SHORT COMMUNICATION
63rd STAPP CAR CRASH CONFERENCE

SC19-04

# Pediatric Cervical Spine Strength and Stiffness in the Sagittal Plane

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**ABSTRACT** – In the pediatric safety field the use of computer simulations to assess passenger kinematics is becoming more prevalent. However, there is a need for volunteer data to serve as a baseline for biomechanical responses to better appraise the biofidelity of these simulations. The objective of this study is to provide volunteer data of cervical spine strength and stiffness in 5–7 year old children. An isokinetic dynamometer was used to quantify strength and stiffness measurements. Twenty-three subjects with a mean age 5.9±0.7 participated. Children were stronger at mid-range of motion in both flexion and extension, and strongest in extension. Stiffness calculations for initial motions were higher for both flexion (0.277 Nm/°) and extension (0.227 Nm/°) than secondary motions (0.148 Nm/° and 0.095 Nm/°, respectively). This study offers a unique perspective to pediatric volunteers' c-spine strength and stiffness, and can provide a better understanding of the head-neck kinematics of this young population.

## INTRODUCTION

Cervical spine (c-spine) injuries account for an estimated 60–80% of pediatric spine injuries (Kreykes & Letton, 2010). Consistently, motor vehicle crashes have been reported as the primary cause of pediatric c-spine injuries (Murphy et al., 2015; Anissipour et al., 2017). As the crash safety field trends toward the inclusion of more finite element modeling as a medium for predicting injury response to a car crash for the pediatric population, it is important to understand the biomechanical responses, specifically of the head and neck, of this population. Weak neck musculature, incomplete ossification of the vertebrae, large head mass-to-body ratio, and increased elasticity of soft tissue structures make the pediatric population especially unique and complex to study (Greaves et al., 2009; Kasai et al., 1996). Currently, pediatric models rely on scaling of adult data or the use of segmental data for c-spine properties that better represent this young population (Dong et al., 2013). Volunteer pediatric spine stiffness data are needed to improve the biofidelic response of the computer model simulations in frontal impacts and pedestrian model development.

## METHODS

This study was reviewed and approved by the Institutional Review Board at the Ohio State University, Columbus OH. Parental consent and participant assent were obtained upon arrival.

**Figure 1.** Custom head fixture.

A custom head fixture was designed and machined as an attachment to a Biodex Isokinetic Dynamometer (Biodex Medical Systems, Shirley, NY) to quantify c-spine strength and stiffness of pediatric volunteers (Figure 1). The fixture and the testing protocol were adapted from Seng & Lam (2002). Pediatric volunteers aged 5–7 years old were recruited for this study. Exclusion criteria were injury to the neck within the last year, neck surgery within their lifetime, and excessive kyphosis. Subjects wore bilateral surface electromyography (EMG; Noraxon Inc., Scottsdale AZ) electrodes on the sternocleidomastoid and upper trapezius muscles. C-spine strength was measured as maximum voluntary isometric contraction (MVIC) at neutral (0°) and mid-range of motion (30°) for both flexion and extension. Subjects were asked to maximally engage with the testing equipment at each location three times for a duration of 5.0s. Strength measurements (Nm) were averaged across all repetitions and an average isometric strength value was determined at each location and direction.

C-spine stiffness was calculated as the slope of the torque by anatomical position curves (Nm/°). For this portion of the protocol, the testing equipment was set to move at a rate of 30°/s from 35° in flexion to 35° in extension. Subjects were asked and encouraged to push with the motion as hard as they could to produce the torque measurements. Stiffness calculations were considered as maximally active engagement with the testing equipment. Stiffness data was only evaluated from 30° in flexion to 30° in extension. This truncating of the data was performed to prevent an artificial increase in torque values at the end of motion due to change in direction. For all trials, subjects started from

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a maximally flexed position. Stiffness values were calculated for the last 10° of motion in each direction: initial extension, secondary extension, initial flexion, and secondary flexion (Figure 2). The distinction of initial and secondary movements was made when subjects passed neutral (0°).

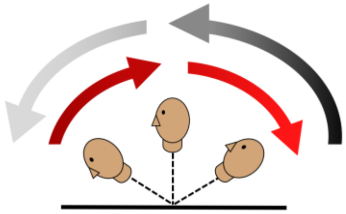

**Figure 2.** Subject motion during the flexion and extension stiffness protocol. Dark red: Initial extension. Red: Secondary extension. Black: Initial flexion. Light grey: Secondary flexion.

Statistical analyses were performed using JMP 14 (SAS Institute Inc., Cary NC). Analyses of variance (ANOVA) by sex and by age were performed for both strength and stiffness measurements. Student's t-tests were performed to assess differences between the 5, 6, and 7 year old groups. When possible, matched pair analyses were conducted to assess differences in direction within subjects.

## RESULTS

Twenty-three pediatric volunteers between 5-7 years old (mean±SD: age 5.9±0.7 years old, weight 22.0±5.3 kg, and stature 117.9±7.9 cm) completed the testing protocol. Subjects had equal sex distribution (f=11). No statistical differences were found between subjects when comparing by sex.

### Isometric Strength

Subjects had difficulties when performing the strength measurements at 0° in flexion; three subjects' measurements were unable to be quantified as they did not activate the dynamometer for data collection. Similarly, at 30° of flexion strength values for one subject were unable to be collected. Calculation of average strength measurements were not possible for all three trials for all subjects. The first measurement in the 0° location for flexion had to be excluded for 11 subjects and in extension for 4 subjects.

Average isometric strength measurements were greater at 30° for both directions (Table 1). ANOVA analyses had statistical significance in extension at the 0° location (p=0.035). Statistical significance was also found at the 30° locations for both flexion (p=0.012) and extension (p=0.022). For both flexion and extension, matched pair analyses showed that subjects were statistically stronger at the 30° location (p<.0001, p<.0001). In flexion there was a 206% increase in strength at the 30° location, while in extension this change was 53%. Matched pair analyses comparing flexion and extension strength at both 0° and 30° showed that subjects were statistically stronger in extension than in flexion (p<.0001, p<.0001). Average strength in extension at 0° was 173% larger than in flexion. At the 30° position this difference was 37%.

**Table 1**. Isometric Strength in Flexion and Extension

| Motion | Isometric Strength (Nm) Neck Position 0° | Neck Position 30° |
|---|---|---|
| Flexion | 1.6±1.0 | 4.9±1.4 |
| Extension | 4.4±2.5 | 6.8±2.0 |

### Stiffness Measurements

Initial motions had higher stiffnesses than secondary motions for both extension and flexion (Table 2). No significant differences were found by age for initial and secondary extension stiffnesses. The ANOVA results by age for flexion stiffness showed that both the initial and secondary flexion stiffnesses were significantly different (p=0.024 and p=0.001). Student's t-tests for initial flexion showed that the 7 year old group had a higher stiffness compared to the 5 and 6 year old groups (p=0.019 and p=0.010). For secondary flexion the 7 year old group also had significantly higher stiffness when compared to the 5 and 6 year old groups (p=0.001 and p=0.001).

**Table 2**. Stiffness in Flexion and Extension

| Motion | Mean Stiffness (Nm/°) | RMSE | n |
|---|---|---|---|
| Initial extension | 0.277 | 0.071 | 22 |
| Secondary extension | 0.095 | 0.019 | 15 |
| Initial flexion | 0.227 | 0.086 | 22 |
| Secondary flexion | 0.148 | 0.026 | 18 |

Matched pair analyses showed significance differences between initial and secondary values for both flexion and extension, p=0.0001 and p<.0001, respectively. A matched pairs analysis comparing stiffness values between initial flexion and initial extension resulted in statistical differences, p=0.025. Statistical significance was also found when comparing secondary flexion to secondary extension, p<.0001.

## DISCUSSION

This study quantified pediatric c-spine isometric strength and stiffness in flexion and extension. Sex was not a significant covariate for strength or stiffness measurements. These finding are consistent with previous reports of sex not being a significant covariate for prepubescent children when measuring hand grip strength as a proxy of general health (Häger-

Ross & Rösblad, 2002). Older children were significantly stronger than the younger children in the cohort; this finding supports previous works that found that age but not sex can be an influencing factor in c-spine strength (Eckner et al., 2014). Initial stiffness measurements were significantly stiffer than secondary measurements. We hypothesize that this difference in stiffness can be linked to the differences in muscle engagement when changing direction of movement. Moreover, subjects were consistently stronger at the mid-range of motion than at neutral position. Previously research with adult male volunteers found similar trends in increasing strength further away from the neutral position (Seng, Peter, & Lam, 2002).

Stiffness measurements were significantly higher in extension for the initial portions of the motions. Pediatric subjects were significantly stronger in extension than flexion at both neutral and mid-range position. Previous volunteer testing with both adult and pediatric cohorts have consistently reported higher strength in extension than in flexion (Seng, Peter, & Lam, 2002; Eckner et al., 2014). This is not unexpected given the differences in size and amount of the musculature that move the neck in flexion and extension. Surprisingly, however, for the secondary stiffnesses, subjects were stiffer in flexion than extension.

A limitation of this study is that subjects were not restrained during the testing protocol. While it was originally planned, subjects' comfort level did not allow for the implementation of the four-point restraint. Limitations were also seen in the inconsistency in engagement during stiffness protocol. Subjects needed to be reminded to continuously engage with the testing equipment. Future work will incorporate the quantification of muscle activation percentages using EMG analyses when performing the stiffness protocol. Future work will also incorporate each subject's kinematics to quantify postural difference when performing the testing protocol. Kinematic analysis will allow the quantification of how subjects conducted the test, that is, if subjects were using more than just their neck musculature when performing the testing protocol.

## CONCLUSION

This study represents a preliminary analysis of pediatric c-spine strength and stiffness in flexion and extension. Subjects were stronger and had higher stiffnesses at mid-range of motion. Age not sex contributed to significant differences at this young age. Further analyses are required to better assess the significance of stiffness differences and how these relate to subjects' efforts and strength. Understanding these distinctions in strength and stiffnesses of this pediatric population may allow for more biofidelic boundary conditions when creating crash simulations involving kinematic responses of the head and neck.

## ACKNOWLEDGMENTS

The authors would like to acknowledge the National Science Foundation (NSF) Center for Child Injury Prevention Studies at the Children's Hospital of Philadelphia (CHOP) for sponsoring this study and its Industry Advisory Board (IAB) members for their support, valuable input and advice. The views presented are those of the authors and not necessarily the views of CHOP, the NSF, or the IAB members. The authors thank the Center for Child Injury Prevention Studies (CChIPS) for sponsoring this project. Thank you to the Jameson Crane Sports Medicine Research Institute, and the IBRC family for their invaluable help during this project.

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