

Linear Effects of Subject-Level Variation on Structural Properties of Human Ribs

Elina Misicka, Yun-Seok Kang, Michelle M. Murach, Amanda M. Agnew

Injury Biomechanics Research Center, The Ohio State University

INTRODUCTION

- The human thorax is commonly injured in motor vehicle crashes. Rib fractures in particular are highly prevalent, and contribute to high mortality rates (Kent *et al.*, 2005). In order to gain a better understanding of variability in response and injury tolerance of the human thorax, an ongoing project is aimed at examining variation in rib structural properties.
- Age and sex have been identified as significant predictors of various structural properties in univariate models (Schafman *et al.*, 2016), however there has been little attempt to characterize rib properties with respect to body size, and no previous work has been able to take into account interfering effects between such predictors.
- The objective of this study was to examine the multivariate effects of four subject-level factors (age, sex, weight, and stature) on two structural properties of the human rib which represent its ability to resist loading: peak force and structural stiffness.**

MATERIALS & METHODS

- One hundred eighteen sixth-level ribs from one hundred six post-mortem subjects (71 male, 20-97 years; 35 female, 17-108 years) were included in this study. Weight (kg) and stature (cm) of each subject were measured before rib removal. Each rib was impacted in a dynamic (2 m/s) frontal impact bending scenario (Fig. 1). Peak force (F_{PEAK}) was identified and linear structural stiffness (K) was calculated as the slope of the elastic portion of the Force-Displacement curve (Fig. 2).
- Univariate and multivariate regressions were performed to model the effects of age, sex, weight, and stature on F_{PEAK} and K (Fig. 2). Specifically, multivariate linear regression was employed to identify the effects of all predictors on a single structural property: 1st to examine the effects of single predictors in combination on F_{PEAK} and on K, and 2nd for each structural property, subsequently taking into account first-order interaction terms between predictors.

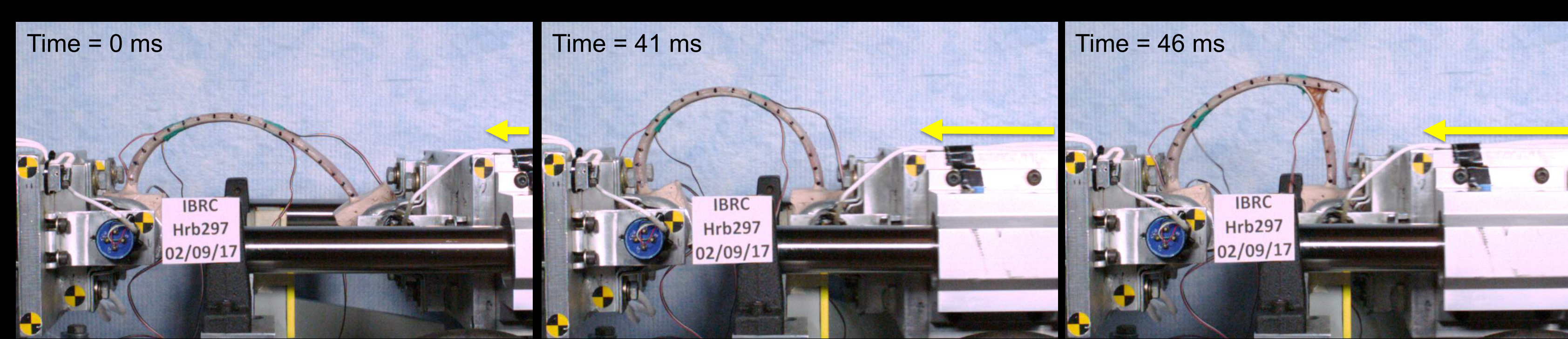


Figure 1. Experimental bending test for an exemplar rib at various times throughout the event

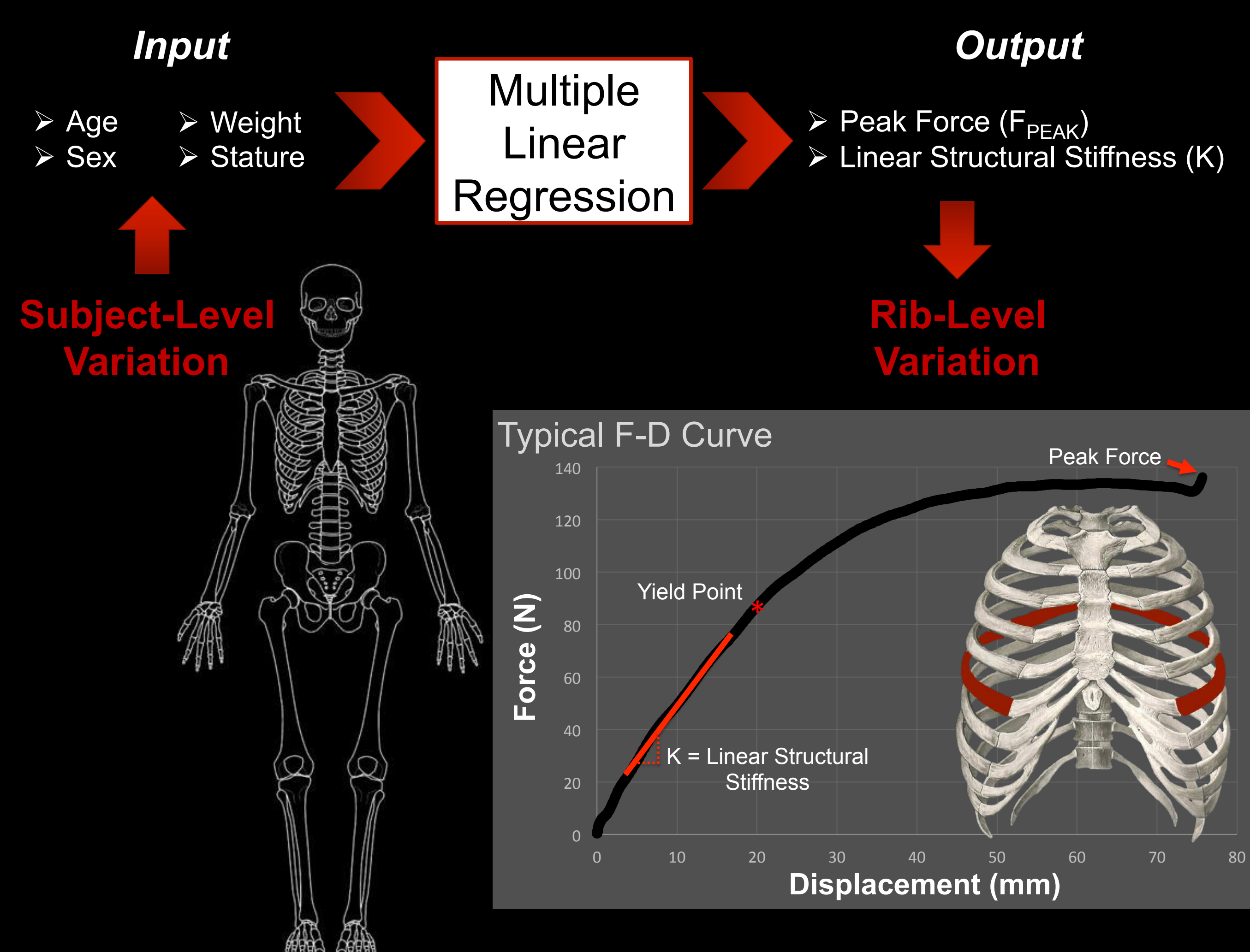


Figure 2. Schematic of multiple linear regression model input and output details

REFERENCES CITED

- Kent R, *et al.* Structural and material changes in the aging thorax and their role in crash protection for older occupants. *Stapp Car Crash J*, 2005, 49:231-249.
- Schafman M, *et al.* Age and Sex alone are insufficient to predict human rib structural response to dynamic A-P loading. *J Biomech*, 2016, 49:3516-3522.
- Murach M, *et al.* Rib geometry explain variation in dynamic structural response: Potential implications for frontal impact fracture risk. *Ann Biomed Eng*, 2017, *in press*.

ACKNOWLEDGEMENTS

Thank you to all of the students and staff of the Injury Biomechanics Research Center. Thank you to the National Highway Traffic Safety Administration (NHTSA) and Autoliv for sponsoring testing contributing to this work. OSU's Body Donor Program, LifeLine of Ohio, and the donors for their generous gifts.



RESULTS & DISCUSSION

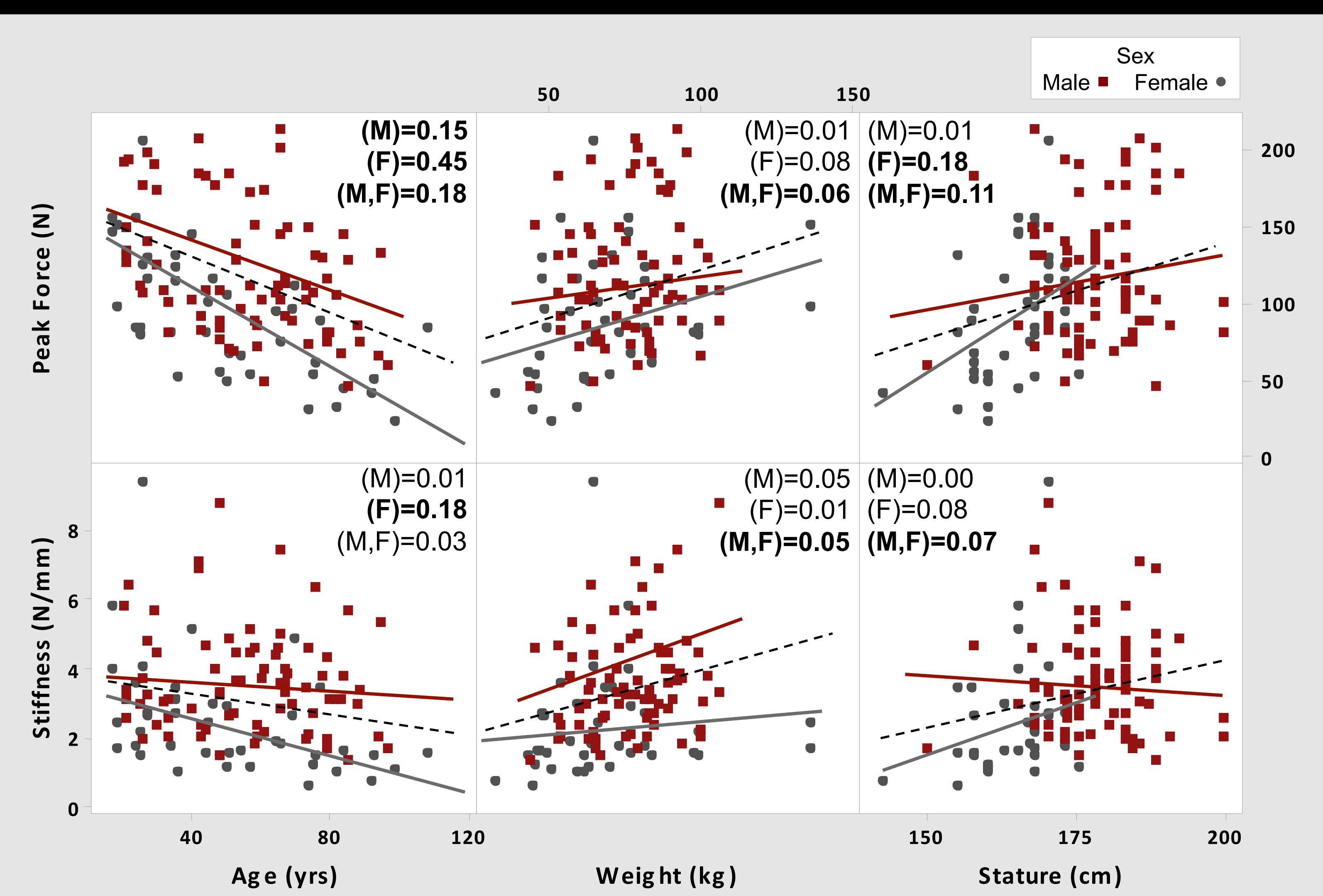


Figure 3. Univariate linear regressions between each continuous predictor and F_{PEAK} (top) and K (bottom). R^2 values are presented for males (M), females (F), and the combined sample (M,F). Statistical significance is indicated in bold.

- Univariate trends showed a decline in F_{PEAK} and K with age, and an increase with weight and stature, although none of these relationships were strong (Fig. 3). Females exhibited a sharper decline in F_{PEAK} and K with age than males. However, there were less-discernible sex-specific trends in structural property changes with weight and stature.
- Age and sex had the strongest effects on response variables in multiple regressions (Table 1). The only significant interaction (Weight*Sex) suggests that weight may be a confounding variable in the prediction of stiffness.
- Schafman *et al.* (2016) identified statistically significant univariate relationships of age and sex with K and F_{PEAK} . The current study utilized a slightly different sample with similar results. Additionally, multiple regression models showed that when included with age and sex, the effects of weight and stature were insignificant. These findings suggest that subject mass and length based scaling techniques likely cannot capture variances in individual rib response or injury.

Table 1. Multiple Regression Results			
		F_{PEAK}	K
Multiple Regression (Predictors Only)	R^2	0.34	0.15
	p(Age)	<0.001	0.025
	p(Weight)	0.489	0.309
	p(Stature)	0.597	0.801
	p(Sex)	0.002	0.001
Multiple Regression (Predictors and Predictor Interactions)	R^2	0.30	0.20
	p(Age)	<0.001	0.002
	p(Weight)	0.902	0.622
	p(Stature)	0.972	0.361
	p(Sex)	0.009	0.001
	p(Age*Weight)	0.869	0.320
	p(Age*Stature)	0.762	0.790
	p(Weight*Stature)	0.991	0.098
	p(Age*Sex)	0.230	0.094
	p(Weight*Sex)	0.354	0.004
	p(Stature*Sex)	0.991	0.973

CONCLUSIONS

- Multiple regression models are a useful tool to better understand sources of variation in rib structural properties. Age and sex were stronger predictors of F_{PEAK} and K than weight and stature, however the amount of variance explained by the models remained low ($R^2 = 15-34\%$). This suggests that utilizing additional predictor variables and alternate modeling techniques may improve our understanding of variability in rib response.
- An unbalanced sample with regard to sex is a limitation of this study. Furthermore, not all datasets were normally distributed.