Changes in Naturalistic Postures Observed in Belt-Positioning Booster Seats Over Time.

Rosalie R. Connell, Gretchen H. Baker, Julie A. Mansfield

Abstract Motor vehicle collisions remain one of the leading causes of death for children despite the high effectiveness of child restraint systems. Specifically, belt-positioning booster (BPB) seats elevate children between 4 and 12 years old to achieve appropriate belt positioning. However, occupant posture also contributes to belt fit. Previous work has shown that BPB occupants' postures, and subsequently safety, are highly dependent on their environment and comfort. There are limited investigations into the varying nature of BPB occupant posture over extended time periods and the relationship to comfort motivated factors. Pediatric volunteers (n=30) were randomly assigned to two out of five possible seating configurations installed in a mock vehicle setting. Ideal reference postures were recorded, then volunteers were instructed to assume comfortable postures throughout a 30-minute trial during which postural data were continuously collected from XSENS inertial measurement units and video footage. Children significantly changed their posture over time trending towards slouched postures. These changes in posture were greatest for the no-BPB configurations. Incompatibility between child anthropometry and seating configurations contributes to such behaviors as children accommodate to the seat geometry to become comfortable. Future work can utilise these data to evaluate injury risks associated with naturalistic postures.

Keywords Belt-positioning booster seats; child passenger safety; inertial measurement units; pediatric injury biomechanics; pediatric occupant posture

I. INTRODUCTION

Motor vehicle collisions remain one of the leading causes of death for children across the world [1]. Child restraint systems (CRS) can mitigate injury and death for children in the event of a motor vehicle collision when properly utilised. The risk of injury is reduced by up to 45% for belt-positioning booster (BPB) occupants between four and eight years old compared to similar occupants in seat belts alone [2]. Despite the effectiveness of BPB seats in protecting children between 4 and 12 years old, booster-aged occupants particularly have high CRS misuse rates [3-5], contributing to their increased risk of injury during motor vehicle collisions within the pediatric population [6]. Shoulder belt positioning along the mid-clavicle and lap belt positioning along the bony pelvis are essential in the effectiveness of BPB seats, yet many children manipulate their belt position as they deliberately or unintentionally change their posture during travel. One such example of these behaviors is slouching, or forward translation and posterior rotation of the pelvis. This commonly assumed posture is associated with increased injury risk as lap belt placement along the abdomen can lead to unfavorable outcomes associated with presubmarining [7-10].

Posture analysis for BPB occupants has been conducted in both in-vehicle and laboratory settings to better understand the range of postures assumed and their influence on belt fit. Laboratory-based posture analysis has primarily been conducted on instantaneous, idealistic posture measurements [11-14]. On-road or vehicle-based studies, typically dependent on video footage, include naturalistic observations of BPB occupants in more realistic environments [15-20]. However, vehicle interiors are restrictive in terms of instrumentation capabilities and can lead to occlusions of bony landmarks of interest, such as the pelvis, that are pivotal to posture and belt fit analysis. Inertial measurement units (IMUs) offer a useful way to continuously capture anatomical segment orientation over time without the need for sensor visualisation in both laboratory and vehicle settings. These sensors have previously been used to monitor BPB occupant postures over short durations within the laboratory [21].

These previous studies on BPB occupant posture have found that changes in posture are related to BPB characteristics. Boost height or profile [9][13], stiffness [9], and the presence of side wings [19] have all been shown

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to influence BPB occupant posture. Changes in posture observed through these studies were associated with comfort, specifically changes that were related to slouching and belt rerouting behaviors [17-19]. Discomfort avoidance behavior (DAB) rate was recently developed as a metric to further explore relationships between comfort and BPB occupant behaviors [22]. This methodology quantitatively assesses occupant comfort by counting the number of discomfort avoidance behaviors (such as movement of the extremities, leaning, or belt rerouting) over specific time increments. Significant correlations between comfort and appropriate BPB use have been determined through this method [18][22], warranting further exploration of comfort motivated behaviors as they relate to BPB features, occupant posture, and appropriate restraint use.

Comfort driven changes in posture with respect to time have yet to be explored explicitly. Therefore, the objective of this study was to quantify how children naturally modify their postures over time in BPB seats. Inertial measurement units and discomfort avoidance behavior rate were primarily investigated to measure both posture and comfort continuously over 30-minute periods. These data can provide insight into how pediatric occupants adapt their postures and behaviors to become comfortable within BPBs and may ultimately contribute to models for future analyses of these naturalistic postures.

II. METHODS

Volunteers

Ethics approval was obtained from The Ohio State University's Institutional Review Board (Protocol 2022H0268). Thirty children were recruited based on their age (between 5 and 12 years old), height (107-145 cm; 42-57 in), and weight (18-45 kg; 40-100 lbs) to ensure that they fell within the manufacturers' specifications for the two BPB seats used in the study. Additionally, all volunteers verified their ability to sit for two 30-minute periods.

Seating configurations and laboratory setup

Two BPB seats were selected to represent a high-profile (12.7 cm boost) and low-profile (6.0 cm boost) BPB, to represent models in the US market with an average and low boost height [23]. The high-profile BPB was additionally selected for its adjustable armrest feature. A second-row captain's chair from a current model minivan was used for all BPB installations. The two BPB seats installed with or without armrests in the captain's chair, along with a baseline condition (no BPB, no armrests) allowed for five different seating configurations to be achieved (Appendix A, Fig. A1). Each volunteer was pseudo-randomly assigned two of the seating configurations from Table I (Fig. A2), after verifying that they fit within BPB manufacturers' guidelines. This resulted in 60 total trials, with 12 trials per BPB configuration. Each trial lasted 30 minutes to surpass previously documented thresholds for discomfort in vehicle seating arrangements [24] and to imitate longer travel durations based on averages in the US [25].

TABLE I:
SEATING CONFIGURATIONS

	BPB	Armrests
Baseline	None	No
Low-profile with armrests	Low-profile	Yes (from captain's chair)
Low-profile without armrests		No
High-profile with armrests	High-profile	Yes (from BPB)
High-profile without armrests		No

Tests were conducted within a stationary laboratory environment that simulated the interior of a current model minivan. The setup included both a front row and a second-row captain's chair that were positioned 75 cm apart and set at nominal 25° recline angles. The rear seat was elevated such that the seat pan was 38.7 cm above the floor to mimic an average minivan's interior dimensions [26] (Fig. 1). Volunteers sat in the rear captain's chair where the integrated belt was used for all configurations. Additional details can be found in [27].

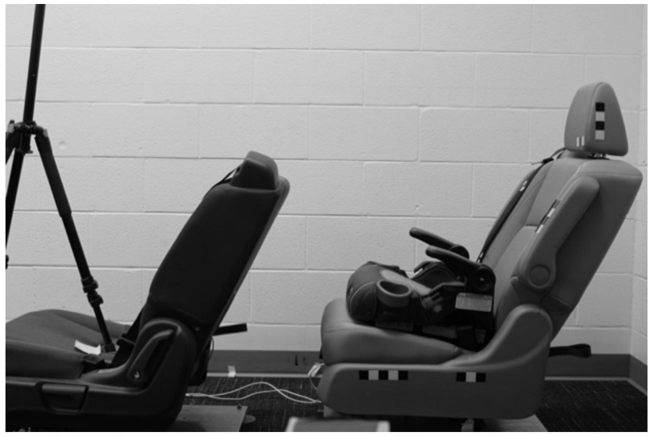

Fig. 1. Exemplar laboratory setup with a BPB (high-profile with armrest) in the rear captain's chair where the volunteer would be positioned for the trial.

Data Collection

Two video cameras were positioned to obtain a frontal and sagittal view of the participant in the rear seat throughout data collection. Entertainment was provided to the volunteers throughout the trials by mounting a tablet playing a movie of their choice to the back of the front captain's chair. Pressure mats (TekScan, model 5250) were placed along the belt-positioning booster or vehicle seat surface to collect pressure metrics (centre of force position [27], surface force, and surface area) at 60 Hz. Sensors were aligned and secured to the surface, such that they were centered, and covered the entire seating surface. Pressure mats were calibrated prior to each trail by placing known weights along the sensor. Along with pressure readings, video footage was recorded continuously to monitor discomfort avoidance behavior rate and changes in posture. Lastly, surveys were periodically provided to both the volunteer and their caregiver. Volunteers were asked to rate their comfort on a five-point Likert scale and indicate where, if at all, they were experiencing any discomfort. Caregivers were asked to rate their perception of their child's comfort and to indicate if their child behaved in a typical manner throughout the trial.

All subjects were instrumented with 17 non-invasive, wireless XSENS inertial measurement units (IMUs) (XSENS MVN Awinda, Henderson, NV) to continuously capture posture data throughout each trial. These sensors were placed on anatomical landmarks of interest according to previous analyses of BPB occupant posture as in [21] (Fig. A3). Velcro straps, athletic tape, and a specific shirt were used to securely position IMU along relevant anatomical regions of interest (Fig. 2). At the start of each volunteer's data collection, the XSENS system was calibrated according to the XSENS protocol [28]. Calibration procedures consist of having the volunteer stand in a neutral posture (N-pose), briefly walk forward, turn around, return to their original position, and assume N-pose again. Anatomical segment positions and joint angles were continuously collected at 60 Hz over the entire 30-minute trial. Specifically, XSENS IMUs were used to collect pelvis orientation, hip flexion angle, and knee flexion angle continuously over the 30-minute trials without the need for visualisation.

Subject Protocol

Upon arriving to the research facility, both seated and standing anthropometric measurements (Table A-I) were collected. XSENS and pressure mats were calibrated simultaneously. Following all calibration procedures, volunteers were instructed to sit in the rear captain's chair in their first assigned seating configuration. A certified Child Passenger Safety Technician assisted with fastening the seatbelt and instructing the volunteer to achieve ideal seating positioning within the configuration. Initially, the volunteers were directed to sit in ideal, upright postures. These "reference postures" were recorded when volunteers were settled, sitting up straight, and all the way back in the seat. Data were briefly collected including a photo, XSENS measurements, and pressure readings. After documenting the "reference" or ideal posture of the volunteer within the seating configuration, the child was given a verbal cue to assume comfortable postures, like they typically would within a vehicle, for the remainder of the trial (Fig. 2). This initiated the start of the 30-minute trial. Every 10 minutes, the volunteer was provided a two-question survey to gage their comfort. At the end of the first 30-minute trial, volunteers were allowed to stretch and walk around. The procedures were repeated after the second configuration was installed and sensors recalibrated.

Fig. 2. Exemplar subject in the upright, ideal, reference posture (left) and a self-selected comfortable posture assumed naturally during the 30-minute trial (right).

Data Analysis

All data recorded from the XSENS IMUs were reviewed for quality. Trials were removed based on poor calibration or sensor misalignment during data collection that resulted in outputs that greatly deviated from expected outcomes with respect to video footage. All segment orientation and joint angle data were interpolated over each minute of the 30-minute trial using a simple averaging technique. The average value at each minute was compared to the reference value (ideal posture) for each subject to determine the changes in posture over time. Statistical analysis was conducted on these differences to evaluate the influence of seating configuration (represented through armrests and profile as separate fixed effects) and time on postural changes.

The data reported below are in accordance with the segment coordinate systems at each joint [28]. Pelvis orientation is reported about the y-axis, which describes the anterior-posterior rotation of the pelvis. A more posterior rotation (i.e., backward leaning) is shown through a more negative y-orientation of the pelvis. Hip and knee flexion are reported in accordance with a coordinate system with the y-axis pointing superiorly, the x-axis pointing anteriorly, and the z-axis pointing to the volunteer's right. Therefore, hip and knee flexion are reported as increases in joint angle about the z-axis.

All statistical analyses were conducted using JMP Pro 17 (SAS Institute Inc., Cary, NC). Initial matched pairs t-tests were used to assess differences between the first and second trials, as well as left and right measurements for all reported metrics. Mixed models were used to assess the influence of the seating configuration (profile and armrests) on reference values for pelvis orientation, hip angle, and knee angle. Subject was included as a random effect. Additionally, average change, absolute maximum change, and cumulative changes in pelvis orientation, hip and knee angles over time were analysed with respect to seating configuration using the same mixed model. Average change was the mean deviation from reference posture over the 30-minute trial. Maximum changes from reference were the absolute greatest deviation in posture over the 30 minutes determined from the interpolated differences. Cumulative changes were evaluated by summing the absolute value of the interpolated changes with respect to reference posture over the 30 minutes as an assessment of the total amount of shifting of the volunteers with time. Changes over time were also evaluated using mixed models with time nested within subject as a random effect and both time and configuration included as fixed effects. Post hoc Tukey tests were used to further evaluate significant differences between profiles and armrests. The alpha level was set to 0.05 for all analyses.

Discomfort avoidance behavior (DAB] rate was collected from video-footage determined by documenting the number of DAB (stretching, shifting weight, fidgeting, etc.) over each minute throughout the entire trial [22]. DAB rate was also statistically analysed with respect to seating configuration and time following the model described previously. Further, XSENS data describing the pelvis and lower extremity posture were used to predict DAB rates through mixed models to relate changes in posture to occupant comfort.

III. RESULTS

Volunteers

Data from 30 volunteers were collected for this study. Fifteen boys and 15 girls between the ages of 5 and 12 were recruited. Each volunteer successfully completed two trials, for a total of 60 trials. Eighty percent of the participants (n=24) were current belt-positioning booster users. Relevant anthropometry for the cohort is summarised in Table A-I. Out-of-position postures were assumed by most volunteers (Fig. A4). In 44 trials (73.3%), caregivers reported their children behaved as they normally would during vehicular travel.

XSENS Posture Measurements

Initial matched pairs t-tests showed no significant differences for any metrics between the first and second trials of each volunteer, therefore all trials were assessed simultaneously. Matched pairs t-tests also showed no significant differences between measurements taken from the left and right hip and knee joint flexions, so average values were taken for left and right hip and knee flexion for further analysis (Table B-I). After removing poor-quality trials, 51 sets of XSENS data remained for analysis. The following results compare data from the 51 trials across the five seating configurations: baseline (n=11), low-profile with armrests (n=11), low-profile without armrests (n=10), high-profile with armrests (n=9), and high-profile without armrests (n=10). A summary of the collected metrics is included in Appendix A (Table A-II).

Reference postures, or ideal measures of pelvis orientation, hip flexion, and knee flexion, were first assessed between seating configurations, summarized in Table B-II. Reference posture pelvis orientation was not significantly influenced by seating configurations ($p_{profile}$=0.3318; $p_{armrest}$=0.1279)(Fig. 3). Seating profile influenced hip flexion ($p_{profile}$=0.0188; $p_{armrest}$=0.1444) and knee flexion ($p_{profile}$=0.0003; $p_{armrest}$=0.2813) in reference postures whereas the presence of armrests had no significant effects.

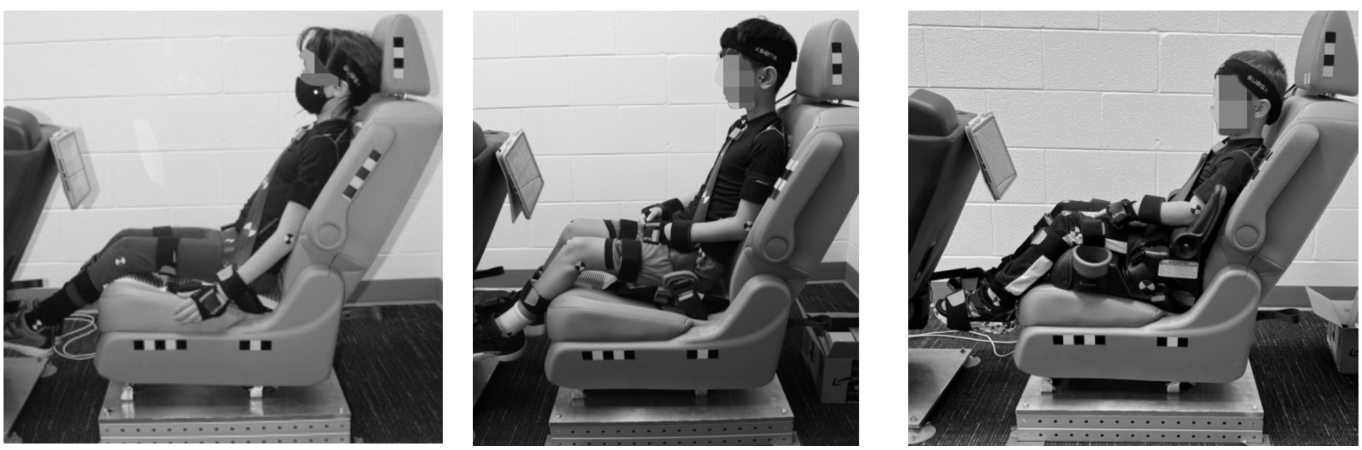

Fig. 3. Volunteers assuming their reference postures within baseline (left), low-profile (centre), and high-profile (right) configurations.

Deviations from the reference posture were analysed through the average difference, the maximum deviation, and the cumulative changes from reference posture assumed over time. Changes in pelvis orientation, hip flexion, and knee flexion were quantified through these metrics and analysed independently using the same model described above. Seating configurations did not have any significant influence on the average, maximum, or cumulative changes in pelvis orientation, hip flexion, or knee flexion (p>0.05, Table B-II).

After determining armrests did not significantly influence posture, additional analyses were conducted with profile as the sole fixed effect classified into three levels: baseline (n=11), low-profile (n=21), and high-profile (n=19). Details from this model can be found in Appendix B (Table B-III). Profile significantly influenced the average (p=0.0181), maximum (p=0.321), and cumulative (p=0.0242) changes in pelvis orientation from reference posture.

Post hoc Tukey tests revealed a significantly greater average change in pelvis orientation in baseline conditions when compared to high-profile (p=0.0307) and low-profile (p=0.0278) conditions (Table B-III). This demonstrates that volunteers modified their postures by posteriorly rotating their pelvis to the greatest extent in the baseline configuration. Baseline configurations had significantly greater maximum (p=0.0275) and cumulative (p=0.0183) changes in pelvis orientation when compared to high-profile configurations. Changes in hip flexion were not significantly influenced by profile when considering the average (p=0.2952), maximum (p=0.0925), or cumulative (p=0.1092) changes during the trials. Alternatively, profile had a significant influence on the average (p=0.0148) and cumulative (p=0.0186) change in knee flexion from the reference posture but not on the maximum change in knee flexion from reference posture (p=0.3346). Baseline configurations had significantly greater average (p=0.0147) and cumulative (p=0.0273) changes in knee flexion compared to high-profile configurations throughout the 30 minutes based on post hoc Tukey tests.

XSENS Posture Measurements Over Time

To account for the influence of time, mixed models with configuration and time as fixed effects and time nested within subject as a random effect were used to evaluate how changes in posture measured from XSENS IMUs were influenced over time and between configurations simultaneously. Initially, interaction terms between configuration and time were explored; however, no significant interactions were observed for any of the XSENS metrics (Table B-IV) and therefore not included in further analyses. Simplified models, including only time and configuration as fixed effects with a random effect to account for subject and time, were used to evaluate changes in pelvis orientation, hip flexion, and knee flexion over time.

Both seating configuration and time significantly contributed to changes in pelvis orientation over the 30-minute trials. With respect to profile, baseline configurations had significantly greater posterior rotation changes compared to high-profile (p<0.0001) and low-profile (p<0.0001) over time by $-4.5 \pm 0.7°$ and $-3.8 \pm 0.7°$ respectively. There were no significant differences in pelvis orientation changes between high-profile and low-profile configurations. Configurations that included armrests had significantly less changes in posterior rotation than those without armrests by an average of $3.8 \pm 0.5°$ (p<0.0001). Across all configurations, there was an average increase in pelvis posterior orientation by $11.1 \pm 2.2°$ over the 30 minutes. Post hoc Tukey tests suggest that on average, adjustments in pelvis orientation primarily occurred within the first three minutes of the trials (Fig. 4). Additional details from the mixed models are included in Appendix B (Table B-V).

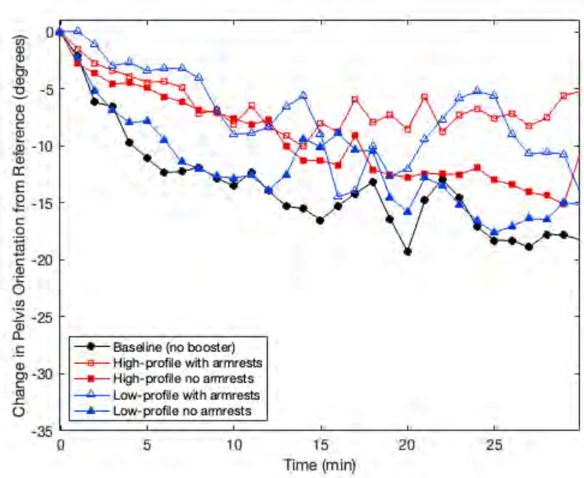

Fig. 4. Change in pelvis orientation with respect to reference posture measurements over time where posterior rotations are represented by greater negative values. Average values across each configuration are shown - baseline as black circles, low-profile as blue triangles, and high-profile as red squares. Configurations without armrests are depicted with filled points and with armrests are not filled.

Changes in hip flexion were also significantly influenced by both configuration and time. Concerning seating configurations, both profile and armrests were significant factors in the change in hip flexion throughout the trials. Baseline and low-profile configurations had significantly less average deviation from reference hip flexion over the 30 minutes than high-profile configurations by 3.6 ± 0.8° and 3.7 ± 0.7° respectively (p<0.0001). There were no significant differences between baseline and low-profile configurations for this metric. Configurations without armrests had less hip flexion over the trial duration by 1.4 ± 0.6° compared to those with armrests (p=0.0190). Across all configurations, hip flexion decreased by an average of 18.0 ± 3.0° over the 30 minutes, with most of the change in hip flexion occurring within the first eight minutes (Fig. 5a).

Changes in knee flexion from reference postures were not significantly different between configurations or over time (Fig. 5b). Profile was the only influential factor in changes to knee flexion throughout the 30 minutes. Baseline configurations had the greatest average changes in knee flexion between profiles by 9.8 ± 0.9° compared to high-profile (p<0.0001) and 4.3 ± 0.9° compared to low-profile (p<0.0001). Low-profile also had significantly greater change in knee flexion by 5.5 ± 0.7° compared to high-profile configurations (p<0.0001).

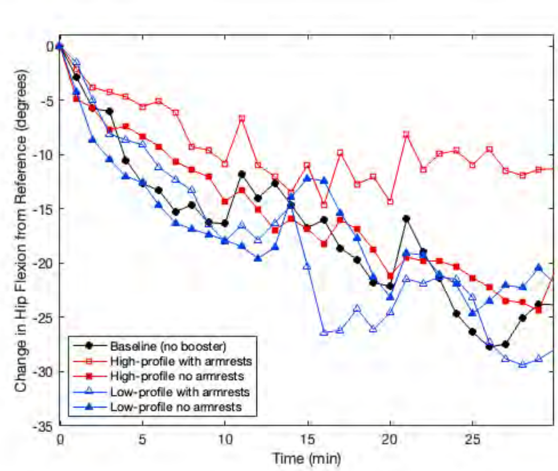

Fig. 5a. Average change in hip flexion with respect to the reference posture measurement over time. Negative values correspond to decrease in hip flexion, or greater hip extension.

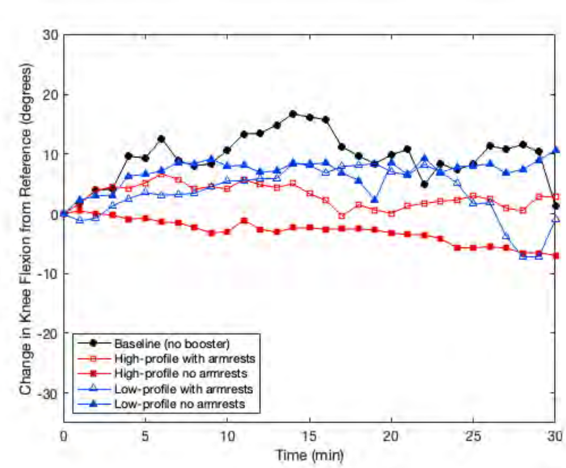

Fig. 5b. Average change in knee flexion with respect to the reference posture measurement over time. Increases in joint angle correspond to increases in knee flexion.

Discomfort Avoidance Behavior (DAB) Rates

Summaries for DAB rate metrics can be found in the appendix (Table A-III). There were no significant differences found in average DAB rate ($p_{profile}$=0.9188; $p_{armrest}$=0.9637) or the total DABs ($p_{profile}$=0.9188; $p_{armrest}$=0.9637) over the 30 minutes when comparing across configurations. These conclusions were true when considering armrests and profile independently as well. Additionally, DAB rates did not significantly change over time (p=0.2809). Analysis was conducted to determine if occupant posture metrics, as measured through XSENS IMUs, were able to predict DAB rates. Change in pelvis orientation was the only significant predictor of DAB rate (p=0.0008).

IV. DISCUSSION

XSENS Posture Measurements

Data collected from XSENS shows that children significantly manipulate their posture over time within belt-positioning booster (BPB) configurations with common trends across seating configurations. Such behaviors have previously been explored and reported, but this study was able to report lower extremity segment orientation and joint angles that otherwise have previously been difficult to determine. Previous work that utilised XSENS IMUs to measure BPB occupant postures across different BPB designs found that on average children's pelvis orientations were 46.6 ± 7.8° in low-profile BPBs and 32.9 ± 7.2° in higher profile, high back BPBs [12], comparable to those reported in Table A-II when considering similar segment coordinate systems orientations. Further, similar work has revealed no significant difference in pelvis orientation between ideal postures and more naturalistic postures, such as those assumed when using electronic devices, in short-duration static vehicle trials [11]. These outcomes are different than those determined in this study, where volunteers significantly changed their postures from ideal when given the opportunity to assume more naturalistic postures. Differences in our findings may be related to the fact that posture data was previously collected and assessed over shorter periods (<10 minutes), whereas the current study allowed children to settle into their seating environment for 30 minutes.

Pelvis anterior/posterior orientation magnitudes were still comparable to previous work despite differences in these outcomes. As expected, average and maximum changes in pelvis orientation showed significant posterior rotation throughout across all configurations. Particularly volunteers in baseline (no-BPB) configurations had significantly larger changes towards posterior orientation when considering the average and maximum deviations from reference posture, suggesting that volunteers in this configuration assumed more slouched postures with time. Also, cumulative changes in pelvis orientation were greatest in baseline configurations, meaning that volunteers frequently adjusted their posture throughout the 30-minute trials in this configuration. This aligns with previous assumptions in literature, that children more commonly assume slouched postures when not using BPB seats because vehicle seat geometries are not compatible with children's anthropometry, provoking slouching, and other movements during use [11][13].

This study was one of the first to report changes in hip and knee flexion for BPB occupants. In the reference postures, both hip and knee flexion angle were significantly influenced by the BPB profile. Changes in hip flexion were not further affected by seating configurations in relation to the average change, maximum change, or cumulative changes throughout the trial duration. This cohort of volunteers assumed a wide variety of naturalistic postures throughout the 30 minutes, ranging from large degrees of hip extension to hip flexion, which may contribute to the lack of significance between configurations in average and maximum outcomes. The average change in hip flexion was -16.0 ± 5.3° from the reference, further supporting the idea that children assumed more slouched postures (increased hip extension) with time. Time-dependent posture analysis offered a novel perspective as the summary metrics did not offer any insight concerning BPB's influence on posture, while statistical models including time highlighted the relationship.

Knee flexion average and maximum changes were influenced by profile. Data from XSENS was supported by video footage, as it was observed that children were not able to bend their knees to the same degree across the profiles when prioritizing an ideal, or upright posture, during reference measurements (Fig. 3). Baseline and low-profile configurations had significantly greater average changes in knee flexion compared to high-profile configurations, which supports previous conclusions that children will modify their posture within vehicles by shifting forward to comfortably clear their knees over the front edge of their seating surface [11][13]. While most of these claims have been rooted in qualitative observations previously, these behaviors were also observed from centre of force data from the pressure mats in the current dataset [27]. Both no-BPB configurations and low-profile configurations have longer effective seat pan lengths, essentially equal to the vehicle seat pan length (47.8 cm), which is 47.3% greater than the average buttock-popliteal length of this cohort of children. Incompatibilities between children and seat geometries contribute to restraint misuse and non-ideal postures, such as slouching, as children must accommodate to their seating environments to sit comfortably. Alternatively, several children supported their feet along the front edge of the seat, or the seat-back in front of them (Fig. 6), which may have contributed to the findings that average change in knee flexion was significantly less in baseline configuration compared to high-profile configurations. Straight legged support against the front-seat back was more common in baseline configurations, whereas support by flexed knees on the front of the seat pan edge was more common in the high-profile configurations (Fig. 6).

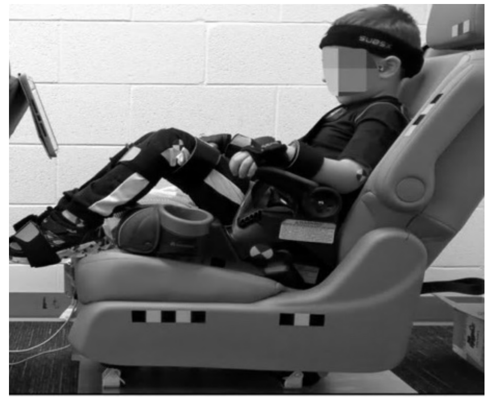

Fig. 6. Examples of how volunteers modified their posture to support their feet along the back of the front captain's chair (left, baseline configuration), and on the front edge of the seat pan (right, high-profile configuration).

Across XSENS summary measurements (average, maximum, and cumulative change), BPB profile alone seemed to significantly influence changes in pelvis orientation and knee flexion. These results suggest that including time as a factor in such prolonged naturalistic investigations adds great value to the interpretation of these data.

XSENS Posture Measurements Over Time

This is one of few studies that has investigated how time contributes to detailed postural changes within belt-positioning booster settings. Previous work has reported changes in head and gross torso positioning over time [15-16][19]; however, this was the first study to report changes in pelvis orientation, hip flexion, and knee flexion. Both pelvis orientation and hip flexion significantly changed over time, towards more posterior pelvis rotation and decreased hip flexion, across all seating configurations. The extent of these changes was dependent on the seating arrangement, with baseline and low-profile configurations having greater posterior changes in pelvis orientations and subsequently decreases in hip flexion. These results suggest a greater propensity toward slouching over time for children in seating configurations with longer effective seat pan lengths.

Post hoc Tukey tests related to time show that significant changes in posture occurred within the first ten minutes of the 30-minute trials across postural metrics. This was also observed via changes in centre of force position within the same dataset [27]. This suggests that children assumed comfortable postures that deviated from the ideal over time but were able to settle into comfortable postures for large durations of the study. This is also supported by DAB rate, discussed below, and pressure results [27]. Based on these results, it would be beneficial to conduct future observations of prolonged postures among BPB occupants at intervals ranging from 15 to 20 minutes to foster naturalistic behaviors while minimising excessive data collection.

Analyses over time showed that armrests also contributed to changes in posture over time, which was not evident from the summary metrics (average, maximum, and cumulative change) explored above. Configurations with armrests had significantly less change in pelvis orientation and hip flexion compared to no armrest configurations. Armrests were utilised an average of 54.8% of the time when present. There were even instances where children utilised armrests in the disengaged position. This data suggests that children were able to utilise armrests when available to support themselves and remain more aft in the seat (closer to their reference posture). In other words, they were able to better resist slouching when armrests were present. Data collected from pressure mats did not show the same influence of armrests [27]. Armrests were not able to prevent forward translation of occupants' centre of force over time, as many children moved forward to comfortably clear their knees over the front seat edge. Rather, armrests offered support to reduce the extent of hip extension and posterior pelvis orientation amidst this posture modification. Posture adjustments were not correlated to changes in centre of force position, showing the value in both measurements. While there has not been any additional work explicitly investigating the use of armrests in this manner, other investigations have demonstrated that similar BPB features influence occupant behaviors and postures [18][29]. Armrests may be worth further investigation as to how they contribute to posture over extended periods of time and how they influence comfort and BPB usage.

Discomfort Avoidance Behavior Rates (DAB)

No significant differences were found for DAB rate values on average or over time. Previous work has reported similar outcomes over extended time periods, with time having no significant influence on DAB rates [18], although it was originally expected that children might become more uncomfortable with time and therefore would exhibit higher DAB rates. XSENS IMUs and pressure mapping were able to supplement DAB analysis throughout this study to offer potential explanations. First, posture and pressure data show that children modify their postures over time, initially changing a great deal before reducing the overall magnitudes of adjustment. As mentioned above, this may suggest that children settle into more comfortable, naturalistic postures, which would result in steady DAB rates over time. Volunteers do not seem to stop shifting altogether, but rather, the overall amount to which they change their posture from minute to minute reduces once they are able to adapt their posture to their seating environment. Additionally, when exploring mixed models that include changes in posture to predict DAB rate over time, changes in pelvis orientation were able to significantly predict DAB rates. Additional investigations should be completed to understand how DAB rate can be related to other quantitative biomechanical data to expand the application of such methodologies.

Limitations and Future Work

Children exhibited a wide variety of postures and behaviors across similar configurations which makes statistical analyses challenging. Additionally, a relatively small sample size limited this investigation in statistical power and the ability to investigate the influence of anthropometry or other occupant characteristics on posture and behavior. The two belt-positioning booster (BPB) seats used within this investigation do not comprehensively represent BPB seats throughout the global market. The study was conducted in an indoor laboratory environment rather than a realistic moving vehicle. Further, providing children with entertainment throughout the trials and their awareness of being observed throughout the study may have influenced their behaviors.

Future analysis should be conducted to gain more insight into the relevance of the observed postures within the field and how these postures contribute to BPB misuse or injury. For example, applying XSENS IMUs within on-road vehicle environments to further quantify and understand naturalistic BPB occupant behaviors. Consistent changes observed in postures across seating configurations with respect to time, and the prevalence of such behaviors observed in previous investigations, suggest that additional exploration should be conducted to understand injury implications and potential mitigation strategies for such non-ideal postures. The data presented can potentially be utilised to position simulations or other crash surrogates to begin investigating the implications that observed postures have on injury outcomes in the event of a crash. This work should include consideration of additional BPB models and features, such as armrests, that may influence changes in occupant postures. Additionally, consideration should also be granted to anthropometric, sex, and other behavioral influences or adaptive needs of each child as they would influence the postures and engagement between the occupant and CRS.

V. CONCLUSION

This study was the first to quantify pediatric vehicle occupant postures over 30-minute periods using inertial measurement units (IMUs). Specifically, these data explored the influence of seating profile, the presence of armrests, and time on changes from ideal, reference postures towards naturalistic, comfortable postures. Data trends suggest that children modify their postures to accommodate the seating geometries over time, especially when seating conditions are incompatible with their anthropometries. Wireless sensors allowed for continuous quantification of these changes in pelvis and lower extremity orientation to better capture comfort-motivated postures that may be associated with BPB seat misuse.

A wide variety of postures were observed across seating configurations and subjects. Despite the large amount of variance, significant trends towards slouched postures (more posterior pelvis orientation and decrease in hip flexion) were observed across seating configurations and over time. Slouching was specifically apparent in baseline (no BPB) and low-profile BPB configurations without armrests. Changes in posture, specifically related to changes in pelvis orientation, were significant predictors of discomfort avoidance behavior rate. Future work will continue to utilize these methodologies to explore the relationship between comfort and posture within BPBs with additional consideration for occupant characteristics. However, the data presented in this study can be leveraged to begin evaluating the implications that the observed non-ideal postures may have on injury outcomes in crash simulations and crash surrogate positioning.

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VII. REFERENCES

[1] World Health Organization (2022). Road traffic injuries https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries [20 June 2022].

[2] Arbogast, K. B., Jermakian, J. S., Kallan M. J., Durbin D. R. (2009) Effectiveness of Belt Positioning Booster Seats: An Updated Assessment. Pediatrics, **124**(5): pp.1281–1286.

[3] Chakraborty, M., Mahmud, S., Gates, T. J. (2022) Child Restraint Use and Seating Position of Child Passengers in Motor Vehicles and Their Correlations: Application of a Random-Effects Bivariate Probit Model. Transportation Research Record, **2676**(12): pp.267–279.

[4] Brown, J., Hatfield, J., Du, W., Finch, C. F., Bilston, L. E. (2010) Population-level estimates of child restraint practices among children aged 0-12 years in NSW, Australia. Accident Analysis & Prevention, **42**(6): pp.2144–2148.

[5] Boyle, L. L. (2023) National Highway Traffic Safety Administration, The 2021 National Survey of the Use of Booster Seats, Washington, DC.

[6] Ghetti, C. B., Rooney, A.S., *et al.* (2023) Evaluating pediatric car safety compliance in motor vehicle collisions: Identifying high-risk groups for improper restraint usage. Journal of Pediatric Surgery, **58**(1): pp.125–129.

[7] Slusher, G., Sarfare, S., Falciani, C., Belwadi, A., Maheshwari, J. (2022) Analysis of 6YO pediatric human body model kinematics and kinetics to determine submarining across naturalistic seating postures. Traffic Injury Prevention, **23**(S1): pp.111–S116.

[8] Bohman, K., El-Mobader, S., Jakobsson, L. (2022) Effects of restraint parameters using PIPER 6y in reclined seating during frontal impact. Traffic Injury Prevention, **23**(S1): pp.123–S129.

[9] Forman, J., Miller, M., Perez-Rapela, D., Gepner, B., Edwards, M.A., Jermakian, J. S. (2022) Investigation of factors influencing submarining mitigation with child booster seats. Traffic Injury Prevention, **24**(1): pp.75–81.

[10] Maheshwari, J., Sarfare, S., Falciani, C., Belwadi, A. (2020) Pediatric occupant human body model kinematic and kinetic response variation to changes in seating posture in simulated frontal impacts-with and without automatic emergency braking. Traffic Injury Prevention, **21**(S1): pp. S49–S53.

[11] Baker, G. H., Bohman, K., Mansfield, J. A., Jakobsson, L., Bolte IV, J. H. (2023) Comparison of Self-Selected, Holding Device, and Nominal Conditions on the Belt Fit and Posture of Children on Belt-Positioning Boosters. Proceedings of the International Research Council on Biomechanics of Injury, Cambridge, England.

[12] Baker, G. H., Mansfield, J. A., Hunter, R. L., Bolte IV, J. H. (2021) Comparison of Child and ATD Static Belt Fit and Belt Torso Contact on Belt-Positioning Booster Seats. Proceedings of the International Research Council on Biomechanics of Injury. https://www.ircobi.org/wordpress/downloads/irc21/pdf-files/2160.pdf

[13] Jones, M. L. H., Ebert, S., Manary, M. A., Reed, M.P., Klinich, K. D. (2020) Child Posture and Belt Fit in a Range of Booster Configurations. International Journal of Environmental Research and Public Health, **17**(3): pp.810 – 830.

[14] Reed, M. P., Ebert-Hamilton, S. M., Manary, M. A., Klinich, K. D., Schneider, L. W. (2005) A New Database of Child Anthropometry and Seated Posture for Automotive Safety Applications. SAE International Journal of Transportation Safety, Paper No. 2005-01-1837.

[15] Arbogast K. B., Kim J., *et al.* (2016) Naturalistic driving study of rear seat child occupants: Quantification of head position using a Kinect™ sensor. Traffic Injury Prevention, **17**(S1): pp.168–74.

[16] Forman, J., Segui-Gomez, M., Ash, J. H., Lopez-Valdes, F. J. (2011) Child posture and shoulder belt fit during extended night-time traveling: An in-transit observational study. Annals of Advances in Automotive Medicine, **55**: pp. 3–14.

[17] Jakobsson, L., Bohman, K., Stockman, I., Andersson, M., Osvalder, A. L. (2011) Older Children's Sitting Postures when Riding in the Rear Seat. Proceedings of the International Research Council on Biomechanics of Injury, Krakow, Poland.

[18] Albanese, B., Bohman, K., *et al.* (2020) Influence of child restraint system design features of comfort, belt fit and posture. Safety Science, **128**.

[19] Osvalder, A. L., Hansson, I., Stockman, I., Carlsson, A. (2013) Older Children's Sitting Postures, Behaviour and Comfort Experience during Ride – A Comparison between an Integrated Booster Cushion and a High-Back Booster. Proceedings of the International Research Council on Biomechanics of Injury, Gothenburg, Sweden.

[20] Andersson, M., Bohman, K., Osvalder, A. L. (2010) Effect of Booster Seat Design on Children's Choice of Seating Positions During Naturalistic Riding. Annals of Advances in Automotive Medicine - 54th Annual Scientific Conference, **54**(October): pp.171–80.

[21] Baker, G.H., Mansfield, J.A., Hunter, R.L., Bolte IV, J.H. (2021) Application of an Inertial Measurement Unit (IMU)-Based Motion Capture System for the Quantification of Child Posture on Belt-Positioning Booster Seats. Proceedings of the International Protection of Children in Cars Conference*,* Munich, Germany*.*

[22] Fong, C. K., Bilston, L. E., Paul, G., Brown, J. (2017) A novel method for quantifying comfort in children passengers demonstrates an association between child restraint comfort and errors in use of booster seats. Traffic Injury Prevention, **18**(S1): pp.109–S115.

[23] Baker, G. H., Connell, R. R., Mansfield, J. A. (2023) Comparison of Vehicles Seat and Booster Geometries with Child Anthropometries. Proceedings of the International Protection of Children in Cars Conference*,* Munich, Germany.

[24] Porter, J.M, Gyi, D.E., Tait, H.A. (2003) Interface pressure data and the prediction of driver discomfort in road trials. Applied Ergonomics, **34**(3): pp. 207-214.

[25] Steinbach, R., Tefft, B.C. (2023). AAA Foundation for Traffic Safety, *American Driving Survey: 2022 (Research Brief).* Washington, D.C.

[26] Mansfield J. A (2024). Compatibility Between Vehicle Seating Environments and Load Legs on Child Restraint Systems (CRS). SAE International Journal of Transportation Safety, Paper No. 2024-01-2751.

[27] Connell, R. R., Baker, G.H., Mansfield, J. A. (2023) Quantifying naturalistic occupant postures in belt-positioning booster seats through pressure mapping. Proceedings of the International Protection of Children in Cars Conference, Munich, Germany.

[28] XSENS. XSENS MVN User Manual, Document MV0319P, Revision X. 2018.

[29] Albanese, B., Cross, S. L., *et al.* (2022) Child restraint headrest and belt routing design features and their association with child passenger behavior and restraint misuse. Traffic Injury Prevention, **23**(7): pp.446–451.

VIII. APPENDIX

Appendix A

High-profile BPB *Low-profile BPB*

Fig. A1: a) High-profile BPB model with a boost height of 12.7 cm, seat pan length of 40.4 cm, and seat angle of 23.5°. b) Low-profile BPB model with a boost height of 6.0 cm, seat pan length of 31.7 cm, and seat angle of 16.5°. Boost height measurements were taken along the front of the seat pan.

Fig. A2: Five seating configurations used to assess the influence of boost height (baseline, low-profile, and high-profile) and the presence of armrests.

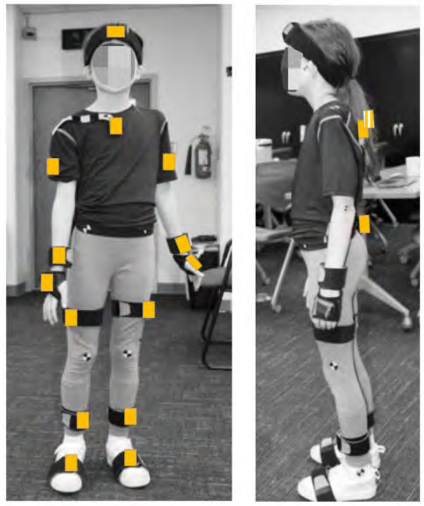

Fig. A3: XSENS sensor placement.

TABLE A-I:
AVERAGE ANTHROPOMETRY FOR PEDIATRIC COHORT

Measurement	Average ± SD	Range
Age (years)	8.10 ± 2.0	5-12
Weight (kg)	26.29 ± 7.4	18.3-53.7
Stature (cm)	128.28 ± 12.5	107.3-151.0
Seated height (cm)	66.61 ± 4.4	57.6-76.8
Hip height (cm)	64.63 ± 7.9	52.8-79.4
Knee height (cm)	37.42 ± 4.9	25.8-47.1
Buttock popliteal length (cm)	32.62 ± 3.8	26.0-39.1

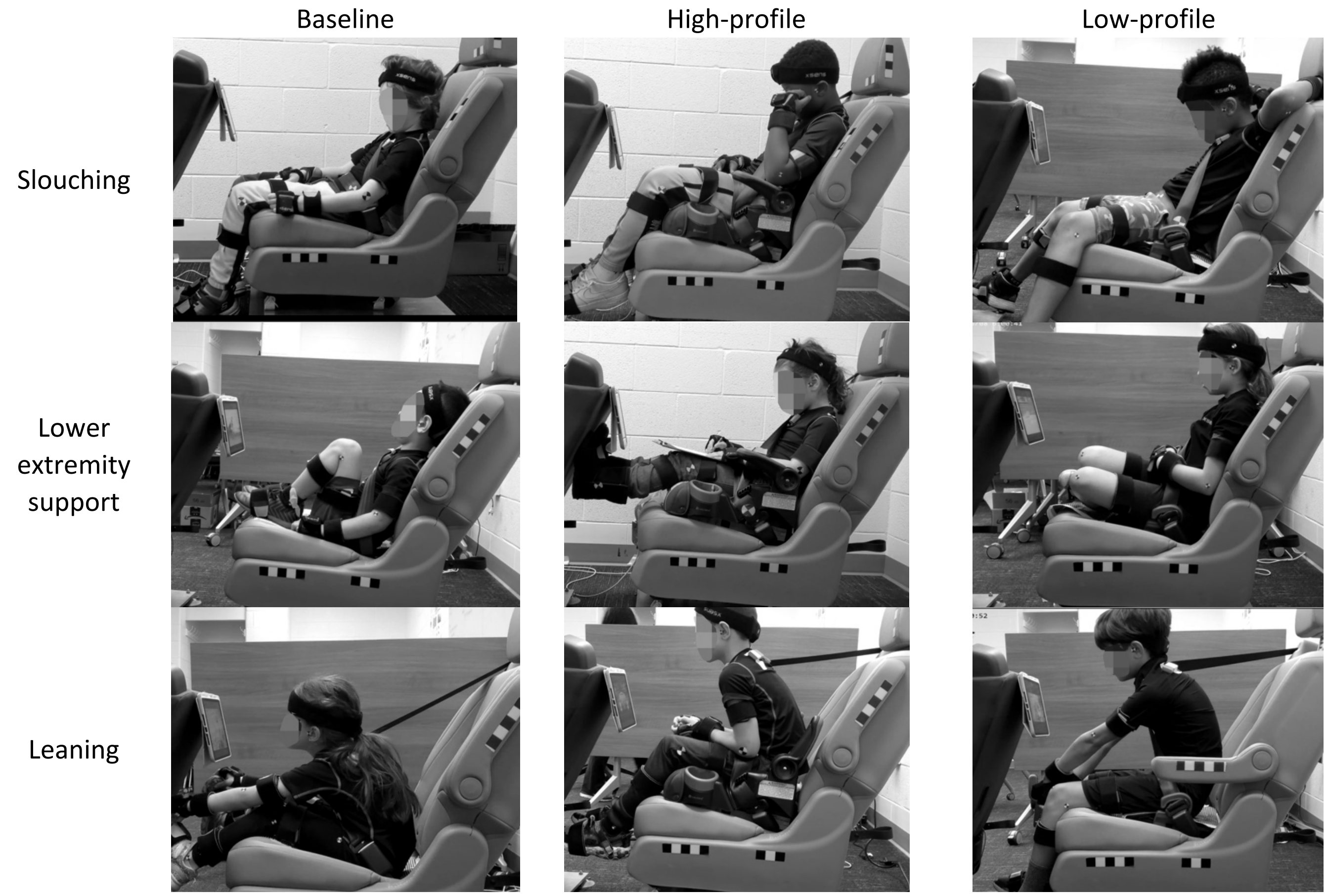

Fig. A4: Exemplar postures and behaviors exhibited by volunteers in each seating profile.

TABLE A-II:
MEAN ± STANDARD DEVIATION OF SUMMARY METRICS COLLECTED FROM XSENS IMUS (IN DEGREES)

		Overall (n=51)	Baseline (n=11)	Low-profile (n=21)	High-profile (n=19)
Pelvis Orientation	Reference	-38.95 ± 15.2	-35.26 ± 16.1	-35.69 ± 14.0	-44.69 ± 14.9
	Avg	-49.04 ± 3.1	-49.23 ± 9.2	-45.43 ± 12.5	-52.92 ± 11.8
	Max*	-57.77 ± 9.0	-59.23 ± 9.0	-55.02 ± 7.9	-59.97 ± 9.63
Change in Pelvis Orientation	Avg	-10.09 ± 3.1	-13.98 ± 10.8	-9.73 ± 8.4	-8.22 ± 4.9
	Max	-13.85 ± 3.8	23.98 ± 11.4	-19.32 ± 8.6	-15.28 ± 7.5
	Cumulative	352.81 ± 301.3	458.89 ± 290.6	379.63 ± 155.1	261.76 ± 137.5
Hip Flexion	Reference	57.20 ± 17.2	66.57 ± 15.6	55.99 ± 18.0	53.12 ± 15.8
	Avg	41.79 ± 15.5	47.16 ± 12.0	39.83 ± 15.7	40.79 ± 9.9
	Max	60.19 ± 18.3	69.30 ± 19.0	59.49 ± 18.6	55.69 ± 16.6
Change in Hip Flexion	Avg	-15.99 ± 5.3	-17.23 ± 11.5	-18.18 ± 11.4	-12.85 ± 8.0
	Max	-23.08 ± 4.5	-31.70 ± 11.0	-32.37 ± 11.4	-23.68 ± 11.7
	Cumulative	529.53 ± 376.4	598.63 ± 219.7	599.75 ± 276.7	411.94 ± 216.5
Knee Flexion	Reference	56.98 ± 12.7	56.93 ± 18.6	55.08 ± 9.4	59.10 ± 12.0
	Avg	61.25 ± 12.6	66.68 ± 21.2	60.48 ± 9.7	58.97 ± 8.0
	Max	72.92 ± 17.7	81.13 ± 30.8	73.31 ± 12.3	67.73 ± 10.3
Change in Knee Flexion	Avg	4.27 ± 1.8	9.74 ± 11.7	5.31 ± 8.8	-0.13 ± 6.0
	Max	21.11 ± 17.4	28.43 ± 25.9	24.44 ± 14.7	13.20 ± 7.7
	Cumulative	260.90 ± 358.2	363.83 ± 309.8	301.32 ± 185.7	156.63 ± 110.6

**Maximum values are the absolute greatest posterior orientations and flexion values recorded over the 30- minute trials. Greater indicate larger deviations from ideal posture.*

TABLE A-III:
MEAN ± STANDARD DEVIATION OF DISCOMFORT AVOIDANCE BEHAVIOR (DAB) METRICS

	Overall (n=51)	Baseline (n=11)	Low-profile (n=21)	High-profile (n=19)
Average DAB Rate (DAB/min)	3.45 ± 1.3	3.72 ± 1.4	3.44 ± 1.7	3.31 ± 0.8
Total DABs	103.00 ± 39.6	111.63 ± 42.8	103.14 ± 49.9	99.42 ± 22.6

Appendix B

TABLE B-I:
INITIAL MATCHED PAIRS T-TESTS

	Trail 1 vs. Trail 2					Left vs. Right				
	Mean 1 ± SD	Mean 2 ± SD	DF	t-Ratio	p-value	L. Mean ± SD	R. Mean ± SD	DF	t-Ratio	p-value
Avg DAB Rate (DAB/min)	3.34 ± 1.2	3.37 ± 1.2	58	-0.204	0.8390	-	-	-	-	-
Reference Pelvis Orientation (degrees)	-38.77 ± 14.9	-38.99 ± 14.9	52	-0.117	0.9074	-	-	-	-	-
Avg. Pelvis Orientation (degrees)	-9.85 ± 8.2	-9.91 ± 8.2	52	0.048	0.9621	-	-	-	-	-
Reference Hip Flexion (degrees)	58.47 ± 17.0	57.91 ± 17.7	50	-0.235	0.8152	57.99 ± 16.9	56.42 ± 17.7	50	-2.139	0.9813
Avg. Hip Flexion (degrees)	42.25 ± 12.6	42.63 ± 12.7	50	-0.199	0.8429	42.51 ± 12.7	41.04 ± 13.8	50	-2.230	0.9850
Reference Knee Flexion (degrees)	57.63 ± 14.6	57.65 ± 14.6	53	-0.009	0.9923	57.83 ± 14.5	56.14 ± 11.9	54	-1.385	0.1718
Avg. Knee Flexion (degrees)	62.15 ± 13.4	62.27 ± 13.3	53	-0.050	0.9600	62.36 ± 13.3	59.76 ± 14.6	54	-1.606	0.1141

** Indicates significant outcomes (α<0.05).*

TABLE B-II:
MIXED MODEL OUTCOMES FOR SUMMARY XSENS METRICS BY SEATING CONFIGURATION

		Fixed Effect: Armrests				Fixed Effect: Profile			
		df	DFden	F Ratio	p-value	df	DFden	F Ratio	p-value
Changes in Pelvis Orientation	Reference	1	21.5	2.507	0.1279	2	26.0	1.151	0.3318
	Avg	1	24.3	3.998	0.0568	2	33.2	2.150	0.1324
	Max	1	25.8	0.032	0.8589	2	35.5	3.239	0.0510
	Cumulative	1	26.1	1.215	0.2805	2	37.7	2.817	0.0072
Changes in Hip Flexion	Reference	1	23.8	2.278	0.1444	2	30.8	2.322	0.1150
	Avg	1	25.4	0.266	0.6107	2	33.6	0.996	0.3800
	Max	1	25.1	0.224	0.6399	2	38.4	2.173	0.1276
	Cumulative	1	26.5	0.066	0.7992	2	37.9	2.160	0.1293
Changes in Knee Flexion	Reference	1	21.5	1.221	0.2813	2	25.0	10.054	0.0006*
	Avg	1	30.3	0.035	0.8522	2	42.9	4.325	0.0194*
	Max	1	32.0	0.004	0.9486	2	44.5	3.256	0.0479*
	Cumulative	1	32.0	0.005	0.9426	2	44.6	3.975	0.0258*

Each row represents a single mixed model used to assess the influence of profile (baseline, low-profile, and high-profile) and armrests (armrests or no armrests) as a fixed effects on the dependent variable listed in the first two columns. Subject was also included in each model as a random effect.

** Indicates significant outcomes (α<0.05).*

TABLE B-III:
MIXED MODEL OUTCOMES FOR SUMMARY XSENS METRICS BY PROFILE

		Fixed Effect: Profile				Tukey Tests p-value		
		df	DFden	F Ratio	p-value	B vs. L	B vs. H	H vs. L
Changes in Pelvis Orientation	Reference	2	27.5	2.185	0.1316	0.4371	0.1106	0.7147
	Avg	2	35.2	4.051	0.0181*	0.0278*	0.0307*	0.9823
	Max	2	36.5	3.783	0.0321*	0.4697	0.2624	0.0275*
	Cumulative	2	39.5	4.093	0.0242*	0.2613	0.0183*	0.3731
Changes in Hip Flexion	Reference	2	32.3	4.506	0.0188*	0.0264*	0.0361*	0.9482
	Avg	2	34.0	1.265	0.2952	0.8701	0.2958	0.5472
	Max	2	39.4	2.531	0.0925	0.8468	0.1107	0.2267
	Cumulative	2	38.5	2.347	0.1092	0.9457	0.1524	0.2050
Changes in Knee Flexion	Reference	2	25.8	11.275	0.0003*	0.0230*	0.2858	0.0002*
	Avg	2	43.9	4.641	0.0148*	0.4851	0.0147*	0.1209
	Max	2	45.7	3.535	0.0374*	0.8507	0.0581	0.0952
	Cumulative	2	45.9	4.352	0.0186*	0.7398	0.0273*	0.0690

Each row represents a single mixed model used to assess the influence of profile, as a fixed effect, on the dependent variable listed in the first column. Subject was also included in each model as a random effect. Post hoc Tukey tests, for comparison between profiles, are included. Profiles include baseline (B), low-profile (L), and high-profile (H).

** Indicates significant outcomes (α<0.05).*

TABLE B-IV:
TIME-DEPENDENT MIXED MODEL OUTCOMES WITH INTERACTIONS

	Fixed Effect: Time				Fixed Effect: Profile				Fixed Effect: Armrests				Profile*Time				Armrests*Time			
	df	DFden	F Ratio	p-value	df	DFden	F Ratio	p-value	df	DFden	F Ratio	p-value	df	DFden	F Ratio	p-value	df	DFden	F Ratio	p-value
Change in Pelvis orientation	29	909	3.154	<0.0001*	2	1201	21.72	<0.0001*	1	829.6	53.74	<0.0001*	58	1217	0.3478	1.000	29	829	0.7018	0.8790
Change in hip flexion	29	919	5.831	<0.0001*	2	1110	18.88	<0.0001*	1	800.4	5.417	0.0202*	58	1120	0.3830	1.000	29	800	0.4954	0.9890
Change in knee flexion	29	943	1.252	0.1697	2	1308	71.01	<0.0001*	1	925.5	0.850	0.3569	58	1331	0.6400	0.9840	29	926	0.3344	1.000

Each row represents a single mixed model used to assess the influence of seating configuration, coded as profile (baseline, low-profile, and high-profile) and armrests (armrests or no armrests), as a fixed effects, on the dependent variable listed in the first column. Subject was also included in each model as a random effect along with interaction terms between time and configuration.

** Indicated significant outcomes (α<0.05).*

TABLE B-V:
TIME-DEPENDENT MIXED MODEL OUTCOMES

	Fixed Effect: Time				Fixed Effect: Profile				Fixed Effect: Armrests				Tukey Tests p-value		
	df	DFden	F Ratio	p-value	df	DFden	F Ratio	p-value	df	DFden	F Ratio	p-value	H vs. L	B vs. H	B vs. L
Change in Pelvis orientation	29	776	3.743	<0.0001*	2	1305	22.15	<0.0001*	1	913	55.11	<0.0001*	0.4104	<0.0001*	<0.0001*
Change in hip flexion	29	799	6.199	<0.0001*	2	1201	19.37	<0.0001*	1	875	5.520	0.0190*	<0.0001*	<0.0001*	0.9845
Change in knee flexion	29	798	0.984	0.4908	2	1399	72.72	<0.0001*	1	998	0.8430	0.3588	<0.0001*	<0.0001*	<0.0001*

Each row represents a mixed model used to assess the influence of profile and time as fixed effects, on the dependent variable listed in the first column. Time was also nested with subject as a random effect within each model. Post hoc Tukey tests, for comparison between profiles, are included. Profiles include baseline (B), low-profile (L), and high-profile (H).
** Indicates significance (<0.05)*