Cushion Stiffness of Upholstered Wooden Seat Foundations When Subjected to Human Sitting Forces

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The effects of the tensile elastic properties of fabrics used as cushion covers, foam thicknesses of cushion cores, seat bases as the support of an upholstered wooden furniture seat foundation, and sitting areas of subjects were studied relative to the load-deformation behavior of cushions situated on wooden seat base frames when subjected to human sitting forces. The experimental results indicated that the sitting area of a subject, fabric tensile elastic constant, and foam thickness had significant effects on the cushion stiffness, but the seat base type did not. The sitting area of a subject had the greatest effect on the cushion stiffness constants, followed by the fabric tensile elastic constant and foam thickness. A regression technique was proposed to derive a power equation for the estimation of the cushion stiffness using the parameters investigated in this study.

Keywords: Fabric tensile elastic property; Cushion compressive stiffness; Sitting forces; Upholstered wooden seat foundation; Sitting area

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INTRODUCTION

Humans use wooden furniture throughout their lives for many different purposes, including eating, sleeping, working, and resting. As such, this furniture should feature both an optimum design and maintain all of its structural properties while in use (Jucienė and Vobolis 2012). Cushioning is one of the most important parts of an upholstered wooden seat because it can affect the sitting experience in terms of the sitting comfort, such as the feeling of softness or hardness of the seat, experience of the seat, *etc.* (Bennington 1985; Helander *et al.* 1987). Comfort is often a concern in seat design. For an upholstered wooden seat, comfort refers to the static comfort, which is the sitting impression of the seated occupants (Ebe and Griffin 2001). The human static sitting comfort of a seat is related to the basic properties of a seat itself, such as the shape, size, and stiffness (Bennington 1985; Grujicic *et al.* 2009). Measuring the stiffness of a cushion is the most common way to evaluate the comfort of an upholstered seat (Grujicic *et al.* 2009).

The stiffness of a seat cushion, which consists of foam as its padding material and is covered with fabric or leather materials, can be affected by the tensile elastic property of the fabric cover materials, *i.e.*, the tensile load-extension behavior and compressive stiffness property of the core foam materials. It is common in the manufacturing sector to use a fixed cover size to enclose core foam blocks. Therefore, variations caused by the tensile elastic properties of the different cover materials can result in an inconsistent cushion stiffness and further impact the sitting experience. Recently, upholstered furniture manufacturers have been experiencing quality issues related to differences in the cushion performance caused by variations in the fabric tensile property. Manufacturers would like to understand how cushion stiffness is affected by the elastic properties of the fabric used.

Limited literature is available on the effects of the tensile elastic properties of the cover materials on the cushion stiffness in upholstered wooden seats subjected to human sitting forces. Generally, the compression properties of cushion materials are measured with a mechanical testing machine (ASTM D5034-95 2003; ASTM D3574-11 2011). However, cushion stiffness is an important parameter used to evaluate the human sitting experience. Because of different motion mechanisms, the mechanical testing machine cannot exactly simulate human sitting movements. Therefore, the machine load force should be replaced by a human sitting force when studying cushion stiffness as it relates to the human sitting experience.

Lee and Ferraiuolo (1993) reported that the sitting comfort of a seat was affected by the foam thickness and stiffness. Xu *et al.* (2015) investigated the effects of the compressive load magnitude, cover, and core materials on the force-deformation-time behavior of seat cushions commonly used in upholstered furniture. It was concluded that changing the cover material from leather to a fabric had no remarkable effect on the elastic constant of the tested cushion materials, but it increased the viscosity and delayed the elastic-deformation-related damping constants. There has been no tensile elastic property data reported for leather and fabric materials. In Hu (2014), it was demonstrated that the load-deformation behavior of cushion materials was noticeably affected by the loading head size. This implied that the contact area should be considered in cushion stiffness studies that are employing human sitting forces. Swearingen *et al.* (1962) investigated the relationship between sitting area and human subject body weight through human subjects sitting tests and concluded that each tested human subject yielded their only unique area-weight curve (*i.e.*, each human subject yielding a different area-weight curve), even after the sitting load reached to human subject body weight, if continuously loading the subject with extra dead weight. This indicated that the sitting area is the most significant factor, rather than human height and weight. Moreover, Li (2017) showed that the seat base type had a remarkable effect on the sitting experience and overall seat deformation performance.

The main objective of this study was to investigate the effect of the fabric cover tensile elastic constants on the load-deformation behavior of the cushion in upholstered wooden seats subjected to human sitting loads. The specific objectives were to: 1) evaluate the effects of the fabric tensile elastic constants on the cushion stiffness, 2) evaluate the effects of different foam thicknesses as core materials on the cushion stiffness, 3) evaluate the effects of the seat base type on the cushion stiffness, 4) evaluate the effects of the sitting area of a subject on the cushion stiffness, and 5) propose a regression technique to derive an empirical equation for predicting the stiffness of seat cushions that takes into consideration various factors in upholstered wooden seat foundations.

EXPERIMENTAL

Experiment Design

A 3 × 3 × 3 × 2 completely factorial experiment was designed to study the stiffness of cushions when seat foundations were subjected to sitting forces from human subjects. The four factors were the fabric tensile elastic constant in the warp direction (18.88 N/cm, 69.47 N/cm, and 206.85 N/cm), foam thickness (12.7 cm, 14.0 cm, and 15.2 cm), sitting area of a subject (1025 cm^2, 1237 cm^2, and 1497 cm^2), and seat base type (panel, spring). Each of the three participants sat three times (Chorin *et al.* 2015) for each of the 54 experimental combinations to determine the variations that occurred during sitting, including variations in the human body weight center, seated location, and sitting speed.

Participants

Three healthy human subjects were selected in this experiment to represent three sitting areas (1025 cm^2, 1237 cm^2, and 1497 cm^2). These areas were calculated by multiplying the hip width by the sitting depth. The popliteal height, which is defined as the vertical distance from the underside of the foot to the underside of the thigh at the knees, was used to adjust the sitting heights of the subjects to the same level. Ethical approval was obtained from the Mississippi State University Institutional Review Board. Written informed consents were received from all of the participants.

Table 1. Summary of the Anthropometric Measurements of the Participants

Subject	Gender	Height (cm)	Popliteal Height (cm)	Weight (kg)	Hip Width (cm)	Sitting Depth (cm)	Sitting Area (cm^2)
1	F	162	43.2	48	29.5	34.8	1025
2	F	160	40.6	62	34.8	35.6	1237
3	M	180	49.5	86	36.8	40.6	1497

Materials

Seat foundation

The wooden seat foundation of upholstered furniture usually consists of a wooden base frame with a solid panel as a support (Fig. 1a) or a top surface area installed with springs (Fig. 1b). Foam cushions are generally covered with fabric or leather materials (Fig. 1c). Figure 1 shows the configurations and dimensions of the two wooden seat bases, spring and panel-top, that were used in this experiment. Holes were drilled in the supporting panel of the solid surface seat base frame (Fig. 1a) to allow air to escape from a tested cushion. Five evenly spaced Standard Wire Gauge #8 flat sinuous springs (Flexsteel Industries Inc, Starkville, MS, USA) were installed on the top of the spring type seat base frame (Fig. 1b).

The 51-cm^2 polyurethane foam blocks used in this experiment had a density of 28 kg/m^3 and 25% indentation force deflection of 169 N (ASTM D3574-11 2011). Three types of polyester woven fabrics were used for the cushion covers in this experiment. A typical woven fabric structure has two thread orientations, filling (or weft) and warp (Barber 1991). The warp direction is the lengthwise or longitudinal thread in a fabric roll, while the filling direction is the transverse thread or yarn drawn through the warp yarns to create the fabric (Lomov *et al.* 2006). Figure 1d shows that a cushion cover consisted of four pieces: top and bottom square pieces, each sized 51 cm × 51 cm; and two narrow side pieces, where the short piece was for the zip side and the long piece covered the other three sides. All of the pieces had a 1.3-cm margin. The top/bottom, short side, and long side pieces had tensile elastic constants of 18.88 N/cm, 69.47 N/cm, and 206.85 N/cm in the warp direction (16.99 N/cm, 43.32 N/cm, and 118.82 N/cm in the filling direction), respectively (ASTM D5034-95 2003; Zhou 2016). The coefficient of correlation between the warp and filling elastic constants was 0.9994, which indicated that the elastic constant of these three fabrics in the warp direction had a strong positive correlation with that in the filling direction. Therefore, only three levels of elastic constants in the fabric warp direction were used in the experimental design when considering the fabric tensile property effect. All of the foam blocks, with different thicknesses, seat bases, and sewed covers, were prepared and provided by a local upholstery furniture manufacturer (Lane Furniture, Tupelo, MS, USA).

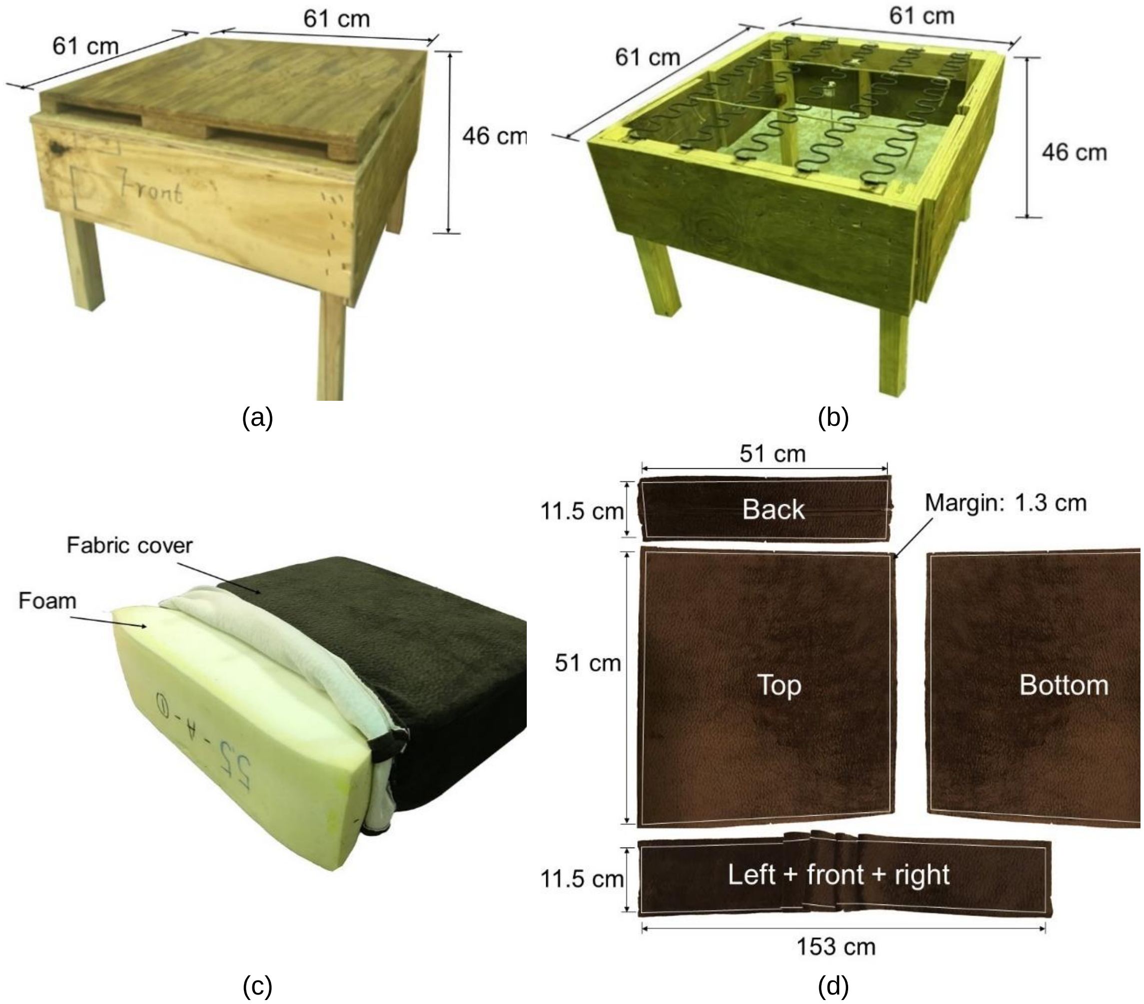

Fig. 1. Illustration of the seat foundation components used in this study: (a) solid panel base frame; (b) flat spring base frame; (c) cushion; and (d) fabric cover

Methods

Figure 2 shows the seat foundation with four load cells (PT Global, LPX-250, Auckland, NZ) attached to the bottom of each of the foundation legs, and two linear position transducers (Unimeasure PA-40-N20-D1S-10T, Corvallis, OR, USA) with their line ends attached to the centers of the tested cushion top (Tag 1) and middle spring of the seat base (Tag 2). A National Instruments SCXI-1000 system (Austin, USA) with two 1102B modules (each using a 1303 interface) simultaneously recorded the voltage outputs of the load cells and transducers at a rate of 100 Hz. A height adjustable footrest platform in front of the seat foundation was used to adjust the seat height for each participant, *i.e.*, the vertical distance from the top surface of the seat foundation to the footrest platform surface, to match the participant popliteal height.

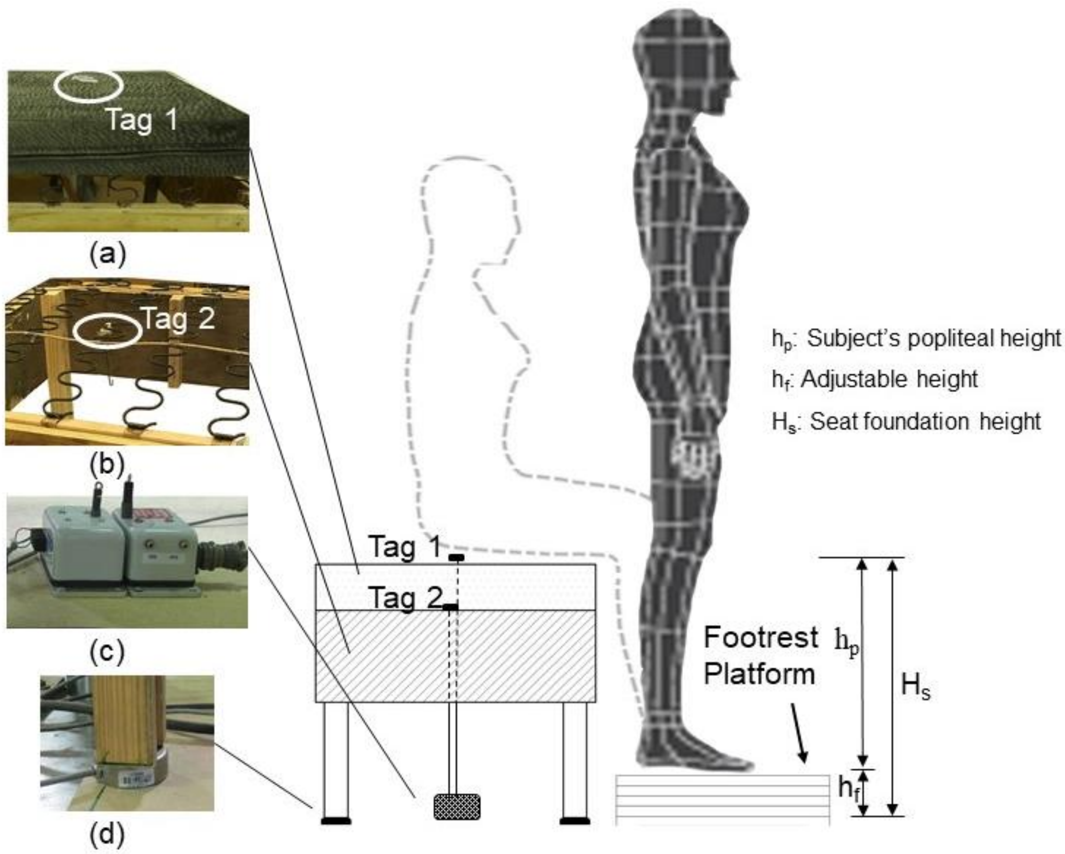

Fig. 2. Schematic of the setup for the sitting tests, including the details about the: (a) Tag 1 location; (b) Tag 2 location; (c) two linear transducers; and (d) load cells

Measurements of the participants were taken at the beginning of the sitting tests. The participants performed normal sitting at a speed less than 25 cm/s with their arms crossed (Li *et al.* 2017). Potential inter-subject differences due to movement of the upper limbs were minimized by requiring subjects to fold their arms across over their chest throughout the experiment (Laudani *et al.* 2014). The four load cells recorded the vertical sitting forces on the seat foundation as a function of time, and two linear position transducers simultaneously recorded the deformation at the center of the seat foundation as a function of the time during the period a participant was sitting. The magnitude of a vertical sitting force on the seat foundation was the sum of the four loading forces recorded with the four load cells. The maximum deformation recorded at the center of the seat foundation was used to calculate the cushion stiffness because the deformation distribution in the middle front-to-back cross section of the seat was not uniform. The maximum cushion deformation measured was the difference between the two displacements recorded by the two linear position transducers. A sitting force cushion deformation curve was constructed for each sitting experiment based on the two previous data sets recorded, *i.e.*, sitting force-time and cushion deformation-time. The cushion stiffness property was expressed as the stiffness constant (*K*, N/cm), *i.e.*, the slope of the sitting force-cushion deformation curve.

Statistical Analyses

A four-factor analysis of variance (ANOVA) on the general linear model (GLM) procedure (SAS Software, SAS Institute Inc., Cary, USA) was performed first using the following full linear model (Eq. 1) to analyze the significances of the four main effects and their interactions on the stiffness constant of the tested cushions,

$$K_{ftbs} = \mu + \alpha_f + \beta_t + (\alpha\beta)_{ft} + \gamma_b + (\alpha\gamma)_{fb} + (\beta\gamma)_{tb} + (\alpha\beta\gamma)_{ftb} + \delta_s + (\alpha\delta)_{fs} + (\beta\delta)_{ts} + (\alpha\beta\delta)_{fts} + (\gamma\delta)_{bs} + (\alpha\gamma\delta)_{fbs} + (\beta\gamma\delta)_{tbs} + (\alpha\beta\gamma\delta)_{ftbs} + \varepsilon_{ftbsm} \quad (1)$$

where K_{ftbs} is the cushion stiffness (N/cm); μ is the overall mean of the cushion stiffness (N/cm); α_f is the continuous variable representing the effect of the fabric tensile elastic properties (N/cm); f is 18.88 N/cm, 69.47 N/cm, and 206.85 N/cm; β_t is the continuous variable representing the effect of the foam thickness (cm); t is 12.7 cm, 14 cm, and 15.2 cm; γ_b is the continuous variable representing the effect of the sitting area of a subject (cm^2); b is 1025 cm^2, 1237 cm^2, and 1497 cm^2; δ_s is the discrete variable representing the effect of the seat base type; s is the panel and spring seat bases; ε_{ftbsm} is the random error term; and m is 1 to 3 replicates.

In general, mean comparisons were performed using the protected least significant difference (LSD) multiple comparisons procedure if any significant interaction was identified; otherwise, the main effects were concluded. All of the statistical analyses were performed at the 5% significance level.

RESULTS AND DISCUSSION

Figure 3 shows a typical load-deformation curve of the evaluated cushions. Two linear regions (corresponding to slopes K_1 and K_2) were observed in the curve. The stiffness constant of a cushion evaluated in this study was expressed as the slope of the second straight line (K_2), and the least square linear regression technique was used to derive the slope. The coefficients of determination (R^2) for all of the derived stiffness constant values ranged from 0.67 to 0.94. Table 2 summarizes the mean values of the cushion stiffness constants for each experimental combination of the seat base type, foam thickness, fabric tensile elastic constant, and sitting area of a subject.

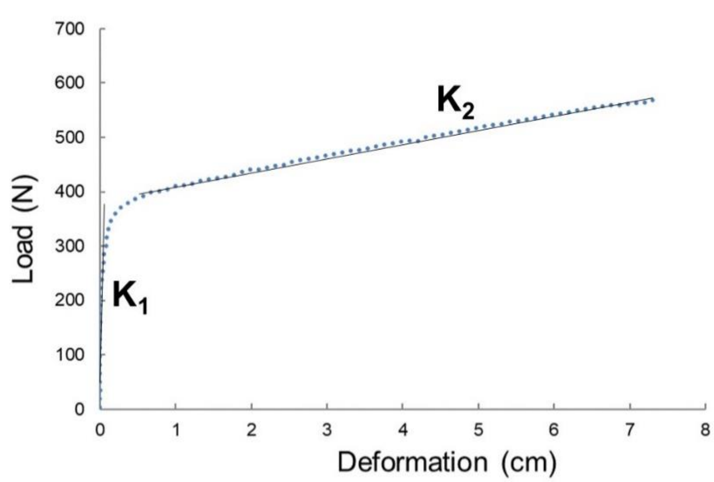

Fig. 3. Typical load-deformation curve of the cushions evaluated in this study

Table 2. Mean Values of the Cushion Stiffness Constant for the Fabric Tensile Elastic Constant with Each Combination of the Sitting Area of a Subject, Foam Thickness, and Seat Base Type

Sitting Area of Subject (cm^2)	Foam Thickness (cm)	Seat Base	Fabric Tensile Elastic Constant (N/cm)		
			18.88	69.47	206.85
1025	12.7	Panel	28.06 N/cm (7%) A	32.08 N/cm (4%) B	35.51 N/cm (2%) B
		Spring	27.37 N/cm (3%) A	32.86 N/cm (1%) B	33.45 N/cm (1%) B
	14.0	Panel	28.35 N/cm (6%) A	33.75 N/cm (3%) B	37.28 N/cm (10%) B
		Spring	28.94 N/cm (3%) A	32.77 N/cm (3%) AB	35.02 N/cm (5%) B
	15.2	Panel	28.94 N/cm (5%) A	35.22 N/cm (10%) B	36.79 N/cm (6%) B
		Spring	30.61 N/cm (5%) A	35.12 N/cm (3%) B	36.10 N/cm (6%) B
1237	12.7	Panel	30.31 N/cm (4%) A	33.84 N/cm (4%) AB	37.87 N/cm (4%) B
		Spring	30.51 N/cm (4%) A	34.14 N/cm (2%) AB	36.98 N/cm (4%) B
	14.0	Panel	32.47 N/cm (3%) A	34.24 N/cm (2%) A	39.63 N/cm (4%) B
		Spring	32.37 N/cm (2%) A	34.53 N/cm (3%) A	39.24 N/cm (5%) B
	15.2	Panel	33.65 N/cm (4%) A	37.57 N/cm (4%) AB	40.91 N/cm (7%) B
		Spring	34.43 N/cm (5%) A	37.18 N/cm (3%) AB	40.61 N/cm (1%) B
1497	12.7	Panel	36.40 N/cm (7%) A	38.46 N/cm (17%) A	45.32 N/cm (6%) B
		Spring	34.63 N/cm (2%) A	38.55 N/cm (8%) A	42.97 N/cm (3%) B
	14.0	Panel	37.38 N/cm (11%) A	44.44 N/cm (4%) B	47.28 N/cm (5%) B
		Spring	36.89 N/cm (6%) A	43.36 N/cm (3%) B	46.21 N/cm (2%) B
	15.2	Panel	38.75 N/cm (12%) A	44.73 N/cm (4%) B	48.76 N/cm (4%) C
		Spring	39.63 N/cm (4%) A	43.75 N/cm (0%) B	46.30 N/cm (5%) B
Values in parentheses are the coefficients of variation in percentage; means in each row not followed by a common letter are significantly different from one another at the 5% significance level; the LSD value is 4.00 N/cm					

Mean Comparisons

The skewness and Kurtosis values were examined for the full linear model in Eq. 1 to check the normality of the random error term, ε_{ftbsm}. The calculated skewness and Kurtosis values were -0.52 and 2.57, respectively, which indicated that the random errors followed a normal distribution (Kim 2013).

The ANOVA results of the cushion stiffness constants (Table 3) based on the linear model in Eq. 1 indicated that the four-way, three-way, and two-way interactions were not significant. The main effects of the fabric tensile elastic constant, foam thickness, and sitting area of a subject were all considered statistically significant at the 5% level, while the seat base was not significant. Further analysis of the magnitudes of the F-values (Table 3) indicated that the fabric tensile elastic constant and sitting area of a subject had the same level of magnitude, while the foam thickness had a lower F-value compared with the other two factors.

Table 3. ANOVA Results Obtained from the GLM Procedure Performed on Four Factors for the Cushion Tests

Source	F-value	P-value
Foam thickness	24.49	< 0.0001
Fabric tensile elastic constant	127.85	< 0.0001
Foam thickness × Fabric tensile elastic constant	0.34	0.8488
Sitting area of subject	195	< 0.0001
Foam thickness × Sitting area of subject	1.25	0.2958
Fabric tensile elastic constant × Sitting area of subject	1.82	0.1293
Foam thickness × Fabric tensile elastic constant × sitting area of subject	0.56	0.8084
Seat base	1.58	0.2119
Foam thickness × Seat base	0.19	0.8293
Fabric tensile elastic constant × Seat base	1.38	0.2564
Foam thickness × Fabric tensile elastic constant × Seat base	0.35	0.8421
Sitting area of subject × Seat base	0.53	0.5887
Foam thickness × Sitting area of subject × Seat base	0.09	0.9863
Fabric tensile elastic constant × Sitting area of subject × Seat base	0.1	0.9831
Foam thickness × Fabric tensile elastic constant × Sitting area of subject × Seat base	0.1	0.9992

Conclusions derived from the interpretation of the main effects depend on the relative magnitudes of the interactions and individual main effects (Freund and Wilson 1997); therefore, the significance of the three main effects on the cushion stiffness constants were analyzed by considering the nonsignificant four-way interaction. Tables 2, 4, and 5 summarize the mean comparison results of the cushion stiffness constants for the fabric tensile elastic constant, foam thickness, and sitting area of a subject, respectively. The results were based on a one-way classification created with 54 parameter combinations with respect to the four-factor interaction and the mean comparisons among these combinations using a single LSD value of 4.00 N/cm. Additionally, mean comparisons of the seat base type based on the four-way interaction yielded the same results obtained from the mean comparisons with respect to the main effects, which indicated that there was no significant difference in the stiffness constant values between the two different seat base types.

Table 2 indicates that the stiffness constant values of the tested cushions increased as the fabric tensile elastic constant values increased. The cushions covered with the high tensile elastic fabric (206.85 N/cm) had significantly higher stiffness constant values than those covered with the low tensile elastic fabric (18.88 N/cm). This observation implied that sitters might experience a higher spring bouncing effect rather than a cushion flatten bottom-up effect when sitting on cushions covered with high tensile elastic fabrics (Ebe and Griffin 2001). The significance of the stiffness constant values of the cushions covered with the medium tensile elastic fabric (69.47 N/cm), if compared with those covered with fabrics with low or high tensile elastic constants, depends on the experimental combination of the sitting area of a subject, foam thickness, and seat base type.

Table 4 indicates that the cushion stiffness constant values in general increased as the foam thickness increased, but the significance of the foam thickness effect was only found when the sitting area of a subject was 1497 cm^2. Specifically, the 12.7-cm thick foam cushions had significantly lower stiffness constant values than the other two foam cushion thicknesses when the cushions were covered with the medium tensile elastic fabric. There were no significant differences in the stiffness constant values between the cushions with 14-cm and 15.2-cm thick foams. These results indicated that changing the foam thickness did not significantly alter the stiffness constant of the cushions when subjected to a sitting area less than 1237 cm^2, but they might experience significant cushion stiffness changes if the sitting area was 1497 cm^2.

Table 4. Mean Comparisons of the Cushion Stiffness Constant for the Foam Thickness for Each Combination of the Sitting Area of a Subject, Fabric Tensile Elastic Constant, and Seat Base Type

Sitting Area of Subject (cm^2)	Fabric Tensile Elastic Constant (N/cm)	Seat Base	Foam Thickness (cm)		
			12.7	14.0	15.2
1025	18.88	Panel	28.06 N/cm A	28.35 N/cm A	28.94 N/cm A
		Spring	27.37 N/cm A	28.94 N/cm A	30.61 N/cm A
	69.47	Panel	32.08 N/cm A	33.75 N/cm A	35.22 N/cm A
		Spring	32.86 N/cm A	32.77 N/cm A	35.12 N/cm A
	206.85	Panel	35.51 N/cm A	37.28 N/cm A	36.79 N/cm A
		Spring	33.45 N/cm A	35.02 N/cm A	36.10 N/cm A
1237	18.88	Panel	30.31 N/cm A	32.47 N/cm A	33.65 N/cm A
		Spring	30.51 N/cm A	32.37 N/cm A	34.43 N/cm A
	69.47	Panel	33.84 N/cm A	34.24 N/cm A	37.57 N/cm A
		Spring	34.14 N/cm A	34.53 N/cm A	37.18 N/cm A
	206.85	Panel	37.87 N/cm A	39.63 N/cm A	40.91 N/cm A
		Spring	36.98 N/cm A	39.24 N/cm A	40.61 N/cm A
1497	18.88	Panel	36.40 N/cm A	37.38 N/cm A	38.75 N/cm A
		Spring	34.63 N/cm A	36.89 N/cm AB	39.63 N/cm B
	69.47	Panel	38.46 N/cm A	44.44 N/cm B	44.73 N/cm B
		Spring	38.55 N/cm A	43.36 N/cm B	43.75 N/cm B
	206.85	Panel	45.32 N/cm A	47.28 N/cm A	48.76 N/cm A
		Spring	42.97 N/cm A	46.21 N/cm A	46.30 N/cm A
Means in each row not followed by a common letter are significantly different from one another at the 5% significance level; the LSD value is 4.00 N/cm					

Table 5 indicates that the stiffness constant values of the evaluated cushions in general increased as the sitting area of a subject increased. Cushions that were subjected to sitting areas of 1497 cm^2 showed significantly higher stiffness constant values than those subjected to sitting areas of 1025 cm^2 and 1237 cm^2. The differences in the stiffness constant values between the cushions subjected to sitting areas of 1025 cm^2 and 1237 cm^2 tended to become significant as the foam thickness increased. These results implied that subjects with larger sitting areas tend to experience a higher spring bouncing effect when they sit on a thicker foam cushion than sitters with smaller sitting areas. The above results were consistent with the results found in Hu (2014), which indicated that the cushion could be stiffer when loaded with a larger size loading head in mechanical tests.

Table 5. Mean Comparisons of the Cushion Stiffness Constant for the Sitting Area of Subject for Each Combination of the Foam Thickness, Fabric Tensile Elastic Constant, and Seat Base Type

Foam Thickness (cm)	Fabric Tensile Elastic Constant (N/cm)	Seat Base	Sitting Area of Subject (cm^2)		
			1025	1237	1497
12.7	18.88	Panel	28.06 N/cm A	30.31 N/cm A	36.40 N/cm B
		Spring	27.37 N/cm A	30.51 N/cm A	34.63 N/cm B
	69.47	Panel	32.08 N/cm A	33.84 N/cm A	38.46 N/cm B
		Spring	32.86 N/cm A	34.14 N/cm A	38.55 N/cm B
	206.85	Panel	35.51 N/cm A	37.87 N/cm A	45.32 N/cm B
		Spring	33.45 N/cm A	36.98 N/cm A	42.97 N/cm B
14.0	18.88	Panel	28.35 N/cm A	32.37 N/cm B	37.38 N/cm C
		Spring	28.94 N/cm A	32.37 N/cm A	36.89 N/cm B
	69.47	Panel	33.75 N/cm A	34.24 N/cm A	44.44 N/cm B
		Spring	32.77 N/cm A	34.53 N/cm A	43.36 N/cm B
	206.85	Panel	37.28 N/cm A	39.63 N/cm A	47.28 N/cm B
		Spring	35.02 N/cm A	39.24 N/cm B	46.21 N/cm C
15.2	18.88	Panel	28.94 N/cm A	33.65 N/cm B	38.75 N/cm C
		Spring	30.61 N/cm A	34.43 N/cm A	39.63 N/cm B
	69.47	Panel	35.22 N/cm A	37.57 N/cm A	44.73 N/cm B
		Spring	35.12 N/cm A	37.18 N/cm A	43.75 N/cm B
	206.85	Panel	36.79 N/cm A	40.91 N/cm B	48.76 N/cm C
		Spring	36.10 N/cm A	40.61 N/cm B	46.30 N/cm C
Means in each row not followed by a common letter are significantly different from one another at the 5% significance level; the LSD value is 4.00 N/cm					

Prediction Equation

To quantify the effects of the fabric tensile elastic constant, foam thickness, and sitting area of a subject on the cushion stiffness constants and obtain functional relationships between the cushion stiffness constant and parameters that might be practical for seat design purposes, the least squares regression technique using a power equation (Eq. 2) was proposed to fit to the individual test data points,

$$K = a\alpha^{b} \times \beta^{c} \times \gamma^{d} \tag{2}$$

where K is the cushion stiffness constant (N/cm); α is the fabric tensile elastic constant in the warp direction (N/cm); β is the foam thickness (cm); γ is the sitting area of a subject (cm^2); and a, b, c, and d are regression fitting constants.

Additionally, a linear equation was also utilized to fit to the test data, but its R^2 value was lower than that for the power equation. The regression analysis yielded the following significant power equation (Eq. 3) with an R^2 of 0.83 and p-value less than 0.0001:

$$K = 0.06\alpha^{0.088} \times \beta^{0.505} \times \gamma^{0.651} \tag{3}$$

This indicated that Eq. 3 could be useful for predicting the mean stiffness constant of a cushion as a function of different factors, such as the fabric tensile elastic constant, foam thickness, and sitting area of a subject, *i.e.*, the regression method proposed in this study could be a useful technique for deriving the relationship between the cushion stiffness and its significant factors. However, more research needs to be done in this area to validate this regression technique and identify other significant factors. Additionally, the standardized regression coefficients were 0.569, 0.246, and 0.67 for the fabric tensile elastic constant, foam thickness, and sitting area of a subject, respectively. These coefficient values implied that the sitting area of a subject had the greatest effect, followed by the fabric tensile elastic constant, while the foam thickness had the smallest effect (Freund and Wilson 1997).

CONCLUSIONS

1. The sitting area of a subject, fabric tensile elastic constant, and foam thickness had significant effects on the cushion stiffness constants, but the seat base type did not.
2. The sitting area of a subject had the greatest effect on the cushion stiffness constants, followed by the fabric tensile elastic constant and foam thickness.
3. A power equation was derived for the estimation of the cushion stiffness constants using certain parameters, but it was limited to the cushion materials used in this study. Further validation is required to determine if these derived equations can be used for general applications.

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