

Can We Predict Cushioning Perception from the Mechanical Properties of Shoes?

Matthew Q. Salzano^{a*}, Gillian Weir^a, John Kuzmeski^a, Jessica Thompson^b, Matthieu B. Trudeau^b, Chris Ertel^b, Kayley Dear^b, Steffen Willwacher^c, and Joseph Hamill^a

^aUniversity of Massachusetts Amherst, Amherst, MA, USA

^bBrooks Running Research Laboratory, Seattle, WA, USA

^cOffenburg University of Applied Sciences, Offenburg, Germany

Introduction

In addition to biomechanical and mechanical testing, subjective ratings of footwear such as comfort, cushioning and overall satisfaction provide valuable information for footwear design. Prior studies on perception and footwear have found that, in general, shoes with softer midsoles are the most preferred (Sterzing et al., 2013). The ability to predict footwear satisfaction based on footwear mechanical properties would be invaluable to footwear manufacturers. In addition, identification of properties most important for satisfaction would help direct shoe design.

Purpose of the study

The purpose of this study was to determine if overall satisfaction ratings of running shoes can be predicted from its mechanical properties and runner demographics.

Methods

Shoe mechanical properties and footwear perception data (compiled from multiple studies) from 105 individuals (34 males, 71 females, 36.4 ± 8.8 yr, 66.0 ± 9.2 kg, 1.68 ± 0.07 m) and 65 shoes (from 7 brands) were analyzed for this study. Briefly, perceptual data was gathered after subjects ran on a force-instrumented treadmill at 3.35 m/s for 2 minutes. Runners rated their overall satisfaction (7-point Likert scale; 1: very dissatisfied to 7: very satisfied) in addition to

willingness to purchase the shoe (Y/N). In analysis, Likert scores were transformed to a 3-point general satisfaction scale, where all dissatisfied responses (Likert <4) were scored as a 1, neutral (=4) as a 2, and all satisfied (>4) as a 3. Shoe mechanical properties were assessed with an impact tester (Exeter Research, Brentwood, NH, USA) using the ASTM F1976-13 standard. Variables tested at the heel and forefoot (FF) were: Gmax, energy return (ER), loading rate (LR), time-to-peak (TTP), and durometer (duro). Stack height (heel & FF), heel-toe drop, and longitudinal flexibility were also measured.

Three random forest models were built to assess the predictive power of shoe mechanical properties on overall satisfaction. Each model used one of the overall satisfaction measures as its outcome variable (Model 1: Likert scale; Model 2: transformed scale; Model 3: purchase decision), with shoe properties, neutral/support classification, body mass, age, and sex as predictors. For each model, data were first subdivided (80/20 split) into a training set and validation set. Models were built on the training set using 10 repeats of 5-fold cross validation, using default tuning parameters. The validation set was then used to test the prediction accuracy of the final random forest model. All analyses were done in R (R Core Team, Vienna, Austria). Accuracy was compared against the no information rate

(NIR; $\alpha = 0.05$), where values above NIR indicate good prediction.

Results

Model 1 showed poor prediction accuracy. Prediction accuracy in Model 2 was good but not statistically significant ($p = 0.051$). Model 3's prediction accuracy was significantly greater than the NIR ($p = 0.008$). Heel stack height, heel-toe drop, and heel energy return tended to be among the five most important mechanical predictors across all 3 models.

Table 1. Prediction accuracy [95% CI] and NIR for each random forest model.

Model	Accuracy	NIR	p-val
1	23.1% [14.9 – 33.1]	25.3%	0.722
2	70.3% [59.8, 79.5]	61.5%	0.051
3	66.3 [55.7, 75.8]	53.3%	0.008

Discussion and Conclusion

Our results suggest that shoe mechanical characteristics may be able to predict general satisfaction with a shoe (Model 2) and willingness to purchase (Model 3). Similar to previous research, cushioning is one of the top 3 most desired shoe features (Schubert et al., 2011). In addition, we show that heel stack

height, heel-toe drop, and heel energy return are consistently three of the most important variables for predicting shoe satisfaction. Although the exact relationship between cushioning parameters and satisfaction is still unclear, these findings inform the strategic process of footwear design for optimizing comfort and satisfaction of running shoes.

Acknowledgements

This study was funded by Brooks Running Inc.

References

- Bishop, C., Buckley, J. D., Esterman, A. E., & Arnold, J. B. (2020). The running shoe comfort assessment tool (RUN-CAT): Development and evaluation of a new multi-item assessment tool for evaluating the comfort of running footwear. *Journal of Sports Sciences*, 38(18), 2100–2107.
- Schubert, C., Oriwol, D., & Sterzing, T. (2011). Gender and age related requirements of running shoes: A questionnaire on 4501 runners. In *Footwear Science:3:sup1*, S148-S150.
- Sterzing, T., Schweiger, V., Ding, R., Cheung, J. T. M., & Brauner, T. (2013). Influence of rearfoot and forefoot midsole hardness on biomechanical and perception variables during heel-toe running. *Footwear Science*, 5:2, 71–79.

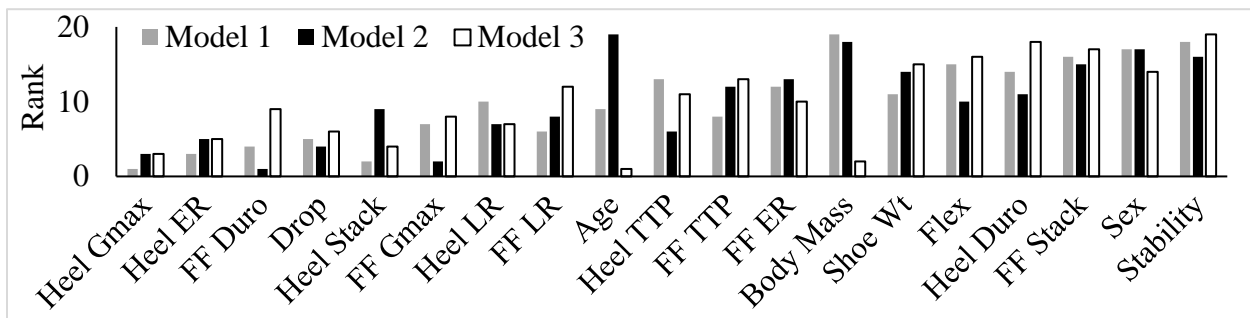


Figure 1. Variable importance ranks for each model (shorter bar = more important).