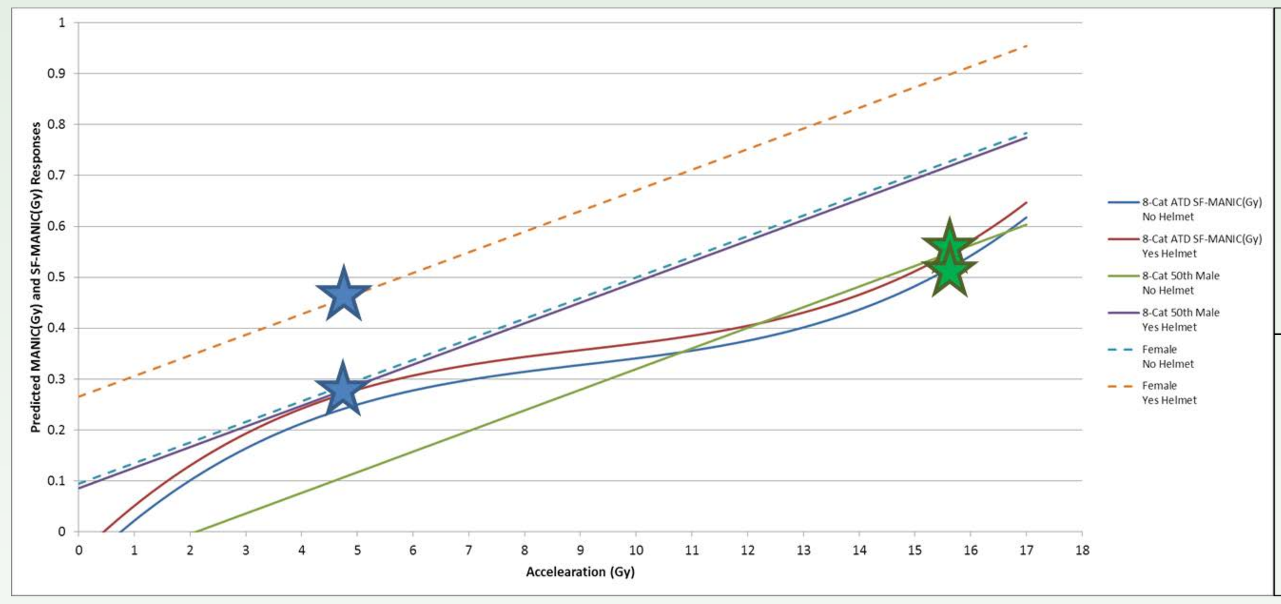
Start 0ms (a)	Peak Gy 73ms (b)	Peak MANIC(Gy) 135ms (c)

Start 0ms (a)	Peak Gy 36ms (b)	Peak MANIC(Gy) 98ms (c)	Peak SF-MANIC(Gy) 105ms (d)

Calculated human and ATD MANIC(Gy) responses for the six studies under investigation (Air Force Biodynamics Data Base study 201610, 199101, 199805, 199801, 199501, and FAA study 2011) are summarized in the adjacent graphs.

Mx (side bending) significance in the ATD SF MANIC(Gy) response was confirmed through the t-test (p <0.0001), and is apparent in the adjacent slow motion video captures. The primary neck responses to Gy acceleration are observed as Mx for ATDs and combined Mz/My for humans. Thus the MANIC(Gy) calculation is appropriate for humans (excludes Mx) and the SF MANIC(Gy) is appropriate for ATDs.

Multiple Regression Model Results and Human To ATD Transfer



Multiple Regression Predicted MANIC(Gy) Responses

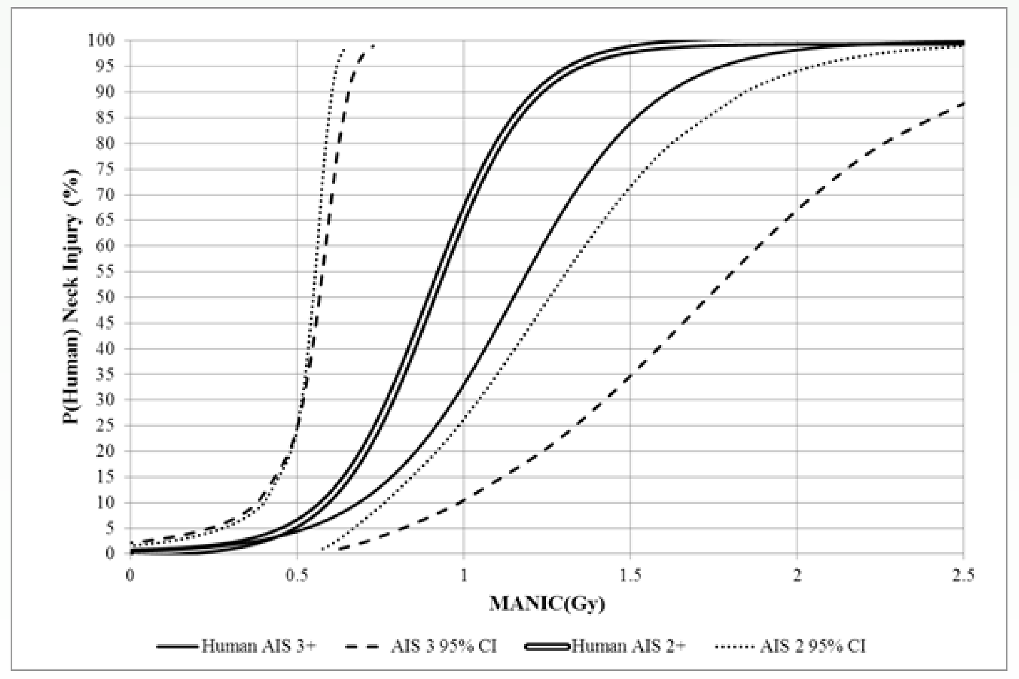
Model	Equation
MR 8-Cat ATD SF-MANIC(Gy)	$0.223043 + (Peak\ G * 0.013273) - ([Peak\ G - 8.48851]^2 * 0.000709) + ([Peak\ G - 8.48851]^3 * 0.000381) + \left(Match[Helmet\ Y/N]\begin{Bmatrix} N = -0.014602 \\ Y = 0.014602 \end{Bmatrix}\right)$
MR (RTO) 8-Cat 50th Male MANIC(Gy)	$(Peak\ G * 0.040524) + \left(Match[Helmet\ 'Y/N']\begin{Bmatrix} N = -0.085506 \\ Y = 0.085506 \end{Bmatrix}\right) + \left(Match[Subject\ Type]\begin{Bmatrix} F = 0.18 \\ M = 0 \end{Bmatrix}\right)$

Multiple Regression Model Equations

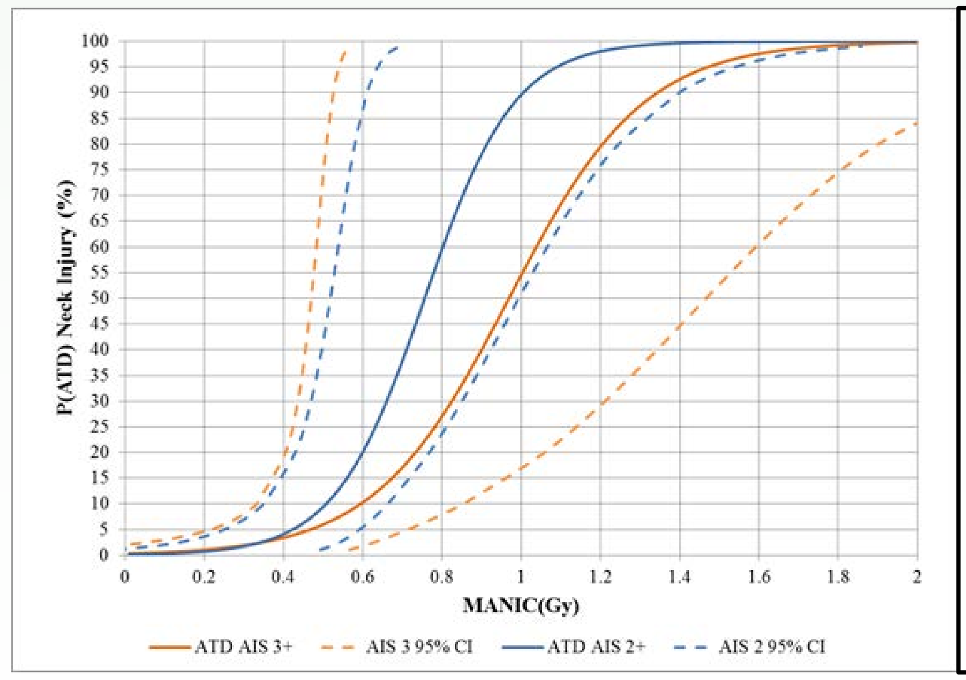
Multiple regression characterized the human MANIC(Gy) and ATD SF MANIC(Gy) responses across the six studies under investigation.

Significant factors for ATDs are G^3 and helmet wear (Y/N). The third order response of the Hybrid III ATD neck to lateral loading was also apparent during bench testing [8]. Significant factors for humans are G, Helmet (Y/N), and subject type (M/F). Test points with studentized residuals above three were excluded from the models as outliers.

ATD Survival Analysis for Converted Data



Human Survival Analysis Risk Curves



ATD Survival Analysis Risk Curves

$$P(\text{Human AIS}\geq 2) = \frac{1}{1+e^{\frac{0.9024-MANIC(Gy)}{0.1459}}}$$

$$P(\text{ATD AIS}\geq 2) = \frac{1}{1+e^{\frac{0.9024-MANIC(Gy)}{0.1459}}}$$

AIS 2+ Survival Analysis Equations

Using the regression model predicted values at instantaneous peak G, human MANIC(Gy) responses were converted to equivalent ATD SF MANIC(Gy) response. The resulting ATD equivalent responses were then associated with the AIS value from their human counterpart. This enabled parametric survival analysis using the transformed ATD results to produce the ATD risk curves shown above. The human risk curves shown above the same as those presented by Parr et al [3].

Conclusions

This research developed a MANIC(Gy) transfer function to make MIL-HDBK-516 criteria applicable to cost effective ATD escape system testing in the Gy acceleration axis. Statistical analysis of the six primary neck loads for ATDs revealed Mx (side bending) response significance through the t-test (p <0.0001). This result necessitated adjustment to the human MANIC(Gy) calculation developed by Parr et al. before applying it to ATDs [3]. Multiple regression of ATD SF MANIC(Gy) and human MANIC(Gy) produced models for quantifying differences in human and ATD responses across the applicable Gy acceleration range. The resulting deltas at instantaneous peak Gs between the regression models defined the transfer function between ATD and human responses. Parametric survival analysis for transformed ATD MANIC(Gy) responses produced ATD injury risk curves for AIS 2+ injury. This method reveals 5% of AIS 2+ neck injury during Gy accelerations correspond to a MANIC(Gy) of 0.473 (95% CI 0.28,0.67) for humans and 0.423 (95% CI 0.25, 0.359) for ATDs.

Differences in ATD and human MANIC(Gy) responses necessitate use of the ATD risk curves with ATD testing and human risk curves with human subjects to ensure accurate risk evaluation in accordance with MIL-HDBK-516.

References

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Disclosure Information

I have no financial relationships to disclose.

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

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AUTHORS (FIRST NAME INITIAL LAST NAME): S. J. Satava[1], J. Parr[1], M. E. Miller[1], C. E. Perry[2]
INSTITUTIONS (ALL):
1. Systems Engineering and Management, Air Force Institute of Technology, Xenia, OH, United States.
2. Biodynamics Branch, 711 Human Performance Wing, Wright Patterson Air Force Base, OH, United States.
Abstract Body: INTRODUCTION: Modern Helmet Mounted Displays (HMD) provide pilots with night vision, weapons cuing, onboard systems management, and many other enhancements to operational capability. These additional HMD capabilities are essential in today’s advanced military operating environment, but come at the cost of higher head supported mass. Increasing HMD mass combined with expanding pilot mass ranges increases the risk for neck injuries during ejection.

METHODS: Existing neck load data from military and university experiments with anthropomorphic test devices (ATDs), post mortem human subjects (PMHS), and human subjects subjected to Gy acceleration were used to compute a peak multi-axial neck injury criteria (MANIC) Gy. Linear regression models of the MANIC-Gy to peak acceleration relationship were developed for the both the combined human/PMHS data and the ATD data.

RESULTS: Comparison of the linear regression models of the Human/PMHS and ATD responses indicates that the Human predicted response is consistently higher than the ATD. The peak expected value of the MANIC(Gy) at 16Gs for ATD response was 0.6 and for Human/PMHS response was 1.05. 16Gs is approximately the highest predicted Gy acceleration a pilot could experience in a typical ejection environment.

DISCUSSION: The transfer function developed in the research and associated MANIC(Gy) risk functions provide a foundation for evaluating military escape system testing in the Gy plane of motion. Additionally, stochastic analysis in this work served to validated research by Zinck et al. (2015) who developed a transfer function in the Gx plane. Together the Zinck et al. (2015) and the current work has set the foundation for a final analysis of the Gz plane in future research. These transfer functions make previously developed human-centric neck injury criterion (Parr, 2014) directly applicable to dynamic testing with ATDs as part of the developmental and operational testing of escape systems. Collectively, this research is expected contribute to a complete set of multi-axial neck injury criteria that can be applied to ATD testing to predict human neck injury risk in any domain where head supported mass is required in high acceleration environments.