Improve Cutting Skill According to Skill and Difficulty Level

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Abstract. In this paper, we aim to measure the cutting skill for creative paper cutting and increase practice effect. The practice effect changes according to the difficulty level of the cutting pattern and the skill level of the user. The cutting pattern of the picture consists of a straight line and a curved line, and we generalized the index of difficulty (ID) based on Steering law. One of cutting skills that shows the difference between novices and experts is time to cut. Besides, we developed a system consisting of a drawing display and a stylus with a knife to measure the cutting movement times (MT). The system measures MT according to the ID of the cutting pattern. We confirmed skill improvements by measuring changes in MT with various patterns from three experiments. In test 1, we confirmed the degree of conformity between the straight and curve pattern based on the steering law. In test 2, we measured skill improvement in repeatedly cutting patterns. In test 3, we compared the change in skill improvement of novices and artists. In these tests, we measured the reduction rate of MT to investigate the effectiveness of practice with various ID. As a result, we confirmed the difference in practice efficacy according to each ID.

Keywords: Cutting · Point task · Human motor performance · Steering law

1 Introduction

Currently, everyone can learn to create artistic designs from books and the Internet. However, it is difficult for novices to adapt motifs created by other artists, because of skill gaps between novices and experts. Therefore, novices satisfy their willingness to create themselves by improving their skills by repeating practice. Also, adjustment of the level of difficulty in practice is indispensable to enhance the effect. Practice at an appropriate level of difficulty leads novices to flow state. The flow state through creative and other activities yields fulfillment and happiness [12]. Paper-cutting is an art performed by controlling a knife and cutting paper. The creation of paper-cutting helps with concentration and has a relaxing effect. Actually, creating paper-cutting has a distraction effect of temporarily suppressing negative thinking [9]. When the difficulty level is inappropriate concerning the skill level, the effect of flow state decreases.

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We focus on paper-cutting, which is a craft art. Paper-cutting is an art performed by controlling a knife and cutting paper. One of the creative skills in the paper-cutting is cutting pressure. Thus far, we have developed a system to support the improvement of skill to control cutting pressure [8]. Moreover, we have generalized the index of difficulty (ID) based on the steering law by patterning on straight lines and curves that compose a picture [7]. In this paper, we focus on cutting time which is one of the skills, confirm the skill improvement.

Our goal is to design difficulty levels suitable for skill improvement for novices. We show the relation between difficulty level and skill level by quantifying ID by width and distance. We generalize the index of difficulty (ID) based on the Steering law by patterning on straight lines and curves that compose the picture. We confirm practice effect based on the cutting time when novices cut various ID. The practice effect is affected by the difficulty level of the cutting pattern and the cutting skill of the user. One of the differences in cutting skill between novices and experts is the time to cut paper, so we compare the change of working time in each pattern. We developed a system to measure the cutting movement times (MT) by creating an improved drawing display and stylus. From three experiments, we evaluated the difficulty level of practice patterns to improve the skills of novices effectively. Test 1 confirms the degree of conformity between the straight and curve pattern based on the steering law. Test 2 measures skill improvement when participants repeatedly cut patterns of various difficulty levels. Test 3 compares the change in skill improvement when novices and artists cut the pattern with the same difficulty level. Finally, we discuss and summarize the improvement in cutting skill.

2 Related Work

Modeling human movement is a core theme in the field of human-computer interaction (HCI). Well-known models include Fitts Law [6], which predicts the time required for a one-dimensional pointing task, and a refined model for two-dimensional tasks by Accot and Zhai [3] or include modeling of the time to navigate a long, narrow path, known as the steering law [1]. All of these depict a linear relationship between the index of difficulty (ID) and the movement time (MT) of a task.

The difficulty level of a straight tunnel (ID_s) and a circular tunnel (ID_c) show the following calculation (Fig. 1).

$$ID_s = A/W \tag{1}$$

$$ID_c = 2\pi R/W \tag{2}$$

Where A and $2\pi R$ are the lengths of the tunnel and W is the tunnel width [1]. The Steering law can show as

$$MT = a + b \times ID \tag{3}$$

for both the straight and circular tunnels [2]. The a and b are empirically determined constants. In this paper, we adapted the ID and MT in the Steering law to the difficulty level and creative time required for the paper-cutting pattern.

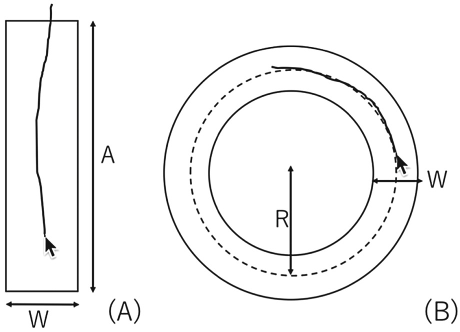


Fig. 1. For a straight tunnel, A is the length, and W its width (A). For a circular tunnel, the movement amplitude A is equal to the circle circumference $2\pi R$, where R is the circle radius (B).

Thus far, many researchers have measured the performance with various devices and for multiple shapes. For example, researchers have investigated operations with multiple types of input devices (mouse, stylus, touch panel, trackball) [2,5]. Moreover, several researchers have studied pen stroke gestures in letter writing [4] and the drawing of simple figures [10]. Curves contain many deformations according to the curvature, and [11] researchers have investigated the steering law that adapts to them. Additionally, shape-based differences have investigated in [13]. [14] modeled the cutting behavior by scissors. Many researchers have been examining intricate patterns based on the steering law.

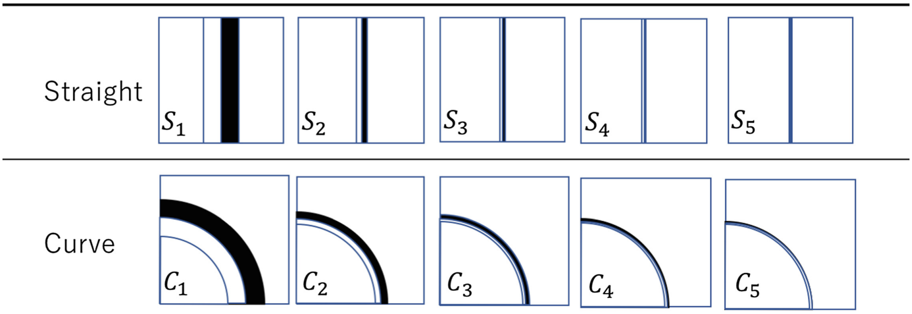
3 Difficulty Level Measurements

3.1 Width for Novices

The artist cuts the border between a white and black area in a monochrome picture for creating a paper-cutting. In the paper-cutting, the width of the pattern constitutes the difficulty level; the narrower the width of the boundary, the more difficult it is for novices. We interviewed five instructors and artists to design the standards for two patterns (easy and difficult) for novices. These instructors are experts, with five years of experience for three of the experts and six years of experience for two of the experts. From the above result, we designed the width that the novice can cut allow plenty of time as 13 mm (SD = 0.89) and narrow width was 5.0 mm (SD = 0.31). In many workshops, the instructors modify the difficulty level of the motif according to the skills of the students from this range.

3.2 Pattern Design

We have measured the difficulty level for each straight line and curve pattern based on the steering law [7]. The steering law can measure the difficulty level



W (mm)	65.0mm	13.0mm	7.2mm	5.0mm	3.8mm
ID	2.3	12.0	20.8	30.0	39.2

Fig. 2. Straight-line patterns and curve patterns were composed of the same width and ID.

based on the steering task in the tunnels of various widths and distances [1,2]. Based on the features above, we designed the level for each straight line or curve to cut paper.

In this paper, we designed 10 patterns with various widths from this range (Fig. 2). The difficulty level of these models monotonically increases based on Steering law. We designed each difficulty pattern lengths of 150 mm.

4 System for Measuring Skill Level

4.1 Stylus with Blade

Our device is designed to measure the cutting pressure. A blade is attached to the tip of the stylus. The user cut paper on the drawing display using our knife. The purpose of our system is to measure the cutting time with which the user cuts the paper.

We have modified the stylus to collect data by attaching a blade (NT BDC-200P) to the tip of the touch pen (Wacom PenPro2) (Fig. 3A). We have glued the tip of the knife and the stylus with ultraviolet resin (Fig. 3B). In our system, this stylus has a pressure sensor. It recognizes the cutting distance from 0.1 mm and the pressure from 0 to 500 g from 7000° at a response speed of 250 ms.

4.2 Display Unit

The drawing display (Wacom Cintiq Pro16, 3860 × 2140 pixels, 275 dpi) shows pictures (Fig. 4A). The system only responds when the stylus is in contact with the screen. Although the tip of the stylus and the surface of the screen are not in contact, the display can recognize the stylus's coordinates. It can obtain the location and angle data for the stylus via electromagnetic induction. Paper is

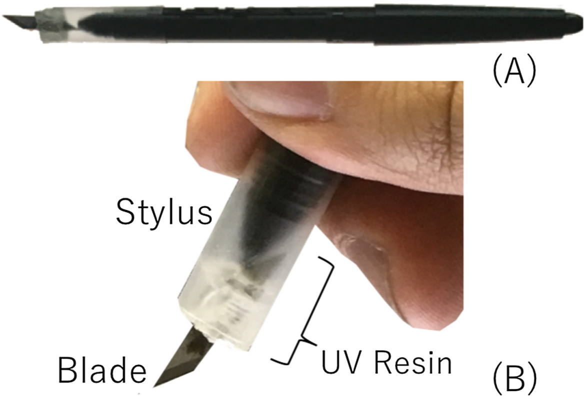


Fig. 3. A blade is attached to the tip of the stylus (A). The gap is covered with ultraviolet resin (B).

fixed on the screen, which is protected with tempered glass. The user cuts the paper with the device, and our system measures moving time and coordinates.

The user cuts the paper on the display at the start area, moves along the cutting line, and finishes at the end area (Fig. 4B). The timer starts when the knife passes the start line and stops when the blade crosses the end line. When the user cuts the paper beyond the width, the system beeps, signaling a failure. In that case, the user cuts the same pattern again. The participants were instructed to perform the required operation as quickly and accurately as possible in our experiments.

5 Test 1: Adaptable of Steering Law

5.1 Objective

In this test 1, we evaluate the adaptability of changes in the skills and Steering laws by novices. The purpose is to confirm the fitness as a motion of the paper cutting with the knife according to the steering law. We measure the cutting time and coordinates when participants cut the patterns using our knife device.

5.2 Sequence of Trials

The participants were 10 novices (average age: 27.2 years, SD: 1.15) who have never created paper-cutting. They exhibit visual acuity that does not interfere with creating paper-cuttings, and everyone was right-handed. First, they cut five types of straight lines, next cut five types of curves patterns (Fig. 2). They repeated these actions ten times.

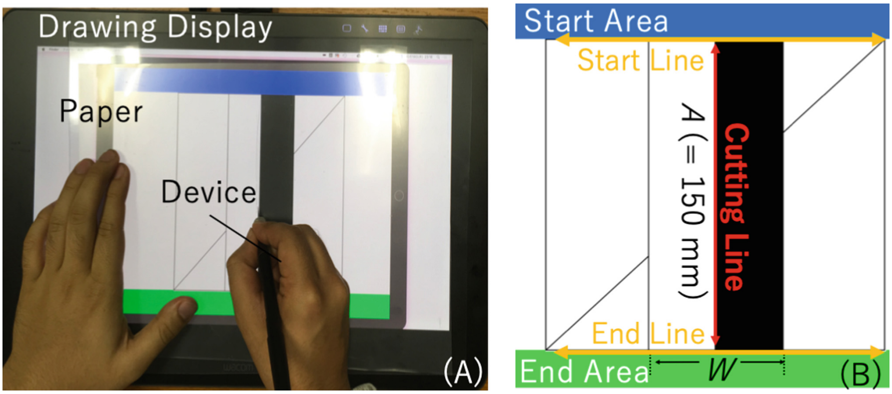


Fig. 4. Participants cut paper placed on the drawing display (A). The display shows images of six types of straight lines and curves (B).

5.3 Result on Change in MT According to ID

Cutting Time. Repeated measures ANOVA showed that significant effect of start position ($F_{4,45} = 4.229$; $p < .05$ for straight tasks, $F_{4,45} = 3.375$; $p < .05$ for curve tasks) upon steering time was observed. Figure 5 displays the relationship between ID and MT for straight and curve patterns. The plotted points represent the average of 500 trials each (5 widths × 10 frequency × 10 participants). The average operation time was 7458.3 ms for the straight and 9679.0 ms for the curve task. Figure 5 shows the interaction of the ID × MT on a straight line and a curve. All of the steering laws indicated a high degree of conformity ($R^2 > 0.9$, the number of data points is N = 5).

Error Rate. The error rate also increased as ID increased in both the straight and curved lines. By repeating the cutting, the error rate decreased. The error rate of each pattern is (Pattern in Fig. 2, Error rate) = (S1, 0.0%), (S2, 0.2%), (S3, 6.2%), (S4, 7.0%), (S5, 12.4%), (C1, 0.0%), (C2, 0.6%), (C3, 7.8%), (C4, 9.2%), (C5, 13.4%). Accordingly, even for identical paths, it was found that operational mistakes increased for the narrowing direction.

5.4 Conclusion of Test 1

From the above results, we confirmed the fitness between the straight line and the curve pattern and the steering law that make up the cutout. The Fig. 5 presents the relationship between MT and ID and R^2 is very high (straight: 0.967, curve: 0.932). There was no significant difference between the straight line and the curve pattern. Moreover, when novices cut these patterns, the error rate increased as the width became thinner for both beginners. As a characteristic point, the error

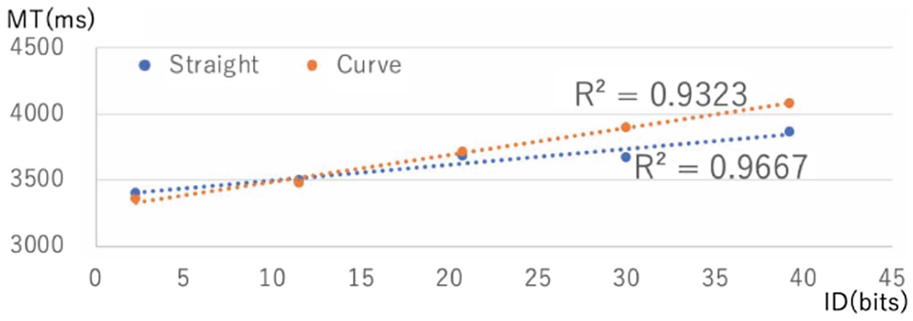


Fig. 5. Steering law fitness in straight and curve patterns.

rate of the curve was higher than the straight line at all difficulty levels. As a cause of this, cutting a straight pattern is a simple direction, but because cutting a curve requires a rotating motion of a wrist along an arc, we considered that the cutting operation has become complicated.

6 Test 2: Impact of the ID and Practice Effect

6.1 Objective

In this test 2, we confirm changes the skills to effective improve by practicing with the ID pattern corresponding to their abilities. The purpose is to compare the practice effects provided by various difficulty level. We measure the cutting time and coordinates when participants cut the patterns using our knife device.

6.2 Sequence of Trials

The participants were 20 novices. They (average age: 27.2 years, SD: 1.47) have previously never created paper-cuttings. They exhibit visual acuity that does not interfere with creating paper-cutting, and everyone was right-handed. They cut five types of straight lines, followed by five curves (Fig. 2). They repeated these actions 10 times. After the experiment, we interviewed the participants on the difficulty level of the patterns.

6.3 Result of Practice Effect

Cutting Time. The graph in Fig. 6 shows the average MT when participants cut 10 times repeatedly. The MT of the widest patterns (S1 and C1) were continuous for 5000 ms. Moreover, the MT in S2, S3, C2, and C3 converged to 5000 ms similarly. The participants cut the S4 line with the most reduced MT (59.8%) (Fig. 6A). The MT decreased with increasing difficulty, while the MT of S5 did not reduce as much as that of S4 (37.8%). Moreover, the curves demonstrated

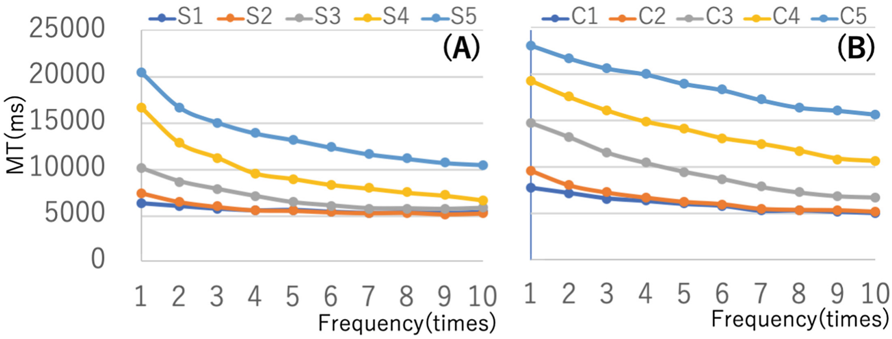


Fig. 6. Horizontal axis represents cutting frequency, and vertical axis represents MT in straight (A) and Curve pattern (B).

similar results (Fig. 6B). In the curve, the changes in MT reduced the most in the C3 line (54.9%). In addition, the amount of reduction in C4 and C5 decreased more than that in C3.

The MT decreased with increasing frequency. The decrease rate of each pattern is (Pattern in Fig. 2, Decrease Rate) = (S1, 10.3%), (S2, 25.7%), (S3, 36.7%), (S4, 59.8%), (S5, 37.8%), (C1, 30.1%), (C2, 34.8%), (C3, 54.9%), (C4, 48.2%), (C5, 33.8%).

Convergence. From the results above, the pattern in which the MT decreased the most among the 10 cuts by the novices is S4. Figure 5 shows the change in MT of the novices and experts in S4. The change of this MT synchronized with the improvement amount of the cutting skill, and the convergence of the MT signifies the mastery of the skill. The novices will improve their skills by acquiring considerable experience and converge to a MT cut of the experts.

6.4 Conclusion of Test 2

From the results above, we confirmed that MT changes according to ID. In particular, for low ID, the decrease in MT converged by repeating cutting. Additionally, for patterns with high ID, the reduction in MT is less pronounced than for low ID patterns. These causes are due to the difference between participant skill levels and design difficulty levels. From the above results, we measured the improvement of the skill from the change of MT.

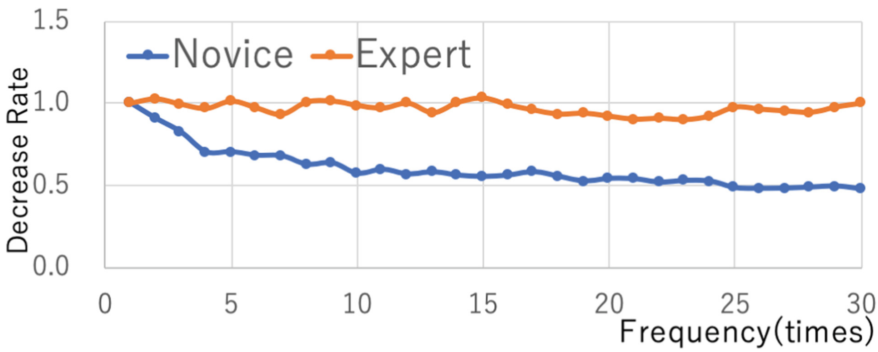


Fig. 7. The horizontal axis represents the cutting frequency, and the vertical axis represents the decrease rate for MT by novices and experts.

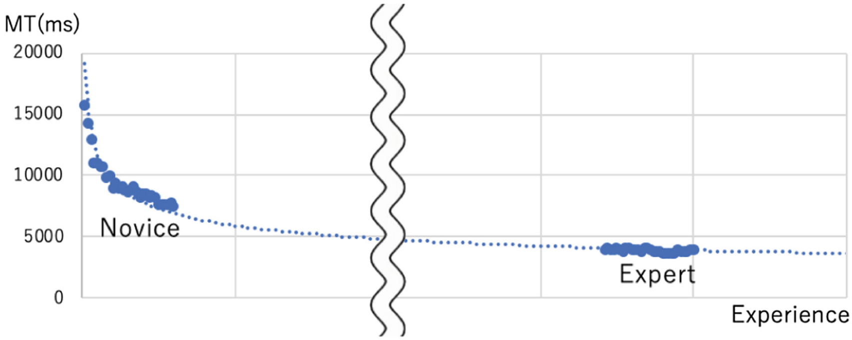


Fig. 8. Changes in skill improvement by novices and experts. X-axis is experiences.

7 Test 3: Change in MT Between Novices and Experts

7.1 Objective

In test 3, we compare the cutting skill between novices and experts. The purpose is to compare the practice effects provided by various difficulty level. We measure the cutting time and coordinates when participants cut the patterns using our knife device.

7.2 Method and Sequence of Trials

The participants were 10 novices and 10 experts. The novices (average age: 24.2 years, SD: 0.78) have never created paper-cuttings. Further, the experts (average age: 34.1, SD: 4.01) were either artists or instructors of paper-cutting. They exhibit visual acuity that does not interfere with creating paper-cuttings, and everyone was right-handed.

From the result in test 2, the pattern reflected the skill improvement of the novices as S4. Therefore, they cut the S4 pattern 30 times. After the experiment, we interviewed the participants regarding their skills.

7.3 Result of Improving

Decrease Rate of MT. Figure 7 shows that the novices' MT decreased by 44% from the first time to the time; however, it subsequently decreased to only 12% from the 20th time to the 30th time. Meanwhile, that of the experts decreased only 10% from the 1st time to the 30th time and changes as much as those of the novices were not observed.

Skill Improvement Model. Figure 8 shows the change in MT of the novices and experts in S4. The change in this MT is synchronized with the improvement amount of the cutting skill, and the convergence of the MT signifies the mastery of the skill. We consider that the novices will improve their skills by acquiring considerable experience and converge to the MT cut of the experts.

7.4 Conclusion of Test 3

From the above results, we compared changes in skill improvement with the same level of difficulty between beginners and experts. We confirmed the difference in cutting time in the same pattern between novices and artists. The MT of novices decreased in the early stage as the frequency increased, but the MT became constant at the end. On the other hand, the MT of the experts kept all changes within 10%.

8 Discussion

We verified the improvement in cutting skills from three tests in this paper. Our goal is to design each difficulty level for the creation paper-cutting. We designed the boundary pattern by white and black regions with 5 levels of ID. We measured the high adaptability of these patterns and Steering law. Moreover, we compared skill improvement with cutting patterns of various difficulty levels. We confirmed the change in the improvement amount of MT according to the ID by the difference between the beginner's skill level and the difficulty level to practice. In addition, we compared the change in skill when a novice and an artist cut off the same pattern. We measured the practice effects provided by various difficulty level. We showed the practice effect of each difficulty level on the change of cutting skill.

In these experiments, to improve the practice effect for novices, measurements were made by those who had no experience of cutting picture creation. Therefore, when targeting an intermediate person with experience of creation, the practice effect varies. Therefore, we measure the relationship between the skill level and the practice effect from the cutting action of the user. By doing this, we match the skill level according to users of various skills and give the user the best level of difficulty practice.

9 Conclusion

In this paper, we measured the improvement of participants' skills from the change of it MT. Therefore, we designed the difficulty level in the cutting pattern based on the steering law (Fig. 2). Moreover, we developed a system to measure the cutting time, which was one of the cutting skills. We confirmed the practice effect of each difficulty level on the change of cutting time. In test 1, the relationship with MT when the participants cut various ID patterns showed a high fitness to Steering law. In test 2, we compared the change in practice effect for novices by measuring the MT for each ID. As a result of cutting the low ID pattern, the change in MT was small, and the improvement effect was little. Moreover, the practice effect with the low ID pattern is small, the practice effect increases as the difficulty level rises. However, decreases when the width too hard for practicing, and the amount of MT decrease was small, and improvement of the skill of participants who performed with that pattern is also weak. In test 3, we compared the change in skill when a novice and an artist cut off the same pattern. From these experiments, we confirmed the change of novice's cutting skill according to difficulty level and the impact of practice effect according to skill level.

In future research, we will create a skill map to generalize the cutting skill. The skill map will be able to measures the difficulty level optimal for the skill level of the user, and the novices will be able to practice with optimal difficulty according to their changing his/her skills. We will try to adapt the combination of the artist's skill and painting difficulty.

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