Load-weighting Strategy between the Pre-pretensioner Belt and Neuromuscular Control in Forward-leaning Children in Frontal-Oblique Pre-crash Manoeuvres

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I. INTRODUCTION

Understanding the interplay between the seat-belt load and muscle activation is essential because occupants' biomechanics are shaped not only by inertial forces but also by voluntary and reflexive muscular responses, and by the degree of coupling between the body and the restraints before a crash occurs. Previous studies have shown that, in both pure frontal and pure side pre-crash manoeuvres, the pre-pretensioner (PPT) belt slack reduction and early tension provide an external stabilising force to the body. The PPT led to increased seat-belts loads and reduced muscular effort to brace compared to conditions without the PPT in non-booster-seated child and adult occupants [1-2], even in the case of forward-leaning postures [3]. The objective of this study is to understand if the same load-weighting strategy between PPT and neuromuscular control is adopted by booster-seated children when forward leaning during a frontal-oblique pre-crash manoeuvre.

II. METHODS

Eight child volunteers between the ages of 6 and 7 years old (mean: 6.6 ± 0.5 years) participated in the study (4 males, 4 females; weight 24.2 ± 2.1 kg; standing height 125.8 ± 4.4 cm; seated height 64.4 ± 3.9 cm). Volunteers were seated on a pneumatically actuated, hydraulically controlled low-speed impact sled in a high-back belt-positioning booster seat (BPB) on a rear vehicle bench seat restrained with a 3-point seat belt equipped with a pre-pretensioner (PPT) in the retractor. The volunteers were exposed to a far-side impact 30° from frontal with a maximum acceleration of 1 g and duration of 265 ms [3]. Four testing conditions were examined in a randomised order and repeated twice: seat-belt conditions with PPT (85 N force activated 250 ms prior to the sled onset) and without PPT, and initial seating postures of a standard posture and a forward-leaning posture [3]. Wireless surface electromyography (EMG) sensors (Trigno Wireless, Delsys, Natick, MA) were placed bilaterally on the sternocleidomastoid (SCM), middle trapezius, rectus abdominus, anterior deltoid, biceps brachii, and rectus femoris. Maximum Voluntary Isometric Contraction (MVIC) measurements were used to normalise the muscle activation recorded during the trials. Multiple of MVIC activation was averaged over the sled pulse duration for each muscle. Data points 3 standard deviations above the means were removed. Repeated measures 3-ways ANOVAs were conducted to examine the effect of PPT (on vs off), Posture (forward vs standard), and Repetition on multiple MVIC activations ($p<0.05$).

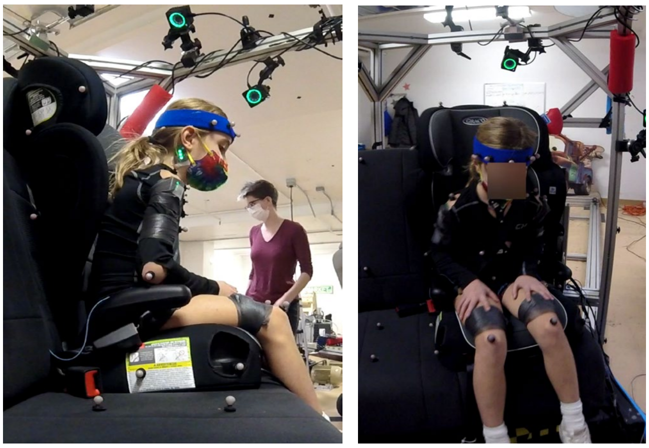

Fig. 1. Side and front view of the forward-leaning posture.

III. INITIAL FINDINGS

The main effect of PPT was found in right and left biceps ($p<0.04$), left rectus abdominis ($p<0.04$), and left rectus femoris ($p<0.05$) and it showed that with the PPT, muscle activation was reduced (Fig. 2 a, b, c, e). Right rectus abdominis and Rectus femoris (Fig. 2 d, f) and right and left deltoids did not show statistically significant differences ($p>0.06$). The effects of Posture and Repetition and all interaction effects were also not statistically significantly different across all muscles ($p>0.06$). Bilateral SCMs and middle trapezii showed values above 1 multiple of MVIC, so those were discarded from the analysis as the MVIC may not have represented the children's

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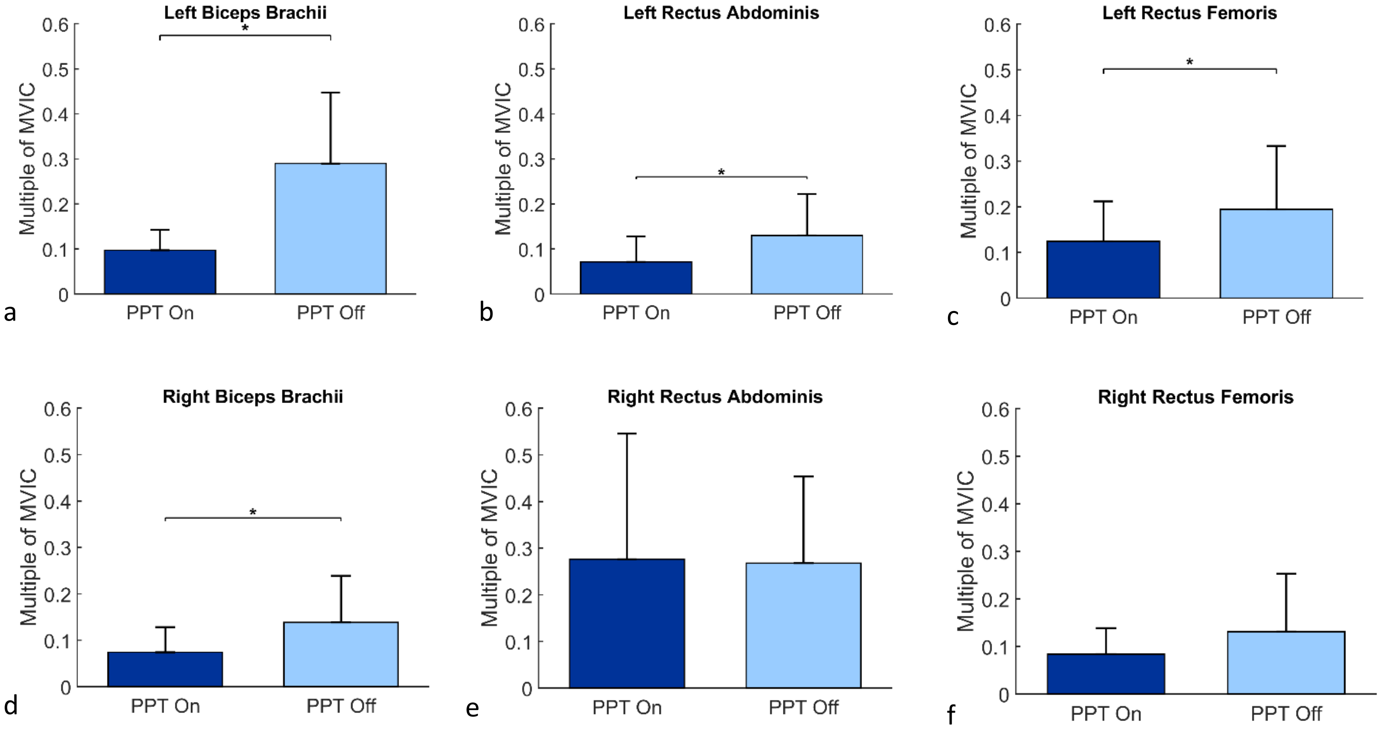

Fig. 2. Means (SD) across PPT conditions for left and right bicep brachii (a, d), rectus abdominis (b, e), and rectus femoris (c, f). *$p<0.05$

IV. DISCUSSION

These findings showed that, similar to older children and adults [1-3], forward-leaning booster-seated children also adopt a load-weighting strategy between the PPT and neuromuscular control when bracing. However, in oblique pre-crash manoeuvres, reduced or increased muscle activation in tests with or without the PPT, respectively, is not predominantly bilateral or unilateral across all muscles. The Rectus femoris and abdominis showed the load-weighting was only present on the left muscles, likely because the left shoulder is belted so that the left part of the body interacts with the PPT more directly and the PPT load is more concentrated on the shoulder-belt portion. This interpretation is in line with the findings related to the seat-belt load previously published from the same cohort of participants: the shoulder seat-belt loads were greater in the PPT on conditions compared to the PPT off conditions [3].

The biceps showed instead a bilateral load-weighting strategy, likely because the children braced with both hands on their thighs (Fig. 1), as shown by video evidence. The deltoids did not show a statistical difference between PPT conditions, although the trend was similar to that found in the biceps, highlighting the sample size as a study limitation.

The SCM and trapezii, which both control the neck, showed activations up to 8 times the MVIC. It is plausible that the startle reflex (usually found in the neck muscles) caused by the pre-crash sled motion caused a surge in activation in the SCM and trapezii muscles that possibly was not captured by the MVIC. Speculatively, this may suggest that the startle reflex might wash out the down-weighting or up-weighting of muscle activation versus seat-belt load in the presence or absence of the PPT, respectively.

Overall, these results suggest that the load-weighting strategy was mainly dominated by the PPT, as a main effect of Posture and an interaction effect of PPT by Posture were not found. It is possible that this PPT-neuromotor control coupling occurs regardless of seating positions and it is more influenced by the manoeuvre loading direction than by occupant postures. Future studies with larger sample size and a variety of non-standard seating positions are needed to confirm these preliminary interpretations.

V. REFERENCES

[1] Berkery, *et al*., 2024. Traffic Injury Prevention
[2] Ghaffari, *et al*., 2019. Traffic Injury Prevention
[3] Graci, *et al*., 2022. Traffic Injury Prevention