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MEASUREMENT OF ACCELERATIONS EXPERIENCED BY ROUGH STOCK RIDERS

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MEASUREMENT OF ACCELERATIONS EXPERIENCED BY ROUGH STOCK RIDERS

by

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Approved by the Supervisory Committee

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Dedicated to:

Rick Watkins - my husband and best friend

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MEASUREMENT OF ACCELERATIONS EXPERIENCED BY ROUGH STOCK RIDERS

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Supervising Professor R. Johnson

Introduction: Head injury is common in many sports, but it is of particular concern in professional rodeo events. Rough stock events (bareback, saddle bronc, and bull riding) provide multiple opportunities for injury. Head injuries sustained during a rough stock event may be the result of whiplash effects or impact with the animal. Although there are a few recent studies investigating the incidence of head injury in rodeo events, little is known about the acceleration profile experienced by the riders.

Methods: This study was conducted at the 2007 Houston Livestock Show and Rodeo. Two subjects were enrolled: one bull rider and one bareback rider. The subjects were fitted with custom-molded accelerometers and a waist mounted data recorder. The head accelerations experienced during the subjects' scheduled rodeo events were then measured and recorded. The motions of the riders were also captured on video.

Results: This study demonstrated the ability to record both the magnitude and direction of the head accelerations experienced. Data were obtained from both subjects and revealed significant accelerations in all axes, particularly the z-axis. The maximum resultant acceleration for the bull rider was 258 m/s^2 (26 g's), while the bareback rider experienced a greater magnitude acceleration of 450 m/s^2 (46 g's).

Conclusions: Head accelerations experienced by rough stock riders are high in magnitude and have the potential to result in injury. Further studies of accelerations experienced during actual rough stock events are needed.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

AIS	Abbreviated Injury Scale
ATD	Anthropomorphic Test Dummy
AFRL	Air Force Research Laboratory
CDC	Centers for Disease Control
DAS	Data Acquisition System
HIC	Head Injury Criterion
HLSR	Houston Livestock Show and Rodeo
IRB	Internal Review Board
JSMT	Justin Sportsmedicine Team
NSBRI	National Space Biomedical Research Institute
PRCA	Professional Rodeo Cowboys Association
SI	Severity Index
SRHI	Sports Related Head Injury
UTMB	The University of Texas Medical Branch
WSTC	Wayne State Tolerance Curve

INTRODUCTION

Head injuries are a major cause of death and disability in the United States. It is estimated that 1.4 million head injuries occur annually, and many of these injuries occur as a result of participation in sports [Langlois, 2006]. Injuries are especially common in fast-paced, contact sports. Rodeo rough stock events are among those known to have high rates of head injury, particularly concussion.

Head injuries may occur during rough stock events as a result of whiplash or impact with the animal. A recent report reveals that bull and bareback events are those with the highest rates of head injury [JSMT, 2006]. Although rodeo-related head injuries are a major concern, few studies have examined the mechanisms behind these injuries. Therefore, the relationship between head injury and the accelerations experienced by rough stock riders is not well understood.

Since little is known about the accelerations which give rise to head injury in rodeo riders, it is important to quantify the acceleration profiles encountered during a typical competition ride. To this end, a collaborative, multidisciplinary team was formed to develop a test protocol and hardware to examine head accelerations during the 2007 Houston Livestock Show and Rodeo (HLSR).

Two professional rough stock riders were enrolled in this preliminary study and data were collected using accelerometers and a data recording device. The accelerometers were mounted in custom earpieces and were capable of measuring linear acceleration in three dimensions. The waist-mounted data acquisition system was able to capture the acceleration data during the ride and store it for later analysis. During the 2007 rodeo, each subject completed one competition ride wearing the hardware as a first step in understanding the acceleration profiles encountered during these rough stock events.

The data collected in the study reveal that bull and bareback riders are subjected to significant accelerations during competition. The maximum resultant accelerations experienced by the bull and bareback riders were 258 m/s^2 (26 g's) and 451 m/s^2 (46 g's), respectively. The Head Injury Criterion (HIC), a calculated value used to relate measured accelerations to injury potential, was of a magnitude sufficient to produce headache and dizziness in the bull rider. The HIC calculated for the bareback rider revealed that the rider was subjected to accelerations with the potential for concussion. This preliminary study provides a glimpse of the magnitude of accelerations encountered during rough stock competition events.

CHAPTER 1: BACKGROUND

1.1. Historical Aspects

The study of bodies in motion has been of interest for hundreds of years. Our modern understanding of acceleration is based upon the studies of Galileo Galilei in the late sixteenth century and Sir Isaac Newton in the seventeenth century. Galileo's studies produced the first valid theories of accelerated motion. Newton later formulated three laws of motion, the second of which defines the relationship between force, mass, and acceleration.

Galileo was the first to examine the transit time of an object down planes of varied inclination. Through these observations, he discovered that the distance the object traveled was proportional to the transit time squared. This led to the first theory of accelerated motion [Serway, 1996].

Newton expanded upon Galileo's work. Newton spent years studying the structure of the universe and recognized that an unseen force acted on the celestial bodies. In his second law of motion, Newton demonstrated that the acceleration of an object is proportional to the force applied and inversely proportional to the mass of the object. He went on to conclude that gravity was a type of acceleration [Serway, 1996].

1.2. Anatomy and Physiology of Acceleration

The following description of the vestibular system is based upon the tenth edition of Guyton and Hall's Textbook of Medical Physiology. The vestibular apparatus is the human sensory organ responsible for detecting changes in equilibrium. The vestibular system responds to acceleration and presents this information to the brain via the nervous system. The human ability to detect acceleration is necessary for balance and coordinated locomotion.

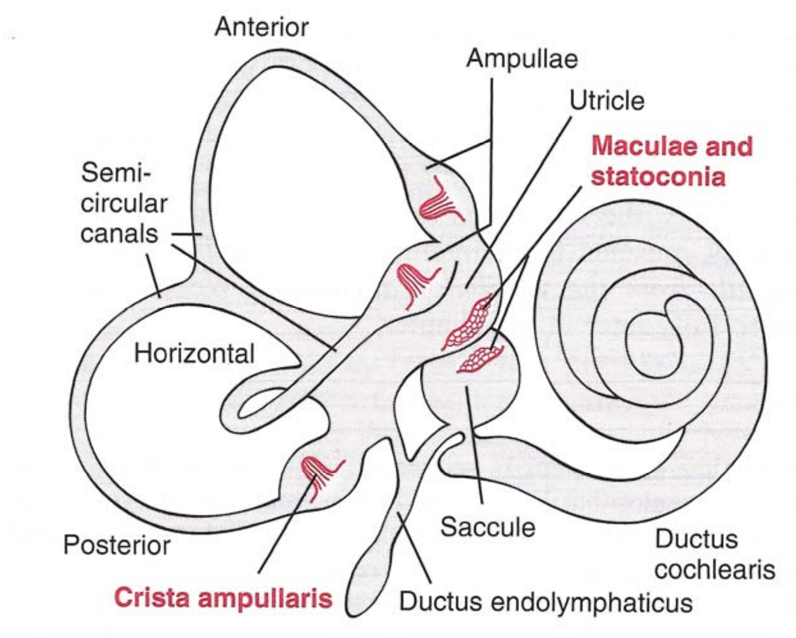

Figure 1: Membranous labyrinth

(Reprinted with permission from Guyton and Hall: Textbook of Medical Physiology, 10th Ed. Philadelphia: WB Saunders CO, 2000)

There are two distinct portions of the vestibular apparatus: the bony labyrinth and the membranous labyrinth. The bony labyrinth is located in the temporal bone of the skull and contains the delicate membranous labyrinth. The membranous labyrinth is made up of tubes and chambers and is the functional part of the vestibular apparatus. The membranous labyrinth is comprised of the cochlea, semicircular canals, utricle and saccule.

1.2.1. The Otolith Organs and Detection of Linear Acceleration

The utricle and saccule are known as the otolith organs. These are the sensory organs responsible for determining the orientation of the head with respect to gravity. The macula, a small area approximately two millimeters in diameter, is located on the inside surface of each utricle and saccule. The utricle's macula is oriented in the horizontal plane, and the saccule's macula is oriented in the vertical plane. Therefore, in the upright position, the saccule is most sensitive to gravity. The orientation of each macula and the hair cells within the macula help to establish head position relative to gravity.

A gelatinous layer known as the statoconial membrane covers each macula. The membrane is named for the small crystals called statoconia that are embedded within it. Hair cells in the macula project thousands of cilia into the statoconial membrane. Each hair cell has many small cilia, known as stereocilia, and one kinocilium. The kinocilium is the largest cilium of the group and is always located at the periphery of the hair cell. The stereocilia are scattered around the hair cell, and the height of the stereocilia decrease as the distance from the kinocilium increases. Small filaments connect the stereocilia to the kinocilium in order of height.

The arrangement of the cilia is important for cell signaling. Under resting conditions, the hair cell's nerve fibers transmit continuous impulses at a constant rate. When the stereocilia bend in the direction of the kinocilium, the tension in the filaments increases. This triggers reactions within the hair cell that ultimately lead to receptor membrane depolarization and increased impulse rate. Conversely, when the hair cells are deflected away from the kinocilium, the tension in the filaments decrease, triggering hyper-polarization of the hair cell. This results in a decrease in the impulse rate of the cell [Guyton & Hall, 2000].

Because the specific gravity of the statoconial membrane is higher than that of the surrounding tissue, changes in head position with respect to gravity cause displacement of the membrane with respect to the hair cells. This results in deflection of the hair cells and alteration of the impulse rate. The change in signal is detected by the brain and is interpreted as a departure from equilibrium. Since the maculae have hair cells oriented in many directions, the otolith organs are able to detect linear acceleration in three dimensions.

1.2.2. Semicircular Canals and Detection of Angular Acceleration

Each vestibular apparatus contains three semicircular canals. Each canal is named according to its position within the head: anterior, posterior, and lateral. The canals are arranged so that they lie in planes that intersect at right angles. The orthogonal orientation of the canals acts as a three dimensional coordinate frame for sensing angular acceleration.

The canals are ring-shaped structures with a widening at one end, called the ampulla. The ampulla is the important sensory component of the semicircular canal. The ampulla and canal are filled with a fluid known as endolymph.

The ampulla contains many hair cells, and the cilia from these hair cells are embedded in a gelatinous mass known as the cupula. The kinocilia of each hair in the ampulla is oriented in the same direction with respect to the canal. Movement of the cupula in the direction of the kinocilium ultimately results in depolarization of the hair cell and increased firing rate. When the cupula is deflected away from the kinocilum, the firing rate of the cell decreases.

When the head begins to rotate, the canals also rotate. Initially, inertia causes the endolymph in the canals to remain stationary. The movement of the canal relative to the fluid causes the endolymph to flow through the canal into the ampulla, resulting in deflection of the cupula and change in the firing rate of the hair cells. This is detected by the brain and interpreted as angular acceleration of the head with respect to space [Guyton & Hall, 2000].

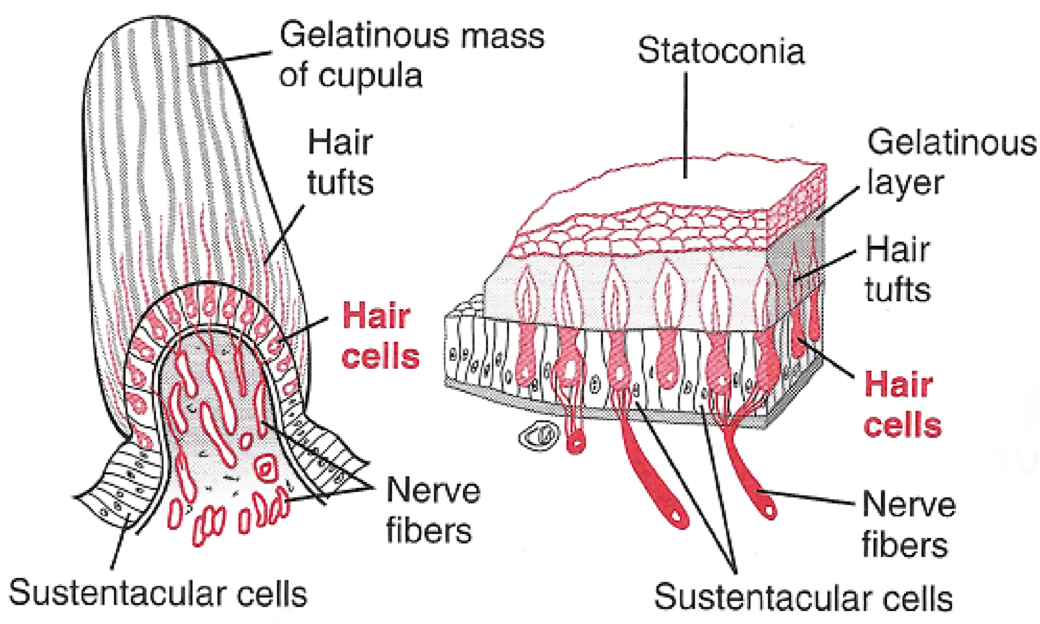

Figure 2: Crista ampullaris and macula

(Reprinted with permission from Guyton and Hall: Textbook of Medical Physiology, 10th Ed. Philadelphia: WB Saunders CO, 2000)

1.3. Measuring Acceleration

Acceleration is defined as the rate of change of velocity with respect to time [Merriam-Webster Online, 2008]. It is typically expressed in m/s^2 or as a multiple of acceleration due to gravity. The acceleration due to gravity on the surface of the Earth is approximately 9.8 m/s^2

An accelerometer is a device for measuring acceleration. Many types of accelerometers exist, but the most basic accelerometer system only requires (1) a known mass and (2) a method for measuring the displacement of the mass. Consider a system with a mass (m) and a spring with spring constant (k). In the configuration shown in Figure 3, the spring and mass are oriented in the vertical plane. Gravitational acceleration (g) acts on the mass, causing it to be displaced by an amount denoted as Δz.

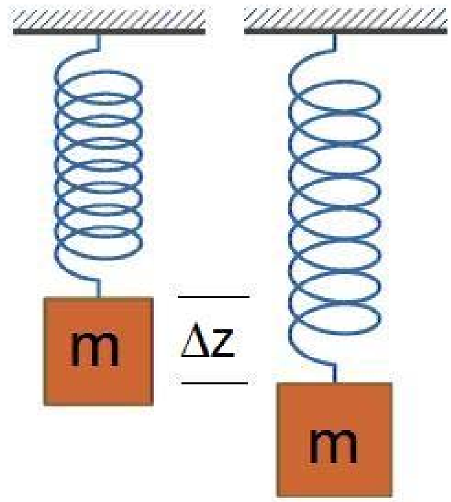

Figure 3: A simple accelerometer (spring-mass system)

There are two forces holding this mass in equilibrium: gravity (m*g) and the reaction force of the spring (k*Δz). In this case, the acceleration is known (g). If the entire system is accelerated in the z-axis, the acceleration can be calculated by:

$$a = \frac{k(\Delta z)}{m} - g$$

Equation 1: Calculation of acceleration for a spring-mass system

In Equation 1, the quantities m, g, and k are known and Δz is the measured displacement. This is the basic principle behind the accelerometer. In some systems, the mass' deflection is measured using the actual change in position, but more often, an electrical system replaces the “spring-mass” system, and changes in voltage are detected.

Accelerometers can be configured to measure acceleration in a single axis or in multiple axes. Tri-axial accelerometers are able to detect acceleration in three dimensions, mimicking the human otolith organ’s ability. Quantification of both the magnitude and direction of acceleration is important when determining its potential effect on human physiology.

1.4. Acceleration and Head Injury

Recent statistics reveal that approximately 1.4 million head injuries occur annually in the United States [Langlois, 2006]. Many of these injuries are sustained during sports-related activities. The most common head injury sustained during sports activities is concussion, which may have serious consequences such as memory loss and behavioral changes [CDC, 2007]. Concussion is defined by the Congress of Neurological Surgeons as a clinical syndrome characterized by the immediate and transient post-traumatic impairment of neural function such as alteration of consciousness or disturbance of equilibrium due to brainstem involvement [Congress of Neurological Surgeons, 1966].

Although concussion is a common consequence of head injury in athletes, it is often challenging for clinicians to diagnose and manage. There are a myriad of possible concussion symptoms, including amnesia, loss of consciousness, headache, dizziness, blurred vision, attention deficit, postural instability, and nausea [Goldberg et al., 2006]. However, while some athletes may display many of these symptoms, others may experience none of these.

Of particular concern are repetitive head injuries, especially in athletes involved in high-speed or contact sports. The long-term risks of multiple concussions and the potential for catastrophic outcomes after sports-related head injury are topics of ongoing study. Post-concussion recovery time is variable, taking hours in some cases or several weeks in others. It is unclear how long the concussed brain remains at increased risk of re-injury. Because there are limited data on which to base return-to-play decisions, it is difficult to determine when it is safe to return an athlete to competition [Standaert et al., 2007].

The classification of injury severity is a topic of ongoing debate. There are currently over 25 published sport related concussion grading scales [Butterwick et al., 2005], but the scoring of these scales is subjective. Devising a grading scale that is both scientifically valid and clinically useful has proven challenging. Therefore, neurocognitive testing is often used in conjunction with grading scales. A wide array of neurocognitive deficits have been noted in concussed athletes, including reduced attention and disturbances in memory and learning [Butterwick et al., 2005].

1.4.1. Understanding Head Injury

Head injuries are a leading cause of death and disability [CDC, 2007]. Studies examining head injuries are usually conducted using anthropometric test dummies (ATD's), animals, or cadaveric components. Since the data are not collected from living human subjects, these studies are often augmented by mathematical models.

Mathematical models of head injury take into account the three major components of the human head. These are: the bony skull, the skin and soft tissue, and the skull contents (the brain, meninges, and vessels). For every impact, there are usually three separate collisions that can be considered.

Consider the example of a motor vehicle accident. The first collision occurs between the car and another object (e.g., a second car or a fixed roadside object). The second collision occurs as the occupant impacts the car. The third collision occurs within the occupant, and is the result of the movement of the occupant's internal organs within the body cavity.

In the case of rodeo riders, the first collision occurs when the animal bucks or impacts the ground. The second impact is the collision of the rider with the animal. The third impact occurs within the skull as the brain impacts the more rigid skull and may result in serious head injury.

1.4.2. Head Injury Criterion

The relationship between the magnitude of acceleration and the duration of an impulse with respect to head injury was first described by researchers from Wayne State University in 1960 [Lissner et al., 1960]. This became known as the Wayne State Tolerance Curve (WSTC). This curve, originally based on a series of six data points, indicated that accelerations became less tolerable as the duration of the impulse increased. Later, the WSTC was plotted on a logarithmic plot and an approximated linear function was developed that became known as the Gadd Severity Index (SI) [Gadd, 1966].

Later, the National Highway Traffic Safety Administration (NHTSA) defined a new parameter, the Head Injury Criterion (HIC) [NHTSA, 1972]. The HIC was based on an analysis of the relationship between the WSTC and SI. While the WSTC is calculated using the frontal axis acceleration, the HIC is based on the resultant translational acceleration.

In 1995, Tyrell et al. correlated levels of loss of consciousness to HIC values based on passenger train crash tests. These results are summarized in Table 1. The data suggest that unconsciousness may result from relatively low HIC levels. The table also describes the possible head injuries that are likely to result from impact events, ranging from linear fractures to non-survivable injuries [Tyrell, 1995]

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

Table 1: Concussion and head injury in relation to HIC

1.5. Acceleration and Injury in the Rodeo Environment

Rodeo is a fast-paced sport that continues to increase in popularity. Over 700 rodeos take place annually in North America [Johnston et al., 2001]. “Rough stock” events include bull, bareback, and saddle bronc riding. The animals and rules of each rough stock event contribute to the acceleration profile experienced by the rider.

Head injury is of particular concern in rodeo rough stock events. By their nature, rodeo events are dangerous – the fast pace and unpredictability of the animals create an environment with the potential for serious injury. Rough stock events are among those with the highest injury rates.

Head injuries sustained during rodeo events have multiple possible etiologies. They may be the result of whiplash effects or actual impact with the animal. In addition, voluntary or involuntary dismount can produce head injuries from impact with the ground or crush injury by the animal [Downey, 2007]. Although participation in rodeo events places riders at risk for these types of injury, the current literature concerning rodeo-related head injuries is sparse and little is known about the accelerations experienced by the riders.

1.5.1. Rough Stock Events

Bull riding is one of the most popular rough stock events. The rules of bull riding are relatively simple, yet the ability to successfully complete a bull ride is rare. The rules require that the rider use a single hand hold to maintain his position on the bull. The rider moves dull spurs along the bull to maintain contact and balance. The bull is selected for competition based on his propensity to spin, turn, and kick. These attibutes make the ride more challenging. The rider's score is determined both by the rider's ability to accommodate the bull's bucking style and by the bull's bucking efforts. The rider is disqualified if he contacts the ground before the eight-second buzzer or if his free hand touches the bull, himself or the rope during the ride [HLSR, 2008].

The rules of bareback riding are similar, but the rider must maintain control of a horse, rather than a bull. The rider is required to maintain a single hand hold on the horse. The rider then uses his skill and agility to ride the horse for eight seconds. Unlike bull riding, however, the rider must “mark out” as he exits the chute. In this manuever, the rider keeps his feet above the horse’s shoulder until the horse’s front feet hit the ground for the first time. The rider then attempts to move in time with the animal. As the horse bucks, the rider pulls his knees up, and as the horse descends, the rider straightens his legs. The final score is based on both the horse’s bucking efforts and the rider’s technique. The rider is disqualified and receives no score if his free hand comes into contact with the horse, himself, or the rigging at any time during the ride [HLSR, 2008].

1.5.2. Rodeo-Related Head Injury

The Justin Sportsmedicine Team (JSMT) has over 25 years of experience with rodeo injuries and covers approximately 20% of Professional Rodeo Cowboys Association (PRCA) sanctioned rodeo performances annually. A recent report released by JSMT examined injury data collected from 1981 to 2005. Aggregate data from the 25-year report indicate that injuries during bull riding events are most common, accounting for approximately 50% of competition injuries. In bull riders, the most common anatomic sites for injury were head and shoulder. Bareback riding events produced the second largest number of injuries, usually accounting for over 20% of injuries. The head, shoulder, and knee were the three most common sites of injury in bareback riders. Of all injuries reported, the most common sites of injury are the head and face (16% of all injuries in 25-year period) and the most common major injury in rodeo is concussion, accounting for more than 50% of all major injuries [JSMT, 2006].

CHAPTER 2: METHODS

2.1. Study Design

Prior to developing a test protocol and determining the study population, the current literature concerning rodeo-specific injuries and sports related head injuries were reviewed. A search of the PubMed database was performed with keywords: “rodeo injury” and “sports-related head injury.” The search term “rodeo injury” returned fifty-six results, of which seven were found to be pertinent to the study. The search for “sports-related head injury” was limited to articles published in the last five years relating to human subjects. The search returned seventy-two results, of which eighteen were relevant. These articles were then examined in depth.

The literature review demonstrated a lack of human data gathered during actual rodeo events. However, the review revealed several studies in which accelerometers were used in an effort to characterize the acceleration environment encountered by professional athletes. These studies examined the head accelerations experienced by boxers, football players, and racecar drivers.

After review of the pertinent literature, the study team was formed. The principal investigator, Dr. Richard Jennings, brought together a multidisciplinary team to examine the accelerations experienced by rough stock riders. A collaborative relationship was formed with rodeo sports medicine representative, Mr. Don Andrews (Justin Sportsmedicine Team), and engineer, Dr. Ted Knox (Air Force Research Laboratory).

These collaborators assisted with the selection of appropriate hardware and development of a test protocol to measure the data of interest and to be applicable to the rodeo environment. Dr. Knox and his team at the AFRL were instrumental in the selection and development of the hardware used in the study. In order to gather the data desired, a data acquisition system (DAS) and accelerometers were used. The components used in the study are described in detail in section 2.3.

Development of documents for submission to UTMB's internal review board was the next critical step in the process. The research proposal, protocol, and subject consent form were drafted and submitted to the internal review board in late 2006. In January 2007, approval was granted for the use of human subjects.

2.2. Subjects

Two subjects were recruited for this study. Review of the literature demonstrated that bull riding and bareback riding were the two rough stock events with the highest injury rates; therefore, one subject from each event was selected. The number of subjects was limited due to the preliminary nature of the study.

The subjects selected for this study were required to meet certain minimum eligibility criteria. Inclusion criteria included male gender, age 18 to 35 years, and professional rough stock rider status. Exclusion criteria included history of ear pain or other ear problems.

The rodeo setting did not allow for recruitment of women riders. The population of interest, professional rough stock riders competing in the Houston Rodeo, included only males. The male subjects were screened to determine eligibility and to rule out the presence of ear problems that would preclude the subject from participating in the study.

Subjects were recruited from a population of professional rodeo riders scheduled to compete in the 2007 Houston Livestock Show and Rodeo. Study collaborator, Don Andrews, initially contacted the riders. After the subjects expressed interest in being involved in the study, they were given a formal introduction to the study objectives and protocol. The subjects were then given the opportunity to ask questions of the investigators and to examine the study hardware.

Written documentation of informed consent was obtained for each subject. The subjects were given copies of the signed consent forms for their files, and the principal investigator retained the original documents in accordance with IRB guidelines.

2.3. Equipment

Several pieces of equipment were used in the study. The principal components of the acceleration measurement system were the ear-mounted accelerometers and the data-recording device. Other equipment included the connecting wires, padded belt pack, computer, and the analysis software.

2.3.1. Accelerometers

The ear mounted tri-axial accelerometers used in the study were loaned to the research team by the AFRL. The components used in the manufacture of each of these devices included three small linear accelerometers, one angular rate sensor, and a custom mold of the subject's ear canal.

The first step in the manufacture of the ear-mounted accelerometers was creation of a custom molding of the ear canals of each subject. These molds were made by an audiologist using conventional materials and techniques. The molds were made several days prior to the rodeo events in which data were collected.

Each custom mold housed the linear accelerometers, angular rate sensor, and associated components. Three small linear accelerometers were oriented at right angles with respect to one another within the mold. Each earpiece also contained one angular rate sensor. The axes were oriented with the z-axis aligned with the gravity vector when the subject was in the upright position.

Figure 4: Custom molded earpieces with embedded sensors

2.3.2. Data Acquisition System

The data acquisition system was a critical component of the acceleration measurement system used in the study. The data recorder was loaned to the study team by the AFRL, and was configured to collect data from each of the sensor components worn by each subject. A total of eight channels of data were recorded for each subject. Four channels of data were collected from each earpiece: x-, y-, and z-axis accelerations and y-axis angular rate from the left ear and x-, y-, and z-axis accelerations and z-axis angular rate from the right ear. The data recorder collected 500 samples/second for each channel.

Small wires connected the ear-mounted accelerometers to the data recorder. The data recorder was configured to collect acceleration and angular rate data in the seconds before, during, and after the ride. The stored data was then transferred to the computer for further analysis.

Although the accelerometers and DAS were the major components of the study hardware, other items were needed to complete the acceleration measurement system. Small wires connected each ear-mounted system to the DAS. These wires were secured beneath the rider's shirt using sports tape. A padded waist belt was also used to house the DAS. This belt was secured beneath the rider's protective vest. Finally, a computer and analysis software were needed to examine the data collected.

2.4. Overview of the Test Protocol

The initial phase of the test protocol involved recruiting, selecting, and obtaining informed consent from the two rough stock riders. The next critical step was to create the custom molds of the left and right ear canals for each subject. These initial tasks were performed at the 2007 San Antonio Rodeo, which occurred several weeks before the Houston Livestock Show and Rodeo.

After the subjects had been recruited and written documentation of informed consent obtained, an AFRL audiologist made ear molds of the left and right ear canals of each subject. These custom molds were then returned to the AFRL for instrumentation.

Three linear accelerometers, an angular rate sensor, and associated wiring were inserted into each earpiece to create a custom ear-mounted measurement system. These custom systems and the DAS were transported to the Houston Livestock Show and Rodeo. Accompanying the equipment was team member Ted Knox and his associate Chad Ivan.

The study was conducted in a single evening in March at the 2007 Houston Livestock Show and Rodeo. Prior to the rough stock events the components of the acceleration measurement system were gathered. The equipment included: custom earpieces for each subject with wiring, the DAS, batteries, padded waist belt, computer, and transfer cables.

Several minutes prior to a subject's scheduled rodeo event, he was fitted with the study equipment. The subject was assisted with insertion of his custom earpieces. The wires connecting the earpieces to the DAS were run beneath the rider's clothing and secured with sports tape. The padded belt containing the DAS was then secured about the rider's waist and tightened to his comfort. The wires leading to the accelerometers were then connected and the DAS was placed in standby mode. The rider was then free to participate in his usual pre-ride activities.

Moments before beginning his scheduled event, the rider was allowed to enter the chute. The DAS system was then manually placed in recording mode by a study team member, and the subject completed his scheduled ride. At the conclusion of the ride, the DAS was turned off by the study team.

The rider was then assisted with disconnecting the wires leading from the DAS to the earpieces and removing the padded belt containing the DAS. The tape securing the wires was released, and the earpieces were removed. The subject was then asked about the presence of adverse events or other problems. Finally, the data recorder was connected to the computer, and the data were transferred to the hard drive for further analysis.

The data were then analyzed to determine the magnitude and direction of the accelerations experienced by each rider during his event. The data were also depicted in graphic form using Kaiser-Threde software. The next step in the project will be to further investigate the implications of the accelerations experienced and use this knowledge to modify the hardware and test protocol in preparation for a larger future study.

CHAPTER 3: RESULTS

3.1. Subject Selection

Two subjects were initially approached to participate in the study. Both subjects expressed interest in participation and were found to meet the eligibility criteria. Neither possessed any characteristics requiring exclusion from the study.

Written documentation of informed consent was obtained from each subject. Each subject successfully completed the test protocol. One subject was able to complete his eight-second ride, while the other was thrown from the animal prematurely. The second subject's inability to complete the entire ride was unrelated to the study.

3.2. Accelerations Measured during Bull Riding Event

The accelerations measured during the bull riding event reveal that the rider was subjected to multiple accelerative events. The bull rider was unable to remain in control of the bull for the full eight-second event. He involuntarily dismounted the bull after five seconds. During his five second ride, the bull bucked four times. The subject then impacted the ground with no serious injuries.

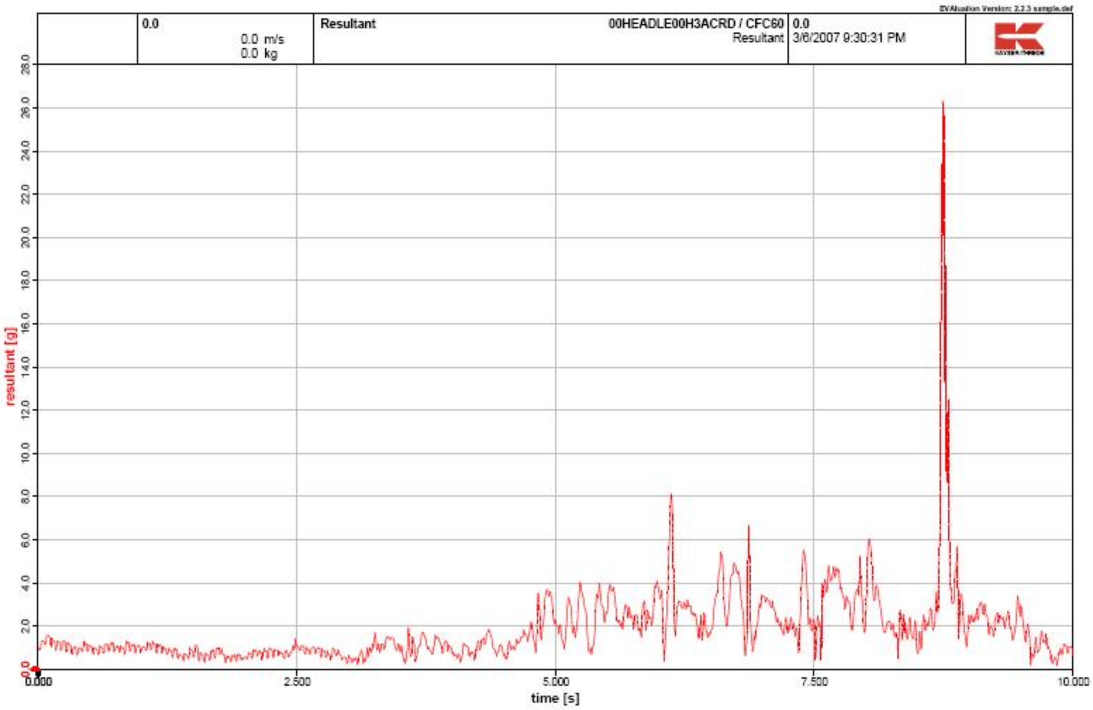

Figure 5: Resultant accelerations experienced by bull rider

Figure 5 shows the resultant acceleration experienced by the bull rider as measured for the left ear. The subject's ride began at the four second mark and concluded with an impact with the ground just prior to the nine second mark. As observed on video, the rider experienced several "bucks" of the bull prior to his involuntary dismount. The rider's upper body did not impact the animal at any point during the ride. His head and neck remained in general alignment with his spine. The video also captured the motions of the bull. The bull's efforts appeared constant throughout the five second ride. Its motions can be described as bucking, clockwise rotation with minimal forward translation.

The peak resultant acceleration was experienced during dismount and was found to be approximately 258 m/s^2 or 26 times the acceleration of gravity (26 g's). The accelerations recorded were greatest in magnitude in the z-axis. These findings were consistent with the motions captured on video.

3.3. Accelerations Measured during Bareback Event

The accelerations measured during the bareback event reveal that the rider was subjected to several accelerations of significant magnitude. The bareback rider remained in control of the horse for the entire eight-second event. He voluntarily dismounted the horse several seconds after the completion of his event and sustained no injuries.

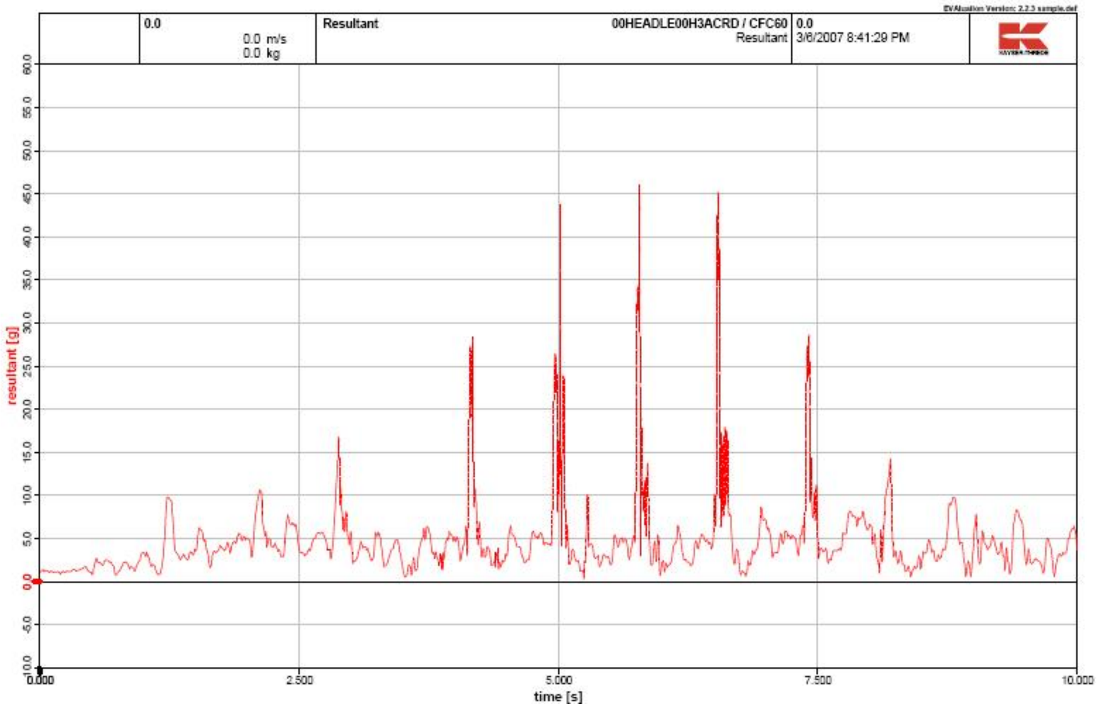

Figure 6: Resultant accelerations experienced by bareback rider

Figure 6 shows the resultant acceleration experienced by the bareback rider as measured for the left ear. The subject's ride began at the one second mark and the official event concluded at the nine second mark. The data shows excellent correlation with the video, which revealed that the rider was subjected to nine observable impulses during his eight second ride. The peak resultant acceleration was experienced at approximately the six-second mark and was found to be 450 m/s^2 or 46 times the acceleration of gravity (46 g's). The accelerations were greatest in the z-axis.

The video footage also revealed that the bareback rider's backward motion was arrested by impact with the animal in each of the nine impulses. The long axis of body of the rider was aligned with the long axis of the animal for the first seven impulses. During the final two impulses, the rider adopted a left-leaning posture. His head and neck remained in line with his spine during these impulses. The horse's motion was also captured on video. The movements of the horse can be described as bucking, forward translation, and slight clockwise rotation. Its bucking efforts appeared to initially increase in intensity until the four-second mark, after which time they appeared relatively constant.

3.4. Calculation of Head Injury Criterion

The maximum resultant accelerations experienced by each subject were used to calculate the maximum HIC. In this equation, "a" is the resultant acceleration experienced, "t_1" is the time recorded when the impulse begins, and "t_2" is the time recorded when the impulse ends [McElhaney, 1976].

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

Equation 2: Calculation of the Head Injury Criterion (HIC)

By convention, the time interval used in calculating the HIC is selected to maximize the computed value. The results of the calculation, as performed by the Kaiser-Threde mathematical analysis software, revealed potential for injury. The calculated HIC for the bull rider and bareback rider were 85 and 706 respectively. The bull rider's calculated HIC placed him at risk for headaches and dizziness. The bareback rider's HIC fell into a range with potential for more serious injury. The accelerations he sustained placed him at risk for loss of consciousness from the whiplash effects alone. Had the accelerations been the result of impact with the animal, his acceleration profile would have put him at risk for skull fracture [Tyrell, 1995].

CHAPTER 4: DISCUSSION

The primary goal of this study was to establish the capability to measure accelerations experienced by rough stock riders during actual rodeo events. The collaborative, multidisciplinary team was able to demonstrate this ability by measuring and recording the accelerations experienced by two professional rough stock riders in a small, preliminary study. This is the first step in understanding how head injury occurs in rodeo riders.

The results reveal that rough stock riders are subjected to high accelerative forces on a repetitive basis. The data demonstrate that rough stock events present danger from whiplash effects in combination with impacts with the animal or with the ground. The data collected from the two subjects suggest that acceleration events encountered during routine competition events have the potential to result in serious injury. Fortunately, the riders enrolled in the study did not experience any adverse events. Neither subject reported injury during the competition events, nor did the riders describe any problems with the protocol or hardware employed in the study.

Current injury prevention strategies in rodeo are limited. Most rodeo riders wear vests to prevent rib injury, and all riders are encouraged to wear helmets. However, few riders currently elect to wear protective headgear. Increased awareness of risks, prevention strategies, and the importance of timely identification and management of head injury is essential for reducing the incidence, severity, and long-term negative health effects of rodeo-related head injury. Quantifying and describing the accelerations experienced by rough stock riders are important steps in the creation of injury prevention techniques and safety devices.

4.1. Limitations of the Present Study

The data collected during this preliminary study suggest that rough stock riders may be exposed routinely to potentially dangerous acceleration profiles. However, the study was intended only as preliminary, proof-of-concept testing. The very limited number of subjects and test runs makes it difficult to draw conclusions regarding typical acceleration profiles and associated risks.

The HIC values calculated in this study suggest the potential for serious injury. However, there are still areas in which the HIC must be investigated. Currently, insufficient data exist to determine if it is appropriate to use the HIC for accelerations that are not the result of impact [Nahum & Melvin, 2001]. Further study of the utility of the HIC in non-impact conditions, such as rodeo whiplash acceleration injury, is needed.

4.2. Future Work

Further study of the accelerations experienced by professional rough stock riders is needed. The collaborative team formed to conduct the study outlined in this work plans to conduct additional studies at upcoming rodeo events. A grant proposal was recently submitted to the National Space Biomedical Research Institute (NSBRI) in an effort to obtain funding for the proposed study.

The proposed study would expand upon the knowledge gained during the 2007 project. Twenty subjects (ten bull riders and ten bareback riders) would be selected for participation. In addition to the larger number of test subjects, the study hardware would be improved to make it lighter and smaller in size. The data would be further enhanced by baseline and post-event neurocognitive testing for each subject.

The rodeo environment presents many challenges for riders. It is the hope of the research team that increasing the understanding of the acceleration profiles encountered by rough stock riders will lead to the creation of injury prevention devices and techniques. The small study outlined in this work serves as an important first step toward that aim.

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