THE EFFECT OF SEAT BELT USE ON THE CERVICAL ELECTROMYOGRAM RESPONSE TO WHIPLASH-TYPE IMPACTS

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ABSTRACT

Objective: The objective of this study was to determine the effect of a standard 3-point lap-and-shoulder seat belt and car seat on the electromyogram (EMG) response of the cervical muscles to increasing low-velocity impacts in comparison with that of a rigid seat and 5-point restraint.

Methods: Seventeen healthy volunteers were subjected to rear, frontal, right and left lateral and bilateral anterolateral, and posterolateral impacts with an acceleration varying from 4.4 to 16.8 m/s² while in a car seat with lap-and-shoulder seat belt.

Results: For rear-end impacts, whether straight on, right posterolateral, or left posterolateral, all muscles generated 50% or less of the maximal voluntary contraction (MVC) EMG. In straight-on rear impacts, the sternocleidomastoid was symmetrically the most active; however, in posterolateral impacts, the sternocleidomastoid contralateral to impact direction was more active than its counterpart. For a right lateral impact, at the highest acceleration, the left splenius capitis generated 47% of its MVC and the left trapezius did 46% of its MVC. In a left lateral impact, the right splenius capitis generated 48% of its MVC and the right trapezius did 57% of its MVC. In a straight-on frontal impact, the left trapezius generated 35% of its MVC and the right trapezius did 48% of its MVC. In a left anterolateral impact, the right splenius generated 60% of its MVC and the right trapezius did 66% of its MVC. Similarly, in a right anterolateral impact, the contralateral splenius muscle increased its activity to 52% of its MVC and the left trapezius was at 52% of its MVC.

Conclusions: Compared with previously reported impact studies with a rigid seat and 5-point harness, the use of a 3-point lap-and-shoulder seat belt with a standard car seat did not appear to adversely affect cervical muscle response. In very-low-velocity and low-velocity impact experiments, seat belt and seat type may not significantly alter cervical EMG and kinematics. (J Manipulative Physiol Ther 2006;29:115-125)

Key Indexing Terms: Electromyography; Neck Muscles; Seat Belts; Whiplash Injuries

Seat belts save lives. However, there has long been concern that seat belts may increase the risk of whiplash injury—a problem that is of significant economic and health burden. It has been further argued that the occurrence of acute neck pain after low-velocity or very-low-velocity rear impacts may be the result of the effect of lap-and-shoulder seat belts, amplifying the injury potential. Thus, there may be a need for further design research to modify seat belt restraint systems so that they would not only maintain a lifesaving function but also mitigate against whiplash injury rather than contribute to it.

Although there have been various theories presented for decades on the mechanism by which seat belts may increase the risk of whiplash injury, the evidence has mainly been presented via epidemiologic studies; that is, some studies have suggested that seat-belted occupants of motor vehicles are more likely to report acute neck pain and other spinal symptoms than are non-belted occupants. As reviewed in detail elsewhere, however, there are a number of methodological issues that preclude any firm conclusion from these latter studies regarding seat belt use and whiplash injury risk.

Another approach may be to determine if cervical muscles (considered probable candidates for acute whiplash injury) respond any differently in the presence of a 3-point lap-and-shoulder seat belt in very-low-velocity impacts. We have previously reported volunteer impact studies accomplished using surface electromyography (EMG) combined with the...
use of regression techniques modeled on very-low-velocity collisions.13-20 This methodology is designed so as not to risk injury to the experiment subjects but to derive data from which further extrapolations can be made. The resulting data provide a detailed understanding of the cervical muscle response and the effect of various factors, including expectation of impact, head rotation or trunk flexion at time of impact, and direction of impact. We have specifically conducted impact studies on 8 directions of impact: rear and frontal straight on, left and right posterolateral, left and right anterolateral, and left and right lateral. Whereas it has been shown that the trapezius muscles mainly bear the burden of the neck perturbation in frontal impacts 16 and the sternocleidomastoids (SCMs) bear most of the burden in rear impacts,13 lateral impacts tend to more equally distribute the burden of impact against these latter muscles and the splenius capitus muscles.19,20 More specifically, the muscles contralateral to the direction of impact bear the impact burden most. The intermediate direction of impacts produces muscle response patterns intermediate between these cardinal directions.14,15,17,18

All our previous studies were conducted with a 5-point restraint system, which may not mimic the factors that potentially increase whiplash injury risk because of the differences between the 5-point restraint system and the typical motor vehicle 3-point lap-and-shoulder seat belt restraint. Furthermore, previous studies used a rigid chair for volunteers, not a typical motor vehicle seat. Given previous impact studies that provide detailed EMG and kinematic data, it would be helpful to know if cervical response depends in part on the type of seat and restraint system used. Most particularly, the restraint system is of chief concern given the aforementioned concerns about seat belts and whiplash injury.

To address a void in current knowledge, we thus undertook a study to assess cervical muscle response for 8 directions of impacts with a standard 3-point lap-and-shoulder seat belt and car seat.

Methods

Patients

Seventeen healthy subjects (5 males and 12 females) with no history of whiplash injury and no cervical spine pain during the preceding 12 months volunteered for the study. The 17 subjects had a mean age of 22.5 ± 2.7 years, a mean height of 172 ± 9.6 cm, and a mean weight of 67 ± 13.0 kg. The subjects were all right hand dominant. The study proposal was approved by the University of Alberta Health Research Ethics Board (Panel B).

Measures and Tasks

Active surface electrodes with 10× onsite amplification were placed on the belly of the SCMs, upper trapezius at the C4 level, and splenius capitus in the triangle between SCMs and trapezi bilaterally. The fully isolated amplifier had additional gain settings up to 10,000× with a direct current frequency response of 5 kHz and a common mode rejection ratio of 92 dB. Before calibrated sled acceleration occurred, the cervical strength of the volunteers was measured to develop a force-EMG calibration factor.21 The seated and stabilized subjects exerted their maximum isometric effort in attempted flexion, extension, and lateral flexion to the left and the right for force-EMG calibration, as described by Kumar et al.21,22 The acceleration device consisted of an acceleration platform and a sled (The full details of the device and the EMG data collection were published previously by Kumar et al.).13-20

After the experiment was discussed with the subjects and informed consent was obtained from them, their age, weight, and height were recorded. The volunteers then were seated on an old Volvo driver’s seat with a lap-and-shoulder seat belt only and were positioned in neutral posture as per previous protocols.13-20 The subjects were then outfitted with triaxial accelerometers (model no. CXL04M3, Crossbow Technology, Inc, San Jose, Calif) on their glabella and the first thoracic spinous process. Another triaxial accelerometer was mounted on the sled. The subjects were then exposed to rear impacts on 3 occasions for 3 directions (straight-on rear impact, left posterolateral, and right posterolateral impacts) of 4.4, 5.7, 7.2, and 13.4 m/s² generated in a random order by a pneumatic piston. On different trial occasions, separated by days to weeks, these same subjects underwent frontal and lateral impacts as well. The subjects were exposed to frontal impacts on 3 occasions for 3 other directions (straight-on frontal impact, left anterolateral, and right anterolateral impacts), with accelerations of 4.4, 6.3, 8.4, and 15.9 m/s² generated in a random order. The subjects were then exposed to lateral impacts on 2 occasions, right and left lateral directions, with accelerations of 5.0, 6.8, 9.2, and 16.8 m/s² generated in a random order. There was no blinding of visual or auditory cues; thus, there was an impact-expected state for the volunteers.13-20

Data Analysis

For each series of impacts, the data on the peak and average accelerations in all 3 axes of the sled, shoulder, and head for all 4 levels of accelerative impacts were measured. In the analysis, the sample of volunteers was collapsed across sex because preliminary analysis showed no statistically significant difference in the EMG amplitudes between the men and women. The sled velocity and its acceleration subsequent to the pneumatic piston impact and the rubber stopper impact were measured. All timing data were referred to the solenoid firing. The time of the peak acceleration was measured. Also, the time relations of the onset and peak of the EMG were measured and analyzed. The time to onset was determined when the EMG perturbation reached 2% of the peak EMG value to avoid false positives caused by tonic
Fig 1. Rear impacts. Head acceleration in the x-, y-, and z-axes of one subject in response to the level of applied acceleration in each of straight-on, left posterolateral, and right posterolateral impacts. The z-axis is parallel, the x-axis is orthogonal, and the y-axis is vertical to the direction of travel. Head X, head acceleration in the x-axis; Head Y, head acceleration in the y-axis; Head Z, head acceleration in the z-axis.
activity. This method was chosen to avoid false positives caused by tonic EMG. This method was in agreement with projection of the EMG line of slope at baseline. Electromyogram amplitudes were normalized against the subjects’ maximal voluntary contraction (MVC) EMG. The ratio percentage of the EMG amplitude vs the MVC normalized EMG activity for each subject allowed us to determine the force equivalent generated as a result of the impact for each muscle. The force equivalents were determined from data on maximum isometric effort in attempted flexion, extension, and lateral flexion to the left and the right for force-EMG calibration, as described by Kumar et al.²¹,²²

Statistical analysis was performed using SPSS Statistical Package (SPSS Inc, Chicago, Ill) to calculate descriptive statistics, correlation analysis between EMG and head acceleration, analysis of variance of the time to EMG onset, time to peak EMG, average EMG, and force equivalents. In addition, a linear regression analysis was carried out for the kinematic variables of head displacement, head velocity and head acceleration, and EMG variables. All regressions were initially carried out to the level of exposure and subsequently extrapolated to twice the levels of acceleration used in the study.

RESULTS

As expected, for all types of impacts, the subjects reported no symptom to suggest injury after the experiment and up to 6 months later.

Head Acceleration

The kinematic responses of the head to the lowest and the highest levels of applied acceleration for 8 directions are shown in Figs 1-3. As anticipated, an increase in applied acceleration resulted in an increase in excursion of the head and accompanying accelerations, regardless of impact
Fig 3. Frontal impacts. Head acceleration in the x-, y-, and z-axes of one subject in response to the level of applied acceleration in each of straight-on, left anterolateral, and right anterolateral impacts. The z-axis is parallel, the x-axis is orthogonal, and the y-axis is vertical to the direction of travel.
Comparing these response patterns with previously reported impacts with the same methodology (same directions, sled system, measurement system, and expectation of impact by volunteers),13-20 no statistically significant difference was apparent.

**Electromyogram Amplitude**

The mean peak (normalized) EMG amplitudes of the cervical muscles tested in this experiment at each applied acceleration level for the various impact directions are shown in Figs 4-7. In a straight-on rear impact, the SCM...
muscles showed the greatest EMG response as compared with the remaining muscles \((P < .05)\). When the impact was a straight-on rear impact, at the highest acceleration, the left SCM generated 47\% of its MVC and the right SCM did 50\% of its MVC. At the highest level of acceleration in a left posterolateral impact, the right SCM generated 43\% of its MVC but the left SCM reached only 21\% of its MVC, a statistically significant difference \((P < .05)\). A similar difference between the right and left SCMs occurred in right posterolateral impacts. At the highest level of acceleration in a right posterolateral impact, the left SCM generated 42\% of its MVC but the right SCM reached only

Fig 5. Normalized peak EMG (percentage of isometric MVC) in straight-on rear, left posterolateral, right posterolateral, straight-on frontal, left anterolateral, right anterolateral, left lateral, and right lateral impacts for left splenius capitis (LSPL) and right splenius capitis (RSPL).
26% of its MVC, again a statistically significant difference ($P < .05$). Thus, the SCM contralateral to the direction of impact is the more active one. Comparing these response patterns again with previously reported impacts with the same methodology, no statistically significant difference was apparent owing to the use of a Volvo car seat and 3-point lap-and-shoulder seat belt in this study vs that of a rigid chair and 5-point restraint in the previous studies.

In a given direction of lateral impact, the contralateral splenius capitis and contralateral trapezius muscle showed...
the greatest EMG response as compared with the remaining muscles ($P < .05$). When the impact was a right lateral impact, at the highest acceleration, the left splenius capitis generated 47% of its MVC and the left trapezius did 46% of its MVC, with all other muscles generating 29% or less of their MVC. For the highest level of acceleration in a left lateral impact, the right splenius capitis generated 48% of its MVC and the right trapezius did 57% of its MVC, with all other muscles generating 29% or less of their MVC—a statistically significant difference between the splenius capitis or trapezius and the other muscles ($P < .05$). Comparing these response patterns with previously reported impacts with the same methodology,19,20 no statistically significant difference was apparent, except that there is a trend ($P = .06$) for the contralateral trapezius to have shown a greater magnitude of EMG response than in previous lateral impact studies with a rigid chair and 5-point restraint.

In a straight-on frontal impact, the trapezius muscles showed the greatest EMG response as compared with the remaining muscles ($P < .05$). When the impact was a straight-on frontal impact, at the highest acceleration, the left trapezius generated 35% of its MVC and the right trapezius did 48% of its MVC, whereas all other muscles generated 21% or less of their MVC values. For the highest level of acceleration in a left anterolateral impact, the cervical muscle response was quite different. With this offset direction of impact, the right splenius now generated 60% of its MVC and the right trapezius was at 66% of its MVC, whereas the left trapezius was less active at 25% of its MVC—the remaining muscles being less than this as well. Similarly, the effect of a right anterolateral impact was noticeable in the muscle response. Here, the contralateral (left) splenius muscle increased its activity to generate 52% of its MVC and the left trapezius was at 52% of its MVC, whereas the right trapezius was less active at 29% of its MVC—the remaining muscles being less than this as well. For both anterolateral directions, these patterns are significantly different from the muscle response for the straight-on frontal impacts ($P < .05$). Comparing these response patterns and their magnitudes with previously reported frontal impacts with the same methodology,16-18 no statistically significant difference was apparent because of the use of a Volvo car seat and 3-point lap-and-shoulder seat belt in
this study vs that of a rigid chair and 5-point restraint in the previous studies. The one exception is that in previous right anterolateral impacts with a rigid chair and 5-point restraint in the previous studies, the splenius capitis muscles did not show as great a variation from their counterparts but the trapezius did and overall EMG activities were otherwise the same as those in this study.

**Timing**

For the 8 impact directions, the time to onset of the head acceleration showed a trend to decrease with increased applied acceleration, as did the time to onset of EMG (data not shown). The mean times at which peak EMG occurred for all the impact directions showed a trend to being reduced with increasing acceleration, but this did not reach statistical significance. There was a trend for times to onset of EMG to be shorter within this series as compared with prior studies using a 5-point seat belt restraint and a rigid chair, but times to peak EMG were in almost all cases not different from the trends observable with prior studies using a 5-point seat belt restraint and a rigid chair.13-20

**DISCUSSION**

This is the first study to make a direct comparison, using standardized methodologies, of the cervical response to different seat belt and chair designs in whiplash-type impacts. For ethical reasons, the impacts in this study were limited to very low velocities, extrapolated into the low-velocity range. Nonetheless, low-velocity impacts are a common source of whiplash claims and remain highly relevant.

In this study, where we used EMG measurements to study the cervical muscle when an occupant is involved in 8 directions of impact with a car seat and 3-point lap-and-shoulder belt, we show that there is no difference in the EMG response and kinematics as compared with identically conducted impacts with a rigid chair and 5-point seat belt restraint. Although we considered conducting an experiment with a lap-and-shoulder seat belt and a rigid chair so as to isolate the effect of changing solely the restraint system, this would not be helpful in itself in terms of approximating road collisions. Thus, we compared a 5-point restraint system and a rigid chair with a typical motor vehicle chair and restraint—and still did not find that these affected the cervical responses overall.

**CONCLUSION**

This study suggests that, at least for the directions of impact studied and under the expected impact condition, seat type and restraint type are not important factors in determining occupant response. This may not be true for other occupant positions or for higher-velocity impacts. More studies will be needed to determine if seat belts affect cervical response to whiplash-type impacts. Until more is known about the effect of seat and restraint designs on cervical response, the relationship between seat belts and whiplash injury remains unknown.

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**REFERENCES**


