Bracing strategies in forward leaning occupants: the effect of seat-belt pre-pretension and a startle warning during braking acceleration

Graci V, Griffith M, Seacrist T, Brase D, Mishra E, Pipkorn B, Nils N, Arbogast K

I. INTRODUCTION

Forward leaning positions may become more common with autonomous driving, but they may present increased injury risks [1]. Current restraints may need to be modified to reposition occupants during a pre-crash scenario. In a recent study, we demonstrated that the pre-pretensioner (PPT) was effective in reducing head and trunk forward position during a pre-crash maneuver characterized by braking acceleration [2]. A startle-based warning, the Acoustic Startling Pre-Stimulus (ASPS), was only effective when the PPT was not present [2]. No differences between sexes were found [2]. However, it is not known what neuromuscular bracing strategy the occupants adopt with different levels of PPT compared to when the PPT is not present, and if the ASPS had any role in the neuromuscular control of head and trunk motion. The aim of this study was to characterize the bracing strategies adopted by forward leaning occupants during a pre-crash maneuver characterized by braking acceleration.

II. METHODS

Sixteen healthy forward leaning (40º, [2]) human volunteers (8 males, age 23.8 ± 4.2 years old, height 175.5 ± 6.8 cm, weight 72.3 ± 8.3 kg) were seated on a vehicle seat and restrained with a 3-point pre-pretensioner (PPT) belt (right side) on a sled simulating a low-speed frontal pre-crash maneuver (approx. 1 g of maximum forward acceleration and 0.3 s duration). The participants were exposed to 6 dynamic conditions repeated twice that included 2 levels of PPT (low and high force levels), ASPS and no-ASPS, and a baseline condition with the sled motion only. Noise cancelling earphones delivered the ASPS at 105 dB, 250 ms before the sled motion for 40 ms. The PPT was also triggered 250 ms before the sled onset. The low PPT force level was about 100 N while the high PPT force level was about 300 N, both measured at the D-ring. After the tests, subjects completed a post-test survey to understand their opinions on the PPT levels and the study overall.

Three lightweight belt webbing load cells (Denton Inc, Rochester Hills, MI) were installed on the shoulder belt, the right and left lap belt and sampled at 10 kHz using an onboard TDAS data acquisition system (DTS Inc, Seal Beach, CA). Surface Electromyography (EMG) wireless sensors (Delsys Inc., Natick, MA) were applied bilaterally to the sternocleidomastoid (SCM), mid-trapezii, anterior deltoids, biceps, brachioradialis, rectus femoris, and tibialis anterior. Subjects performed maximum voluntary isometric contractions (MVIC) before testing. EMG data were detrended, rectified, filtered with a 4th order recursive 6 Hz low pass Butterworth filter, normalized by MVIC and left and right averaged. Mean seatbelt load over the duration of the braking acceleration at shoulder, left and right lap, and mean EMG over the duration of the sled pulse (300 ms) were calculated and compared between the PPT levels and ASPS vs no ASPS conditions.

III. INITIAL FINDINGS

The analysis of the EMG and seatbelt data showed that the main differences in muscle activations and shoulder seatbelt loads were between the three different belt configurations (low and high PPT force level and no PPT), not between ASPS and no ASPS (Figure 1, Table I). The highest muscle activation across all muscles was present with no PPT where the seat belt loads were low (shoulder belt mean force around 75 N), while the lowest muscle activation was present with the high-PPT when the seat belt loads were the highest (shoulder belt mean force about 120 N). Lap belt loads were small (below 50 N). Muscle activation was the highest in the SCM muscle (Figure 1). Biceps, brachioradialis, deltoids, and tibialis show little activation, but they also show a trend across conditions similar to the other muscles: highest activation without PPT and smaller activation with PPT (Figure 1).

Survey responses showed that 100% of participants reported that the belt tightening made them feel safer. Regarding their overall discomfort level during the study, 68.8% of participants reported that their time was “not at all” uncomfortable, while 25.0% reported that they were “a little” uncomfortable; 6.3% reported feeling “a lot” uncomfortable.

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Among the participants who reported noticing the different pre-pretensioner force levels (75%), 50% reported that neither force level was uncomfortable, while 41.2% reported that both force levels were uncomfortable, and 8.3% reported that only the higher force level was uncomfortable.

TABLE I. Mean (SD) of seat belt loads (N)

	ASPS			No ASPS		
	low PPT	**high PPT**	**no PPT**	**low PPT**	**high PPT**	**no PPT**
Shoulder belt loads	115.5 ± 20.9	121.4 ± 24.9	77.7 ± 11.4	118.4 ± 14.8	125.9 ± 22.8	75.0 ± 10.1
Left lap belt loads	30.0 ±7.5	27.6 ± 6.42	38.5 ± 12.6	27.7 ± 7.3	27.9 ± 5.8	38.3 ± 11.9
Right lap belt loads	38.2 ± 9.9	45.7 ± 10.0	27.3 ± 10.0	38.2 ± 9.2	46.2 ± 11.1	23.0 ± 10.2

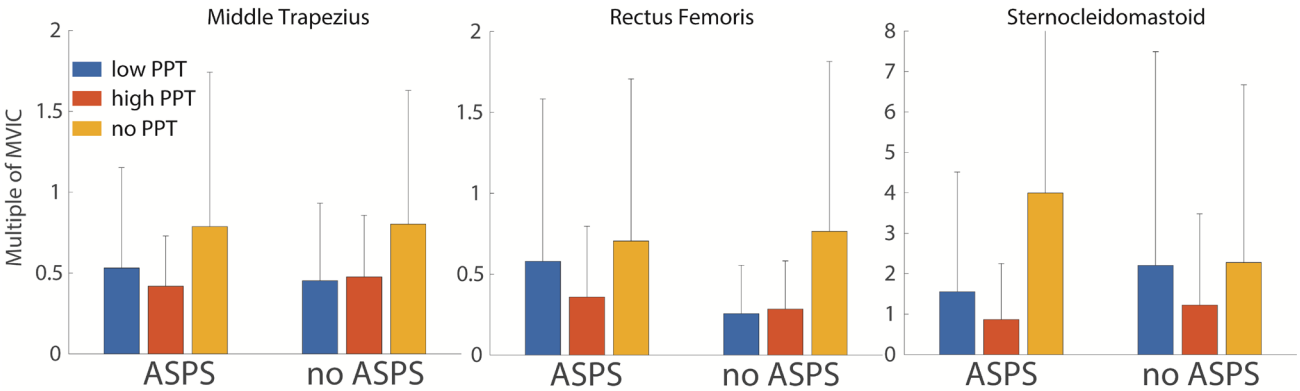

Figure 1. Mean (SD) of left and right averaged EMG over sled pulse duration, shown as multiple of MVIC, for middle trapezii, sternocleidomastoid, and rectus femoris muscles with and without ASPS across PPT levels.

IV. DISCUSSION

The results of this study suggest that overall the participants had increased muscle contractions with the PPT when they actively braced to control their movement, regardless the presence of the ASPS with the exception of the SMC muscle. This result is in line with the kinematic findings showing greater forward motion in the conditions without the PPT [2], which likely led the subjects to adopt an active bracing strategy (i.e., muscle contraction) to counteract the sled motion. Accordingly, the shoulder seatbelt loads were the lowest in the condition without the PPT, and the highest in the condition with the high-PPT (Table I), where the subjects were repositioned and did not need to employ an active bracing strategy. This trade-off between muscle activation and seatbelt loads with the PPT was previously observed in lateral swerving [3]. Under the no PPT condition, the SCM muscle showed greater activation with the ASPS versus no ASPS. The SCM is a muscle involved in the startle reflex [4] and so the SCM might have been more active than the other muscles, particularly in the ASPS condition. The SCM muscle showed greater activation than all the other muscles across all belt configurations, likely because the neck musculature is more involved than other muscles in bracing and head stabilization during a frontal pre-crash maneuver and it is integrated with the sensory systems (i.e., vision and proprioception) [5]. In conclusion ASPS showed some effect on bracing only in the neck muscle, but the PPT was more effective in reposing forward leaning occupants.

V. REFERENCES

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VI. ACKNOWLEDGMENTS

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ERRATUM

Bracing strategies in forward leaning occupants: the effect of seat-belt pre-pretension and a startle warning during braking acceleration

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The second last author's last name was reported incorrectly in the first version of the manuscript: it should appear as "Lubbe N" and not as "Nils N". Please see above for the correct spelling of all authors' last names.

The first sentence of the discussion should be: "The results of this study suggest that overall the participants had increased muscle contractions **without** the PPT when they actively braced to control their movement, regardless the presence of the ASPS with the exception of the SMC muscle."