Effect of Wheelchair Headrest Use During Rear Impact on Pediatric Head and Neck Injury Risk Outcomes

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ABSTRACT
Wheelchair transportation safety research has primarily addressed frontal impact consequences. This study is a first, examining effects of headrest use on pediatric injury measures under rear impact conditions. Two sets of three identical WC19 transit-option manual pediatric wheelchairs were tested: three sled tests were conducted without a headrest and three with a headrest. All tests used a 26 km/h, 10 g rear impact test pulse, seated Hybrid III 6-year old anthropomorphic test device (ATD), and 4-point strap-type surrogate wheelchair tiedowns and 3-point occupant restraints (WTORS). Results suggest a lower risk of head and neck injury with wheelchair headrest use.

KEYWORDS: wheelchair transportation safety, rear impact, pediatric injury risk, neck injury criteria, head injury criteria

INTRODUCTION

Many wheelchair users are unable to transfer to a motor vehicle seat and remain seated in their wheelchairs during transportation. A goal is to make transportation in a motor vehicle as safe for those who travel in wheelchairs as it is for those who travel in original manufacturer installed vehicle seats. Historically, most wheelchair transportation safety research has focused on frontal impact events. Yet, while most fatalities from motor vehicle accidents do occur in frontal impact, rear impact accounts for the greatest number of occupant related injuries [1, 2]. In response to this concern, vehicle manufacturers have focused research efforts on developing effective head restraints [3, 4]. Our research [5] has indicated that wheelchair headrests are prescribed for over 60% of all wheelchair users, and for 80% of all pediatric wheelchair users. However, there has been no previous effort to investigate the effects of wheelchair headrest use for pediatric wheelchair-users in rear impact.

Several different measures have been used in an effort to predict likelihood of human injury based on measurable criteria. Both physical and mathematical models of the head or head and neck, have been used to establish measurable parameters to assess injury risk [6, 7]. Maximum head acceleration, head injury criteria (HIC), neck injury criteria (Nij), rotational head velocity, rotational head acceleration are all measures that have been used in an effort to predict injury likelihood [8].

The purpose of this investigational baseline study was to establish quantitatively the potential benefit or harm of using a postural headrest for a wheelchair-seated pediatric occupant during rear impact. This was evaluated by comparing outcomes to a variety of injury risk measures.

METHODS

Six identical Sunrise Medical Quickie Zippie transit-option (ANSI/RESNA WC19 [9]) pediatric manual wheelchairs (17.9 kg) were tested: three without headrests, three with identical Sunrise Medical single-pad headrests (Table 1).

Table 1: Sled test matrix

Sled Test	Wheelchair configuration
1	No headrest
2	No headrest
3	No headrest
4	Sunrise Medical single pad headrest
5	Sunrise Medical single pad headrest
6	Sunrise Medical single pad headrest

All wheelchairs were tested with a seated Hybrid III 6-year old ATD using a 26 km/h, 10g rear impact crash pulse. Wheelchairs were secured using four-point strap-type surrogate wheelchair tiedowns; the ATD was restrained with a three-point occupant restraint system [9]. At the time of testing, the crash pulse conformed with the then proposed ISO test pulse for use in development of a draft voluntary industry standard for wheelchair performance evaluation in rear impact [10]. All wheelchairs were equipped with matched components and identically configured. A pin, inserted in the Sunrise Medical headrest stem joint, prevented headrest anterior-posterior slippage during rear impact. (Figure 2))

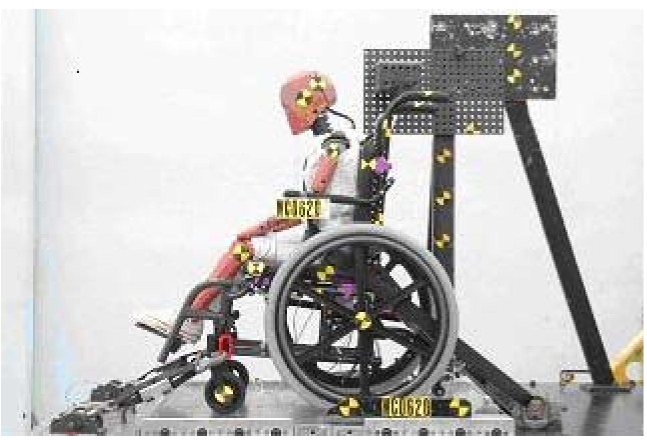


Figure 1: Wheelchair set-up without a headrest

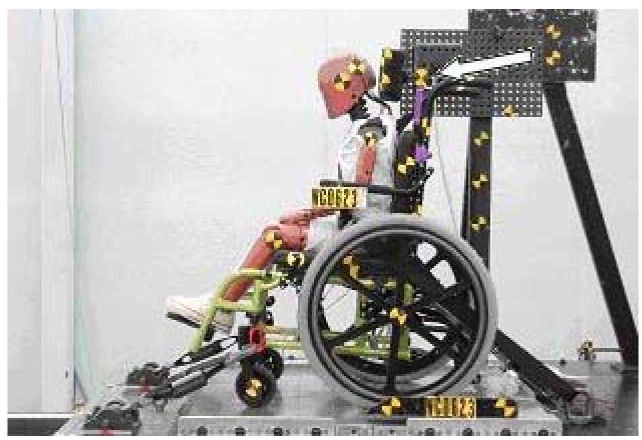


Figure 2: Wheelchair set-up with headrest. Arrow indicates pin location.

ATD instrumentation included a triaxial accelerometer positioned at the head CG to measure head accelerations; an upper neck load cell measured neck loads and moments. High-contrast markers, placed on the ATD head (2), shoulder and knee, indicated position throughout the test. High-speed video cameras (1000 frames/sec) recorded the test. Transducer data were recorded every 0.1 ms and filtered according to SAE J211.

Kinematic data from the tests described ATD response to rear impact. A Matlab program was used to acquire and track high-contrast marker location coordinates [11]. Kinematic data from video images were used to calculate rotational head velocity, and peak rotational head acceleration, which were compared to diffuse axonal injury (DAI) criterion, introduced by Margulies [12]. DAI is associated with maximum change in angular velocity and peak angular accelerations.

Transducer output for head acceleration, neck loads and neck moments, were used to calculate head injury criteria (HIC) values and neck injury criteria (Nij) values. HIC values were calculated using **Error! Reference source not found.** [13]. HIC_{15}, HIC_{36} and HIC_{un} were calculated using corresponding millisecond time intervals.

Equation 1: HIC calculation

$$HIC = \left[\frac{1}{(t_2 - t_1)} \int_1^2 a\,dt \right]^{2.5} (t_2 - t_1)$$

Nij establishes critical limits for neck axial loading and bending moments. Nij was defined by [14]:

Equation 2: Neck injury criteria

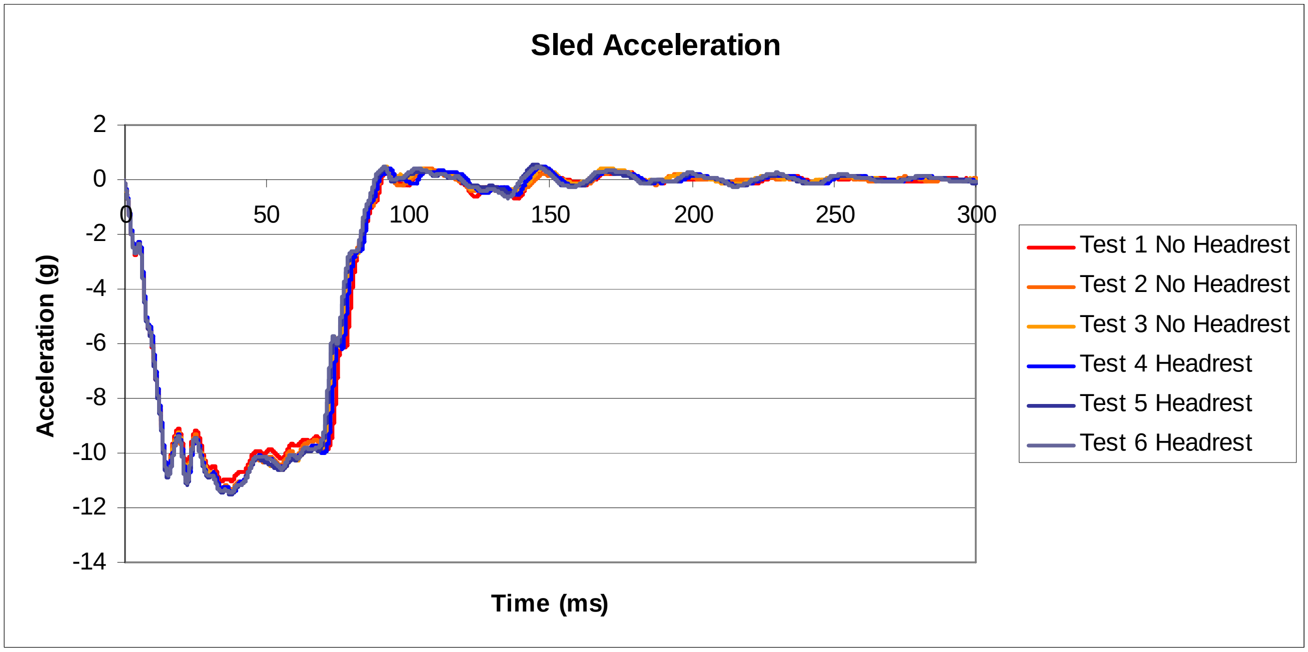
$$Nij = \frac{Fz}{F\,\mathrm{int}} + \frac{My}{M\,\mathrm{int}}$$

F_z = axial load
F_{int} = critical intercept load value used for normalization
M_y = bending moment
M_{int} = critical moment intercept value used for normalization

RESULTS

In all tests, sled acceleration plateau average levels were between -9.6 g and -10.0 g, sled acceleration peaks between -11.0 g and -11.6 g, and sled change in velocity (delta-V) between 25 km/h and 25.6 km/h. Graph 1 shows sled test acceleration profiles and sled acceleration pulse reproducibility.

Graph 1: Sled test acceleration profile



The Zippie wheelchairs remained structurally intact and the ATD maintained an upright posture throughout all rear impact tests. Initial evaluation of sled test video images (Figures 3 and 4) suggests a neck extension reduction with headrest use.

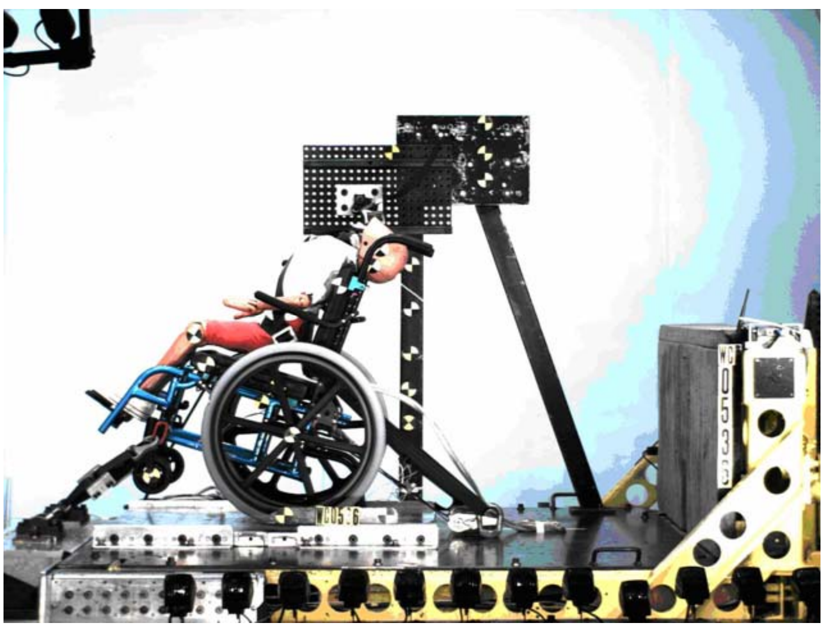


Figure 3: Maximum neck extension for Test 2 with no headrest

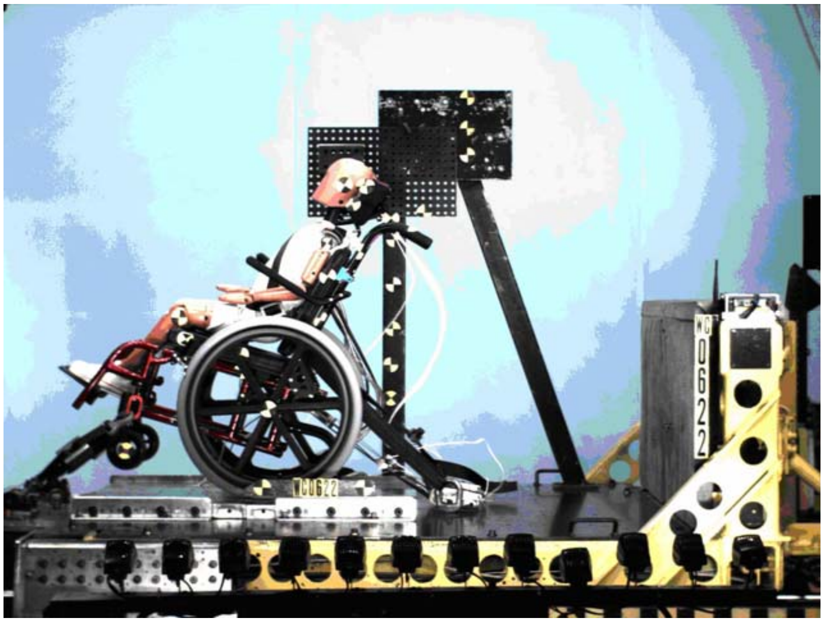
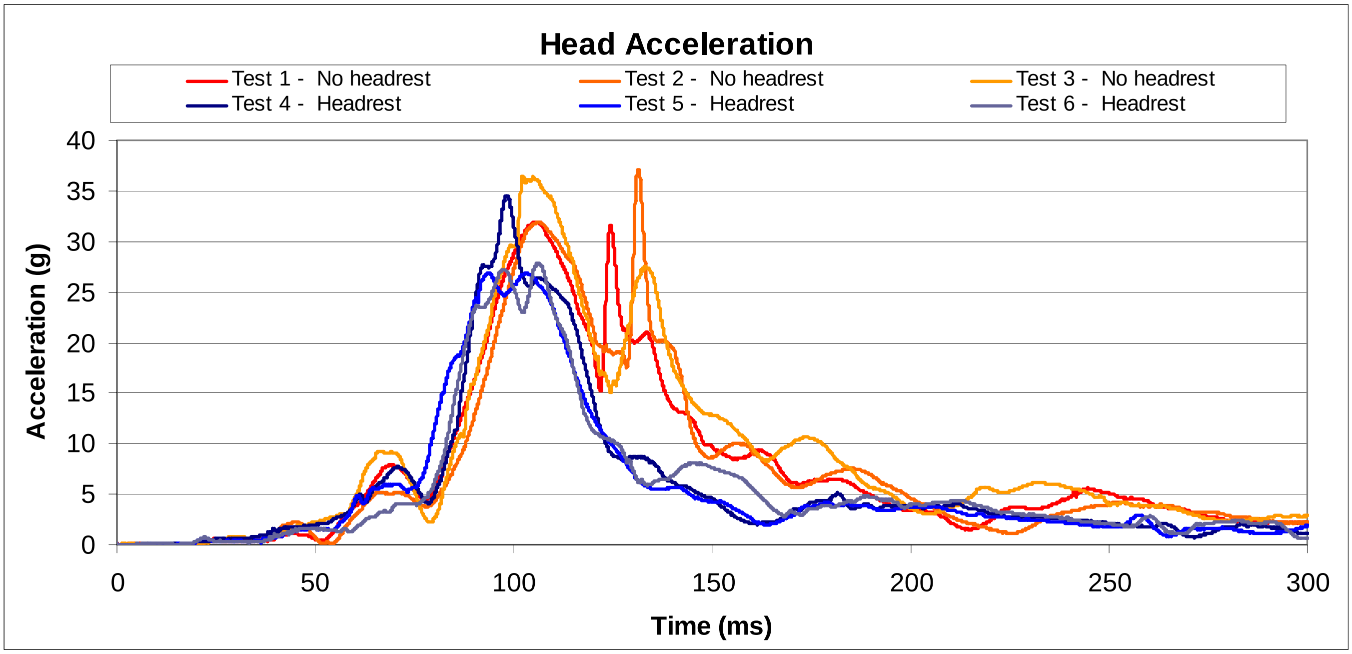


Figure 4: Maximum neck extension for Test 5 with a headrest

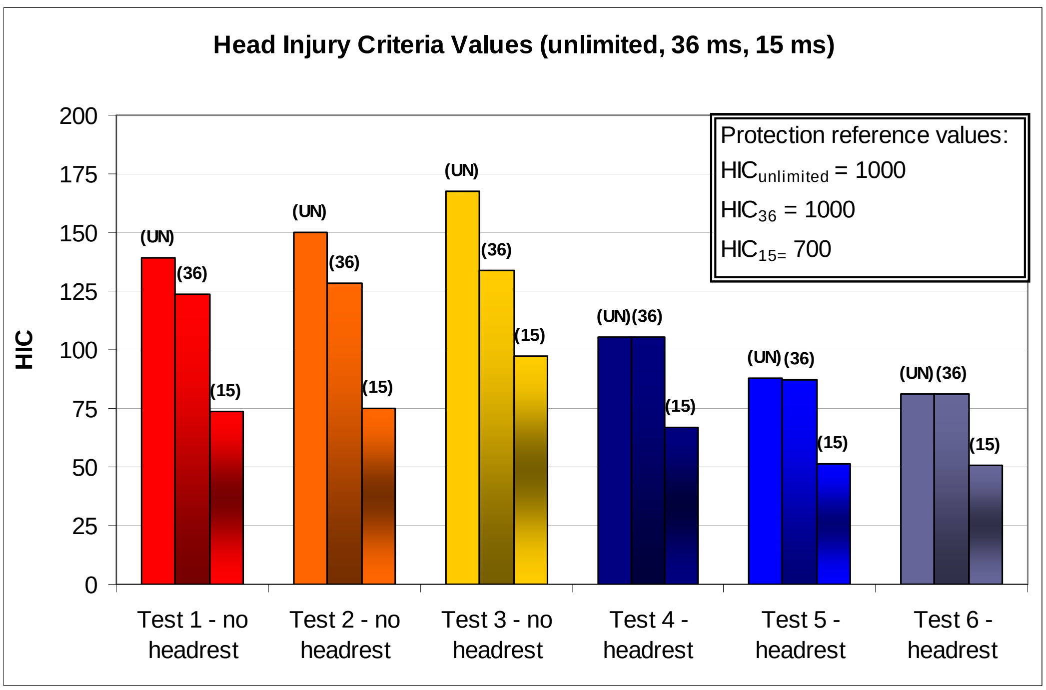
Head acceleration results (Graph 2) show higher peak head accelerations and longer duration of these accelerations during sled tests 1-3 lacking headrests when compared against tests 4-6 with headrests. Tests 1-3 show secondary acceleration peaks occurring during head-seatback contact. When compared to a proposed head acceleration protection reference value (PRV) of 80 g, [6] a low probability of associated head injury is predicted.

Graph 2: Translational head acceleration



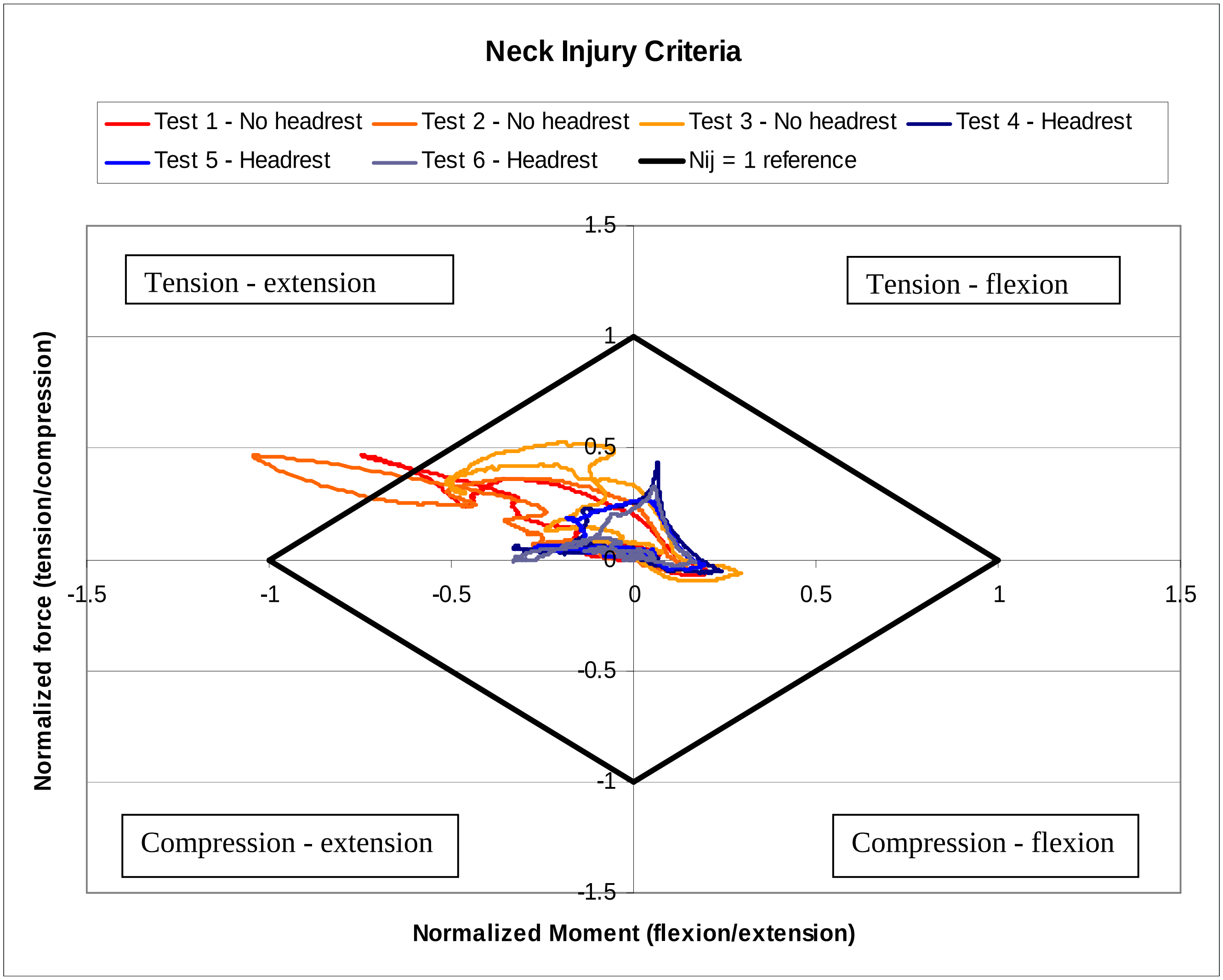
Peak head acceleration and associated duration is used in computing HIC. HIV value results for 15 ms, 36 ms, and the complete test are indicated in Graph 3. The HIC PRV for the 6-year old ATD are: HIC_{un} is 1000, HIC_{36} is 1000, HIC_{15} is 700; these levels are associated with a 23% chance of maximum abbreviated injury scale (MAIS) injury level $\geq$ 3 [6]. Tests 4-6 conducted with headrests yielded average HIC values 34% lower than tests 1-3 conducted without headrests, although all HIC values were below PRVs.

Graph 3: Head injury criteria values

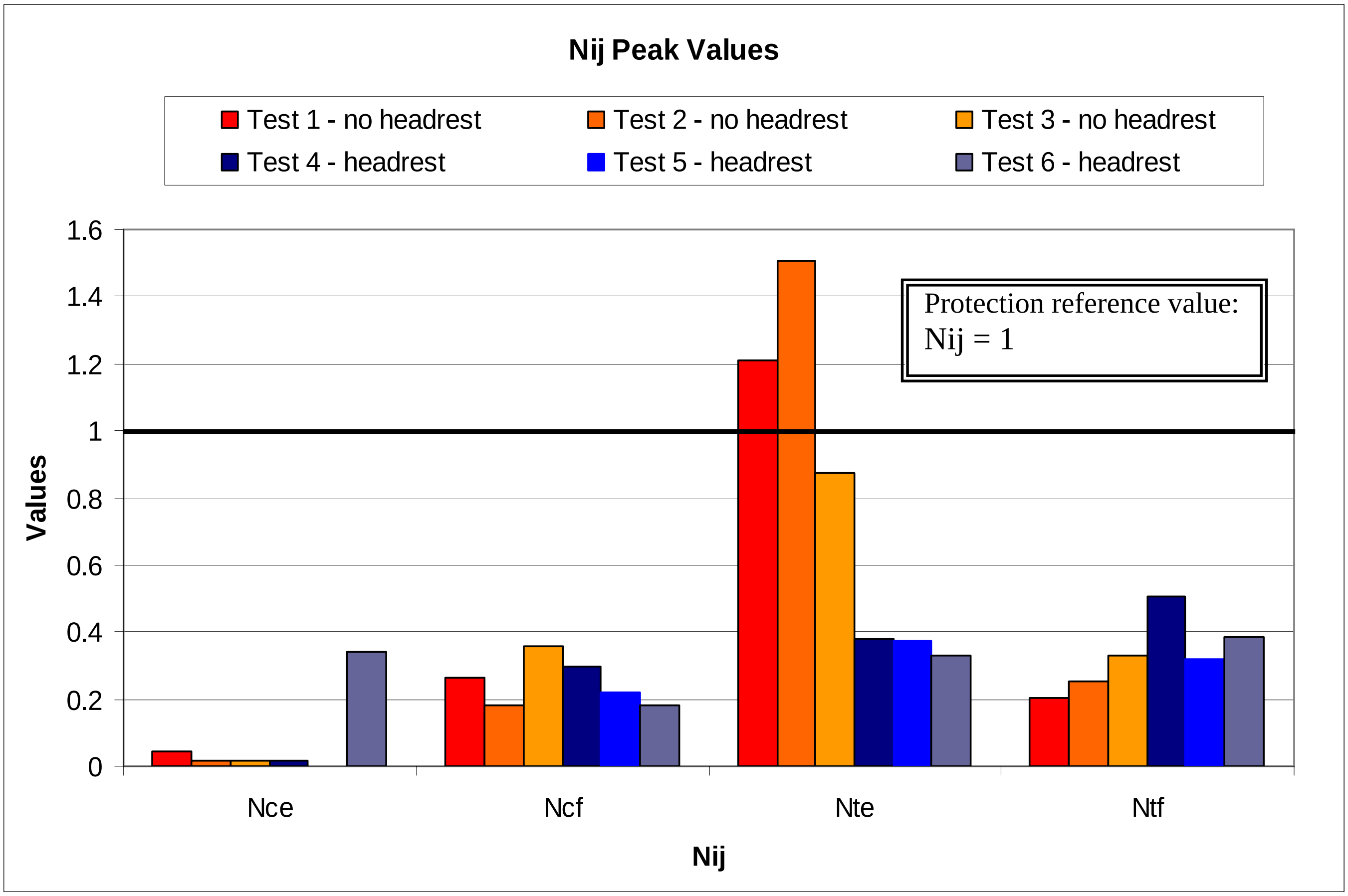


Graphs 4 and 5 highlight improved neck response with headrest use. Nij $\geq$ 1 is associated with 22% serious injury probability (abbreviate injury scale $\geq$ 3) [15, 16]. The mechanism of greatest concern during rear impact is the tension-extension portion of Nij. Our findings show that Nij results indicate ATD neck response in rear impact without a headrest exceeds PRV Nij=1. This occurred when the ATD neck reached maximum extension. Tests with headrests had 70% average reduction in $N_{tension\text{-}extension}$ over tests without headrests.

Graph 4: Neck injury criteria

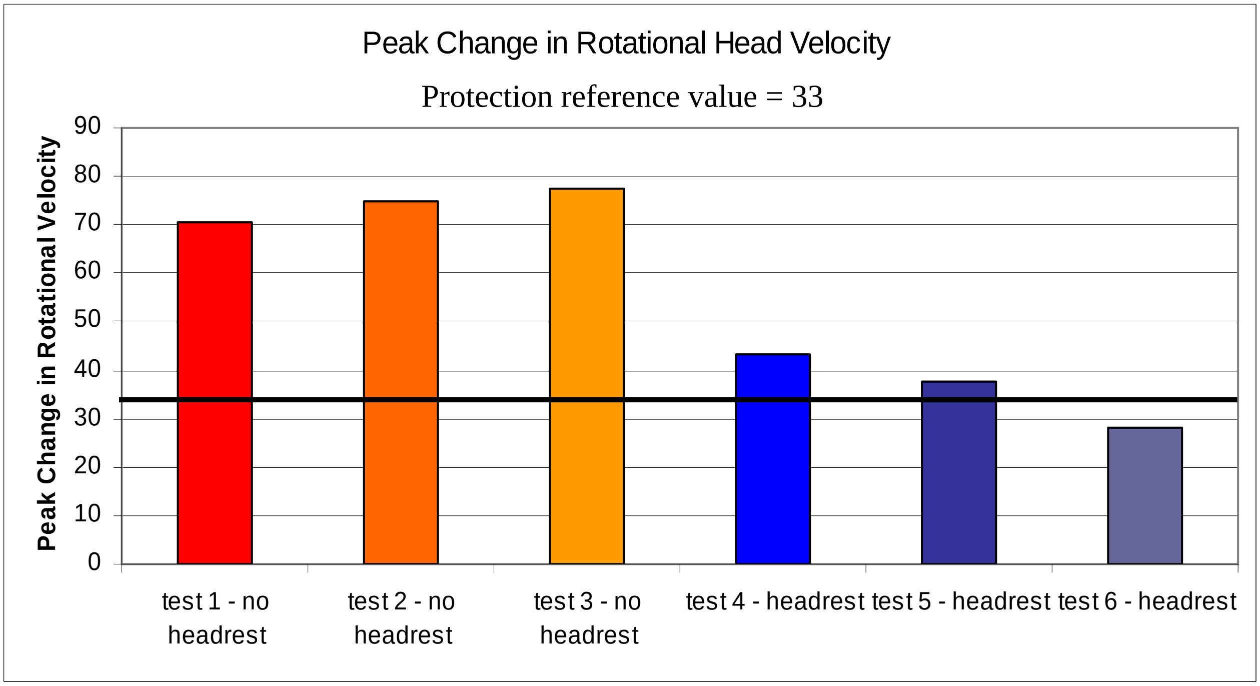


Graph 5: Nij peak values

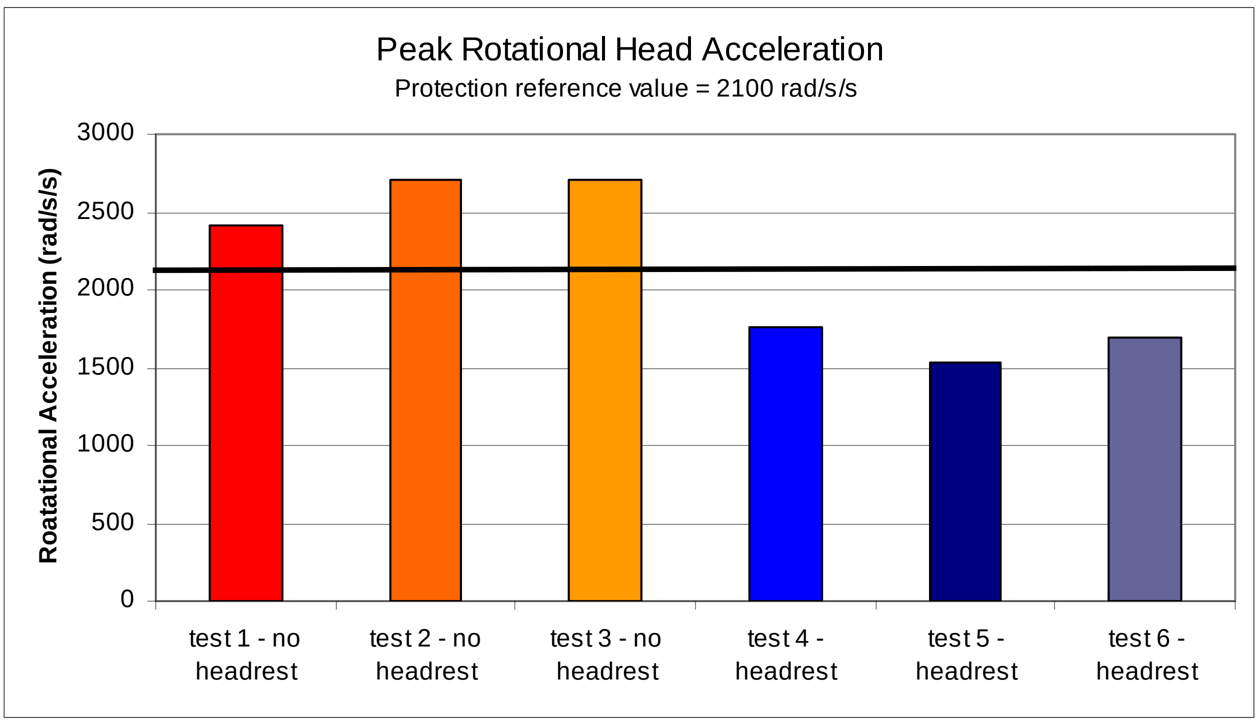


Both peak rotational head velocity change (Graph 6) and peak rotational acceleration (Graph 7) show that headrests reduce the rotational effects on the head. The rotational head response PRVs, not firmly established but cited by Klinich [6] based on Ommaya's work [17], are associated with AIS $\geq$ 3. In both graphs, values for tests without headrests exceed PRVs; those with headrests are close to PRVs. Tests 4-6 with headrests averaged 51% reduction in change in rotational head velocity, and 36% reduction in rotational head acceleration.

Graph 6: Peak change in rotational head velocity

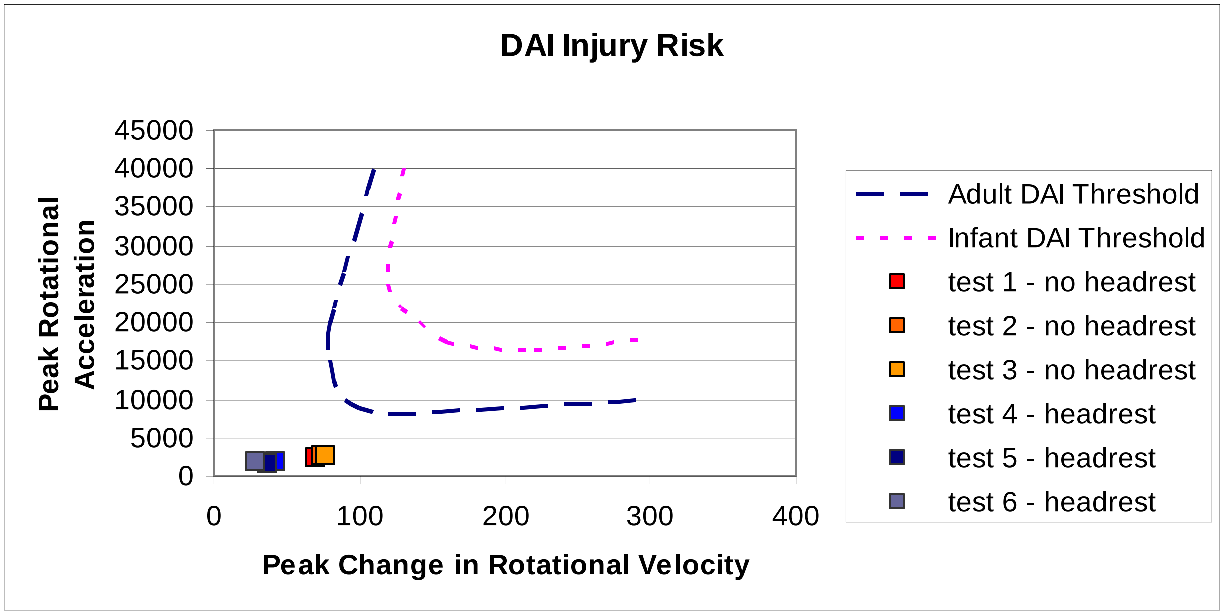


Graph 7: Peak rotational head acceleration



As noted in the DAI graph (Graph 8), all tests were below the injury threshold, with headrest-containing tests falling lowest.

Graph 8: DAI injury risk



DISCUSSION

This exploratory study of pediatric ATD response during rear impact demonstrates that use of a slightly modified commercially available wheelchair headrest designed solely for postural support has the potential to provide improved head and neck protection during rear impact. Each injury outcome measured, showed peak value reductions for tests with headrests; HIC, Nij, rotational head velocity, and rotational head acceleration all showed reductions in excess of 34%, and in some cases as high as 70%. This is a significant finding of this study since three-fourths of pediatric wheelchairs are prescribed with headrests and some school systems require wheelchair users to have a headrest for transportation purposes [5, 18].

It is important to note that there are some limitations associated with this study. Use of the ATD has limitations intrinsic with ATD biofidelity, especially with respect to ATD neck response. The Hybrid III 6-year old ATD neck has come under scrutiny for its response characteristics [19]. Many of the injury criteria PRVs used in this study were initially developed for the 50th percentile male and scaled for smaller ATDs. Many scaling parameters were based on limited testing. Furthermore, DAI injury criteria were derived from primate testing.

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