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Research on Decorative Materials Properties Used in the Production of Cabinets Based on Visual/Tactile Experience

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Abstract: With the further deepening of ageing in China, the ageing-in-place model is gaining more and more attention. In order to improve the quality of home life of the elderly, this paper takes age-friendly cabinets as the research object, from the perspective of material design, and takes the visual/tactile experience of the elderly as the entry point, classifies the current market cabinet materials, and selects the test samples. The physical properties of the samples were examined and analysed with the subjective emotional changes that the elderly experience with different cabinet materials. The objective physical properties of the cabinet materials were correlated with the visual/tactile subjective emotional factors, and through subjective tests and mathematical and statistical methods, an evaluation model of "visual/tactile subjective emotional factors—objective physical properties of materials" was established for the selection of materials in age-friendly cabinet design. It provides scientific guidance for the selection of materials in age-appropriate cabinet design.

Keywords: wood materials; surfaces; age-friendly furniture; structural design; cabinets

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1. Introduction

With the further deepening of ageing in China and the further increase in the elderly population base, the ageing-in-place model is more recognized by the elderly groups and society, and the quality of the elderly home living space needs to be better improved [1]. The design of ageing-friendly homes is directly related to the quality of home life for the elderly, but the current home products on the market are more inclined to children and young people, and the ageing-friendly design of homes is still in its infancy [2,3].

As an important part of modern kitchens, the kitchen is an important part of the home, and its practicality and operability make ageing-friendly design an important factor in ensuring the independent survival of older people in their daily lives [4]. However, in the current research on the design of cabinet systems, most age-appropriate products are still at a preliminary stage, and there is no systematic theoretical system for their design principles and methods [5,6]. In cabinet design, attention should be paid to the unification of rational and perceptual perception of function, in order to achieve the pursuit of physical function, spiritual value, emotional meaning and psychological satisfaction of the product [7]. The colour, material, and texture of the product can give rise to different visual/tactile sensations directly, thus generating a psychological special emotion and, thus, making a subjective judgement on it [8].

Materials are the basis for the product design and functions, and different materials have different user experiences. Wang et al. [9] proposed a method to evaluate the texture preference image of materials, based on a gene expression programming algorithm, to analyse the cognitive relationship between texture elements and preference images. Hong et al. [10] took the material texture elements as independent variables, consumer preference images as dependent variables, and Apple Watch as the research object, and they proposed a material design method for intelligent wearables based on perceptual images,

established a material style image model, and summarized the material design strategy for intelligent wearables based on implicit comfort and explicit signs to improve design effectiveness. Meanwhile, Chu et al. [11] proposed a design method of colour and material patterns of aircraft cabin seats based on perceptual images. By giving different emotions to the colour and material of seats, passengers' riding comfort and user experiences can be improved.

Rahman [12] investigated how visual and tactile senses influence the evaluation process of consumers when purchasing jeans. A qualitative and quantitative approach was used to examine the sensory cognitive responses to a sample of jeans by examining product characteristics (e.g., colour, fabric). It corroborates that affective and cognitive processing occur and co-exist throughout the evaluation process. Zheng et al. [13] conducted an experimental study of material texture images, using discriminant analysis, cluster analysis, multidimensional scaling, and semantic differencing, in order to accurately describe material texture images and establish a quantitative relationship between objective material parameters and subjective perceptions, using a typical plastic material as an example, to quantify consumers' perceived perceptions of materials. Joel et al. [14] investigated the differences in the characteristics of wood use and catalogue images of wood specimens in Sweden and Japan, and they evaluated the Kansei affective feelings in Sweden, as well as the Kansei affective feelings in Japan, regarding the semantic differential approach to wood use.

Liu et al. [15] analysed the design of palace lantern form features based on perceptual engineering and established a linear regression model between palace lantern form elements and perceived images. The relationship between perceptual factors and design form elements was investigated to guide the design treatment of the palace lantern and provide theoretical support for designers' innovative designs. Lin et al. [16] used big data in the Internet era, multidisciplinary cooperation, and integration of multiple mathematical algorithms to serve design practice. Jia et al. [17] investigated consumers' perceptions of wrist visual image evaluation of wearable devices. By identifying five sets of adjectives, participants were asked to express their visual impressions of wrist wearables through questionnaires and factor analysis. The evaluation of the eight samples, using the five sets of adjectives, was analysed using triangular fuzzy theory. The results were similarly corroborated in the assessment of preferences and purchase intentions. The results objectively and validly reflect consumers' evaluations of the visual image and potential demand for wrist wearables. Meanwhile, projects of BaltSe@nioR and BaltSe@nioR 2.0 were conducted by European research terms, which are joint projects between actors in communities, regions, national public institutions, the business sector, universities, organizations, and civil society in different countries. Those two projects aim to create innovative solutions for safe and securely built environments, indoors and outdoors, for senior citizens.

In this work, the aging-resistant cabinet materials were in focus, and the material design perspective was taken as the starting point to study the emotional changes of the elderly towards different cabinetry materials from the perspective of their visual/tactile experience. The correlation between physical attributes and emotional factors is analysed, and through sensory testing and mathematical and statistical methods, an evaluation model of "visual/tactile emotional factors-physical attributes" is established for the evaluation of cabinet materials, and the trend of the influence of physical attributes on tactile sensations is derived with a view to providing guidance for the design of age-friendly products.

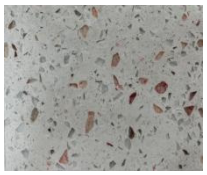
2. Materials and Methods

2.1. Test Materials

In the research on cabinet materials, ten larger brands, such as Oriental Bounty, Europa, Bamberg, and Bologna, were selected, and twelve cabinet sales shops were visited on site to collect summaries and classify the cabinet materials. Finally, combining the expert evaluation method and the KJ method [18], as displayed in Table 1, nine types of cabinet materials that are on sale and have typical representativeness were used in this

work, including joinery board (oak wood), PVC board (PVC + oak wood), fireproof board (fireproof coating + particle board), solid wood (oak wood), painted solid wood (rose wood + transparent paint), melamine board (melamine layer + particle board), painted board (transparent paint + melamine layer + plywood), blister board (ABS + medium density fibre board), and quartz board (quartz crystal + resin).

Table 1. Cabinet material samples.

M1	M2	M3	M4	M5
				
Joinery board	PVC board	Fireproof board	Solid wood board	Painted solid wood board
M6	M7	M8	M9	
				
Melamine board	Painted board	Blister board	Quartz board	

2.2. Visual/Tactile Subjective Evaluation Test

This work was conducted with Chinese elderly people as research subjects. In China, the minimum retirement age is 55 years old, while 70-year-olds are still conscious and capable of taking care of themselves. Thus, 55–70-year-olds were used as research subjects. Meanwhile, subjects were given a subjective evaluation test of tactile sensation in a quiet environment and scored each perceptual imagery. There were 32 participants: 16 men and 16 women. There were 10 groups of visual/tactile perceptual evaluation terms selected through the KJ method combined with expert evaluation: "dry—moist", "cold—warm", "soft and hard", "rough-smooth", "thick-light", "matt—glossy", "cheap—expensive", "rough—fine ", "dull—lively", "uncomfortable—comfortable" (Figure 1).

	−2	−1	0	1	2
Dry - Moist	○	○	○	○	○
Cold - Warm	○	○	○	○	○
Soft - Hard	○	○	○	○	○
Rough - Smooth	○	○	○	○	○
Thick - Light	○	○	○	○	○
Matt - Glossy	○	○	○	○	○
Cheap - Expensive	○	○	○	○	○
Rough - Fine	○	○	○	○	○
Dull - Lively	○	○	○	○	○
Uncomfortable - Comfortable	○	○	○	○	○

Figure 1. Cabinet material visual/tactile perceptual evaluation is on a sub-list.

The experiment was based on the SD method (Semantic Differential) [19,20], and a five-step Likert scale was designed to score and quantify the subjective evaluation of the visual/tactile perception of the cabinet material samples. There were two trials taken with the same subject, and the subjects scored and quantified the visual/tactile perceptual evaluation of nine cabinet material samples, with five-step scoring values of −2, −1, 0, 1, 2. 1, and 2, with smaller scores being closer to the description of the left term and larger scores being closer to the description of the right term [21].

2.3. Surface Roughness Testing

As shown in Figure 2, surface roughness testing is carried out by using the roughness measuring instrument (JB-4C, Tarmin Co., Ltd., Shanghai, China), by the stylus method, in contact measurement. The measuring length is 50 mm, and the measuring direction is along the length of the sample based on the surface roughness measurement standard of GB/T1031-2009 [22]. Meanwhile, each sample is measured five times, and its average value is taken for analysis.

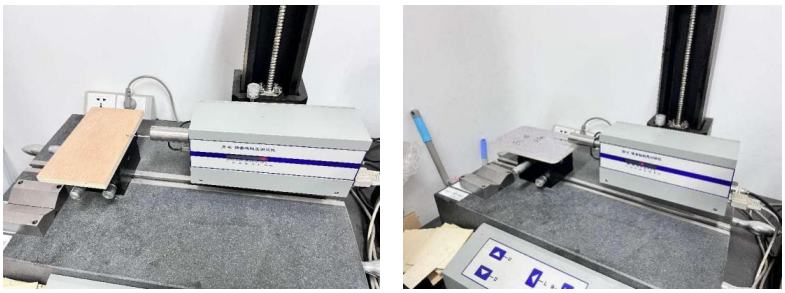


Figure 2. Material surface roughness test.

2.4. Surface Cooling Rate Measurement

As displayed in Figure 3, the room temperature in this work was 28 °C, the humidity was 60%, and the fixed heat source was the tester's palm. The dynamic temperature of the sample was acquired by an infrared imaging camera (A20-M, Thermo Fisher Co., Ltd., Waltham, MA, USA). After dissipating the additional surface temperature, the palm of the hand was placed on the surface of the test material sample for 10 s and then removed. The temperature was recorded as T0, the temperature was recorded every 10 s, the end of the 60th second reading was recorded as Te, and the rate of cooling of the surface of the material sample was calculated as S = (−T0 − Te)/t [23,24].



Figure 3. Material surface cooling rate test.

2.5. Determination of Surface Gloss

As shown in Figure 4, surface gloss testing was carried out in an enclosed room with a cold light source (LED) by using a colorimeter (3NH-NHG 268, Sanenshi Intelligent Technology Co., Ltd., Guangdong, China). In order to improve the accuracy of measurement value, based on the instrument instructions, the measuring angle refers to the angle between the incident light and the vertical direction. When the sample has high gloss (>70 GU), the detailed value of gloss should be acquired at the measuring angle of 20°. When the sample has the medium gloss (10–70 GU), it shall be measured at a measuring angle of 60°. When the sample has low glossiness (<10 GU), the gloss value is suggested to be obtained at a measuring angle of 85°.

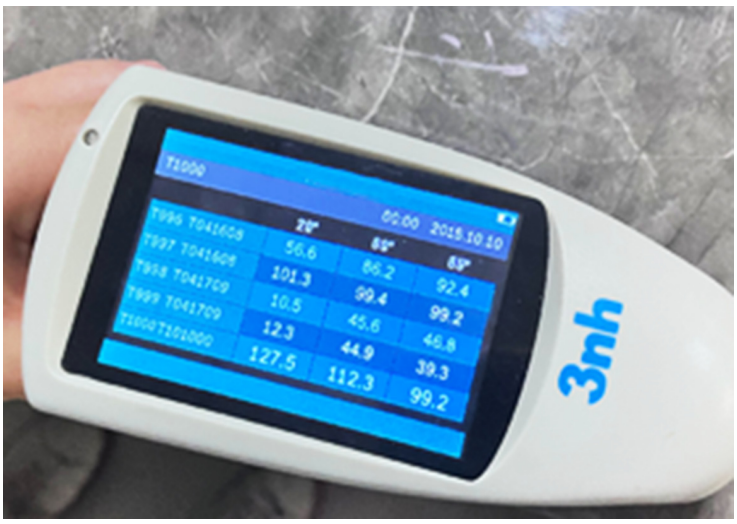


Figure 4. Material surface gloss test.

2.6. Surface Colour Value Test

As displayed in Figure 5, the surface colour with Lab value was measured by using the spectrophotometer (Ci60, X-rite Co., Ltd., Grand Rapids, MI, USA) in an enclosed room with a cold light source (LED). The Lab model is based on an international standard for determining colour established by the Commission International Eclairage (CIE) in 1931. The Lab colour model consists of three elements: L is the luminance, and a and b are two colour channels [25].



Figure 5. Material surface colour value measurement test.

3. Results and Discussion

3.1. Haptic Subjective Evaluation

The test data were first analysed for reliability, and the results showed that the Cronbach coefficient was 0.948, a high value, indicating that the data from this questionnaire had high credibility [26]. After data cleaning and removal of invalid data, 30 sets of valid data were obtained, resulting in a mean score of subjective evaluation for the nine material samples (Table 2).

Table 2. The average score of the tactile perceptual evaluation of the cabinet material.

No.	Drying Wet	Cold Warmth	Soft and Hard	Rough Smooth	Substantial Light and Airy	Matte Glossy	Cheap Expensive	Rough and Tumble Finesse	Dull Lively	Unbearable Comfort
M1	−0.50	−0.40	0.83	0.33	−0.27	−0.47	−0.93	0.20	−0.67	0.33
M2	−0.90	0.57	0.60	−0.07	0.60	−1.17	−0.10	−0.67	−0.13	−0.20
M3	−0.53	0.07	0.77	0.40	0.27	−0.13	−0.27	0.20	−0.07	0.53
M4	−0.90	0.87	0.47	−0.50	0.07	−1.13	−1.27	−1.43	−0.47	−0.80
M5	0.80	−0.60	0.53	1.23	−0.87	1.30	0.83	0.80	0.27	1.00
M6	−0.80	−0.30	0.37	1.00	0.87	1.17	−0.67	0.80	0.00	0.70
M7	0.07	−0.07	0.73	−0.20	−0.73	−0.50	0.30	−0.20	−0.33	0.50
M8	0.13	−0.27	1.13	1.60	−1.23	1.53	0.77	1.30	0.40	1.13
M9	0.07	−1.03	1.47	1.10	−1.47	0.47	0.87	0.67	−0.13	1.00

According to the results of the test, as shown in Figure 6, the comfort ranking of the subjective tactile evaluation test was solid wood board, PVC board, joinery board, painted board, fireproof board, melamine board, painted solid wood, quartzite board, and blister board. The comparison of the two sets of data shows that the highest comfort levels are as follows: painted solid wood, blister board, and quartzite board, while PVC board had the lowest comfort level [27].

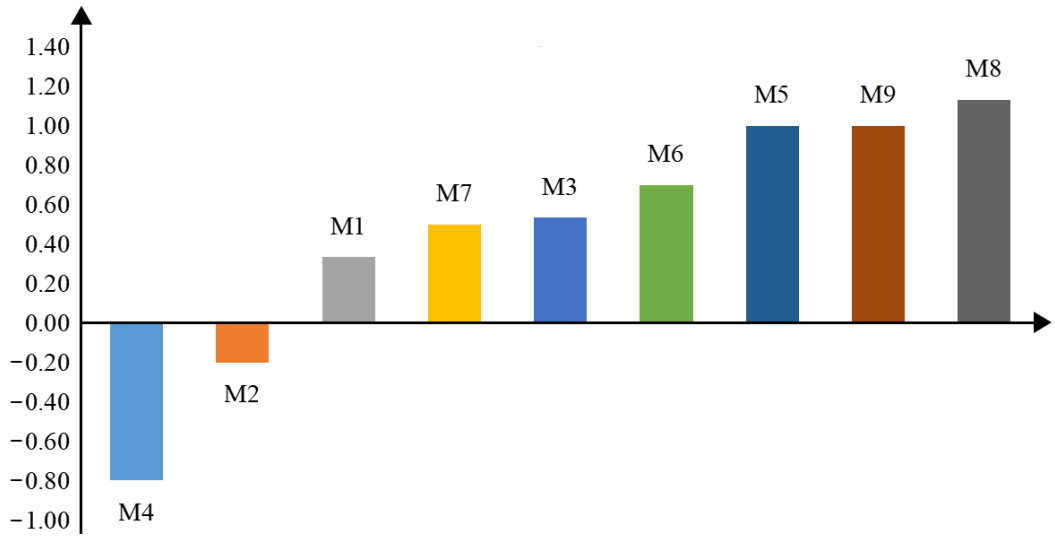


Figure 6. Subjective tactile comfort evaluation (M1: Joinery board, M2: PVC board, M3: Fireproof board, M4: Solid wood board, M5: Painted solid wood board, M6: Melamine board, M7: Painted board, M8: Blister board, M9: Quartz board).

3.2. Evaluation of Physical Properties

According to the test results, as shown in Figure 7, fireproof board had the lowest surface roughness of 0.017 μm, and solid wood board had the highest surface roughness of 10.076 μm. The roughness, in descending order, is fireproof board, joinery board, painted solid wood board, blister board, quartzite board, melamine board, painted board, PVC board, and solid wood.

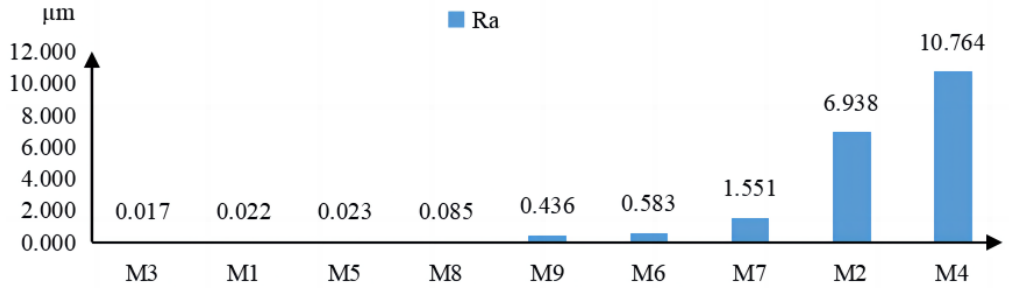


Figure 7. Material surface roughness (M1: Joinery board, M2: PVC board, M3: Fireproof board, M4: Solid wood board, M5: Painted solid wood board, M6: Melamine board, M7: Painted board, M8: Blister board, M9: Quartz board).

According to the results of the test, as shown in Table 3 and Figure 8, blister board had the lowest rate of surface cooling, while the solid wood had the highest rate of surface cooling. In all, the rates of surface cooling of each sample, in descending order, were as follows: blister board, quartzite board, melamine board, fireproof board, painted solid wood board, painted board, PVC board, joinery board, and solid wood board.

Table 3. The rate at which the surface of the cabinet material cools down (M1: Joinery board, M2: PVC board, M3: Fireproof board, M4: Solid wood board, M5: Painted solid wood board, M6: Melamine board, M7: Painted board, M8: Blister board, M9: Quartz board).

No.	0 s/°C	10 s/°C	20 s/°C	30 s/°C	40 s/°C	50 s/°C	60 s/°C	Surface Cooling Rate
M8	29.70	28.80	28.40	28.30	28.00	27.70	27.40	0.038
M9	28.40	26.40	26.20	26.00	25.30	25.20	25.00	0.057
M6	30.70	27.70	27.50	26.60	26.10	27.00	27.00	0.062
M3	31.20	28.40	27.00	27.50	26.80	27.10	27.00	0.070
M5	29.00	26.50	25.90	25.50	24.80	24.50	24.60	0.073
M7	31.40	29.20	28.30	27.40	26.90	26.70	26.40	0.083
M2	31.20	28.10	28.00	27.30	27.00	26.20	26.00	0.087
M1	30.60	27.30	26.40	25.70	25.60	25.10	24.60	0.100
M4	30.90	27.20	26.00	25.40	25.40	25.10	24.70	0.103

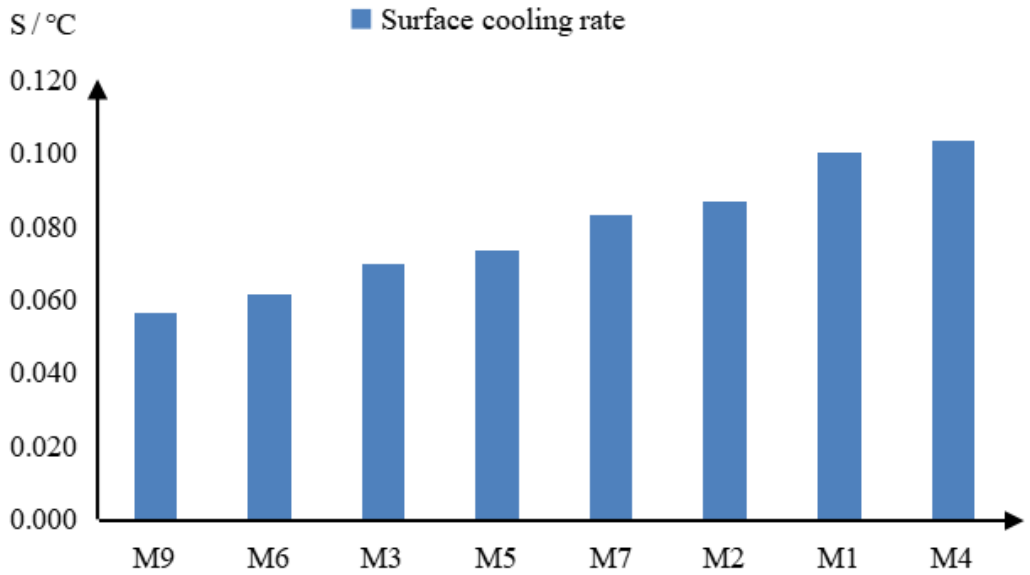


Figure 8. The rate at which the material surface cools down (M1: Joinery board, M2: PVC board, M3: Fireproof board, M4: Solid wood board, M5: Painted solid wood board, M6: Melamine board, M7: Painted board, M9: Quartz board).

Based on the results for the surface gloss test of the cabinet material, the materials' glossiness, in descending order, were as follows: solid wood board, PVC board, joinery board, fireproof board, painted board, melamine board, quartzite board, painted solid wood board, blister board (Figure 9).

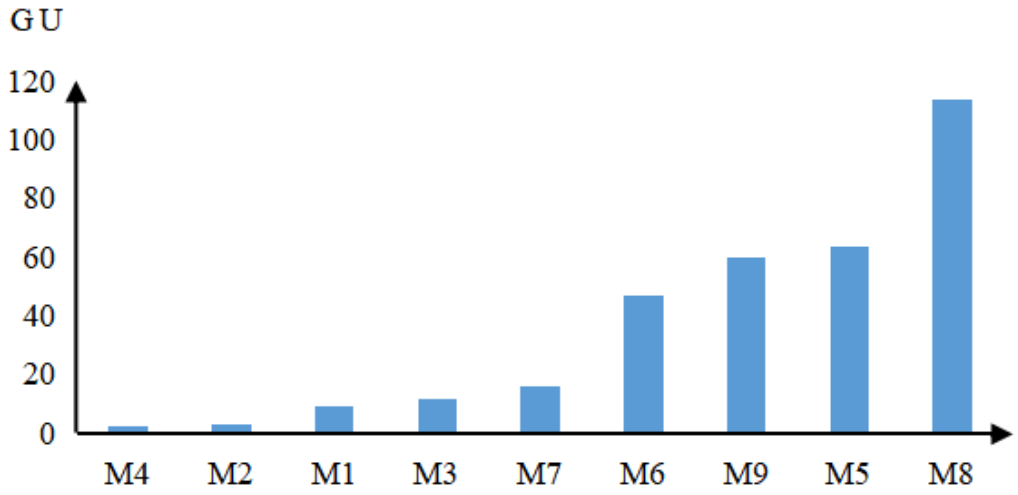


Figure 9. Material surface gloss (M1: Joinery board, M2: PVC board, M3: Fireproof board, M4: Solid wood board, M5: Painted solid wood board, M6: Melamine board, M7: Painted board, M8: Blister board, M9: Quartz board).

As shown in Figure 10, the brightness of the samples, from the minimum to the maximum, is melamine board, solid wood board, blister board, joinery board, PVC board, fireproof board, quartzite board, solid wood board, and painted board. Meanwhile, except for PVC board, the other samples are in varying degrees of reddish in chroma, and all samples are in yellowish.

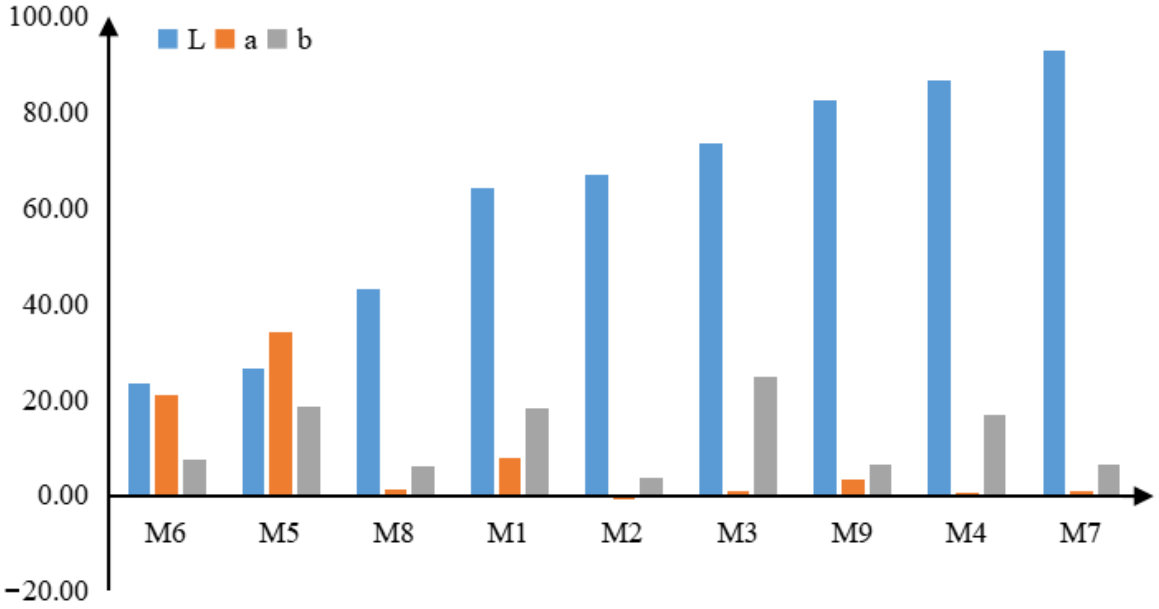


Figure 10. Material surface colour value (M1: Joinery board, M2: PVC board, M3: Fireproof board, M4: Solid wood board, M5: Painted solid wood board, M6: Melamine board, M7: Painted board, M8: Blister board, M9: Quartz board).

3.3. Surface Roughness Polynomial Fit Analysis

3.3.1. "Rough-Smooth"—Polynomial Fitting of Surface Roughness

By fitting the data, the "rough-smooth" polynomial fit function with R^2 of 89.2% to the surface roughness is shown in Equation (1) and Figure 11.

$$y = 0.01434x^2 - 0.27628x + 0.90525 \quad (1)$$

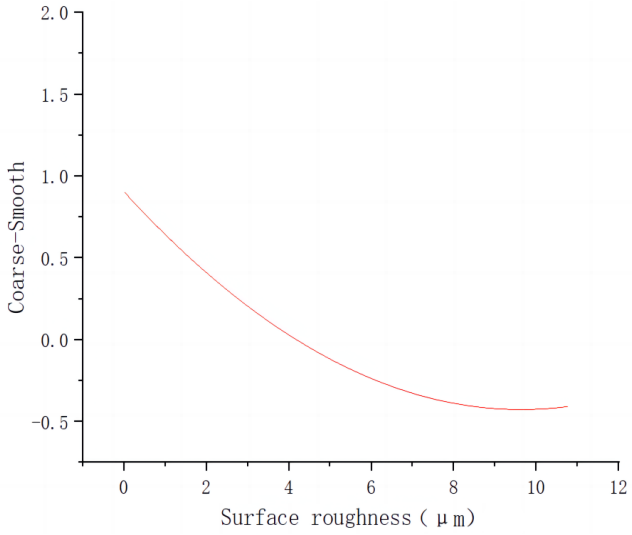


Figure 11. "Coarse-Smooth" and Surface roughness polynomial fitting function.

When the surface roughness is 9.6332 μm, the y-value is the smallest, i.e., the subjective perception is the roughest. This leads to the conclusion that the tactile perception of older people slows down with age and that there is a degree of slowdown in the perception of roughness when the surface degree of the material is greater than 9.6332 μm [28].

3.3.2. "Rough—Fine"—Polynomial Fitting of Surface Roughness

According to the test results, the polynomial fit function of "roughness—fine" and "surface roughness" with R^2 of 91.3% is shown in Equation (2) and Figure 12.

$$y = 0.00584x^2 - 0.25114x + 0.64674 \quad (2)$$

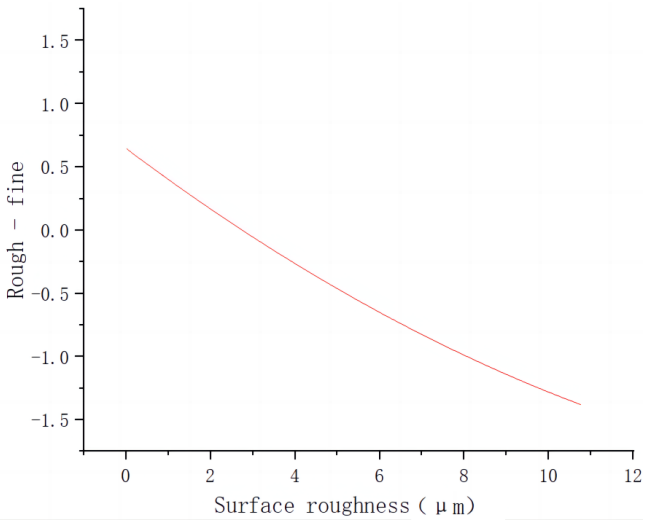


Figure 12. "Rough—Fine" and Surface roughness polynomial fitting function.

As the surface roughness approaches 0, the greater the y-value becomes, which means that the subjective perception is the most delicate [29]. It can be concluded that, although the tactile perception of the elderly deteriorates with age, they are still more sensitive to the fineness of the material surface, and lower surface roughness leads to the finer perception.

3.3.3. "Hard-to-Comfort"—Polynomial Fitting of Surface Roughness

According to the experimental results, the polynomial fit function of "uncomfortable-comfortable" and "surface roughness" with R^2 of 88.1% is shown in Equation (3) and Figure 13.

$$y = -0.00143x^2 - 0.13303x + 0.79489 \quad (3)$$

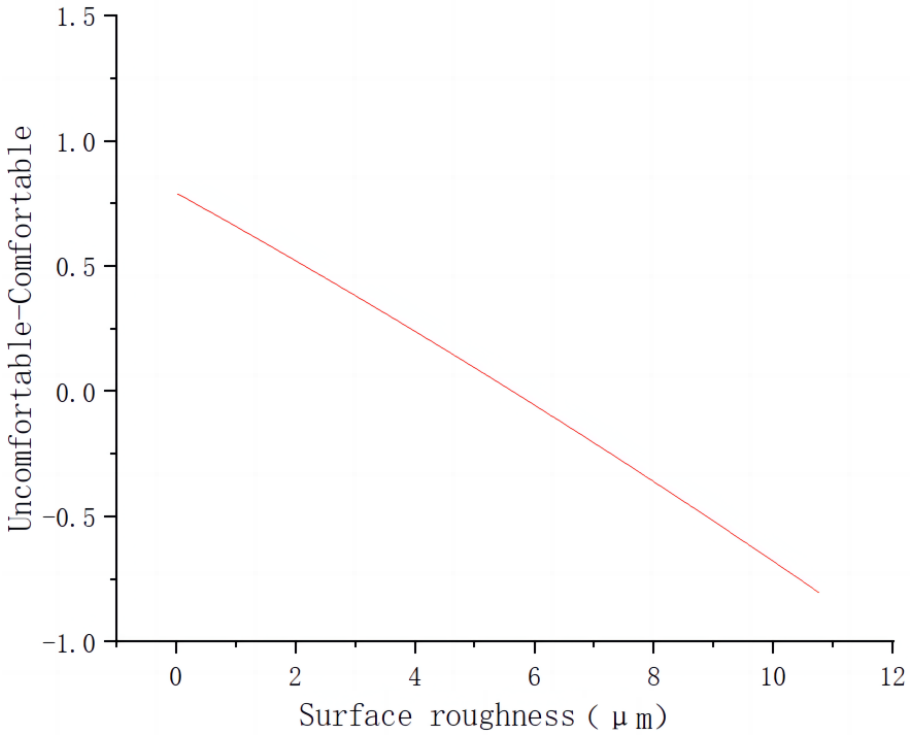


Figure 13. "Uncomfortable-Comfortable" and Surface roughness polynomial fitting function.

As the surface roughness values range from 0 μm to 100 μm, the greater the y-value, the higher the comfort level, and the surface roughness is infinitely close to 0. It can be concluded that the visual/tactile perception of the elderly deteriorates with age, but for the perception of the surface roughness of the material, the smaller the surface roughness of the material, the better the comfort of the elderly will be [30]. Therefore, when designing age-appropriate cabinet surface materials, one should try to choose materials with smaller surface roughness.

3.4. Analysis of Surface Cooling Rate Fitting Results

3.4.1. "Cold-Warm"—Polynomial Fitting of Surface Cooling Rates

Based on the experimental results, a polynomial fit function [31] of "cold-warmth" and "surface cooling rate" with R^2 of 89.9% is shown in Equation (4) and Figure 14.

$$y = -159.69122x^2 + 49.21046x - 2.83022 \quad (4)$$

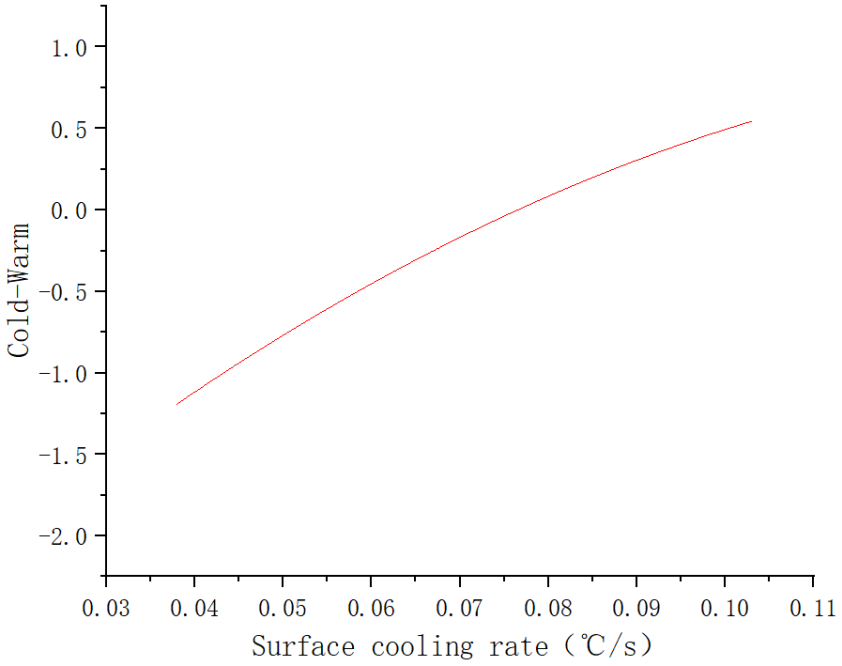


Figure 14. "Cold-Warm"-polynomial and surface cooling polynomial fitting function.

It can, therefore, be concluded that the greater the rate of surface cooling, the greater the y-value, i.e., the warmer the elderly perceive it to be.

3.4.2. "Hard-to-Comfort"-Polynomial Fitting of Surface Cooling Rates

Based on the experimental results, a polynomial fit function of the "uncomfortable-comfortable" and "surface cooling rate" with R^2 of 90.8% is shown in Equation (5) and Figure 15.

$$y = -308.80297x^2 + 20.4321x + 0.78478 \quad (5)$$

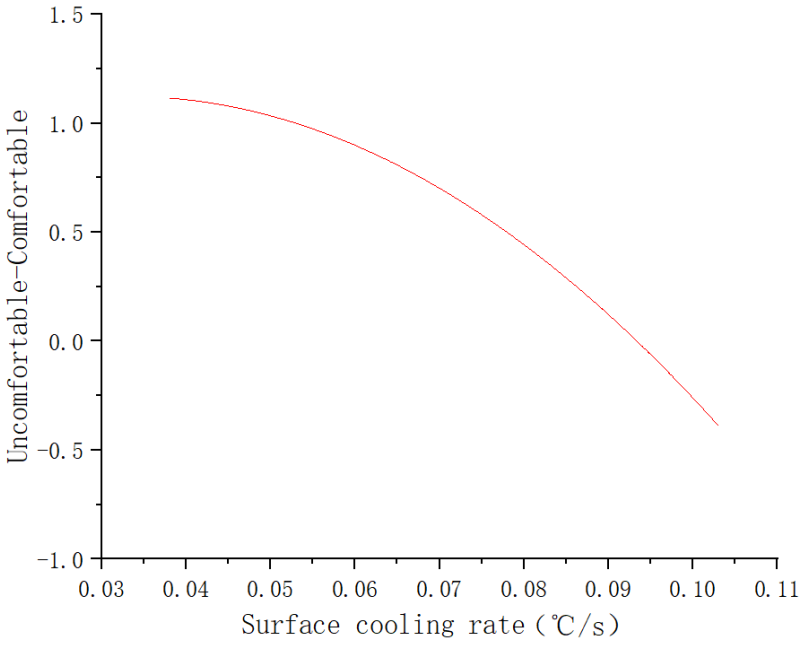


Figure 15. "Uncomfortable-Comfortable" and surface cooling rate polynomial fitting function.

Combined with the polynomial fit function image, as the surface cooling rate increases, the perceived comfort level of the cabinet material decreases, i.e., the warmer perception

resulted in the lower comfort level. Thus, it is suggested to use the materials with lower surface cooling rate for the elderly, in terms of the higher comfort level [32].

3.5. Analysis of Surface Gloss Fitting Results

3.5.1. "Matte-Gloss"—Polynomial Fitting of Surface Gloss

According to the test results, the polynomial fit function of "matte-gloss" and "surface gloss" with R^2 of 85.5% is shown in Equation (6) and Figure 16.

$$y = -2.58892x^2 \times 10^{-4} + 0.0532x - 0.87938 \quad (6)$$

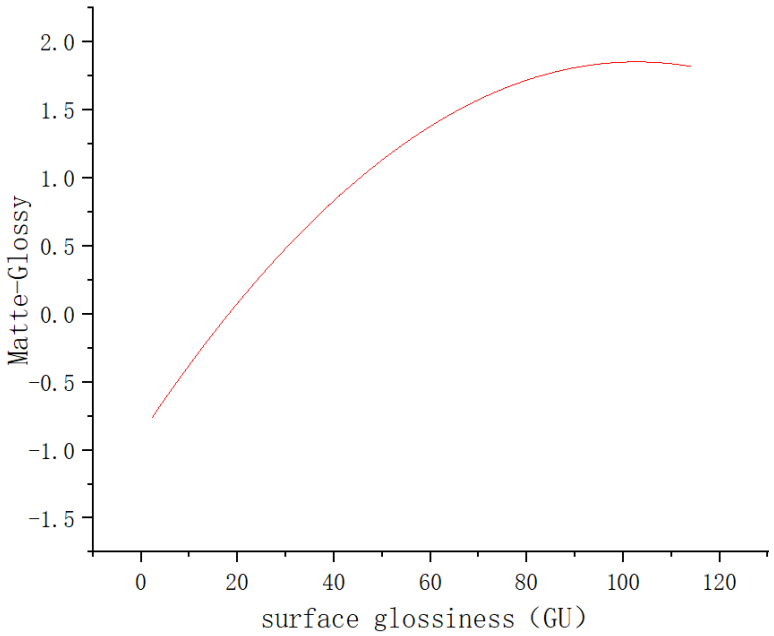


Figure 16. "Matte-Glossy" and surface gloss polynomial fitting function.

Combined with the polynomial fit function images, it appears that older people are more sensitive to the perception of low to medium gloss (≤70 GU) material surfaces and more retarded to high gloss material surfaces.

3.5.2. "Hard-to-Comfort"-Polynomial Fitting of Surface Gloss

Based on the experimental results, the polynomial fit function of "uncomfortable-comfortable" and "surface gloss" with R^2 of 87.1% is shown in Equation (7) and Figure 17.

$$y = -8.19848x^2 \times 10^{-5} + 0.01894x + 0.0896 \quad (7)$$

Combined with the polynomial fit function images, it appears that materials with a higher glossy surface tend to provide a more comfortable visual/tactile perception for older people.

3.6. Analysis of the Results of Fitting the Surface Colour Values

3.6.1. "Dull-Lively"—Polynomial Fitting of Surface Colour Values

The average of the subjective ratings of "Dull—Lively" for all subjects was calculated and entered as Y in the graph, and the X values in the horizontal coordinates represent the material surface colour values L, a, and b, respectively (L represents the material brightness, a represents the colour channel from red to dark green, and b represents the colour channel from blue to yellow), and the vertical coordinate Y is the corresponding subjective rating value. As shown in Figure 18, combined with the image of the multinomial fit function, the fitted curves for the surface colour values of colour luminosity L and red-green are

relatively flat, i.e., they do not have a significant effect on the perception of the material as 'Dull—Lively', while blue-yellow has a more significant effect on the perception of 'Dull—Lively'. The effect of blue-yellow on the perception of "Dull—Lively" is more obvious, and users perceive yellowish materials as more dull.

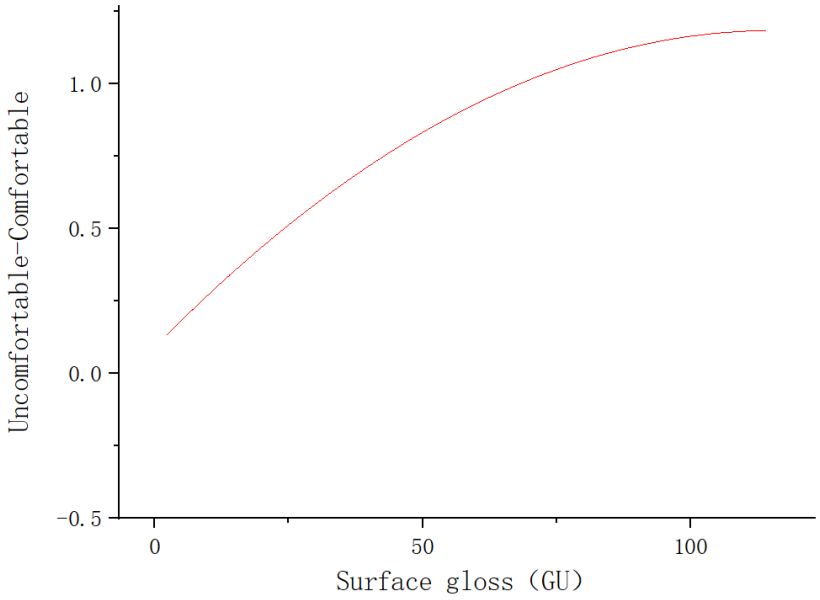


Figure 17. "Uncomfortable-Comfortable" and surface gloss polynomial fitting function.

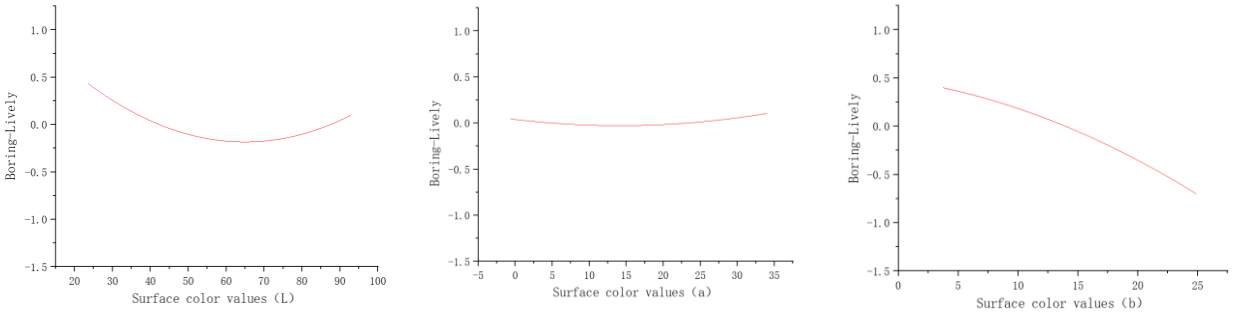


Figure 18. "Dull-Lively" and surface colour polynomial fitting function.

3.6.2. Polynomial Fitting of "Uncomfortable-Comfortable"-Surface Colour Values

As shown in Figure 19, the colour brightness L of the surface colour values has a greater impact on the comfort of the material, with the perceived comfort of older people decreasing further as the material brightness decreases. For the red-green value, the surface colour of the material is more comfortable for older people than the reddish domain. The effect of blue-yellow b values on the perception of "uncomfortable-comfortable" is more moderate.

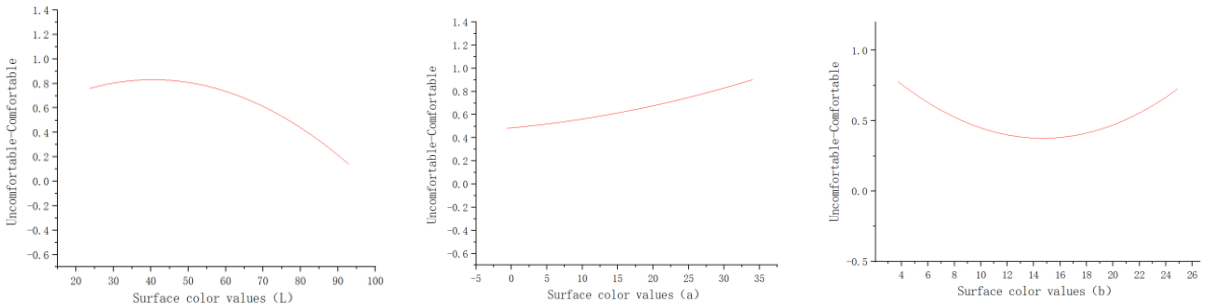


Figure 19. "Uncomfortable-Comfortable" and surface colour polynomial fitting function.

4. Conclusions

(1) For the surface roughness of cabinet materials, with the increase in surface roughness, the perception of the elderly became more delicate. Meanwhile, the lower surface roughness of the sample improved the touch feeling for the elderly. Therefore, the materials with the lower surface roughness are proposed to be selected when designing the surface materials for the age-friendly cabinets.

(2) For the surface cooling rate of the cabinet material, the faster the surface cooling rate, the warmer the elderly perceive it, the slower the surface cooling rate, the colder the elderly perceive it, and the slower the surface cooling rate, the better the elderly perceive their comfort. The slower the surface cooling rate, the colder the surface cooling rate.

(3) For the surface gloss of the cabinet material, the elderly are more sensitive to the low gloss of the material surface ($\leq$70 GU) and slower to perceive the high gloss material surface, but often, the material with higher gloss surface can bring more comfortable visual/tactile perception to the elderly, so when designing the ageing-friendly cabinet surface material, we should choose the material with a higher gloss surface.

(4) For the surface colour values of the cabinet material, the effect of colour brightness L and red-green on the perception of the material as "Dull—Lively" is not significant, while the effect of blue-yellow on the perception of "Dull—Lively" is more pronounced, and older users perceive the material as "Dull—Lively". Users perceive the yellowish material as more dull. The surface colour value of colour brightness L has a greater impact on the perceived comfort of the material, and as the brightness of the material decreases, the perceived comfort of older people is further reduced. For the red-green value, the surface colour of the material is more comfortable for the elderly than the reddish range. The effect of blue-yellow b values on the perception of "uncomfortable-comfortable" is more moderate. Therefore, when designing age-appropriate cabinet surfaces, it is important to choose materials with a higher brightness of surface colour values and a reddish-blue colour gamut.

(5) This work mainly focused the visual/tactile experience of 55–70 years old people for the cabinet materials, in terms of surface roughness, cooling rate, glossiness, and colour elements. In the future research, 3D surface topography, efficiency of temperature acceptance, and friction performance of the material surface will be further focused for more groups with different ages, and it is proposed to provide scientific guidance for the products design and manufacturing.

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