Evaluation of the Load Limiting Capabilities of Football Neck Collars Using Anthropomorphic Test Devices

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ABSTRACT

The objective of this study was to perform a dynamic biomechanical analysis of neck collars in order to determine their effect on neck loading. A total of 32 tests were performed comparing the Cowboy Collar, Bullock Collar, and Kerr Collar. A control and each collar were tested at two speeds (5 m/s and 7 m/s), two impact locations (front and side of the helmet), and two shoulder pad positions (normal and raised). A 50th percentile male Hybrid III dummy was equipped with a helmet, shoulder pads, and the various neck collars mentioned. The helmet was struck with a pneumatic linear impactor. With the front impact location, the Kerr Collar greatly reduced lower neck force (27% reduction) and upper neck moment (43% reduction). The Cowboy Collar had a much smaller effect (<10% reduction) on neck loads. The Bullock Collar had a minimal effect on neck loads. With the side impact location, the Kerr Collar was capable of reducing lower neck moment by 18%. Although the collars had some effect on an impact to the side of the helmet, no collar greatly reduced any other neck load. These reductions in loads correlate with the degree to which each collar restricted motion of the head and neck. By restricting the range of motion of the neck and redistributing load to the shoulders, neck loads can be effectively lowered. To investigate the differences in results that using a different dummy may present, the same methodology was used comparing the Hybrid III and THOR-NT 50th percentile male dummies. 24 matched tests with were performed with the Hybrid III and THOR-NT. The dummies exhibited the same trends, in that either a load was reduced or increased; however, each load was affected to a different degree.

INTRODUCTION

Neck injuries in football can vary from the rare catastrophic event, to the much more frequent but less severe neck stinger. Stingers are a common injury in competitive football. Studies have shown lifetime injury incidences from 49% to 65% in college football (Clancy et al., 1977; Sallis et al., 1992). A stinger is most likely caused by injuring the upper trunk of the brachial plexus, which is made up of the C5 and C6 nerve roots (Robertson et al., 1979). This group of nerves runs from the cervical spine through the shoulder and into the upper arm, traveling directly under the clavicle. Stingers usually involve excessive hyperextension or lateral flexion of the head due to an impact, either with another player or with the ground. There are two main lateral flexion injury mechanisms: traction and compression. In a traction injury, the head is flexed laterally, and the brachial plexus ipsilateral to the impact is stretched. In a compression injury, lateral flexion combined with extension may lead to a pinching of the nerve roots when the foramina close on the contralateral side (Sallis et al., 1992). Many players will wear neck collars to prevent such injuries. These collar designs are based off empirical data, and few experiments have been conducted to quantify their effectiveness.

The neck collars that are worn by football players to prevent stingers were most often designed and put into use without biomechanical testing. Two researchers have attempted to quantify the effectiveness of these collars in reducing range of motion in the lateral flexion and extension planes: Hovis in 1994 and Gorden in 2003. Hovis and his collaborators outfitted a subject with a helmet and various shoulder pad/collar combinations. A pulley system was used to apply a quasi-static load to the subject’s head to produce either hyperextension or lateral flexion of the neck. Gorden took a similar approach in analyzing football neck collars, but opted to apply a force with a hand-held pressure transducer. While both researchers found that the collars limited extension of the neck, no collar was capable of reducing lateral flexion of the neck (Gorden et al., 2003; Hovis et al., 1994). The loading conditions utilized in these studies are not representative of the dynamic impact conditions that can result in stingers.

Due to the severity of injurious impacts in football, human volunteers cannot be tested using dynamic impact testing. Therefore, anthropometric dummies must be used to determine the load limiting capabilities of these collars in a dynamic impact environment. In the past, the Hybrid III has been the gold standard for the automotive industry when used to predict injury. Therefore, the majority of sports injury biomechanics research has utilized the Hybrid III dummy as a human surrogate (Manoogian et al., 2006; Pellman et al., 2003). However, the recent introduction of an advanced dummy, the THOR-NT, has provided another dummy that may be used for such testing.

The objectives of this study were:

1. To determine the load limiting capabilities of neck collars through dynamic impact testing using a Hybrid III dummy.
2. To investigate the influence of dummy design on neck collar testing using a Hybrid III and THOR-NT dummy.

METHODS

Three different neck collars were evaluated in this study: the Cowboy Collar (manufactured by McDavid), the Bullock Collar (designed by Virginia Tech head team physician, Richard Bullock), and the Kerr Collar (prototype designed by Patrick Kerr). The Cowboy Collar consists of a molded polyurethane foam collar that gets laced into the shoulder pads. The Cowboy Collar is designed to limit extension of the neck much more so than lateral flexion. The Bullock Collar consists of a high-density foam collar with a rigid plastic insert that is strapped to the shoulder pads. The Bullock Collar is designed to prevent hyperextension of the neck, with some restriction to lateral flexion. The Kerr Collar consists of a rigid synthetic mold that rests on the shoulders that is laced into the shoulder pads. The Kerr Collar is designed so that the base of the helmet contacts the collar, thus restricting motion in multiple planes.

An instrumented 50th percentile male Hybrid III test dummy was used to assess the effectiveness of these neck collars. The dummy was suited with a set of Douglas CP25 shoulder pads and a medium Riddell VSR4 helmet for all tests. A pneumatic linear impactor was used to strike the helmet. A total of 32 tests were performed where neck collar, impact velocity, impact location, and shoulder pad position were varied. The impacting velocities of stingers have not been studied or determined; therefore impact velocities were chosen so that they would encompass the impact velocities typical of tackling and blocking. The impacting speeds used were 5 m/s, and 7 m/s (Pellman et al., 2003). The locations impacted were the side and front of the helmet. The shoulder pads were tested in a normal and raised position. The raised shoulder pad position was meant to simulate a player assuming a tackling posture, in which the shoulders are naturally raised in anticipation of an impact. In order to raise the shoulder pads, shoulder implants made of expanding polyurethane foam were secured to the shoulders of the dummy.

The dummy was fitted with three single-axis orthogonally mounted accelerometers and a tri-axial angular rate sensor in the center of gravity of the head. The chest of the dummy was also fitted with an angular rate sensor. The dummy was instrumented with angular rate sensors during the 5 m/s tests. The head and neck's range of motion was calculated from the angular rate data using a technique described by Hall (Hall, 1998). The neck was instrumented with upper and lower neck load cells. The impactor arm was instrumented with a load cell and an accelerometer. A light gate was used to measure the velocity of the impactor arm as it contacted the dummy. All instrumentation was sampled at 10,000 Hz and processed in accordance with SAE J211. In addition, a high-speed video camera recorded each test at 1000 frames per second. All impacts were performed with a pneumatic linear impactor (Rowson et al., 2007).

An additional series of 24 matched tests were performed on the 50th percentile male Hybrid III and the 50th percentile male THOR-NT anthropometric test devices. These tests followed the same methodology as noted above, with the exceptions that only the front impact location and two neck collars (Cowboy and Bullock) were tested. The THOR-NT was instrumented with three single-axis accelerometers in the center of gravity of the head. Its neck was instrumented with upper and lower neck load cells as well as with front and rear load cells attached to the compression springs.

In order to properly compare the loads of the neck upper neck of the Hybrid III and THOR-NT, the loads for each dummy were summarized about the occipital condyle pin. To do this, the forces and moments in the neck were transformed to the coordinate system of the head. Then, the forces and moments were summed about the occipital condyle pin.

RESULTS

Neck Collar Comparison

A front impact promotes extension of the neck. Data of interest in a front impact test are the resultant head acceleration, upper and lower neck forces along the x-axis, and upper and lower neck moment about the y-axis. Figure 1 displays the load limiting capabilities of each neck collar for front impacts expressed as a percent reduction of the control tests. With the front impact location, the Kerr Collar greatly reduced lower neck force (27% reduction) and upper neck moment (43% reduction). The Cowboy Collar had a much smaller effect (<10% reduction) on neck loads. The Bullock Collar had a minimal effect on neck loads. A side impact promotes lateral bending of the neck. Data of interest in a side impact test are the resultant head acceleration, upper and lower neck forces along the y-axis, and upper and lower neck moment about the x-axis. Figure 2 displays the load limiting capabilities of each neck collar for side impacts expressed as a percent reduction of the control tests. With the side impact location, the Kerr Collar was capable of reducing lower neck moment by 18%. Although the collars had some effect on an impact to the side of the helmet, no collar greatly reduced any other neck load. No collar has any effect on resultant linear head acceleration for either impact location.

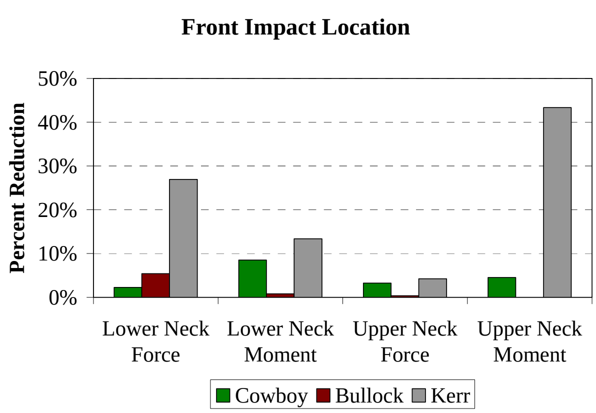

Figure 1: Load limiting capabilities of each neck collar for front impacts.

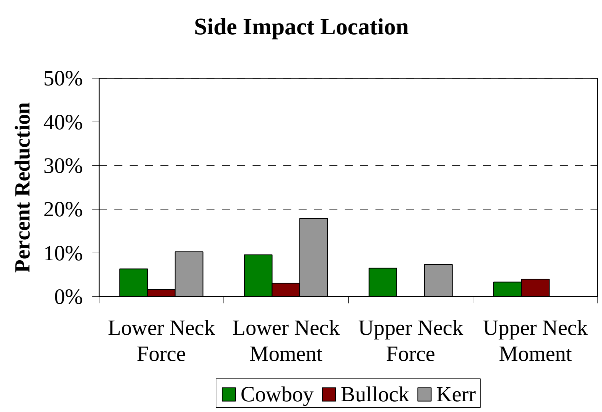

Figure 2: Load limiting capabilities of each neck collar for side impacts.

Each collar was capable of reducing the range of motion of the head and neck at each impact location (Figure 3). The Kerr Collar reduced range of motion to the greatest degree with both the front (38% reduction) and side (43% reduction) impact locations. The Cowboy Collar reduced range of motion by 7% for the front impact location and 6% for the side impact location. The Bullock Collar reduced range of motion by 15% for the front impact location and 5% for the side impact location.

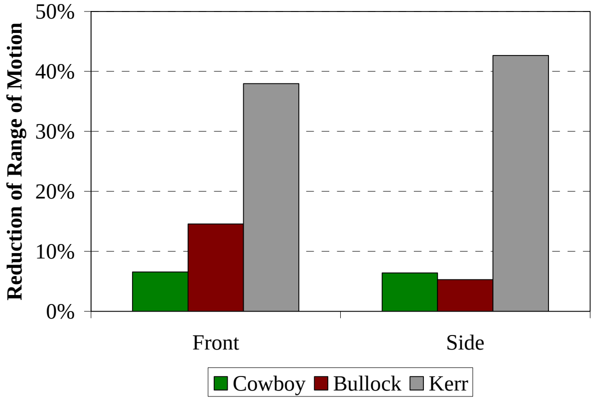

Figure 3: Percent reduction of range of motion for each collar at each impact location.

Dummy Comparison

Figure 4 and Figure 5 describe the overall effect of adding the neck collars to the shoulder pads for both the Hybrid III and THOR-NT. The Hybrid III produced greater loads than the THOR-NT. However, when normalized to the neck loads of the control tests, the Hybrid III had a similar response as the THOR-NT, in that each was capable of predicting a load reduction. The THOR-NT experienced a greater load reduction than the Hybrid III for upper neck force and moment. The Hybrid III experienced a greater load reduction for lower neck force and moment.

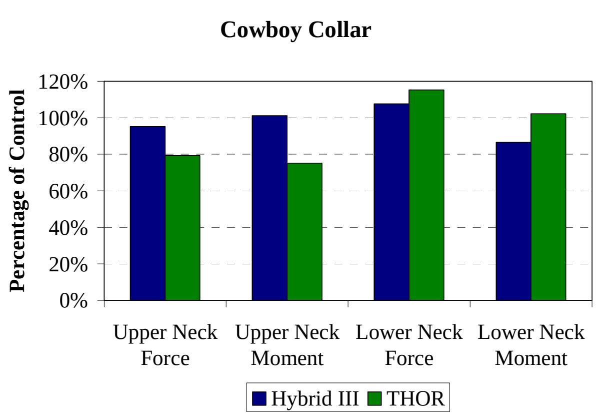

Figure 4: Effect of adding the Cowboy Collar to the shoulder pads for both the Hybrid III and THOR-NT.

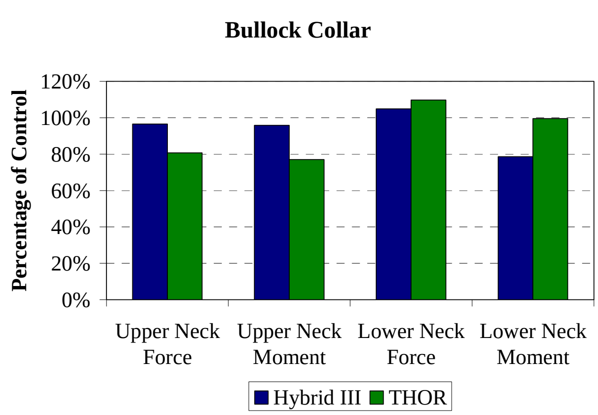

Figure 5: Effect of adding the Bullock Collar to the shoulder pads for both the Hybrid III and THOR-NT.

DISCUSSION

Neck Collar Comparison

The Kerr Collar also provided the most protection during an impact to the front of the helmet. It reduced upper neck moment and lower neck force in all configurations. The Kerr Collar also reduced the lower neck moment, but only in the raised configuration. Upon inspection of the high speed video, the collar restricts the range of motion of the head and neck by contacting the base of the helmet during the impact. This contact between the helmet and collar is responsible for the lower loads. The Kerr Collar typically performed better in the raised position because it contacts the collar sooner and restricts more motion. This is true for any of the collars in the raised position, due to earlier contact with the collar. The Cowboy Collar and Bullock Collar also provided protection for the dummy throughout the front impacts. The reductions of loads were not as large and consistent as the Kerr Collar, but they were capable of reducing loads in some configurations. In a side impact, none of the collars substantially reduced loads in multiple configurations. Only the Kerr Collar reduced the lower neck moment. Again, this is due to the base of the helmet contacting the collar, restricting the range of motion. This movement restriction is most noticeable in the high speed video.

The Kerr Collar performs differently than the other collars tested because it contacts the base of the helmet, which restricts motion of the head and neck. Restriction of motion correlates with load reductions. In the future, manufacturers should consider restricting the motion of the head and neck in more orientations than just hyperextension when designing collars. This restriction of motion should lead toward distributing loads to the shoulders, rather than the head and neck.

Dummy Comparison

Figure 4 and Figure 5 demonstrate the differences the addition of neck collars resulted in for each dummy. Although the each dummy exhibited the same trends, in that either a load was reduced or increased, each load was reduced or increased to a different degree. This is due to the neck collars interacting differently with each dummy's head, neck, and shoulder assemblies. It should be noted that the THOR-NT has been shown to have a more human-like neck response in extension than the Hybrid III (Pintar et al., 2005). Saying this, either dummy can be used for such testing; however, one must be cautious with the results as it is unknown which dummy interacts with the football equipment in a more realistic manner.

CONCLUSIONS

A series of 32 tests using the Hybrid III were performed to assess the dynamic biomechanical effects of neck collars used in competitive football. Each neck collar was tested at two different impact speeds, at two different impact locations, and two different shoulder pad positions. Reductions in loads correlated with how much each collar restricted the motion of the head and neck. With the front impact location, the Kerr Collar greatly reduced lower neck force and upper neck moment. The Cowboy Collar had a much smaller effect on neck loads, while the Bullock Collar had a minimal effect. With the side impact location, only the Kerr Collar was capable of reducing lower neck moment. Although the collars had some effect on an impact to the side of the helmet, no collar greatly reduced any other neck load.

An additional 24 tests were performed comparing the effect of the neck collars on the Hybrid III and THOR-NT. Although the collars exhibited the same trends in load reduction, the magnitude of reduction varied between dummies. These dummies are valuable tools for assessing the effectiveness of football neck collars in a dynamic impact environment. Either dummy can be used for such testing; however, it should be noted that the magnitude of load reduction will be dummy-dependent.

ACKNOWLEDGEMENTS

Thanks to Mike Goforth from the Virginia Tech Sports Medicine Department for providing the Center with equipment for this study. Thanks to Peter Martin of NHTSA for providing the THOR-NT used in this study.

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