SHORT COMMUNICATION: STAPP CAR CRASH CONFERENCE

Anthropometric influences on changes in belt-positioning booster occupant lower extremity postures

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ABSTRACT – Deviation from ideal postures within belt-positioning booster seats (BPB) can lead to increased risks of injury during motor vehicle collisions. Although previous work has observed and measured out-of-position postures, there is a limited understanding of the influence of occupants' age and anthropometry on such changes in posture. A laboratory study was conducted to observe naturalistic postures of BPB occupants over 30-minute time periods. Changes from ideal postures were collected and analyzed with respect to time, seating condition, and occupant characteristics to assess influences of anthropometry on changes in posture. These preliminary investigations suggest that occupant size influences changes in pelvis orientation, hip flexion, and knee flexion. Age, seated height, and buttock-popliteal length were most significant in relation to changes in lower extremity posture. All anthropometric variables assessed significantly contributed to changes in posture when accounting for time. However, this conclusion was highly variable when evaluating summary metrics of average, maximum, or cumulative posture changes. Future work should continue to explore how occupant characteristics contribute to their seated posture, especially when conducting time-dependent posture measurements.

INTRODUCTION

Motor vehicle collisions remain one of the leading causes of death for children in the world, despite the effectiveness of child restraint systems [WHO 2022]. Particularly, belt-positioning booster (BPB) occupants are more commonly injured compared to their younger counterparts [Boyle 2023]. This is partly attributed to premature transitions into and/or out of BPBs, which encompass a large age span (4-12 years old) and therefore a wide range of occupant shapes and sizes. Further, the autonomy associated with BPBs compared to harness restraint systems can lead to restraint misuse in the form of out-of-position postures (OOP) that lead to deviations in ideal belt placement.

Previous work has documented OOP postures instantaneously and over extended periods both within laboratory [Baker et al. 2023; Jones et al. 2020] and naturalistic vehicle settings [Arbogast et al. 2016; Andersson et al. 2010]. These data have suggested that incompatibility between occupants' anthropometry and BPB geometry may influence OOP postures, such as slouching. Yet, there are limited data specifically relating BPB occupant posture to their age and/or anthropometry to support these assumptions. Therefore, this study sought to investigate the influence of occupant anthropometry on changes from ideal postures of the lower extremities (pelvis orientation, hip flexion angle, knee flexion angle) over extended periods.

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METHODS

All methods were approved by The Ohio State University Institutional Review Board (#2022H0268). Thirty volunteers were recruited based on manufacturer specifications from two BPBs available on the US market at the time of the study (5-12 years old, 107-145cm, 18-45kg). Anthropometric measurements were collected while standing, including height, weight, hip (greater trochanter) height, knee height, anterior superior iliac spine (ASIS) breadth, and while seated, including seated height, buttock popliteal length (BPL), and popliteal height. Volunteers were randomly assigned to two out of five seating configurations that manipulated the boost height (high-profile or low-profile) and the presence of armrests (armrests or no armrests) through two BPB models. A fifth no-BPB and no armrest condition was included as well. Each trial consisted of the volunteer sitting on their assigned condition for 30 minutes. During this time, segment positions, orientations, and joint angles were recorded through 17 wireless inertial measurement units (XSENS MVN Awinda) positioned on the volunteer using custom shirts and Velcro straps (FIG 1). Video footage was collected from frontal and sagittal perspectives. Additional information regarding the setup can be found in [Connell et al. 2024]. Initially, a certified Child Passenger Safety Technician ensured the occupant was ideally restrained within the setup, and instantaneous posture data were collected ("reference posture"). Occupants were then provided a verbal cue to assume comfortable postures for the remainder of the trial. All data were collected continuously over 30 minutes and interpolated using simple averaging techniques for each minute.

FIGURE 1: Left: Exemplary volunteer demonstrating relevant XSENS sensor placement with positive (a) pelvis orientation, (b) hip flexion, and (c) knee flexion directions indicated. Right: Exemplary volunteer in their reference posture.

Data analysis

Changes in pelvis orientation, hip flexion, and knee flexion were determined by calculating the difference in posture between the average measurement over each minute and the reference posture. Changes to these measurements were analyzed through summary metrics (average, maximum, and cumulative changes) and with respect to time. An overall average and maximum value were determined from the interpolated differences. Cumulative change, or the absolute sum of the interpolated differences, was used as a third summary metric to quantify the amount of total posture changes over the thirty minutes. Multiple linear regressions, with seating configuration and individual anthropometric variables, were used to assess the influence of anthropometric factors on summary metrics for pelvis orientation, hip flexion, and knee flexion. Mixed model analyses were also conducted, including seating configuration and individual anthropometric variables as fixed effects and time as a random effect, to assess how changes from ideal posture were influenced by anthropometry over time. The alpha level was set to 0.05 for all analyses.

RESULTS

Changes in pelvis orientation

Greater average posterior changes in pelvis orientation were significantly related to greater age ($p=0.018$), height ($p=0.049$), hip height ($p=0.006$), ASIS breadth ($p=0.029$), seated height ($p=0.034$), BPL ($p=0.014$), and popliteal height ($p=0.026$). BPL ($p=0.021$) was the only significant anthropometric variable for maximum change in pelvis orientation. Notably, greater BPL resulted in greater posterior pelvis orientations. Increases in cumulative change in pelvis orientation were associated with increases in hip height ($p=0.021$), ASIS breadth ($p=0.031$), and seated shoulder height ($p=0.031$). ASIS breadth was not a significant predictor for any summary metrics in other posture measurements, although it was significant for all pelvis metrics. All anthropometric variables were significant for models that included time ($p<0.001$).

Changes in hip flexion

Significantly decreased flexion was observed for average changes in hip flexion angle with greater age ($p=0.049$), seated height ($p=0.041$), and BPL ($p=0.016$). Additionally, significant decreases in flexion were also observed for maximum changes in hip flexion angle with increased seated height (0.008) and BPL ($p=0.040$). The only significant anthropometric variable related to cumulative change in hip flexion angle was BPL ($p=0.001$). The least number of anthropometric variables were significantly related to hip flexion summary metrics compared to pelvis orientation and knee flexion metrics. All anthropometric variables were significant for changes in hip flexion when time was included in the model ($p<0.001$).

Changes in knee flexion

No anthropometric variables significantly contributed to the overall average change in knee flexion determined from the interpolated data. Significantly increased flexion was observed for maximum changes in knee flexion angle with increases in age ($p=0.004$), height ($p=0.016$), weight ($p=0.016$), hip height ($p=0.023$), knee height ($p=0.019$), seated height ($p=0.028$), BPL ($p=0.017$), and popliteal height ($p=0.021$). Less cumulative change in knee flexion was related to greater age ($p=0.019$), height ($p=0.035$), weight, ($p=0.034$), hip height ($p=0.015$), knee height ($p=0.046$), BPL ($p=0.007$), and popliteal height. Weight and knee height were the only significant predictors for summary metrics describing changes in knee flexion. All anthropometric variables were significant for changes in knee flexion in models that included time($p<0.001$).

DISCUSSION

This work builds upon previous investigations that found children modify their posture to accommodate to their seating environment. BPL, seated height, and age were the most consistently significant anthropometric factors across all the posture variables assessed. This supports previous observations and assumptions that BPL and seated height are highly influential to occupant posture as they relate to compatibility with seat pan length and shoulder belt placement [Bilston and Sagar. 2007]. Trends observed here between larger anthropometries and lower extremity postures associated with slouching seem to contradict previous assumptions that shorter leg lengths might cause slouching as the child shifts to help their knees to clear the edge of the seat. However, this outcome can be attributed to the wide variety of postures observed in this study. Younger, shorter volunteers extended their lower extremities and supported them on the front seat back, whereas older, larger volunteers tended to slouch because their feet reached or nearly reached the floor. All volunteers engaged in some form of OOP postures; thus, a larger sample size would be required to investigate further.

A novel aspect of this investigation was the time-dependent posture analysis. The results from this investigation suggest that occupant size is significantly associated with changes in pelvis orientation, hip flexion, and knee flexion because all anthropometry metrics were significant when accounting for both time and seating configuration. The relationships between anthropometry and average, maximum, and cumulative posture changes were not consistent. This suggests that future work should continue to investigate changes to posture over time to emulate naturalistic driving environments but must also consider the influence of anthropometry. Although OOP postures, specifically slouching, were assumed by most volunteers [Connell et al. 2024], the degree to which this occurs may be dependent on the occupant's anthropometry in addition to the seating condition. These data demonstrate that slouched postures are assumed by older, larger children, not just younger, smaller occupants when observed over time.

Given that there were only 30 volunteers, and two BPBs evaluated, the statistical power of this study is limited. However, these results suggest that occupant size significantly influences change in lower extremity posture when accounting for time and seating configuration. Therefore, investigations with larger and more diverse volunteer cohorts are warranted as well as including additional BPB models.

CONCLUSION

These data support previous observations that children accommodate to their seating environments, in some cases assuming non-ideal lower extremity postures. Anthropometric influence was inconsistent across summary metrics used to describe changes in posture over time. However, when considering time in the model, anthropometry was consistently significant to changes in pelvis orientation, hip flexion, and knee flexion. Future work should continue to explore the influences of both time and anthropometric variation on booster occupant posture.

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