Original Article

Evaluation of strings braided by using the *Kumihimo* Disk -Comparisons between beginners and experts-

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Abstract

Purpose: Beginners and experts made *Kumihimo* (a Japanese braid) using the *Kumihimo* Disk by controlling the braiding movements and differences in the shape, flexibility, tactile sensation, appearance, and the comprehensive evaluation of the braided strings between beginners and experts were examined.

Methods: Beginners (N = 21) and experts (N = 18) braided the *Yatsu-kongoh* Z-spiral. We measured the thickness and aspect ratio of the braided strings, evaluated the flexibility and tactile sensation, and made a comprehensive evaluation based on a five-point scale.

Results: Strings braided by experts obtained higher scores for appearance and comprehensiveness compared to strings made by beginners. Braids made by experts were less flexible and had a hard texture. No correlation in evaluation scores was indicated between the thickness, flexibility, or tactile sensation of braids made by experts. Moreover, a significant correlation was not indicated between the years of experience and the appearance or comprehensive evaluation scores.

Conclusion: The results indicated that braids made by beginners tend to be thicker and have a softer texture. Variables other than the aspect ratio were not correlated with the appearance evaluation, and there was a significant correlation between comprehensive evaluation scores and the variation in thickness and tactile sensations evaluation scores of braids made by experts. The functions of the string are crucial in the comprehensive evaluation, which might have increased the correlation with tactile evaluation.

Keywords: *Kumihimo* Disk, the thickness of braided strings, tactile evaluation, flexibility evaluation, aspect ratio

Introduction

Kumihimo is a traditional craft that has been developing since the Jomon Period in Japan and has been closely correlated with daily life activities such as festivals, rituals, armor, and clothes, among others. Braids are made in every country of the world. Various studies on braids have been conducted, and workshops have been held (The Braid Society, 2016; The *Kumihimo* Society, 2019). Expert knowledge and unique environments are required to make traditional braids. It is difficult for ordinary people to make braids freely. The *Kumihimo* Disk (after this referred to as "disk") was developed so that even beginners could easily braid strings. The disk is a donut-type instrument made of polyethylene foam with a 10mm thickness and a diameter of 150mm, having 32 slots around the circumference, with a number shown on the right side of each slot. Users put a thread bundle through the center hole with a diameter of 24mm, insert a thread in the slot, hold the disk in one

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hand, and take the thread off the slot using the other hand, insert it in another slot, and braid a string by repeating these movements (Fig.1). The disk was designed by referring to the characteristics of *Maru-dai*. Anyone can easily make braids using the disk, anywhere and anytime (Tada, 2007). Even inexperienced people can make a basic braid if they receive instructions.

The disk is also used for handcrafting, which is making things used in everyday life. We can make different types of straps such as misanga bracelets, decoration strings, and shoelaces, among others, by using the disk. The products can be made into artworks by polishing color schemes and braiding techniques. Studies on technical guidance and education methods for beginners using the disk should be developed to increase the number of people involved in *Kumihimo*.

Today, workshops on using the disk are popular. Although general books about the disk have been published, instruction methods are unclear and not based on data. Kimura *et al.* (2021) held a workshop for 120 beginners using a video, and reported factors affecting braided strings' quality and indicated that the thickness and hardness affected the braids' evaluation, with harder and thinner braids being more highly evaluated. However, Kimura *et al.* (2021) conducted research only with beginners and did not examine the braids made by experts. The present study investigated the difference in the shape, appearance, and comprehensive evaluation of braids between beginners and experts by controlling the braiding movements. Moreover, this study investigated whether the correlation between the shape and flexibility and tactile evaluation might differ between beginners and experts. Based on the results, we have discussed issues to be noted when instructing beginners after considering the correlation between the quality and the shape of braids.

Participants and methods

1. Participants

Healthy adults (N = 39) participated in the experiment. They were classified into the beginner or the expert group based on their *Kumihimo* braiding experience. The beginner group consisted of 21 university students without *Kumihimo* experience, and the expert group included 18 members of the *Kumihimo* Society with 6~50 years of experience (mean 21 years) of experience. We explained the purpose and methods of the experiment to the participants and obtained their consent before the experiment.

Kumihimo Disk

HAMANAKA Co. Ltd Kumihimo Disk (H205-568)

8 woolen threads

Diameter of Kumihimo Disk	**150 mm**
Diameter of center hole	**24 mm**
Thickness	**10 mm**
Weight	**24.5 g**

Figure 1. *Kumihimo* Disk (by courtesy of HAMANAKA Co. Ltd.)

2. Tools and procedures

Participants braided *Kumihimo* in the method known as *Yatsu-kongoh* Z-spiral, which is the most basic braiding style (Figure 2) using the disk (Kumihimo Disk, H205-568, HAMANAKA Co., Ltd.) and 100% Acrylic woolen threads (HAMANAKA BONNY, HAMANAKA Co., Ltd.) They aligned the ends of eight woolen threads having a length of 500mm, tied them up, and put them through the

center hole of the disk. Then, they inserted eight threads in slots numbered 32, 1, 8, 9, 16, 17, 24, and 25 (Figure 1) and braided *Kumihimo* until all the threads were used up.

Yatsu-Kongoh Z-spiral

Section view

Figure 2: *Yatsu-Kongoh* Z-spiral

Figure 3 shows the *Yatsu-kongoh* Z-spiral braiding procedures using the disk (Tada, 2017a). Firstly, participants were instructed to hold the disk in one hand and move the threads using the other hand. Based on a previous study using *Maru-dai* (Kimura et al., 2018), we called one movement a "step" and one process a "cycle." The braiding process was as follows; Step 1: moving a thread from 1 to 15. Step 2: moving the thread from 17 to 31 and rotating the disk clockwise by 90 degrees. Step 3: moving the thread from 25 to 7. Step 4: moving the thread from 9 to 23 and rotating the disk 90 degrees clockwise. The four steps above composed one cycle, which the participants repeated.

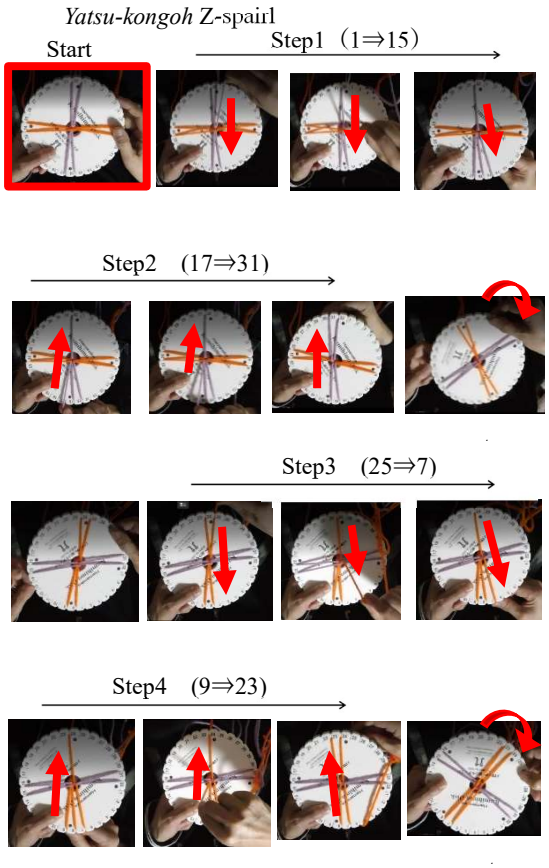

Figure 3: The thread moving path

3. Guidance content

We gathered beginners in one room to provide workshop-style guidance. The teaching materials were prepared to explain thread moving order and methods of using the disk, based on a book for beginners (Tada, 2017ab), and guidance was given using the materials. It took 30 minutes for guidance, consisting of 10 minutes to explain using the teaching materials, 10 minutes for explanations on braiding methods and demonstrations by an instructor, and 10 minutes for individual practice. The instructor did not give individualized coaching during the practice while dealing with problems such as tangled threads. The guidance consisted of explanations about the disk, how to hold the disk and threads, the procedures for setting the threads, the path of moving threads, the rotation angle and direction of the disk, how to identify the braiding part if lost, points to note when moving threads, and how to complete the braiding after using up all the threads. Participants were instructed to rotate the disk 90 degrees clockwise after Steps 2 and 4 (Figure 3) and not to view the distributed materials during braiding.

We distributed the same teaching materials to experts. Experts are familiar with basic methods of moving threads when braiding *Yatsu-kongoh* Z-spiral. In the present study, however, we tried to control the braiding movements between beginners and experts, and especially unify the

angle and direction of rotating the disk after Step 2 and Step 4. Expert participants read the materials and braided *Yatsu-kongoh* Z-spiral without practicing. They were also instructed not to view the distributed materials during braiding.

4. Data collection and evaluation

We recorded participants' movements from the start to finish of braiding *Kumihimo* using a video camera (HDR-CX700; HDR-CX560V, SONY). The participants sat on a chair, holding the disk, and braided *Kumihimo*.

We measured the thickness and cross-sectional shape of the braided strings using a caliper. The major and minor axes of the braided strings were measured at points that were 10, 20, and 30 mm from the end. We regarded the major axes' mean value as the thickness of the string because the apparent thickness is affected by the major axis (Matsunashi et al., 2020). Moreover, we calculated the standard deviation based on mean thickness values at several points and regarded them as thickness variations. We also calculated the shape variations as the minor axis ratio to the major axis because the cross-section's shape approaches a circle when the differences between major and minor axes decrease (Figure 4).

Figure 4. The finished the braided cord

An evaluator assessed the braided strings' shape using the procedure described in a previous study (Kimura, 2021) has confirmed the reproductivity of this procedure, which is based on four assessment items; flexibility, tactile sensation, appearance, and comprehensive evaluation. The evaluator has had seven years of *Kumihimo* experience through conducting studies on *Maru-dai Kumihimo* and disks. Moreover, the evaluator has been producing *Obijime* (a decorative string used when wearing kimono) and other *Kumihimo* products, has been participating in *Kumihimo* workshops that used the disk several times a year, had has a Grade 1 license for the written test, and a Grade 2 license for the practical test conducted by the Kumihimo Society. We verified the reliability of the evaluation in advance, which indicated an intraclass correlation coefficient of over 0.9 for each assessment item.

Flexibility was evaluated by visual inspection using a five-point scale. The strings stood vertically, and the degree of bending was checked, followed by the *Obijime* dealers' evaluation method, i.e., holding *Obijime* at a point of 20cm from the end and standing it, and *Obijime* that stood straight was evaluated as good. The evaluator held a string at a point 100mm from the end and stood it vertically. If the string stood unbending, it earned a score of 5, bending less than 30 degrees was scored as 4, between 30 and 45 degrees as 3, between 45 and 60 degrees as 2, and bending over 60 degrees as 1 point (Kimura, 2021) (Figure 5). Moreover, the evaluator touched all the braided strings and evaluated the hardness three times using a five-point scale ranging from 1 (very soft) to 5 (very hard), which were regarded as tactile sensation evaluation scores.

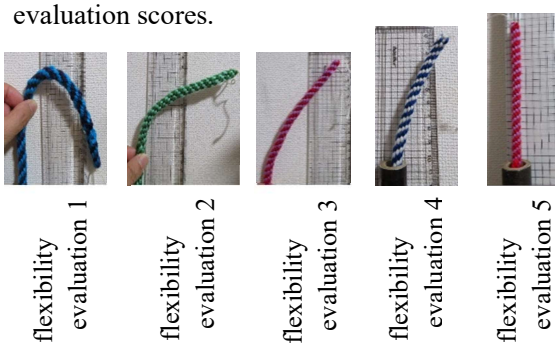

Figure 5. The string's flexibility evaluation (by courtesy of Kimura, 2021)

The appearance was evaluated based on the size of each mesh of the string, the degree of a twist of the string, design, and thickness variations, among others, using a five-point scale ranging from 1 (very bad) to 5 (very good) (Kimura, 2021). Moreover, a comprehensive evaluation was conducted by taking each string in hand and observing it. The sense of touch, the number of mistakes, thickness variations, and the size of each mesh of the string were comprehensively evaluated using a five-point scale ranging from 1 (very bad) to 5 (very good) (Kimura, 2021).

5. Statistical evaluation of items

We conducted a *t*-test on the thickness, thickness variations, and aspect ratios to examine the differences in the shape of the braided strings between beginners and experts. We used the Mann-Whitney U test to examine flexibility evaluation scores, tactile sensation, appearance, and the comprehensive evaluation. In the expert group, we calculated Pearson product-moment correlation coefficients for thickness, thickness variations, and aspect ratios to evaluate the correlation between years of experience and the shape of the braided strings. Moreover, we calculated Spearman's rank correlation coefficients of flexibility evaluation scores, tactile sensation, appearance, and comprehensive evaluation, conducting a simple correlation analysis using Spearman's correlation coefficients to examine the effects of the shape of the braids on the evaluation scores of the above items.

Results

1. Shape

One participant in the beginner group ($N = 21$) made a mistake in the braiding method, and we excluded this participant's data from the analysis. None of the participants in the expert group ($N = 18$) make any mistakes. We examined the differences in the braided strings between beginners and experts using the data shown in Table 1. The minimum thickness value of braided strings in the beginner group was 5.6 mm, the maximum 9.1 mm, and the average was 7.09 ± 0.77 mm. In contrast, the minimum was 5.5 mm, the maximum 8.2 mm, and the average was 6.72 ± 0.62mm in the expert group. We examined the difference in average values between the two groups using a *t*-test, which indicated no significant difference ($t = 1.635$, *n.s.*)

The minimum value of the thickness variations was 0.21 mm, the maximum was 0.99 mm, and the average was 0.41 ± 0.17 mm in the beginner group, whereas the minimum was 0.11 mm, the maximum was 0.61 mm, and the average was 0.28 ± 0.11 mm in the expert group. The results of a *t*-test indicated that the thickness variation of the beginner group was significantly larger than the expert group ($t = 2.844$, $p < .01$). Regarding the aspect ratio, the minimum was 0.894, the maximum was 0.971, and the average was 0.950 ± 0.02 in the beginner group, whereas the minimum was 0.875, the maximum was 0.985, and the average was 0.933 ± 0.028 in the expert group. The results of a *t*-test indicated that the aspect ratio of the beginner group was significantly higher than the expert group ($t = 2.179$, $p < .05$).

The braided strings' flexibility indicated the following: Beginner group; stood unbending (5 points) = 0, bending less than 30 degrees (4 points) = 4, between 30 and 45 degrees (3 points) = 7, between 45 and 60 degrees (2 points) = 8, and bending over 60 degrees (1 point) = 1. Expert group; 5 points = 10, 4 points = 6, 3 points = 2, 2 points = 0, and 1 point = 0. We examined a between-group difference using the Mann-Whitney U test, which indicated a significantly higher score in the expert group ($Z = 2.490$, $p < .05$).

The evaluation of the braided strings'

Table 1: The shape and evaluation of the strings braided by beginners and experts

	Thickness		Thickness variation		Aspect ratio		Flexibility evaluation		Tactile evaluation		Appearance evaluation		Comprehensive evaluation	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Thickness			.422	.064	-.487	.029*	-.676	.001**	-.590	.006**	-.638	.002**	-.694	.001**
Thickness variation	.542	.020*			-.360	.119	-.216	.361	-.218	.356	-.476	.034*	-.512	.021*
Aspect ratio	-.294	.236	-.455	.058			.456	.043*	.532	.016*	.488	.029*	.460	.041*
Flexibility evaluation	-.379	.121	-.554	.017*	.341	.166			.899	.000**	.639	.002**	.759	.000**
Tactile evaluation	-.216	.389	-.371	.129	.600	.008**	.348	.157			.708	.000**	.797	.000**
Appearance evaluation	.224	.372	-.400	.100	.491	.038*	.246	.324	.226	.368			.963	.000**
Comprehensive evaluation	.047	.854	-.498	.035*	.486	.041*	.420	.082	.517	.028*	.819	.000**		

*, p <.05; **, p <.01; Upper right triangle: Beginners; Lower left triangle: Experts

appearance indicated the following: Beginner group; 5 points (highest) = 0, 4 points = 4, 3 points = 11, 2 points = 4, and 1 point = 1. Expert group; 5 points = 3, 4 points = 9, 3 points = 6, 2 points = 0, and 1 point = 0. A Mann-Whitney U test results indicated a significantly higher score in the expert group (Z = 2.596, p < .05). The comprehensive evaluation, including the appearance and the sense of touch, assessed by taking the braided strings in hand indicated the following: Beginner group: 5 points (highest) = 0, 4 points = 1, 3 points = 14, 2 points = 4, and 1 point = 1. Expert group; 5 points = 4, 4 points = 7, 3 points = 7, 2 points = 0, and 1 point = 0. A Mann-Whitney U test results indicated a significantly higher score in the expert group (Z = 3.018, p < .01).

We conducted a simple correlation analysis on the years of experience and each shape variable in the expert group, which indicated no significant correlations: thickness; r =.133, thickness variation; r = -.393, aspect ratio; r =.199, flexibility: r =.104, appearance; r =.245, and comprehensive evaluation; r =.148.

2. Correlations among variables

We conducted a simple correlation analysis to examine the effects of each shape variable on flexibility evaluation. The results indicated a significant negative correlation between flexibility scores and thickness and a significant positive correlation with aspect ratios and tactile evaluation in the beginner group. The flexibility scores were significantly and negatively correlated with thickness variations (Table 1) in the expert group.

The tactile evaluation scores indicated a significant negative correlation with thickness, whereas there was a significant positive correlation between aspect ratios and the beginner group's flexibility scores. The tactile evaluation scores in the expert group had a significant positive correlation only with the aspect ratios. Beginners indicated a significant positive correlation between flexibility scores and tactile scores. In contrast, the experts did not show such a correlation.

Next, we examined the effects of each shape variable on appearance scores (Table 1). In the beginner group, appearance scores showed a

significant negative correlation with thickness and thickness variations, whereas there was a significant positive correlation with aspect ratios, flexibility evaluation, and tactile evaluation scores. In the expert group, appearance evaluation scores indicated a significant positive correlation only with aspect ratios.

Comprehensive scores indicated a significant negative correlation with thickness and thickness variations, whereas there was a significant positive correlation with aspect ratios, flexibility evaluation, and tactile scores in the beginner group. In the expert group, comprehensive evaluation scores had a significant negative correlation with thickness variations, whereas there was a significant positive correlation with aspect ratios and tactile evaluation scores.

Discussion

1. Shape differences between beginners and experts

The present study controlled the braiding movements between beginners and experts to clarify the differences in the products made by these two groups. The results indicated that the strings braided by experts were evaluated higher than those made by beginners in terms of appearance and comprehensive evaluations, suggesting the positive effects of experience. However, the number of years of experience and the appearance or comprehensive evaluation were not significantly correlated in the expert group, suggesting that experience might be more significant than the length of experience. We examined whether a ceiling effect might have caused the above result. The appearance scores of experts were as follows; minimum = 3, maximum = 5, and the average = 3.88 ± 0.7, and the comprehensive evaluation scores were as follows; the minimum = 3, the maximum = 5, and the mean score = 3.81 ± 0.7. These data suggest that there was no ceiling effect. The effects of the years of experience should be further examined, considering the observed positive correlation between the years of experience and product evaluation, even though it was not significant. The non-significant result might have been caused because the expert group included only 18 participants, and relationships other than a linear relationship are possible between years of experience and product quality.

The braids made by experts were less flexible and more rigid compared to those made by beginners. Hardness and flexibility are essential items in evaluating the functionality of strings. Very soft strings tend to become loose when used for tying things, whereas it is difficult to tie using very hard strings. Very hard or soft braids and braids lacking flexibility are not desirable from a functional perspective. A previous study (Kimura, 2021) evaluated strings braided by beginners and indicated that harder and less flexible braids got higher comprehensive evaluation scores, suggesting the significance of making hard strings. However, the previous study did not compare with the braids made by experts. The present study indicated that braids made by beginners were softer and more flexible compared to those braided by experts, suggesting the significance of hardness. The present study results reinforce the finding of the preceding study by suggesting that instructors should encourage beginners to make harder and less flexible braids.

2. Hardness and shape of braided strings

The hardness of a braid is evaluated by the sense of touch and the degree of bending. The previous study conducted with beginners (Kimura, 2021) reported a significant negative correlation between the evaluation of flexibility and thickness, which was supported by the current study, *i.e.*, thicker strings bent more than thinner strings. Moreover, tactile and flexibility

evaluation had a significant positive correlation, such that hard textured strings were less flexible than soft textured strings. The above results are explained by a preceding study on the relationship between bobbins and the *Maru-dai* counterweight (Matsunashi, 2020). When making braids using *Maru-dai,* users suspend bobbins around the round disk, put the braided string into the center hole of the disk, attach a counterweight to the braided string, and provide continuous tension braided strings by balancing the bobbins and the counterweight. It has been reported that the balance between bobbins and counterweights affects the appearance and mechanical characteristics of braided strings (Matsunashi, 2020). When the weight of the counterweight becomes heavier compared to the bobbins, the force in the vertical direction increases, the tightness of the braided threads at the center of the mesh decreases, the flexure of the string increases, and the string becomes softer. In other words, the flexibility of the string is affected by the tightness of braided threads, such that less tight strings become soft and vice versa. The *Kumihimo* Disk was designed based on *Maru-dai*, and the slots play the role of bobbins when a strong force is provided in the horizontal direction, the tensile force in the horizontal direction increases, and the tightness of braided threads at the center of the mesh increases, resulting in a harder string.

Unlike the results of the previous study on beginners, there was neither a correlation between tactile evaluation and thickness nor flexibility evaluation of the expert group's product, which is a significant finding of this study. Some experts made thin strings, and others made thick strings that received similar tactile evaluation scores. Therefore, some strings were flexible, and others were not, although they received similar tactile evaluation scores. Therefore, experts might be able to braid thick, hard, and less flexible strings. Why can experts do this? They are often engaged in producing *Kumihimo* such as *Obijime* and braiding strings by considering the purpose of the products and attempting to meet quality requirements. Moreover, they can control their braiding skills depending on these requirements. Takai (2016) investigated experts' tacit knowledge when braiding strings using *Maru-dai* and reported that it is essential to braid strings by watching the center of the mesh; remember braiding methods so that their hands naturally move without thinking, and uniformly move their right and left hands. The expert participants in this study had experienced using *Maru-dai*. Therefore, they were careful about watching the center of the mesh, inserting the thread firmly in the slots, and braiding using a constant rhythm. There is no tensile force in the vertical direction when braiding strings using the disk because there is no counterweight. Users adjust the tensile force in the horizontal direction and tighten the strings. Therefore, the hardness of braids is highly affected by the force of inserting threads into slots. Participants were instructed to braid strings in the usual method in this study. Therefore, individual characteristics might have been reflected strongly because the quality of the products was not specified.

No significant correlations were shown between the years of experience and flexibility, tactile, or thickness evaluation. Therefore, we concluded that even inexperienced people could acquire *Kumihimo* braiding skills.

3. Relationship between the appearance and comprehensive evaluation of braided strings' shape

Significant correlations were indicated in beginners between all shape-related evaluation scores and appearance evaluation scores. On the other hand, appearance evaluation scores of experts indicated a significant correlation only with aspect ratios. The evaluation of appearance

is essential when perceiving *Kumihimo* as works of art. In the present study, the aspect ratio was significantly correlated with appearance evaluation in beginners and experts, which was expected because *Yatsu-kongoh* Z-spiral is a round-shaped string. When the aspect ratio approaches a value of 1, the shape approaches a circle, which is desirable. Conversely, a significant correlation was shown between appearance evaluation and thickness, thickness variation, flexibility, and tactile sensation only in beginners. Less flexible and harder braids became thinner, and harder and thinner braids got higher appearance evaluation in beginners. Conversely, in experts, variables other than the aspect ratio were not correlated with appearance evaluation. In other words, characteristics of braided strings differed depending on the person, suggesting that a pleasing appearance is composed of different factors.

Comprehensive evaluation scores of beginners were significantly correlated with all the shape-related measurement values and evaluation scores. On the other hand, in the expert group, thickness variation and tactile evaluation scores had a significant correlation with comprehensive evaluation scores. Functionality as a string is considered essential in the comprehensive evaluation, which might increase the correlation with tactile evaluation. Therefore, tactile evaluation is an essential evaluation index also in experts.

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