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Measurement of Accelerations Experienced by Rough Stock Riders: A Model for Examining Acceleration-Induced Head Injuries in Astronauts

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Measurement of Accelerations Experienced by Rough Stock Riders: A Model for Examining Acceleration-Induced Head Injuries in Astronauts

by

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Capstone

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Dedication

For my wife, Rachel, and for the men and women of rodeo.

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Special thanks to www.maltzphotography.com for taking spectacular photos at the 2009 Houston Livestock Show & Rodeo.

Measurement of Accelerations Experienced by Rough Stock Riders: A Model for Examining Acceleration-Induced Head Injuries in Astronauts

Publication No._____________

Charles Hood Mathers, M.D., M.P.H.
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Head injuries result in significant morbidity in rough stock rodeo events. Concussions are the most common injury sustained by rough stock riders, representing 50% of all major injuries. A pilot study conducted in 2007 examined head acceleration experienced by two rough stock riders. Ear-mounted tri-axial accelerometers showed a maximum of 26 G experienced by the bull rider, while the bareback rider experienced 46 G. An aim of the current study was to expand upon this pilot study by examining head acceleration experienced by 10 bull riders and 10 bareback riders during the 2009 Houston Livestock Show and Rodeo. Riders were outfitted with two earplugs, one measuring tri-axial linear acceleration and the other tri-axial angular rates. On average, bareback riders experienced a statistically-significant increase in linear acceleration in the x and z axes compared with bull riders. Bareback riders also experienced a statistically-significant increase in angular acceleration in the x and y axes. There was no difference seen between bareback and bull riders in linear head acceleration in the y axis, and the difference in angular rates experienced in the z axis did not reach statistical significance. Another population at risk for injuries due to repetitive acceleration is astronauts. The

Russian Soyuz spacecraft can expose astronauts to high accelerative forces during re-entry and up to 10 G during ballistic re-entry. Soyuz landing impact has reached 17 G. The new NASA Aries launch vehicle is predicted to experience thrust-oscillation problems that may affect crew health. A second aim of this study was to apply the test procedure, hardware, and knowledge gained at the rodeo toward the development of a protocol for measuring head acceleration experienced by astronauts. The first step will be implementation of the study hardware and protocol in centrifuge training. Once validated, the hardware and protocol can undergo flight certification for testing on Russian and U.S. spacecraft. This would provide invaluable insight into launch loads, vibration, reentry and impact loads to ensure crew health in the new vehicle design.

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Introduction

This study is based on the 2007 capstone by Sharmila Watkins, M.D., M.P.H., which introduced the use of ear-mounted tri-axial accelerometers for examining head acceleration experienced by rough stock riders. One of the aims of this study was to expand upon this previous pilot study by examining head acceleration experienced by 10 bareback and 10 bull riders during the 2009 Houston Livestock & Rodeo. The following sections will outline the background for this study, outline the methods used, show how they differ from the previous study, and discuss the results. In particular, this study aimed to categorize the magnitude, type, and direction of head acceleration in rough stock riders, and to compare head acceleration in two separate rough stock events, bareback and bull riding.

A second aim of this study was to utilize the hardware, procedures, and lessons learned during the 2009 Houston Livestock Show & Rodeo to develop a protocol for testing head acceleration in astronauts. Since astronauts are exposed to high amounts of acceleration during launch and re-entry, the system developed for the rodeo offers a tool for examining head acceleration in this population. The following sections will outline a procedure for testing head acceleration in astronauts and recommend changes based on the lessons learned at the Houston Rodeo.

Chapter 1: Background

1.1. Rodeo Background

The sport of rodeo traces its roots to skills necessary for ranching and handling livestock. Rodeo includes timed events, such as steer wrestling, barrel racing, team roping and calf roping, and “rough stock” events, such as bareback, saddle bronc, and bull riding. It is a fast-paced sport with over 700 major events occurring annually in the United States and Canada. (Downey 2007) Despite the inherent danger for trauma in events such as bull riding, few requirements exist for protective equipment. This creates an environment in which “high speed and large bodies of mass in motion combine to create high kinetic energy and high potential for serious injury.” (Downey 2007)

Head injuries have been recognized as a major cause of morbidity during rough stock events. The Justin Sportsmedicine Team (JSMT) is an organization that provides event medical support to rodeo participants. The JSMT published a study on injuries sustained during Professional Rodeo Cowboys Association (PRCA) rodeo events from 1981 to 2005. (JSMT 2006) Injuries during bull riding were most commonly reported, accounting for 50% of all injuries. Bareback riding caused the second most number of injuries at 20%. Out of all the injuries reported, the head and face were injured the most, accounting for 16% of all the injuries reported. Concussion was the most common major injury reported in rodeo events, accounting for 50% of major injuries.

According to the Summary and Agreement Statement of the 2nd International Conference on Concussion in Sport, “concussion is defined as a complex physiologic process affecting the brain, induced by traumatic biomechanical forces.” (McCrory 2005)

Concussions all share a set of common features, in which they: 1) may be caused by a direct blow to the head or by a transmitted “impulsive” force 2) usually cause temporary impairment of neurologic function 3) can cause permanent injury, but acute symptoms are largely reflective of a functional brain disturbance 4) may or may not involve loss of consciousness 5) are usually associated with normal imaging studies of the brain. (McCrory 2005)

Despite these statistics, according to the agreement statement from the 1st international rodeo research and clinical care conference in 2004, bull riders ages 18 or over are only encouraged to wear head protection during rough stock events. (Butterwick 2005) Bull riders less than 18 years of age are required to wear helmets; however, no guidelines exist for wearing head protection in other rough stock events such as bareback and saddle bronc riding. Many bareback riders wear home-made pads around their necks to prevent neck hyper-extension during their event (see Illustration 2). However, the effectiveness of these devices at preventing injuries is unknown.

1.2. Acceleration and Head Injury

Acceleration is defined as “the rate of change of velocity.” (Davis 2008). According to Newton’s first law of mechanics, a body in motion will say in motion or a body at rest will stay at rest unless acted upon by a force. Newton’s second law states that Force = mass x acceleration (F=ma). Newton’s third law states that for every action there is an equal but opposite reaction. (Davis 2008) The value “g” is the acceleration due to gravity which is 9.8 m/s^2. “G” is expressed as the “acceleration experienced by a person as a result of a force, and is expressed as: G = a / g. (Davis 2008) Thus, the "G" forces commonly referred to in aviation represent multiples of the force of gravity.

G-forces are often expressed as vectors, since they possess both magnitude and direction. (Davis 2008). Illustration 1 displays a coordinate system with the G vectors labeled in the x, y, and z-axis. There are variations in the symbols used as well as differences about the direction of the positive and negative axes between physiologic and engineering systems. The DTS hardware expressed the G-axes as illustrated in figure 1. As shown, the positive Gx vector travels towards the back of the head. The positive Gy-axis travels from the right ear to the left ear, and the positive Gz axis travels from the head to the feet.

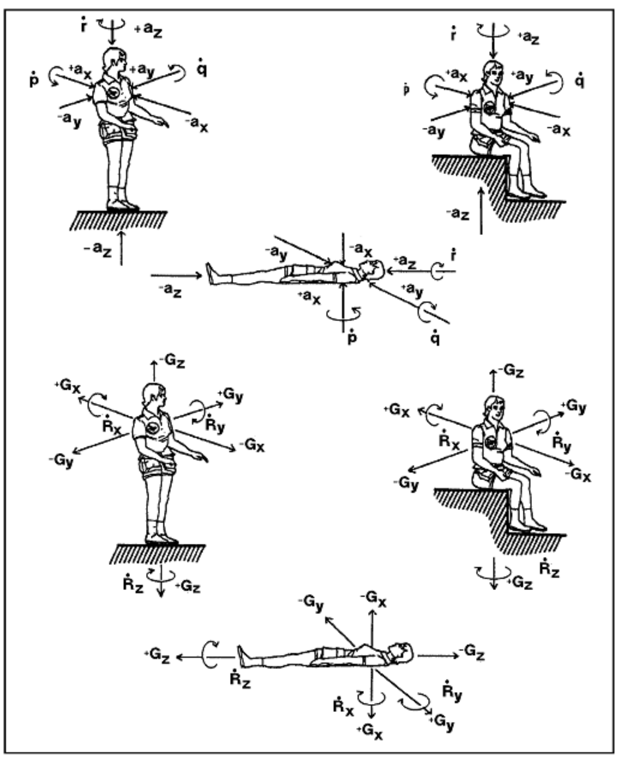


Illustration 1: Acceleration Environment Coordinate System (Courtesy of NASA, available at http://msis.jsc.nasa.gov/images/Section05/Image158.gif)

There are two kinds of acceleration that can lead to concussions. The first is translational or linear acceleration in which the “total applied force passes through the center of gravity of the head.” An example of this type of acceleration would be when the head impacts directly on the steering wheel during a motor vehicle accident. (Olvey 2005) Linear acceleration is measured in units of G. A second type of acceleration is angular, in which “force generates motion around an axis.” Examples of this would be whiplash injury, where an impact causes forced flexion and extension of the neck. (Olvey 2005) Angular acceleration is displayed in illustration 1 as Rx, Ry, and Rz, and is measured in degrees/second or radians/sec. Acceleration forces can also be categorized by their time course 1) short (< 1 sec) or impact and 2) sustained acceleration (> 1 sec).

Studying head acceleration and its association with head injuries began with the establishment of the Wayne State Tolerance Curve (WSTC) in 1960. (Lissner 1960) The WSTC curve described how tolerable levels of acceleration decreased as the duration of acceleration increased. However, research that produced this curve used short durations, in the 1 to 6 millisecond range, and used linear skull fractures in cadavers as injury criteria. A linear function was later developed based on the WSTC known as the Gadd Severity Index (GSI). (Gadd 1961) The WSTC and GST were both used to establish the Head Injury Criteria (HIC), which was adopted by the National Highway Transportation and Safety Board for use in crash tests in 1972. (Versace 1971 and NHTSA 1972) A study by Tyrell et al in 1995 correlated HIC to concussion and head injuries during passenger train crash tests, and suggested that unconsciousness may result from relatively low HIC levels. (Tyrell 1995) Figure 1 shows the predicted correlation between HIC values and level of brain concussion and head injury.

$$HIC = (t_2 - t_1)\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)\,dt\right]^{2.5}$$

where

a = resultant acceleration of the head in g's
t_1 = start of time interval in seconds
t_2 = end of time interval in seconds

Head Injury Criterion	Level Of Brain Concussion And Head Injury
135 – 519	Headache or dizziness
520 – 899	Unconscious less than 1 hour – linear fracture
900 – 1254	Unconscious 1 – 6 hours – depressed fracture
1255 – 1574	Unconscious 6 – 24 hours – open fracture
1575 – 1859	Unconscious greater than 25 hours – large hematoma
> 1860	Non survivable

Figure 1: Predicted level of brain concussion and injury with HIC score (Adapted from Tyrell 1995)

Recent studies have focused on the use of accelerometers to obtain acceleration data directly from the head of living subjects. Much of the data on brain injury has been obtained from manikin and cadaver subjects as well as computer models. (Olvey 2004) However, other populations exposed to high accelerative events, such as football players, have also been studied. In 2009, Rowson et al. published a study examining linear and angular head acceleration using helmet-mounted tri-axial accelerometers in collegiate football players. Of 1712 impacts recorded, most were low intensity (<30 G's of linear acceleration and <2000 rad/sec of angular acceleration). However, some impacts were greater than 40 G's and 3000 rad/sec. No concussions were reported in the data set. (Rowson 2009) One study by Funk et al. proposed that levels of head acceleration in football could predict risk of mild traumatic brain injury. (Funk 2007). However, a study by Guzkiewicz, also in 2007, found no relationship between impact linear and angular acceleration and symptom severity in concussed football players. (Guzkiewicz 2007)

Interestingly, many of the studies examining head acceleration use only linear accelerometers. The HIC score is calculated using linear acceleration, and this may account for the use of linear accelerometers in these studies. In 2008, Greenwald et al. suggested that use of multiple biomechanical inputs is more sensitive for predicting risk of mild traumatic brain injury over linear acceleration alone. These inputs include "linear acceleration, rotational acceleration, impact duration, and impact location," which taken together form a weighted principle component score (wPCS). (Greenwald 2008) Though developments such as the wPCS could help define concussion risk in football, the lack of consensus among the research indicates that further research is needed.

Another population exposed to high accelerative forces is boxers. Wililko et al. studied both translational and angular acceleration with punches, though a dummy was used as the test subject. The authors recorded up to 58 g's of linear acceleration and over 6000 rad/sec of angular acceleration. (Wililko 2005) Motor sport also offers an excellent environment for testing head acceleration during high-speed impacts. Weaver et al. evaluated maximum G forces sustained in Indy Car crashes in relation to brain injury. The study concluded that impact forces > 50 g's were associated with traumatic brain injuries. However, acceleration data was collected with a recorder mounted on the vehicle, not the human occupant. (Weaver 2004) Ear-mounted accelerometers offer a means of examining the forces directly applied to the head. Olvey, Knox, and Cohn developed an ear-mounted tri-axial accelerometer system with the Indy Racing League and the Air Force Research Laboratory. (Olvey 2004) This system was the basis for testing head acceleration in rough stock riders.

1.3. Pilot Rodeo Study

A small pilot study examining head acceleration experienced by rough stock riders was conducted in 2007 at the Houston Livestock Show and Rodeo. (Watkins 2008) The study examined head acceleration in one bareback rider and one bull rider. The test hardware consisted of a custom-fitted earplug with three imbedded linear tri-axial accelerometers and one angular rate sensor oriented in the y-axis. The bull rider wore an earplug in the right ear and the bareback rider wore an earplug in the left ear. The ear-mounted accelerometers were connected by wires to a data recorder worn on the rider's belt. Prior to their scheduled rodeo events, informed consent was obtained and the riders were fitted with the test hardware. Just prior to the start of their ride, the test hardware was armed to collect data. Following the rider's event, the test hardware was collected and the data downloaded to a personal computer.

The study found that the bull rider's head experienced a peak of 26 G or 258 m/s^2 in the z-axis during dismount. The bareback rider's head was exposed to several accelerative events of higher magnitude, with maximum acceleration measured at 46 G or 450 m/s^2 in the z-axis. The collected data was used to calculate Head Injury Criteria (HIC) scores. The HIC score for the bull rider was 85, which placed him at risk for headaches and dizziness according to HIC criteria. The bareback rider's HIC score was

706, placing him at risk for loss of consciousness or skull fracture had his head impacted the animal. Though neither of the riders sustained injuries, the author concluded that the accelerations experienced by rough stock riders could place them at risk for serious injuries. Bareback riders were subjected to particularly high, repetitive accelerations. The study was limited by small sample size and the large size of the data recorder. In addition, a study by Nahum and Melvin pointed out that it may not be appropriate to use the HIC in accelerations that are not the result of an impact. (Nahum 2001) A larger study with improved hardware was needed to further evaluate the use of HIC in non-impact conditions. (Watkins 2008)

1.4. Spaceflight Background

In regards to spaceflight, exposure to high G-forces during launch and re-entry has been recognized for many years. The Russian Soyuz spacecraft experiences 4 to 5 Gx during a nominal re-entry. However, the Soyuz can re-enter the atmosphere using a steeper, "ballistic" profile, which can expose occupants to even higher forces, up to 8-9 sustained Gx. (DeHart 2002). An understanding of the G specifically measured at the head of occupants would allow flight surgeons to evaluate the risk of head injury during these ballistic descents. With the current development of the NASA Aries I launch vehicle, an understanding of these forces could help engineers design a safer vehicle for astronauts.

With the Space Shuttle set to retire in 2010, NASA's Constellation Program is currently developing their next generation spacecraft. The Aries I launch vehicle will lift the Orion Command Module into orbit, which will carry up to four astronauts to the

International Space Station and the Moon. Preliminary data has revealed that the Aries I vehicle will be subject to thrust oscillations that could affect crew health. Thrust oscillation occurs when the burning of solid rocket propellant creates vortices within the vehicle. (Bergin 2008) This oscillation will occur during the last 20 seconds of the Aries I 1st stage, exciting a 12 Hz resonance on the Orion Command Module. (Dory 2008) This could create vibrations as high as 4 G root mean square (rms), although only a maximum of 0.7 G rms would be allowed.

These vibrations have previously been known to cause decrements in crew performance. A study by Vykukal and Dolkas in 1966, which was done to support development of the Gemini spacecraft, showed significant decrements in performance when subjects were exposed to as low as 0.3 Gx at 11 Hz. (Vykukal 1966) When Gx levels exceed 3.7 G, these vibrations can induce health effects in crewmembers. (Dory 2008) Vibration can also impair an astronaut’s ability to see during launch. Studies are currently underway using laboratory and centrifuge testing to understand the effects of thrust oscillation on crew health and vision. However, once flight testing begins, NASA will need a system capable of measuring head acceleration in astronauts that can operate independently.

Chapter 2: Methods

2.1. Study Design and Materials

During the study in 2007, the rodeo riders commented that the data recorder was too large and could have potentially interfered with their event. In fact, a follow-up study in 2008 was cancelled because the hardware could not be miniaturized sufficiently. For the 2009 study, a new hardware company was recruited, Diversified Technical Systems, Inc. (DTS). DTS specializes in small data recorders, and their Slice Nano data recorder was selected for this study. Measuring approximately 20 mm^3, it offers an important improvement in size over the previous data recorder. DTS was contracted to furnish UTMB with one data recorder unit, which consists of the Slice Nano data recorder, a 9-volt battery compartment, and wires. These components were encased in a plastic cover. The assembled data recorder unit is approximately the size of a smart phone. Small wires connect the data recorder to earplugs with embedded accelerometers. Another wire from data recorder connects to a small red button and a green LED light. Pressing the red button begins the data collection, while the LED light provides a visual confirmation of activation. See illustration 1 on the following page for a picture of the complete hardware configuration.

Two sets of earplugs with embedded tri-axial accelerometers were obtained by DTS from the Indy Racing League (IRL). The left earplug was embedded with three

Illustration 1: Data recorder unit with earplugs and USB cable. (Courtesy of DTS, Inc.)

linear tri-axial accelerometers, while the right earplug was embedded with three angular rate sensors. This configuration offers significant advantages over the earplugs in the previous study. In 2007, each rider wore one earpiece. The earpiece was embedded with three linear tri-axial accelerometers and one angular rate sensor. The new configuration allows for the collection of six channels of data as opposed to four, and allows for data collection on angular rates in the x, y, and z-axis during rough stock rides. Angular rates provide more accurate information about accelerations experienced by rough stock riders.

This is because the rider's head is accelerated on a rotational axis during their event, with the neck being the center of rotation.

The study received approval from the UTMB Institutional Review Board for recruitment of twenty subjects. Don Andrews from the Justin Sportsmedicine Team, one of the study's collaborators, contacted the subjects prior to the 2009 Houston Livestock Show and Rodeo. On the day of each rider's event, the rider was introduced to the study team and hardware. The purpose of the study, hardware, procedure, risks and benefits were explained to the rider. After allowing the rider to ask questions, the rider indicated his willingness to participate by signing a research consent form.

2.2. Study Protocol

Approximately 45 minutes prior to the rider's scheduled event, the rider was outfitted with the study hardware. The data recorder unit was first strapped to the rider's upper abdomen using an elastic strap. The data recorder unit itself was placed in a commercially-available camera case for added protection. Next, the earplugs were placed in the rider's ears. The earplugs were secured in place using athletic trainers' tape. Benzoin, a substance that helps secure and sweat-proof the tape, was placed on the rider's ears prior to tape application. The wires connecting the earplugs to the data recorder unit were taped above the rider's clavicle on each side. The rest of the wires and data recorder unit were secured underneath the riders vest or shirt. The red button and LED light were taped to the rider's gripping arm. This is the arm the rider uses to hold on to the horse or bull during the event.

Illustration 2: Rodeo rider wearing study hardware. Note the data recorder unit strapped to the center of the rider's chest and the small red trigger taped to the rider's right shoulder. Wires extend from the data recorder unit to the rider's ear. Photo courtesy of Maltz Photography (www.maltzphotography.com)

Once the hardware was secured, the rider proceeded to the arena. Illustration 2 shows a rider wearing the study hardware. Approximately 15 minutes prior to their scheduled event, the study team met with the rider again to arm the system.

This arming process consisted of placing the 9-volt battery into the data recorder unit, plugging the unit into a laptop computer, performing a final system check of the hardware, and arming the unit for data collection. Since the 9-volt battery provides approximately 45 minutes of charge to the data recorder unit, the arming process had to occur in the arena just prior to the event. About 1 minute prior to the rider's event, a representative from the Justin Sportsmedicine Team depressed the red button taped to the rider's shoulder, thus beginning the data collection. The rider then completed his rough stock event. Once the red button is depressed, the hardware records data for 10 minutes continuously. Data on linear and angular head acceleration was recorded to the Slice Nano data recorder at 2000 samples per second.

Upon completion of the event, the rider returned to the study team. The hardware was removed and the data recorder unit was plugged into the laptop computer to begin downloading the data. The data was analyzed using commercially-available software from DTS, Inc. and a Dell Laptop computer. The rider was given a copy of the signed consent form. The goal of the study was to collect data on one bareback and one bull rider each night. Data was collected on 14 days of the 2009 Houston Livestock Show and Rodeo. Several scheduling conflicts and one malfunction of the hardware necessitated adding extra days to the data collection period.

In total, data was collected on 10 bareback and 10 bull rides. One bareback rider was able to complete two rides within the 10 minute recording period. This was possible because the rider was awarded a "re-ride." This occurs in rodeo when the judges feel that the rider's animal did not perform adequately for judging to take place.

Chapter 3: Results

3.1. Head Acceleration

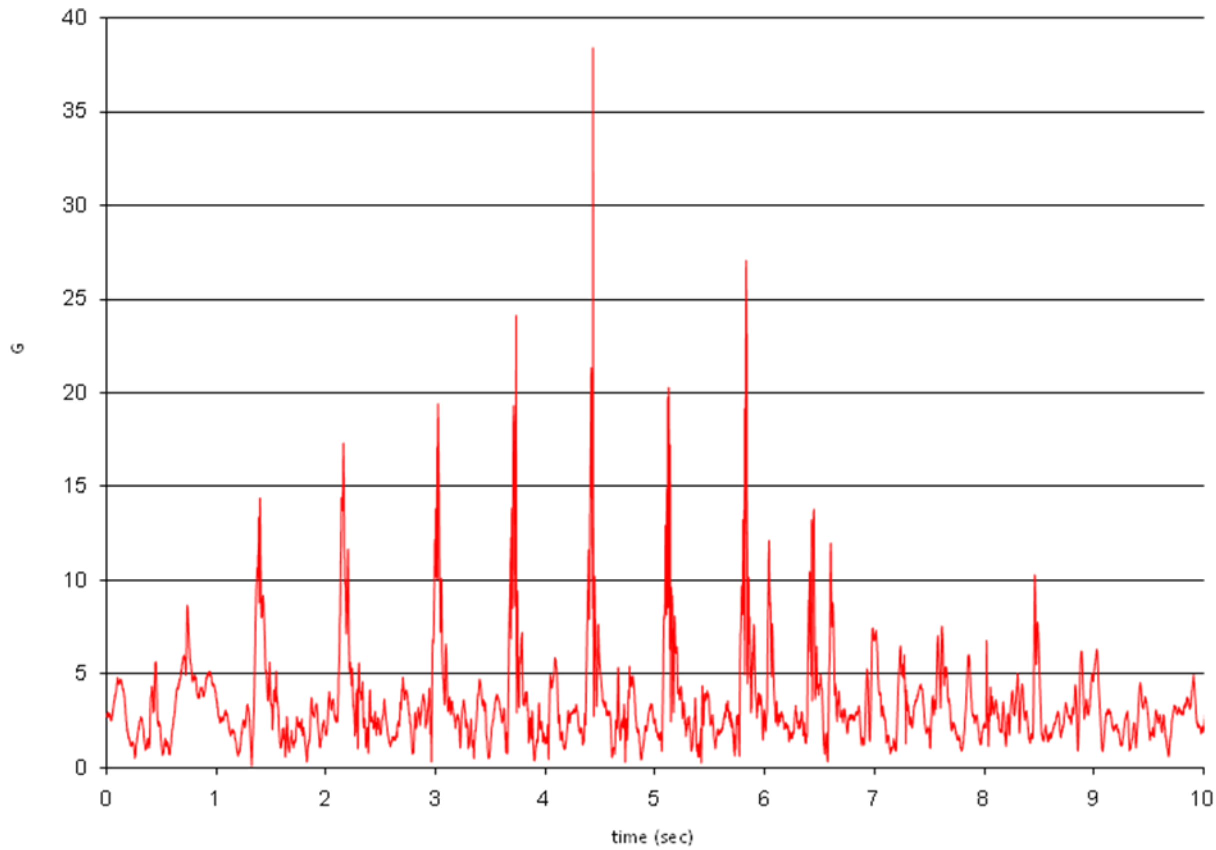
	Bareback	Bull riding	P-value
Axis			
Linear x (G)	**27.6**	**10**	**0.020**
Linear y (G)	**17.5**	**12.2**	**0.447**
Linear z (G)	**24.9**	**10.2**	**0.003**
Angular x (deg/sec)	**2109.7**	**1104.8**	**0.039**
Angular y (deg/sec)	**2864.7**	**1008.8**	**0.005**
Angular z (deg/sec)	**2228.7**	**1196.2**	**0.080**

Table 1: Mean maximum linear and angular head acceleration experienced by rough stock riders.

The data was analyzed using Microsoft Excel. Table 1 displays the mean maximum head acceleration experienced in each linear and angular axis in both bareback and bull riders. Bareback riders experienced a mean maximum linear acceleration of 27.6 G in the x-axis, while bull riders experienced mean maximum of 10 G in this axis. In the y-axis, bareback riders experienced a mean maximum linear acceleration of 17.5 G, and bull riders experienced a mean maximum of 12.2 G. In the z-axis, bareback riders experienced a mean maximum linear acceleration of 24.9 G, while bull riders experienced 10.2 G on average.

In regards to angular acceleration, in the x-axis bareback riders experienced a mean maximum angular acceleration of 2109.7 degrees/second, compared with 1104.8 degrees/second in bull riders. In the y-axis, bareback riders experienced a mean maximum angular acceleration of 2864.7 degrees/second, compared with 1008.8 degrees/second in bull riders. In the z-axis, bareback riders experienced a mean maximum angular acceleration of 2228.7 degrees/second, compared with 1196.2 degrees/second in bull riders. A Student's t-test was used to compare the mean maximum acceleration in each axis experienced by bareback and bull riders. Bareback riders experienced significantly more acceleration in all axes except for the linear y-axis and angular-z axes.

Figure 2 graphically depicts the resultant linear acceleration experienced by one bareback rider. Resultant acceleration is the sum of acceleration in the x, y, and z axes. During the rider's 8 second ride, he sustained a maximum linear acceleration of 38.3 G approximately 4 seconds into the ride. Figure 3 displays the resultant angular acceleration experienced by the same bareback rider. Multiple peaks of high angular acceleration can be seen, with a maximum angular acceleration of 2820.8 degrees/second approximately 2 seconds into the ride. Figure 4 shows the resultant linear acceleration in a bull rider. Note the relatively low amount of linear acceleration experienced. Lastly, Figure 5 depicts resultant angular acceleration in a bull rider.



Channel Description	Units	Max	Time	Min	Time
Acceleration Resultant	g	38.3	4.4355	0.1	1.3225

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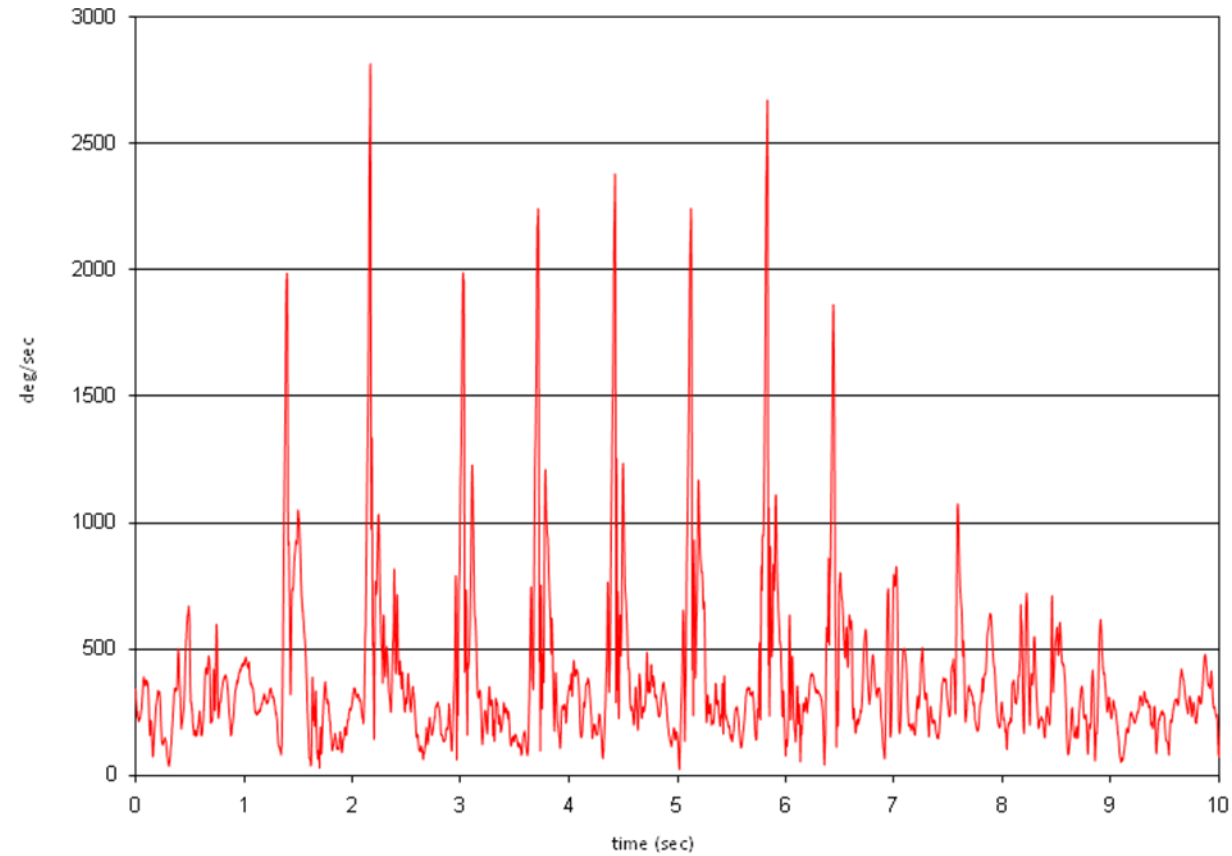
Figure 2: Resultant linear acceleration experienced by a bareback rider



Channel Description	Units	Max	Time	Min	Time
Angular Rate Resultant	deg/sec	2820.8	2.1675	21.0	5.0195

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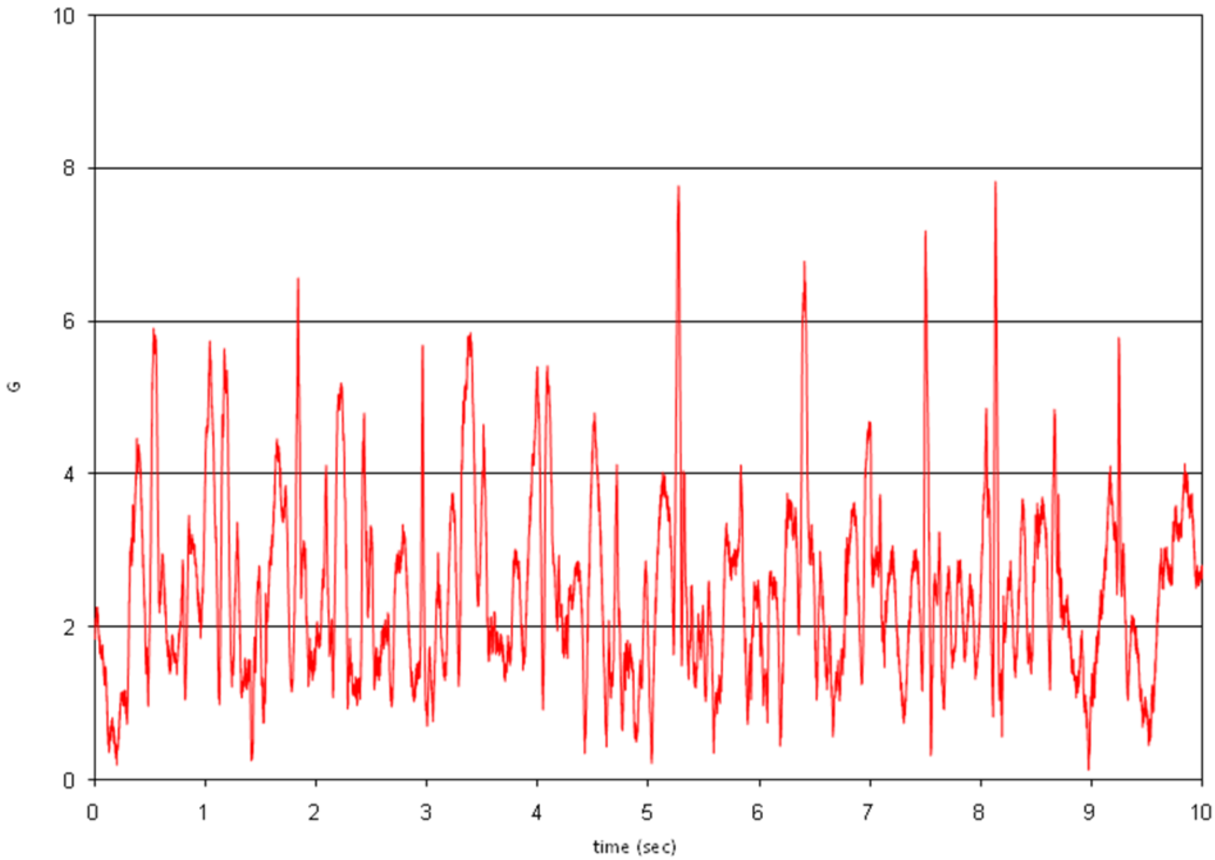
Figure 3: Resultant angular acceleration experienced by a bareback rider



Channel Description	Units	Max	Time	Min	Time
Acceleration Resultant	g	7.8	8.13	0.1	8.97

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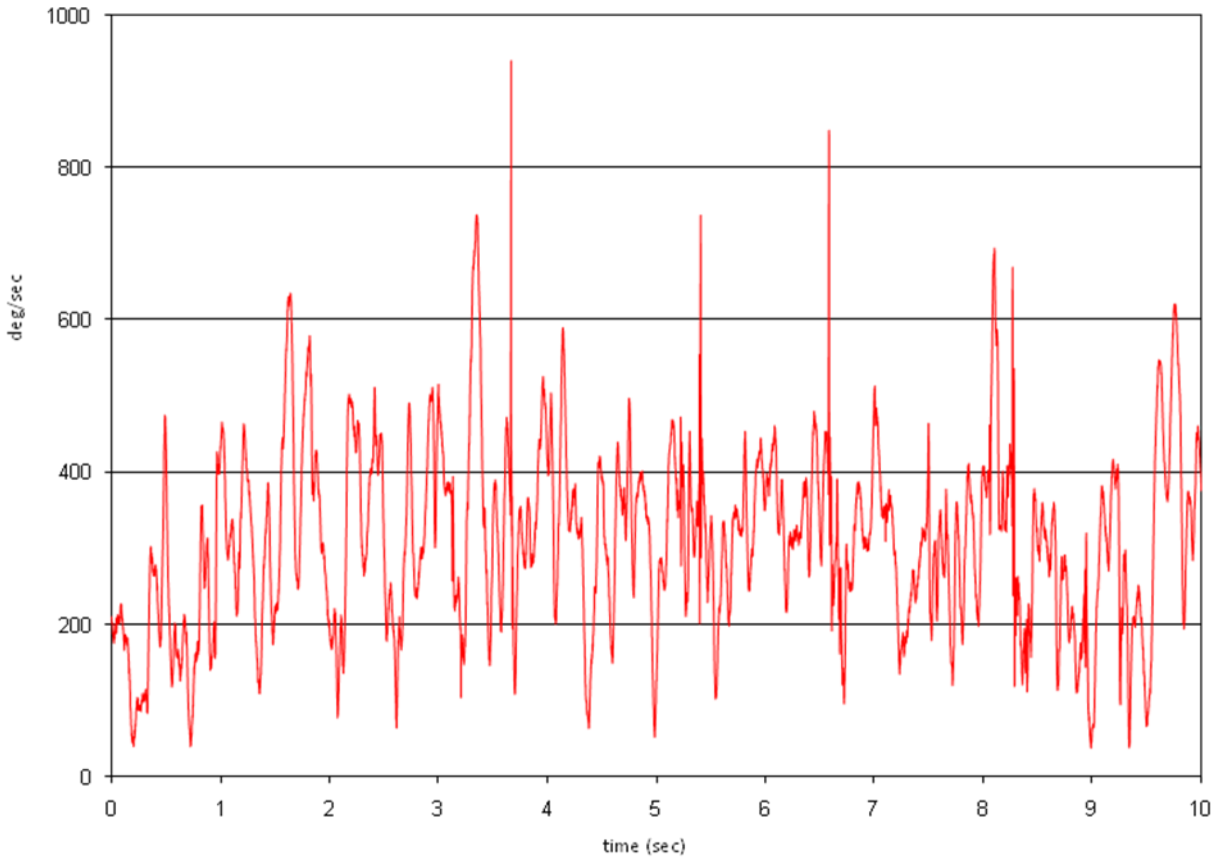
Figure 4: Resultant linear acceleration experienced by bull rider



Channel Description	Units	Max	Time	Min	Time
Angular Rate Resultant	deg/sec	938.6	3.67	38.7	8.99

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Figure 5: Resultant angular acceleration experienced by a bull rider

3.2. Bull Rider Impact Injury

One of the study subjects, a bull rider, was thrown from his bull and subsequently struck in the head by the bull's horn. The rider sustained a laceration to his scalp, and was evaluated by the Justin Sportsmedicine Team. It was determined the rider did not sustain a concussion as a result of the impact. However, it was discovered that the rider's head was exposed to head accelerations higher than the average bull rider experienced. Table 2 compares the mean maximum values of head acceleration in the injured bull rider to the average accelerations experienced by the group.

Axis	Rider 6	Average
Linear x (G)	25	12.7
Linear y (G)	60	20.5
Linear z (G)	25	11.7
Angular x (deg/sec)	3834	1086.8
Angular y (deg/sec)	3743	1007.9
Angular z (deg/sec)	3400	1199.1

Table 2: Maximum head acceleration experienced during an impact in a bull rider compared with mean maximum head acceleration among all bull riders

3.3. Calculation of HIC Values

Table 3 and 4 displays the Head Injury Criteria scores for bareback riders and bull riders. Bull rider number 2's data was excluded from analysis since we could not determine where the ride took place in the data. This could be due to the magnitude of acceleration during the ride being as low as acceleration during other events such as ambulation, preparing for the bull ride, or removing the earplugs. HIC36 listed in tables 3 and 4 refers to the measurement being taken over 36 milliseconds. HIC values may be calculated using varying levels of duration (Greenwald 2008).

Bareback Rider	1	2	3	4	5	6	7	8	9	10
HIC36	56.3	76	12.9	121.4	76.5	345.8	48.3	37.9	25.6	140.6
Average g	19	21.4	10.6	25.8	21.6	39.4	17.9	16.2	13.8	27.5

Table 3: HIC scores for bareback riders

Bull Rider	1	3	4	5	6	7	8	9	10
HIC36	5.3	6.2	3.2	26.8	99.3	4.1	5.4	5.1	2.6
Average g	7.7	7.9	6.1	14.1	50.1	6.6	7.4	7.3	5.5

Table 4: HIC scores for bull riders

Chapter 4: Discussion

4.1. Rodeo Results

Based on the data obtained at the Houston Rodeo, it seems that bareback riders on average are exposed to high amounts of repetitive head acceleration. Bareback riders are also exposed to an approximately two-fold greater magnitude of acceleration when compared with bull riders. These findings are consistent with the 2007 pilot study, but provide more insight into the magnitude of angular acceleration experienced by these riders. In the absence of contact, bull riders seem to be exposed to less head acceleration, possibly due to the increased mass of the bull as compared to a horse. However, one bull rider was exposed to an impact from the bull. An interesting finding is that this bull rider experienced head acceleration more consistent with the average acceleration experienced by a bareback rider. This finding reinforces the severity of head acceleration experienced during bareback riding.

We found that the difference in mean maximum acceleration between bareback and bull riders was statistically significant in most of the axes studied. There was no difference found in bareback and bull riders in the linear y-axis. However, a statistically-significant difference was seen in the angular y-axis. This could be explained by the ability of the angular rate sensors to capture the true motion of the head during rough stock rides. When a bull or horse forcibly moves its rider to the left or right, the rider's head moves in a rotational axis about the neck. Thus, the angular rate sensors were likely capturing the true motion of the head, and may represent more valid data in this case.

We also found no statistically-significant difference between bareback and bull riders in the angular z-axis. If we assume an alpha of 0.05, the p-value falls just out of range of significance. However, there was a statistically-significant difference found in the linear y-axis. Since acceleration in the z-axis transmits force from the head to the feet and vice versa, linear accelerometers may capture this acceleration better than angular rate sensors. Acceleration in the true z-axis would not cause head rotation without interaction from acceleration in the x or y-axis. Thus, for examining z-axis acceleration, the linear accelerometers may capture this information better than the angular rate sensors.

Looking at figures 2 and 3, we can examine the resultant linear and angular acceleration during a bareback rider's individual ride. Figure 2 shows resultant linear acceleration, which is characterized by a tall peak of acceleration approximately 4 seconds into the ride and several smaller peaks. Figure 3 shows resultant angular acceleration, and is characterized by multiple peaks greater than 2000 deg/sec of angular acceleration. The angular acceleration data illustrates the multiple, high acceleration that bareback riders experience. Figures 4 and 5 display resultant linear and angular acceleration experienced by one bull rider. The overall magnitude of accelerations seems less in both linear and angular acceleration.

In regards to HIC scores, the scores obtained in this study are much lower than the scores obtained in the 2007 study. In the pilot study, the author calculated a HIC score of 85 for the bull rider and 706 for the bareback rider. Following the table outlined by Tyrell (see figure 1), these scores placed the bareback rider at risk for serious head injury. In the current study, however, we found only 2 of 9 bull riders had a HIC score > 10. Similarly, we calculated only 2 of 10 bareback riders having HIC scores > 100. This discrepancy could suggest differences in sensitivity between the equipment used in the two studies, or perhaps that rides used in 2007 represent outliers. Referring back to the comment by Nahum and Melvin, this discrepancy might also suggest that HIC values may not be a valid measure for predicting head injury risk in non-impact situations. Indeed, the intensity of angular acceleration experienced by the bareback riders in particular does not seem to correlate with the relatively low HIC values seen in these riders.

It might be more appropriate in this population to utilize metrics that take into account multiple inputs, such as the wPCS score postulated by Greenwald. This score uses linear and angular acceleration, as well as impact location and duration to determine risk for head injuries during accelerative events. Further research is needed to determine the feasibility of incorporating the rodeo data into a metric like the wPCS score, and if this score is indeed appropriate for determining head injury risks in non-impact situations.

The data collected for this study could be used to design better safety equipment for rough stock riders, especially bareback riders. The homemade neck pads worn by bareback riders do not seem to mitigate the high angular accelerations these riders experience. For example, bareback riders experienced the most angular acceleration in the y-axis, an axis not well protected by the neck pads. Safety equipment designers could use evidence-based data to design equipment that targets the areas of greatest acceleration. Regarding current regulations for safety equipment, the PRCA should consider mandating the use of helmets in all rough stock events. It is troubling that the average acceleration experienced by a bareback rider was equivalent to the acceleration experienced during an impact injury in a bull rider. With the potential for bareback riders impacting the animal and experiencing even greater acceleration, the need for better head protection seems paramount.

4.2. Protocol for Examining Head Acceleration in Astronauts

As discussed in the background section, NASA is currently investigating the impact of thrust oscillation on human performance in the new Aries I launch vehicle. In September 2008, the Constellation program conducted a vibration + 3.8 G x centrifuge study at Ames Research Center. The study utilized a 20-G centrifuge and instrumented subjects with a dual tri-axial accelerometer assembly. This assembly was mounted to the forehead using a strap that wrapped around the subjects head. The study looked at error rates and response time in reading tasks using different font sizes while being exposed to varying levels of vibration. Vibration levels were increased while being exposed to 3.8 Gx. In general, the study found increased error rates and response times with increasing levels of vibration. (Adelstein et al. 2008)

Eventually, NASA will need to perform similar experiments in more flight-like conditions, using vehicle mockups and launch & entry suits, culminating with actual flight tests of the Aries launch vehicle. The current accelerometer assembly employed at the Ames Research Center tests will not allow characterization of head acceleration in a helmeted crewmember. The ear-mounted tri-axial accelerometers used at the 2009 Houston Rodeo offer NASA a means of measuring head acceleration in astronauts by offering an unobtrusive and independent data collection system. The rodeo hardware could even be modified for testing during actual launch and re-entry of the Orion capsule.

NASA astronauts currently fly into space aboard the Russian Soyuz spacecraft. As already discussed, several astronauts have been exposed to high G-forces as a result of ballistic re-entries. Characterizing the head acceleration experienced by astronauts during these re-entries could not only help NASA gain a better understanding of the potential for injury in the Soyuz, but also provide flight data that could aid in the development of the Aries I and Orion spacecraft. Though modifications for flight certification would be expected, the current system is light, portable, and has little power requirement. It can be armed using any laptop computer, and the data will be stored in the data recorder until return to Earth.

A good starting point would be implementation of a protocol similar to the 2009 Houston Rodeo in centrifuge testing. Plans are underway to present a proposal to NASA for this purpose. Validation of the hardware in current Constellation centrifuge studies could pave the way for further testing in the flight environment.

4.3. Proposed hardware modifications

Several lessons were learned as a result of testing the hardware at the 2009 Houston Rodeo. These lessons can guide proposals for further research in the flight environment. During testing, the data recorder unit was noted to produce high amounts of heat. The heat did not bother the rodeo riders, since the data recorder unit was enclosed in the commercially-available camera case. This heat, however, could pose a thermal health risk to an astronaut or affect ECLSS (environmental control and life support systems) aboard a spacecraft. Another modification would involve reinforcement of the connector which attaches the earplug wires to the data recorder unit. One of these wires broke during rodeo testing, likely due to a jerking motion during one of the rides. Three sets of earplugs will be available for future testing to provide redundancy in case this situation arises again.

During the 2009 Houston Rodeo, the Indy Racing League was only able to provide medium and large size earplugs for testing due to availability. As a result, the earplugs were slightly large for some rodeo riders. The use of athletic tape securely coupled the earplug to the rider’s ear, so we feel this did not affect the quality of the data. However, it did pose a safety risk, since the earplug protruded from the ear in some riders. A possible solution to this would be the use of custom-fitted earplugs in spaceflight testing. The low number of subjects likely to be involved in such tests could allow the creation of custom earplugs that would provide a safer and more comfortable fit. As technology advances, smaller linear accelerometers and angular rate sensors may also become available.

Conclusion

The study conducted at the 2009 Houston Livestock Show & Rodeo showed that bareback riders on average experience significantly more head acceleration than bull riders. In particular, bareback riders experience high, repetitive angular accelerations in their heads. It took a head impact for a bull rider to experience head acceleration similar to a bareback rider. Further analysis of this data will involve reviewing video footage of the riders' events from the 2009 Houston Rodeo. More research is needed on how to characterize this acceleration data in terms of risk for head injury. The Head Injury Criteria may not be an appropriate means of analyzing risk for head injury in this case, since rough stock riders experience mostly non-impact related head acceleration.

The hardware and protocols tested at the 2009 Houston Rodeo offer a means of examining head acceleration in astronauts. This hardware can supplement on-going research in the Constellation program and provide a portable testing platform for launch and re-entry. Validation of the hardware and protocol can first be accomplished during centrifuge-based training and research, and modifications can be proposed for flight certification.

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Vita

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