2012 Occupant Protection Risk Standing Review Panel

Evidence Review for: *The Risk of Injury from Dynamic Loads*

Final Report

I. Executive Summary and Overall Evaluation

The 2012 Occupant Protection (OP) Risk Standing Review Panel (from here on referred to as the SRP) met for a site visit in Houston, TX on November 8 - 9, 2012. The SRP reviewed the new Evidence Report for the Risk of Injury from Dynamic Loads (from here on referred to as the 2012 OP Evidence Report), as well as the Research Plan for this Risk that is in the Human Research Program's (HRP) Integrated Research Plan (IRP Rev. D).

Overall, the SRP thinks the well-qualified research team has compiled an excellent summary of background information in the 2012 OP Risk Evidence Report.

II. Review of the Evidence for the Risk of Injury from Dynamic Loads

1. Evaluate the 2012 OP Evidence Report using the following criteria:

A. Does the 2012 OP Evidence Report provide sufficient evidence that the Risk is relevant to long-term space missions?

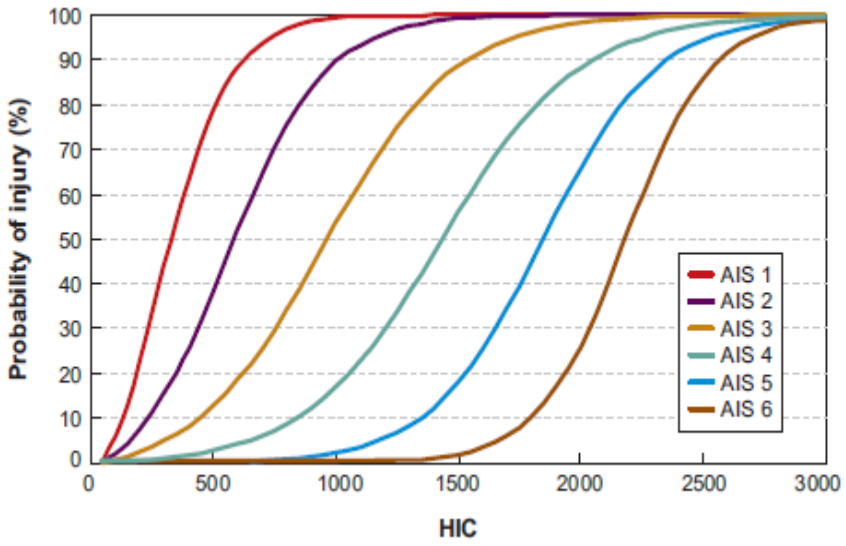
In general, yes, the SRP thinks that the 2012 OP Evidence Report provides enough evidence that the OP Risk is relevant to long-term space missions. There are several specific times during space missions, including take-off; docking, re-entry, and landing that were identified as relevant operational periods where occupant protection measures should be put into practice. Occupant protection is dependent on occupant tolerance to potentially injurious scenarios. There was strong evidence provided that astronauts experience bone loss during prolonged spaceflight. With bone loss comes decreased strength and tolerance to impact and therefore, as mission duration increases, the occupant protection risk from dynamic loads will increase.

There are a few considerations that the authors should incorporate to further the evidence for occupant protection measures. The authors should reference the current federal motor vehicle safety standards that include several standard tests to expose the dummy occupants to different crash directions. This reference would provide evidence that perhaps one type of evaluation will not address all the concerns for occupant protection during a space mission. As such, it is suggested to expand Table 3.1 on page 12 of the 2012 OP Evidence Report to include front, side, and rear data. The report should also include a specific discussion about how human body tolerance changes as a function of acceleration direction. It may be useful to data mine the old Naval Biodynamics Laboratory data that was collected in the 1960's and 1970's; this is currently in the possession of Wright Patterson Air Force Base and US Army

Base Fort Rucker. There are many tests that were run at low levels in different directions (vertical and horizontal) on human volunteers that may provide insight. The discussion centered around more severe trauma (The Abbreviate Injury Scale (AIS) =3+) because that was what was developed for the automotive environment; a greater emphasis on moderate and lower-severity level injuries is desirable. Lower severity injuries may result in astronauts being unable to egress and, or exit the vehicle, whereas for automotive type injuries, these lower level <AIS 3 injuries are not of serious concern. For example, things like a broken leg preventing the astronaut from exiting a vehicle.

Regarding low severity injuries, the 2012 OP Evidence Report could be improved by adding details of the risk for low severity injuries including concussions and soft tissue strains. As addressed on page 4 in Section II. 1. I below, sports-related concussion research should be referenced and discussed: Pellman EJ, Viano DC, et al. "Concussion in Professional Football: Summary of the Research Conducted by the National Football League's Committee on Mild Traumatic Brain Injury." Neurosurg Focus, 2006; 21(4).

The SRP also thinks it would be good to include a set of injury risk curves showing the probability of injury for different AIS values. The following figure was taken from Hayes WC, Erickson MS, and Power ED. "Forensic Injury Biomechanics." Annu Rev Biomed Eng, vol. 9, pp. 55-86, 2007.



Lastly, the SRP thinks that Figure 3-21 on page 25of the 2012 OP Evidence report should be improved. The change in L1-S1 angle is not adequately illustrated. The pre-bed rest image includes lines drawn through the superior endplates of L1 and S1 while the post-bed rest image includes horizontal lines which do not seem to be aligned with any anatomical structures.

B. Is the risk properly stated in the HRP Program Requirements Document?

The SRP suggests rewording the Risk Statement with an expanded definition that includes examples: "Given the range (e.g., magnitude, direction, and duration) of anticipated dynamic loads…" There should also be wording added to the Risk and Risk Statement about possible events that could occur during flight such as docking with another entity or impacts with other objects. It seemed to the SRP that there were other potential risks of occupant injury during the flight portion of the mission – not just on take-off and landing. Indeed, the current desire by NASA standard-3001 is that crewmembers be protected during all "dynamic mission phases".

C. Is the text of the short description of the Risk provided in the HRP PRD clear?

The SRP thinks it was not entirely clear that the description implied an inclusion of off nominal phases of landing such as potential of crew injury with off nominal chute opening (a 500 ms event) that might need to be addressed. Also, the last sentence in the context section on page 24 of the PRD should be in quotes if it is from a report. The SRP suggests deleting the part of the sentence "and should incorporate conformal helmets and neck restraint design similar to those used in professional auto racing" as it refers to a specific intervention that may not always be appropriate.

D. Does the evidence make the case for the knowledge-type gaps presented?

Yes, but the SRP suggests expanding the wording of some of the knowledge-type gaps presented:

- OP1: Quantification of the risk of injury due to vehicle orientations and complex dynamics including multiple collision events transmitted to the occupant.
- OP3: Quantification of the risk of injury related to gender, age, anthropometry, pre-existing degenerative musculoskeletal conditions, and prior history of musculoskeletal injuries.
  - NASA should consider using the scientific term "sex differences" instead of gender.
- OP5: This should be split into two knowledge-type gaps as follows:
  - Determination of criteria for low risk of high-severity injury (<5%). The current injury risk curves for higher-severity injuries are all being used at the 15-50% risk levels. If NASA wants to ensure very low injury risk (<5%) for even these higher-severity injuries, the SRP thinks that additional effort needs to be made to ensure that at the lower-risk levels the curves are still valid. Alternate statistical techniques may be necessary to derive the appropriate risk curves (even using existing data).
  - Not enough knowledge to determine the risk of low-severity injury (e.g., clavicle injuries and concussions).
- OP6: Adequate assessment methods (e.g., models, dummies, human surrogates) validated for the spaceflight environment.

E. Are there any additional knowledge-type gaps in knowledge that should be considered for this specific Risk?

Comments included above in Section II. 1. D.

F. Does the Evidence Report address relevant interactions between this Risk and others in the HRP PRD/IRP (Integrated Research Plan, Rev. D)?

The SRP was pleased with the interaction between the OP discipline and the bone discipline, specifically pertaining to occupant deconditioning and its effect on strength and tolerance to dynamic loads. Toward this end, the SRP thought that spine bone strength data is important and should be included in as a discussion in the 2012 OP Evidence report (hip data is reported).

The SRP encourages the OP discipline to look at other disciplines for relevant interactions. The SRP thought specifically of space human factors engineering to design safe interiors to minimize limb flail injuries during dynamic phases of flight, but there may be other interactions as well.

G. Are the qualifications of the author(s) appropriate for identifying the evidence necessary to characterize the given Risk?

Yes, the SRP thinks the team is very knowledgeable and has enough team members of different disciplines and backgrounds to make assessments. The SRP thinks that the team is very strong in engineering and basic science. The team may be further strengthened by adding or consulting with a flight surgeon.

H. Is there information from other disciplines that need to be included in the Evidence Report?

The SRP encourages the OP discipline to examine other disciplines for information that may influence human tolerance to injury and should be included in their Evidence Report such as:

- Endocrine literature for hormonal changes and their effects on tolerance to injury.
- Quantification of bone mineral density vs. bone strength.
  - A plot from the literature of spine strength vs. bone mineral density should be included.
- Literature pertaining to the effects of muscle bracing on injury risk during dynamic loading. Several groups (e.g., Gunter Siegmund at MEA Forensic Engineers & Scientists) have studied these effects during low-energy rear impacts.

I. Is the breadth of the cited literature sufficient?

In general, the authors have cited a comprehensive literature. The SRP thinks additional reference material would help to improve certain areas. Some suggestions are provided. The authors might refer to the National Automotive Sampling System (NASS-CDS) data reports called "Traffic Safety Facts" which has data on injuries in different crash modes and, or directions (found at: http://www.nhtsa.gov/NCSA) and injury epidemiology from fast boat operators (Ensign W, Hodgdon JA, Prusaczyk WK, Shapiro D, and Lipton M. "A survey of self-reported injuries amoung special boat operators." Naval Health Research Center, NHRC

Report No. 00-48, San Diego, 2000.). The series of medical articles published on low severity head injuries (concussions) from National Football League data (referenced on page 2 in section II. 1. A). There was some head-to-torso kinematic data presented by Philippens in the 2004 International Research Council on the Biomechanics of Impact (IRCOBI) conference on frontal oblique impacts that might help to explain the differences with different directions of impact.

J. What is the overall quality and readability of the Evidence Report?

In general, the SRP thought the 2012 OP Evidence Report was well written, organized, and illustrated and served its purpose well.

2. Provide comments on any important issues that are not covered by the criteria in #1 above.

It was surprising that the modeling data presented did not include more actual acceleration traces from either the vehicle frame or seat structures. Example of gravitational loads in an experimental setting would also be beneficial. Apparently some simulated water landings were conducted at a large facility; the collected data would help to define the potential loads that the cabin is experiencing. It would be very helpful to have seen some examples of acceleration traces in particular orientations to bound the problem a little more clearly. The SRP suggests at least adding the figure from page 16 (Orion Peak Crew Accelerations (Abort and Landing)) of the OP Evidence presentation to the 2012 OP Evidence Report.

Seat acceleration time-history responses that were provided during a previous non-advocate review of the project application entitled "Occupant Protection Data Mining and Modeling Project" may be added to the 2012 OP Evidence Report.

IV. 2012 Occupant Protection Risk SRP Evidence Review: Statement of Task for the Risk of Injury from Dynamic Loads

The 2012 Occupant Protection (OP) Risk Standing Review Panel (SRP) is chartered by the Human Research Program (HRP) Chief Scientist to review the evidence base for the Risk of Injury from Dynamic Loads. The 2012 OP Risk SRP will generate a report of their analyses of the OP Evidence Report, including any recommendations on how to improve the OP Evidence Report, and submit it to the HRP Chief Scientist.

In 2008, the Institute of Medicine reviewed NASA's Human Research Program evidence in assessing the Risks identified in NASA's Human Research Program Requirements Document (PRD). The 2012 evidence for the Risk of Injury from Dynamic Loads was not reviewed by the IOM in 2008.

The 2012 OP Risk SRP is charged to:

1. Evaluate the 2012 OP Evidence Report based on each of the following criteria:
   A. Does the Evidence Report provide sufficient evidence that the Risk is relevant to long-term space missions?
   B. Is the Risk properly stated in the HRP Program Requirements Document (PRD)?
   C. Is the text of the short description of the Risk provided in the HRP PRD clear?
   D. Does the evidence make the case for the knowledge-type gaps presented?
   E. Are there any additional knowledge-type gaps in knowledge that should be considered for this specific Risk?
   F. Does the Evidence Report address relevant interactions between this Risk and others in the HRP PRD/IRP (Integrated Research Plan, Rev. D)?
   G. Are the qualifications of the author(s) appropriate for identifying the evidence necessary to characterize the given Risk?
   H. Is there information from other disciplines that need to be included in the Evidence Report?
   I. Is the breadth of the cited literature sufficient?
   J. What is the overall quality and readability of the Evidence Report?

2. Provide comments on any important issues that are not covered by the criteria in #1 above.

Additional information regarding this review:

1. After the 2012 OP Risk SRP members have received the review materials and had the opportunity to look over the documents, the panel members will participate in a conference call to discuss any issues, concerns, and expectations of the review process to start the review prior to the meeting.
   A. Discuss the 2012 OP Risk SRP Statement of Task and address questions about the SRP process.
   B. Identify any issues the 2012 OP Risk SRP would like to have answered prior to or during the meeting.

2. Attend a meeting at NASA JSC on November 8 - 9, 2012 to discuss the Evidence Reports with the Human Health Countermeasures (HHC) Element. At this meeting, prepare a draft report that addresses each of the evaluation criteria listed in the panel charge (A-J) including any recommendations on how to improve the Evidence Reports. Debrief the HRP Chief Scientist and a representative from the HHC Element on the salient points that will be included in the final report and specifically the items in the panel charge.

3. Prepare a draft final report (within one month of the site visit debrief) that contains a detailed evaluation of the OP Evidence Report specifically addressing items #1 and #2 of the SRP charge. The draft final report will be sent to the HRP Chief Scientist and he will forward it to the appropriate Element for their review. The HHC Element and the HRP Chief Scientist will have 10 business days to review the draft final report and identify any misunderstandings or errors of fact and then provide official feedback to the SRP. The SRP will have 10 business days to address any issues and finalize the 2012 SRP Final Report. The 2012 SRP Final Report will be submitted to the HRP Chief Scientist and copies will be provided to the HHC Element that sponsors the OP discipline and also made available to the other HRP Elements. The 2012 SRP Final Report will be made available on the Human Research Roadmap public website (http://humanresearchroadmap.nasa.gov/).

V. Occupant Protection Risk Standing Review Panel Roster

Panel Chair:

Frank Pintar, Ph.D.
Medical College of Wisconsin
VA Medical Center
Department of Neurosurgery
Neuroscience Research Labs- Research Mail Stop 151
5000 W. National Avenue
Milwaukee, WI 53295
Phone: 414-384-2000
Email: fpintar@mcw.edu

Panel Members:

Paul Ivancic, Ph.D.
Yale University School of Medicine
Department of Orthopaedics & Rehabilitation
200 South Frontage Road
New Haven, CT 06510
Phone: 203-785-4052
Email: paul.ivancic@yale.edu

Michael Kleinberger, Ph.D.
Johns Hopkins University Applied Physics Laboratory
Research and Exploratory Development Department
11100 Johns Hopkins Road
Laurel, MD 20723
Phone: 443-778-7289
Email: michael.kleinberger@jhuapl.edu

Daniel Nicolella, Ph.D.
Southwest Research Institute
Musculoskeletal Biomechanics Section
6220 Culebra Road
San Antonio, TX 78238
Phone: 210-522-3222
Email: daniel.nicolella@swri.org