A reciprocal matrix approach to the analysis of hand-felt softness of facial tissues

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ABSTRACT: Previous studies of household tissue softness based on the hand-felt approach used n^2 or n-1 paired comparisons and ranking methods to distinguish the order of the samples. However, subjective perceptions and objective sample deviations could not easily be excluded. As an alternative, we used a reciprocal matrix analysis, a paired-comparison method to the n(n-1)/2 power, and found it capable of compensating for the biases of testers and samples and generating a more reasonable and robust ranking. We also were able to effectively quantify hand-felt softness of the samples by calculation of weighting eigenvectors. The proposed pretest training materials and method effectively enhanced the perceptive abilities of the examiners. The experience gained in the process can be used to strengthen standard test procedures and establish professional panels to evaluate hand-felt softness.

Application: Tissue manufacturers can use the methods described in this report to obtain a truthful reflection of consumers' preference to the hand-felt softness of facial tissue products, which can be used for process improvement, quality control, and instrumental developmental purposes.

The softness of household tissue papers often is expressed as a hand-felt perception, in addition to the bulk softness and surface softness, which also are widely used [1,2]. Hand-felt softness is a unique characteristic of household tissues that often dictates consumer preference and, as a consequence, has become highly stressed as an aspect of production technology for which manufacturers strive.

Although previous studies recognized that bulk and surface softness are independent of each other, to a degree [3,4], the perception of softness by consumers is mainly based on hand-felt sensing, which is a synthesis of the senses, the so-called integrated softness, a multidimensional perception encompassing bulk and surface softness, and even visual and audio clues [2].

In studies of the softness properties of 16 paper towel specimens [3] and on facial tissues with a three-parameter softness model for 13 test specimens [5], we found that examiners had difficulty maintaining a consistent memory of the softness of specific samples because of the large number of specimens and grades, and the ranking sequence was subject to deviation. As confirmed by psychological studies, in comparing certain attributes, an optimal sample size is five to nine; more samples can lead to greater deviations [6].

Pan et al. [7] described an out-of-plane ultrasonic measurement in which the dependent variable, the artificial softness determination, was obtained by a panel of examiners conducting paired bulk softness evaluations. We think that more rigorous logical proof is needed for a dependent variable based on instrumental measurements, which in turn produce more reliable results.

Three studies had the most rigorous logical deductions within the literature we surveyed: the first one used fuzzy logic in a softness study [8], the second used eigenvectors to analyze tissue softness [9], and the third used a methodology to assess pulp softness [10]. These three papers were the impetus for the present study. A review of the three studies revealed the following limitations hampering further understanding of tissue softness: 1) deviations among the rankings previously were not consistently quantified; 2) methods of hand-felt tests and data analyses were rather divergent; and 3) although fuzzy logic, eigenvectors, and the methodology to assess pulps are fairly rigorous, the authors did not elaborate on the method they used to deduce softness.

Based on those observations and a search of analytic hierarchy process (AHP) theory [11], a U.S. patent on soft papers [9], and the fuzzy analysis concept, we formulated the present study, which examines n(n-1)/2 paired-comparisons in a reciprocal matrix (i.e., encompassing 10 paired-comparisons in a 5 × 5 matrix, 15 paired-comparisons in a 6 × 6 matrix, and so on). We think that through duplicate comparisons and weight calculations in a reciprocal matrix, deviations of samples and subjective perceptions of the examiners can be reduced to a minimum, and a method of quantifying tissue softness can be established.

EXPERIMENTAL PROCEDURES

Our goal for this study was to extend the understanding gained in previous studies on evaluating household tissue softness by using the reciprocal matrix in the AHP theory to establish a method to quantify and analyze facial tissue softness. The study was conducted in three phases. In the first phase, we used a reciprocal matrix to construct models for analysis and deduction. In the second phase, we established methods of specimen analysis and deduction to regulate specimen

preparation and the method of determining hand-felt softness. In the third phase, a trial was implemented by a panel composed of professionals using the framework of the first phase and the test method established in the second phase. Results were replicated and affirmed by a trial panel of consumers. Afterwards, proposed training material was used to train seven layperson consumers.

First phase: Construction of models for analysis and deduction

Building a softness analysis model using a reciprocal matrix

Suppose we have a sample group H, in which $H = \{X_1, X_2, X_3, X_4, X_5\}$. Using paired comparisons, an ideal softness distribution reciprocal matrix can be constructed according to the definition: each i and j belong to N, when data of $a_{ij} > 0$; $a_{ji} = 1/a_{ij}$; and $a_{ii} = 1$. A reciprocal matrix, A, can be established in which $A = (a_{ij})_{5\times5}$ (**Table I**). Each a_{ij} value in matrix A represents the result of a paired X_i and X_j comparison, the outcome of which is in accordance with the description in **Table II**. Any specimen judged to be inferior will use the inverse of the superior specimen; for example, in Table I, X_2 is softer than X_1 by 3 degrees recorded in column a_{21}, then X_1 is inferior to X_2 by 0.333 (1/3), recorded in column a_{12}; whereas $a_{ii} = 1$ represents the result of $X_i = X_i$, a self-same comparison.

Making softness (SF) inferences

According to the reciprocal matrix equations, the data in Table I were obtained by one layperson. **Table III** provides a summary of the inference, which was made in five steps:

1. Calculate the eigenvectors (E_V): Ev_i = 0.033, 0.064, 0.130, 0.264, and 0.509, which represent the weighting factors of paired softness comparison of samples X_1 to X_5.
2. Take logarithms of Ev_i using W_i as the expressions: $\log(Ev_i) = W_i$ = (-1.48, -1.20, -0.89, -0.58, and -0.29).
3. Transfer W_i into softness scales: (SF_i) = (40, 46, 52, 58, and 64). (**Table IV** shows the transfer formula.)
4. Compare the results to the standard softness scale: (SF_{std}) = (38, 43, 55, 56, and 62). In this case, the standard was assumed to be established by five experts before the test.
5. Make inferences of the qualification of the results: tests were conducted for the existence of a significant linear relationship between SF_i and SF_{std} using the t-test. At the level of $\alpha = 0.05$, when $|t| \geq t_{\alpha/2;\, n-2}$, the null hypothesis H_0: $\rho = 0$ (the true correlation is 0) was rejected, and then the alternative H_1: $\rho \neq 0$ (the true correlation is not 0) [12]. In this case, n=5, at the level of $\alpha = 0.05$, then $R^2 = 0.9425$; $|7.0126| > t_{\alpha/2\,;\,5-2} = 3.182$. The result obtained by the layperson was accepted.

A	X_1	X_2	X_3	X_4	X_5
X_1	1.000	0.333	0.200	0.143	0.111
X_2	3.000	1.000	0.333	0.200	0.143
X_3	5.000	3.000	1.000	0.333	0.200
X_4	7.000	5.000	3.000	1.000	0.333
X_5	9.000	7.000	5.000	3.000	1.000

I. Reciprocal matrix A of sample group H.

Preferential No.	Paired Comparison between Samples X_i and X_j
1	X_i and X_j are equally soft (important).
3	X_i is weakly softer (important) than X_j.
5	X_i is strongly softer (important) than X_j.
7	X_i is very strongly softer (important) than X_j.
9	X_i is absolutely softer (important) than X_j.
2, 4, 6, 8	Even numbers can be assigned if the numbers listed above do not fully represent the difference.
Reciprocals	$X_i > X_j$, then $a_{ij} > 0$; $a_{ji} = 1/a_{ij}$.

II. Preferential numbers for scoring differences.

Sample	Ev_i	W_i	SF_i	SF_{std}
X_1	0.033	-1.48	40	38
X_2	0.064	-1.20	46	43
X_3	0.130	-0.89	52	55
X_4	0.264	-0.58	58	56
X_5	0.509	-0.29	64	62

III. Summarized report of the softness (SF) inference deduction.

Second phase: Specimen preparation and method of determining hand-felt softness

Seven commercial facial tissue samples were collected from local stores. All samples were judged to have undergone a creping process by doctor blades during production [13]. The samples were repackaged in blank boxes and were respectively designated with codes A to G for identification.

The samples were subjected to various physical tests, including grammage (TAPPI T410 om-88, with a Mettler Toledo AB204-S balance to a precision of ±0.1 mg), moisture content (TAPPI T412 om-88, with a Hsan-Mi CDV-452 oven with a temperature precision of ±1.0°C), caliper (TAPPI T426 wd-70, determined with Lesson-6820D digital calipers with a precision of 0.01 mm), and machine- (MDT) and cross-direction tensile (CDT) strengths, rate of elongation (TAPPI T494 om-88, by a Lesson 7030B tester with a precision of 0.1 gf).

Before the softness test, specimens were prepared and the rules for scoring were detailed to panel participants. First, according to the code number of the samples, each sample sheet (two plies per sheet) was inspected to be free of tears, dead

W_i	-1.50	-1.40	-1.30	-1.20	-1.10	-1.00	-0.90	-0.80	-0.70	-0.60	-0.50
SF_{scale}	40	42	44	46	48	50	52	54	56	58	60
Formula	Y = X*20 +70; Y= SF_{scale}; X = W_i.										

IV. Rule for standard softness (SF) transformation.

Comparison between Each SF_{std}	Preference No.	Rules for Choosing Numbers
SF_3(60) vs. SF_1(40)	7, 8, 9	Choose 7, 8, or 9 for the softer sample.
SF_2(50) vs. SF_1(40) SF_3(60) vs. SF_2(50)	4, 5, 6	Choose 4, 5, or 6 for the softer sample.
SF_1(40) vs. SF_1(40) SF_2(50) vs. SF_2(50) SF_3(60) vs. SF_3(60)	1, 2, 3	Choose 1 for no difference; 2 or 3 can be chosen if it feels slightly softer.

V. New rules for softness judgment.

Sample		Expert 1		Expert 2		Expert 3		Expert 4		Expert 5		Average	
No.	SF_{std}	W_i	SF_i	W_i	SF_i	W_i	SF_i	W_i	SF_i	W_i	SF_i	Wi	SF_i
A	58.7	-0.48	60.5	-0.48	60.3	-0.77	54.6	-0.62	57.6	-0.45	61.0	-0.57	58.7
B	47.6	-1.17	46.6	-1.00	50.1	-1.36	42.8	-0.88	52.5	-1.42	41.5	-1.12	47.6
C	56.4	-0.63	57.4	-0.69	56.3	-0.56	58.7	-0.77	54.5	-0.77	54.7	-0.68	56.4
D	58.2	-0.71	55.7	-0.71	55.8	-0.44	61.3	-0.63	57.4	-0.69	56.1	-0.59	58.2
E	40.8	-1.36	42.8	-1.51	39.9	-1.56	38.8	-1.46	40.8	-1.53	39.4	-1.46	40.8
F	42.8	-1.33	43.5	-1.36	42.8	-1.43	41.3	-1.16	46.8	-1.45	41.0	-1.36	42.8
G	50.8	-1.10	47.9	-1.02	49.7	-1.08	48.4	-0.92	51.6	-0.77	54.5	-0.96	50.8
W_i/SF_{std}: R^2		0.925		0.949		0.902		0.889		0.880		1.000	
$\|t\| \geqq t_{0.025;5}$: 2.571		7.846		9.643		6.792		6.325		6.056		-----	

VI. W_i and SF_i values obtained by the experts in hand-felt trials.

wrinkles, and other apparent defects. Then each sheet was double-folded into a square pad equal to four sheets or eight plies.

When testing, a tester could touch two specimens simultaneously with both hands to feel the difference in softness, with or without exchanging hands on the same specimens for reconfirmation; or the person could test the two specimens alternately using the same hand. The testers also felt the bulk softness of a specimen by holding and folding it in the palm, and then crunching and stroking it with the fingers. Results of the pair-wise comparison were then scored according to the rules of Table II.

Third phase: Implementation of trials by professionals and laypersons

Two panels, A and B, were formed to conduct the hand-felt tests at room temperature. Panel A was composed of five experts, and panel B was composed of nine ordinary consumers. The trials were implemented as follows:

1. First, the five experts completed the trial and established the experimental and analytic protocols to serve as dependent variables to be compared with the independent paper quality variable, CDT strength.
2. The nine consumer panelists conducted the softness trial following the same protocols to substantiate the conclusions reached by the experts.
3. Seven trainees conducted a softness perception training to subconsciously establish a standard scale to allow a more accurate softness judgment. **Table V** shows the new rules for comparison.

RESULTS AND DISCUSSION

Inferences from expert panel results

Transformation of W_i into softness scales

Table VI shows the W_i and SF_i values obtained by the five experts. The equation, $\log(Ev_i) = W_i$, clearly indicates that W_i and Ev_i have the same weighting factor. Hence, log values of

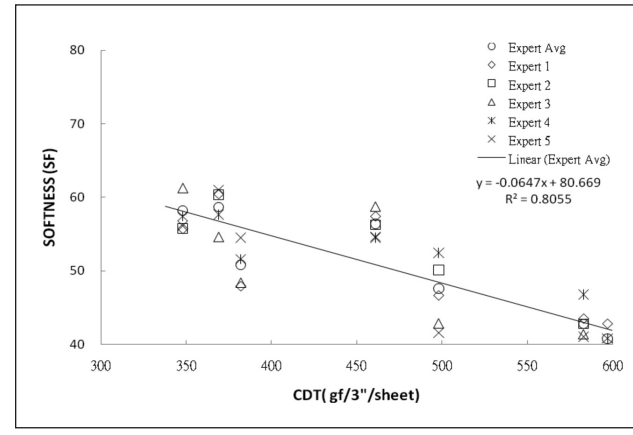
Sample		Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Average
Softness SF_i	A	60.5	60.3	54.6	57.6	61.0	58.7
	B	46.6	50.1	42.8	52.5	41.5	47.6
	C	57.4	56.3	58.7	54.5	54.7	56.4
	D	55.7	55.8	61.3	57.4	56.1	58.2
	E	42.8	39.9	38.8	40.8	39.4	40.8
	F	43.5	42.8	41.3	46.8	41.0	42.8
	G	47.9	49.7	48.4	51.6	54.5	50.8
SF_i/variables R^2	Grammage	0.179	0.104	0.448	0.137	0.256	0.244
	Caliper	0.306	0.107	0.365	0.036	0.342	0.244
	MDT	0.263	0.140	0.326	0.083	0.539	0.291
	CDT	0.592	0.716	0.655	0.768	0.833	0.806
	MDT-CDT ratio	0.017	0.125	0.011	0.250	0.001	0.043
	Elongations	0.000	0.074	0.024	0.216	0.005	0.030
	Moisture	0.128	0.268	0.003	0.262	0.040	0.103

CDT = cross-direction tensile strength; MDT = machine-direction tensile strength.

VII. R^2 values between SF_i of the experts and the physical properties.

W_i can be a basis for selecting standard specimens and establishing a softness scale. Based on the average test values of the five experts, we established a weighted linear relationship, W_i. Then, using the transformation equation in Table IV, it was transformed into softness values, SF_i = (58.7, 47.6, 56.4, 58.2, 40.8, 42.8, and 50.8). These values were then used as the specimen standard, SF_{std}.

Table VI indicates that the coefficients of determination R^2 between the W_i and SF_{std} of the five experts were 0.925, 0.949, 0.902, 0.889, and 0.880. The *t*-test results indicated that the $|t| > t_{0.025;7\text{-}2} = 2.571$, with individual values of 7.846, 9.643, 6.792, 6.325, and 6.056. The R^2 between W_i and SF_i must be 1; hence, there must be the same regression equation, R^2, and $|t|$ between SF_i and SF_{std}.



1. Correlation graph of softness (SF) and cross-direction tensile strength (CDT) as tested by the experts.

Correlation between tissue softness and CDT strength

Table VII shows the outcomes of the physical tests (grammage, caliper, MDT, CDT, the MDT-CDT ratio, elongation, and moisture), and their SF_i values. It shows that the R^2 values between SF_i and CDT were, respectively, 0.592, 0.716, 0.655, 0.768, and 0.833 for the 5 samples tested, and the R^2 value directly correlated between the average SF_i and CDT was 0.806. $|t| = 4.551 > t_{0.025;7\text{-}2} = 2.571$. These values were far greater than R^2 values between the SF_i and any other sheet variables. **Figure 1** shows the correlation graph of *SF* and CDT tested by experts; the regression equation of the two variables was Y = (-0.0647) X + 80.669.

These results are in compliance with papermaking theories and were statistically verified. The main contribution of softness was the destruction of fiber bonding, i.e., through the combined actions of the doctor-blade and creping-agents sprayed on the Yankee cylinder that destroyed the paper strength [13].

Inferences from consumer panel trial

Table VIII shows the trial panel results for nine consumers. Among the nine persons, seven (77.8%) effectively verified the sample softness; their SF_i/SF_{std} results had R^2 values of 0.733, 0.590, 0.967, 0.824, 0.871, 0.947, and 0.618, and $|t|$ values of 3.708, 2.684, 12.13, 4.830, 5.818, 9.473, and 2.842. All t-values were $> t_{0.025;7\text{-}2} = 2.571$. However, two of the testers (22.2%) produced relatively poor coefficients of determination results of 0.373 and 0.366, and did not pass the *t*-test.

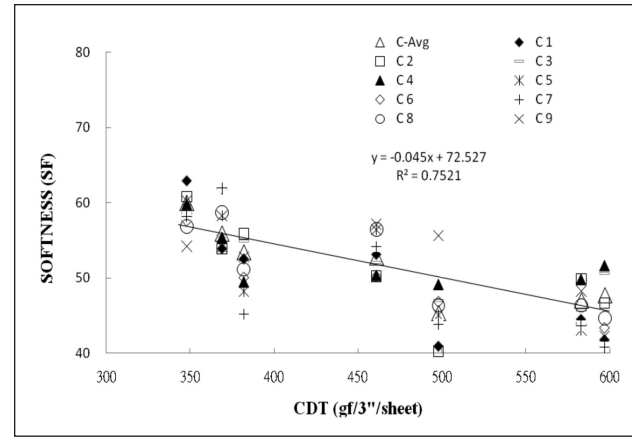
Sample 1		Softness (SF_i) Tested by Consumer									Average - SF_i
No.	SF_{std}	C1	C2	C3	C4	C5	C6	C7	C8	C9	
A	58.7	53.87	53.87	55.61	55.36	58.25	61.82	61.91	58.70	54.12	55.87
B	47.6	40.91	40.26	46.97	49.13	45.05	46.86	43.84	46.34	55.60	45.33
C	56.4	53.10	50.21	52.05	50.35	56.38	50.22	54.11	56.43	57.12	52.70
D	58.2	62.88	60.79	58.58	59.75	60.25	57.60	58.18	56.81	54.18	59.93
E	40.8	41.77	46.62	50.56	51.64	37.75	43.39	40.76	44.62	42.24	47.69
F	42.8	44.48	49.85	45.70	49.81	43.10	44.05	43.64	46.34	48.24	46.99
G	50.8	52.51	55.87	54.91	49.49	48.21	50.07	45.16	51.12	52.77	53.38
W_i/SF_{std}: R^2		0.733	0.373	0.590	0.366	0.967	0.824	0.871	0.947	0.618	0.722
$\|t\| \geqq t_{0.025;5}$: 2.571		3.708	1.726	2.684	1.700	12.13	4.830	5.818	9.473	2.842	3.602

VIII. Results SF_i tested by consumers.

Sample 1		Softness (SF_i) Tested by Consumer									Average - SF_i
No.	CDT	C1	C2	C3	C4	C5	C6	C7	C8	C9	
A	369	53.87	53.87	55.61	55.36	58.25	61.82	61.91	58.70	54.12	55.87
B	498	40.91	40.26	46.97	49.13	45.05	46.86	43.84	46.34	55.60	45.33
C	461	53.10	50.21	52.05	50.35	56.38	50.22	54.11	56.43	57.12	52.70
D	348	62.88	60.79	58.58	59.75	60.25	57.60	58.18	56.81	54.18	59.93
E	597	41.77	46.62	50.56	51.64	37.75	43.39	40.76	44.62	42.24	47.69
F	583	44.48	49.85	45.70	49.81	43.10	44.05	43.64	46.34	48.24	46.99
G	382	52.51	55.87	54.91	49.49	48.21	50.07	45.16	51.12	52.77	53.38
SF_i/CDT: R^2		0.729	0.508	0.736	0.344	0.730	0.774	0.592	0.700	0.471	0.752
$\|t\| \geqq t_{0.025;5}$: 2.571		3.669	2.272	3.733	1.619	3.676	4.135	2.692	3.417	2.111	3.895

IX. Relationship between SF_i and cross-direction tensile strength (CDT) tested by consumers.

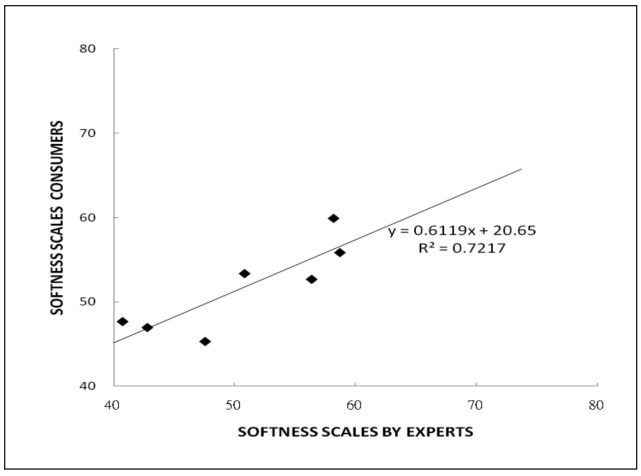
When the W_i results of all nine consumers were averaged and a regression was run against SF_{std}, then the correlation coefficient R^2 value was 0.722. , i.e., average SF_i/SF_{std} : R^2 = 0.722;$|t|=3.602 > t_{0.025;7\text{-}2} = 2.571$. **Table IX** presents correlations between their SF_i and CDT. It shows that SF_i/CDT had R^2 values of 0.729, 0.508, 0.736, 0.344, 0.730, 0.774, 0.592, 0.700, and 0.471, and the R^2 value directly correlated between the average SF_i and CDT was 0.752; $|t|=3.895 > t_{0.025;7\text{-}2} = 2.571$. The distribution of average SF_i and CDT correlations are shown in **Fig. 2**. The regression equation was Y = (-0.045) X + 72.527.



2. Correlation graph of softness (SF) and cross-direction tensile strength (CDT) as tested by consumers.

Examination of differences between experts and consumers

Because consumer and expert panels produced very similar regression equations for the specific sample set, we further



3. Softness comparison between the expert and consumer panels.

examined differences between the two sets (**Fig. 3**). Both panels established highly correlated softness scores for the same sample set, with $R^2 = 0.722$; and a regression equation of Y = 0.6119X + 20.65; $|t| = 3.600 > t_{0.025;7\text{-}2} = 2.571$.

Interim summation of expert and consumer panel trials

Of the seven test specimens used in the trials, if direct comparisons using the n-1 mode had been conducted, the presumed ranking results would have been: E < F < B < G < C < D < A. If we designated these six comparison outcomes, n-1, as sample set D, with D = {d_1, d_2, d_3, d_4, d_5, d_6}, for which d_1 = (E < F), d_2 = (F < B), and so forth, d_i in the *D* sample set could represent only the performance ranking, and was incapable of showing the actual difference in performance. Thus, direct comparisons beg the question of the extent of differences in performance. Are values of d_i*s* equally spaced or not? Are there proportional scales to the performances? As for the direct comparisons by n², we might get 49 results, but face these same questions.

On the other hand, with n(n-1)/2 rounds of repeated comparisons, perceptive differences of the individual examiners could be eliminated and an overall panel perception synthesized. Not only could a reasonable ranking of the specimens be obtained through the weighting relationship, but the softness values were effectively quantifiable. However, we still had two laypersons (22.2% of nine panelists) who showed relatively poor perceptions of tactile softness. To establish a differentiating panel, we endeavored to conduct training for the seven consumers.

Softness perception training

Before the training, the seven consumers underwent a testing trial (Table II). After resting for 10 min, the training program was conducted. The trainer offered three standard specimens to be felt by the seven consumers. SF_{std} values of the standard specimens were $SF_i = 40$, $SF_2 = 50$, and $SF_3 = 60$, which were scored using the rules shown in Table V.

Strengthening of trainee perceptivity of facial tissue softness

The perceptivities of the seven consumers to the softness of the facial tissue specimen set before and after training are

Sample		SF_i Difference													
No.	SF_{std}	Tr1		Tr2		Tr3		Tr4		Tr5		Tr6		Tr7	
		BF	AF	BF	AF	BF	AF	BF	AF	BF	AF	BF	AF	BF	AF
A	58.7	53.87	55.73	53.87	60.31	55.61	56.66	55.36	60.55	51.90	53.00	54.63	62.42	58.58	54.58
B	47.6	40.91	47.65	40.26	39.48	46.97	45.73	49.13	46.04	47.14	47.17	39.78	47.93	45.35	49.07
C	56.4	53.10	54.69	50.21	49.53	52.05	49.93	50.35	60.26	52.64	51.30	46.85	50.37	47.67	55.47
D	58.2	62.88	65.29	60.79	60.07	58.58	64.35	59.75	49.38	58.67	59.71	61.67	57.38	46.86	59.56
E	40.8	41.77	40.43	46.62	43.17	50.56	40.81	51.64	43.52	55.39	40.76	48.49	49.95	49.00	53.17
F	42.8	44.48	41.95	49.85	50.71	45.70	42.57	49.81	45.10	45.13	46.88	36.45	41.30	46.69	46.24
G	50.8	52.51	41.39	55.87	55.93	54.91	53.74	49.49	56.01	58.67	61.68	57.63	53.59	63.92	54.06
$\|t\| \geqq t_{0.025;5}$: 2.571		3.708	3.697	1.726	2.238	2.684	4.128	1.700	2.897	0.928	2.236	1.875	2.744	0.619	2.385
SF_i/SF_{std}: R^2		0.733	0.732	0.373	0.500	0.590	0.773	0.366	0.627	0.147	0.500	0.413	0.601	0.071	0.532
d_i(AF – BE)		-0.001		0.127		0.183		0.261		0.353		0.188		0.461	

X. SF_i perception results of the 7 trainees.

Examiner		Tr1	Tr2	Tr3	Tr4	Tr5	Tr6	Tr7	Avg_d	S_d
SF_i/SF_{std}: R^2	AF	0.732	0.500	0.773	0.627	0.500	0.601	0.532	---	---
	BF	0.733	0.373	0.590	0.366	0.147	0.413	0.071	---	---
d_i(AF – BE)		-0.001	0.127	0.183	0.261	0.353	0.188	0.461	0.225	0.151

XI. Results of paired-comparison t-test before and after training.

presented in **Table X**. Based on the R^2 values of SF_i/SF_{std}, we found that six trainees showed improvements, and only one (Tr1) showed no difference in his/her softness perceptivity. Furthermore, when the before and after training R^2 values of the SF_i/SF_{std} were tabulated (**Table XI**) and a paired t-test was conducted based on d_i(AF – BE) for the statistical significance of the differences, the result of $|t| = 3.929 > t_{0.025,7\text{-}1} = 2.447$ suggested that the null hypothesis of H_0: $\mu_d = 0$ should be discarded. At a confidence level of $\alpha = 0.05$, there was a significant difference accrued after the training, but only four persons were qualified: Tr1, Tr3, Tr4, and Tr6, with respective R^2 values of 0.732, 0.773, 0.627, and 0.601, and $|t|$ values =3.697, 4.128, 2.897, and 2.744 > $t_{0.025;7\text{-}2}$: 2.571.

Interim summation of softness training

The training showed remarkable efficacy in the perception of hand-felt softness. Upon further examining the specimens and discussing the results with the panelists, we deduced the following methods for improvement:

1. The surfaces to be felt should be consistent, i.e., the dryer surfaces of flat tissues should be marked, as should the concave surfaces of embossed tissues.
2. Softness scores of standard test specimens should be verified using a standard operational procedure by a group of professional panelists. Three standard test specimens can be used for each panel test, so that the results will be consistent. For example, if a kit of 20 samples or more are to be tested, they can be separated into four, five, or more panels; then, the test is conducted by comparison with three standard test specimens or by electively placing specimens of known softness in each panel.
3. For each softness trial, at least 10 panelists should be included, including at least five professional softness testers and five or more ordinary consumers. Results of the experts can serve as discriminating criteria for the viability of the test. Laypersons from various trades and with different standards of living could be selected, depending on the purpose of the test, to provide understanding of the response to tissue softness of common consumers or specific groups.

CONCLUSIONS

In this paper, we report the use of a judgmental reciprocal matrix method that can alleviate errors in ranking facial tissue softness. The method provided outcomes that are in compliance with papermaking theories, and are capable of reflecting cross-machine direction tensile strengths of the samples. We found that human perceptions of tissue softness can be quantified and ranked, and the congruency of hand-felt softness perceptions can be enhanced by training. In addition, the process loop can further improve the method of hand-felt softness perception.

Because the relative weakness of softer paper can adversely affect its efficacy in use, a key concern is how to provide a balanced product with good strength and softness perception that meets the demands of the marketplace. If we can adequately quantify the uncertain factor of softness perception, then by adjusting other production parameters, a concrete objective value can be set and achieved through process improvements and quality management, and might used as a basis for developing an infallible instrumental device for that purpose. The analysis described in this paper was based on a reciprocal matrix approach, and the n(n-1)/2 paired comparisons bore out that it can effectively achieve this objective while overcoming deficiencies of the n^2 and n-1 paired-comparison and ranking methods. **TJ**

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ABOUT THE AUTHORS

Softness has become an important factor in marketing household tissue products with which the public is in close daily contact. However, there is no uniformly reliable hand-felt basis that is representative of consumer demands, which gave fresh impetus for the present study.

Thanks to my professional team members, Tser-Ying Teng, Eugene Wang, and colleagues, we spent more than five months reviewing previous studies, establishing inference procedure, and conducting the trials. Essentially, the use of reciprocal matrices is based on the findings of T.L. Saaty in 1980.

All the results indicated that this is an effective method for demonstrating human perceptions of tissue softness; therefore, we are currently conducting a consistency study on reciprocal matrices through trials with embossed paper following the standard operating procedure established in this study. Afterward, we will pursue additional findings by extending the study to compare it with existing merchant softness instruments.



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