Development and design of spinning tops that do not fall over aiming at improvement of quality of life

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ABSTRACT

Using the fingers stimulates brain nerve cells and activates the brain functions. Therefore, it is important for the elderly to use their fingers in their daily lives. We propose the use of spinning tops, which are familiar to Japanese people, as welfare devices that can improve the quality of life of the elderly by preventing the decline of physical function, dementia, and motor disorders and improving the health of the elderly.

Spinning tops have been familiar since early childhood. They come in a variety of shapes and are spun using various techniques. Anyone can enjoyably play with spinning tops with a simple operation using the fingers. Therefore, a continuous effect is expected. From the viewpoints of the prevention of dementia in the elderly and rehabilitation of those who suffer from it, playing with spinning tops can lead to an improvement in their quality of life. In addition, spinning tops can prevent the elderly from feeling isolated mentally and socially because of the communication generated as they play with the spinning tops. For effective rehabilitation, continuity is required. To this end, the concept is that the motion of spinning tops provides the chance for discovery and fun.

In this study, we focused on spinning tops that do not fall over even when they stop rotating, and developed a theoretical equation to describe this phenomenon. In the development and design of such spinning tops to be used in rehabilitation and play, the coefficient of friction was measured to examine the theoretical equation. In addition, the success rates of remaining standing after they stop rotating under various conditions of factors such as friction, material, and shape of the spinning tops were compared. The issues to be resolved and future prospects were discussed.

Keywords: quality of life, welfare devices, rehabilitation, using the fingers, play and delight

1. INTRODUCTION

We propose the use of spinning tops, which have long been familiar to Japanese, as welfare devices for encouraging the elderly to use their fingers in their daily lives. To promote the continuous use of spinning tops as rehabilitation devices, we developed the motion theory of a special type of spinning top that does not fall over even when it stops rotating. Moreover, we designed and manufactured such a type of spinning top.

In this study, the current issues of population aging, the need for long-term care, and the prevalence of cerebral vascular diseases in the Japanese society are discussed first. Then, the characteristics of spinning tops played using the fingers and their potential as welfare devices are described.
For the development and design of spinning tops that do not fall over, theoretical equations are formulated to describe the principle of motion. Spinning tops are manufactured with different dimensions and materials to examine the theoretical equations and compare various conditions. In the examination of the theoretical equations, the coefficient of friction is measured. In addition, the success rates of the tops remaining standing after they stop rotating under various conditions, such as the friction, material, and shape of the spinning tops, are compared[1),2)].
The relationship between the theoretical equations and the factors of spinning tops that do not fall over is clarified in this study. Also, a survey is conducted to evaluate the effectiveness of the spinning tops developed and designed in this study and to find their points of improvement as welfare devices for the elderly. Finally, the issues to be resolved and future prospects are discussed.

CURRENT STATE OF POPULATION AGING AND THE NEED FOR LONG – TERM CARE IN JAPAN, AND PROPOSAL OF SPINNING TOPS THAT DO NOT FALL OVER AS WELFARE DEVICES

The elderly (65 years and above) accounted for 26% of the total population in Japan in 2015[3)]. Japan has become an aging society, in which one in every four persons is elderly. Although the total population is declining, the elderly population is slightly increasing. As a result, the population aging rate is increasing yearly.
Generally, cerebral vascular diseases are the major reasons for the long-term care need of people aged 65 to 84 years. With advancing age, debility and dementia also become major reasons for such a need[3)].
The long-term care need is defined as the condition assumed to require constant and long-term care for a certain period of time in all or some of the basic activities of daily life such as bathing, excretion, and eating due to physical or mental limitations[3)].
Hand control is closely related to the brain. Recently, it has been revealed that hand use increases cerebral blood flow and stimulates the brain. Also, hand movement brings about changes in the brain. This is because of synaptic plasticity, which is the ability of neurons in the brain to bring about changes in the connections between neuronal networks or the transmittance of impulses in response to stimulation[1)]. For example, patients with finger paralysis due to brain disorder can regain finger motion through rehabilitation.
In this study, we propose the use of spinning tops that do not fall over as welfare devices. It is important for the elderly to always use their fingers to prevent the decline of hand and finger functions. However, the elderly often experience difficulty in continuing finger rehabilitation exercises[2)].
Therefore, we focused on spinning tops that can encourage the elderly to use their fingers while playing. The elderly will become curious and continue to enjoy playing with the spinning tops if the motion of spinning tops provides the chance for discovery and fun. To this end, we develop and design a special type of spinning top, namely, the spinning top that does not fall over even when it stops rotating.

PRINCIPLE OF MOTION OF SPINNING TOPS

3.1 *Principle of precession*

Figure 3-1 shows the principle of forces acting on a spinning top. A spinning top is supported by the supporting point on the floor. Gravity acts in the direction that causes the spinning top to fall to the floor. The gravity, in combination with the centrifugal force generated by rotation, causes precession. The spinning top rotates with an angular velocity of precession ω and an angular velocity around the axis of the spinning top Ω. The moment of inertia around the axis is I_{yy} and the angle between the axis of the spinning top and the line perpendicular to the plane is θ.
The torque of centrifugal force acting on the axis is expressed as $T=I_{yy}\Omega\omega\sin\theta$. When the height of the center of gravity of the spinning top is l, the torque of gravity acting in the direction that causes the spinning top to fall to the floor is expressed as $N=Mgl\sin\theta$. Precession occurs and the spinning top does not fall over when the two torques acting on the spinning top (T and N) are equal to each other[4),5)].
Therefore, the condition for precession is given as follows.

$$I_{yy}\Omega\omega\sin\theta = Mgl\sin\theta \quad \cdots\cdots\cdots (1)$$

3.2 *Speed of stand-up motion of spinning tops*

The torque needed for stand-up motion is generated so as to counteract the frictional force generated by the rotation of a spinning top. In time, the spinning top starts to rotate to stay upright.

When the coefficient of dynamic friction is μ, the moment around the center of gravity due to the frictional force, $N_1=\mu Mgl$, acts in the direction that reduces θ. By expanding the equation of motion, the speed of stand-up motion of a spinning top is given as follows[4),5),6)].

$$\dot{\theta} = \frac{\mu Mgl}{I_{yy}\Omega} \quad \cdots\cdots\cdots (2)$$

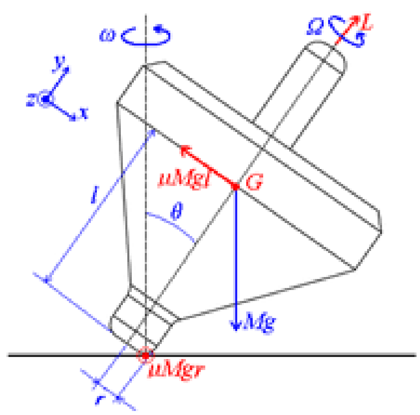


Figure 3-1. *Principle of forces acting on spinning top*

3.3 *Deceleration in rotation*

When the distance between the axis of a spinning top and the ground contact point is r, the moment around the axis owing to the frictional force, $N_2=\mu Mgr$, acts in the direction that decelerates Ω. The equation of motion for angular acceleration in a rotating spinning top is as below, assuming time t [4),5)].

$$\frac{\Delta\Omega}{\Delta t} = -\frac{\mu Mgr}{I_{yy}} \quad \cdots\cdots\cdots (3)$$

From Eqs. (2) and (3), the speed of stand-up motion increases, but the angular velocity decreases as the coefficient of dynamic friction increases. When the spinning top stands upright, it rotates with negligible deceleration of ω because r is sufficiently small. Also, the speed of stand-up motion increases as the position of the center of gravity is lowered and the moment of inertia increases.

From the above, it is assumed that a spinning top does not fall over when Eq. (1) holds as ω and θ approach zero.

3.4 Moment of inertia

The moment of inertia indicates the mass in rotational motion. It shows how difficult it is to change the rotational motion. The moments of inertia in the x-, y-, and z-axes are given as follows.

$$I_{xx} = \sum_i m_i \left(y_i^2 + z_i^2\right) \quad \cdots\cdots\cdots (4)$$

$$I_{yy} = \sum_i m_i \left(z_i^2 + x_i^2\right) \quad \cdots\cdots\cdots (5)$$

$$I_{zz} = \sum_i m_i \left(x_i^2 + y_i^2\right) \quad \cdots\cdots\cdots (6)$$

From Eqs. (4)–(6), the moment of inertia is found to increase with the mass and the distance from the axis of rotation.

Because a spinning top is a rotating object, I_{yy} affects the rotation of the spinning top when the axis rotates. Also, I_{xx} and I_{zz} indicate how difficult it is for an object to rotate in the upward and downward directions at the center of gravity. In the rotation of a spinning top, small-amplitude and short-period motions caused by disturbance and deflection overlap with the period of precession. These short-period motions are called nutation. The rotation of a spinning top is stabilized when the equation for the moment of inertia $I_{xx} = I_{zz}$ holds. A large gap between I_{xx} and I_{zz} causes nutation and, as a result, the spinning top loses its balance[6)].

3.5 Kinetic energy of rotational motion

The circumference of radius r is $2\pi r$. When the rotational speed is ν, the velocity v is $2\pi r\nu$. Therefore, the kinetic energy of rotational motion is given as follows[6)].

$$E = \frac{1}{2}Mv^2 = \frac{1}{2}M\left(2\pi r\nu\right)^2 = 2I\pi^2\nu^2 \quad \cdots\cdots\cdots (7)$$

3.6 Frictional force

The above theoretical equations show that the principle of motion of spinning tops is largely affected by frictional force. In this section, the principle of frictional force is explained.

When an object with mass M is pulled by force P, the frictional force acts in the direction opposite to that of P. When the normal force is N and the acceleration of gravity is g, the frictional force F is generally expressed as follows.

$$F = \mu N = \mu Mg \quad \cdots\cdots\cdots (8)$$

Here, μ is the coefficient of friction, which is a dimensionless quantity. The frictional force F is therefore determined by the normal force N. When the force P equals the frictional force F, the object does not move even if force is being applied. The frictional force in such a state is called the static frictional force F_s. $F = P$ holds at first; however, $F < P$ holds when the object is pulled by a force larger than that at which the object starts moving. The static frictional force F_s reaches its maximum at the moment when the object starts moving, which is called the maximum static frictional force F_{smax}. Also, the frictional force that acts on the object after it starts moving is called the dynamic frictional force F_d. The dynamic frictional force F_d is smaller than the maximum static frictional force F_{smax}.
μ is the ratio of the normal force N to the frictional force F expressed as follows.

$$\mu = \frac{F}{N} = \frac{F}{Mg} \qquad \cdots\cdots (9)$$

4. BASIC DESIGN

4.1 Reference dimensions

The equations describing the principle of motion of spinning tops show that the factors that significantly affect the rotation of spinning tops are 1) the frictional force, 2) the position of the center of gravity, and 3) the moment of inertia. It is also assumed that the size of the ground contact area of the ground contact axis is important for spinning tops to remain standing after they stop rotating.
The differences in frictional force on various measuring planes as well as the differences in the mass and the forces acting on spinning tops due to the differences in the material and shape of spinning tops were examined in the experiments.

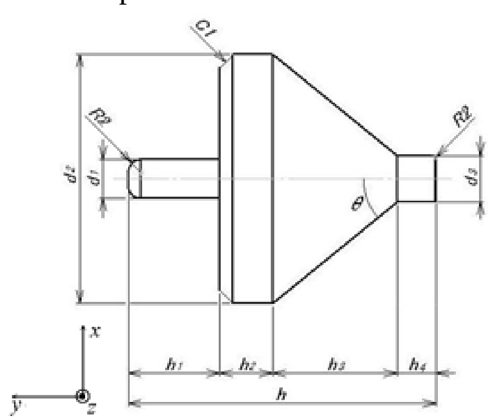


Figure 4-1. *Reference shape of spinning tops that do not fall over*

Table 4-1. *Reference dimensions*

Part name		Dimensions [mm]
Diameter of handle axis	d_1	3.0
Diameter of main body	d_2	19.0
Diameter of ground contact axis	d_3	3.5
Total height	h	23.5
Height of handle axis	h_1	7.0
Height of parallel part of main body	h_2	4.0
Height of parasol-shaped part	h_3	9.5
Height of ground contact axis	h_4	3.0

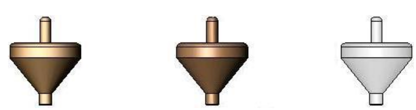
The reference dimensions of a spinning top were set and used as the standard for comparison during the analysis of spinning tops. The dimensions of spinning tops used for shape comparison were determined by referring to the reference dimensions. Figure 4-1 shows the reference shape of spinning tops that do not fall over. The spinning tops that do not fall over must remain standing when they stop rotating. To this end, the ground contact axis of the designed spinning tops has a large ground contact area and a small fillet radius. Table 4-1 shows the reference dimensions.

4.2 Selection of materials

Spinning tops that do not fall over are significantly affected by the frictional force and moment of inertia. The equations described above show that the mass is related to those effects. Also, the frictional force varies depending on the specific gravity and frictional property of materials. Therefore, the success rates of spinning tops of various materials were compared. Considering the characteristics of materials, such as excellent workability, low price, and density homogeneity, brass (C3604), bronze (CAC406C), and acrylic resin (PMMA) were used.

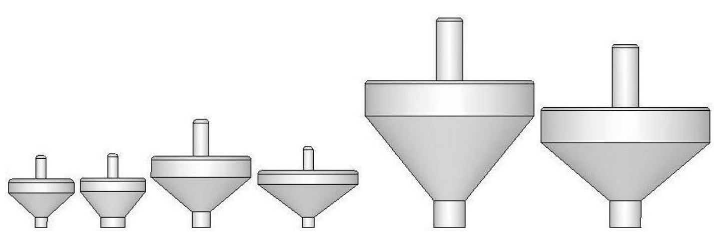
4.3 Determination of dimensions

To develop the theory for spinning tops that do not fall over, spinning tops were manufactured with different shapes, including those with various lengths of the ground contact axis and heights of the center of gravity. Spinning tops of different materials and shapes were designed using SolidWorks. Figures 4-2 and 4-3 show the spinning tops of different materials and shapes. Spinning top 1 was made of brass (C3604), spinning top 2 was made of bronze (CAC406C), and spinning tops 3–9 were made of acrylic resin (PMMA).



(1) *C3604* (2) *CAC406C* (3) *PMMA*

Figure 4-2. *Spinning tops made of different materials*



(4) (5) (6) (7) (8) (9)

Figure 4-3. *Spinning tops (PMMA) of different shapes*

4.4 Manufacturing of spinning tops

A high-speed precision lathe (MK-860, Yamazaki Mazak Corporation) was used for manufacturing spinning tops. The processes for manufacturing spinning tops that do not fall over are divided into the following two parts: 1) machining and cutting of the handle axis and 2) tapering of the ground contact axis and main body.

5. EXPERIMENT AND RESULTS

5.1 Measurement of coefficient of friction

The coefficient of friction depends on the type of object being studied and its state. The coefficient of friction was measured on 1) Kent paper, 2) newspaper, and 3) Japanese paper. The dynamic frictional force F_d and the coefficient of dynamic friction on Kent paper were 160 N and 0.32, those on newspaper were 170 N and 0.34, and those on Japanese paper were 150 N and 0.30, respectively.

5.2 Comparison of friction

The theoretical equations show that the frictional force and shape can significantly affect the restoring force of a spinning top. Therefore, we spun a top (spinning top 1 in Fig. 4-2) 50 times at a certain angular velocity on different measuring planes and determined the success rate of the top to remain standing after it stopped rotating. The cases in which the spinning tops moved away from the center of the measuring plane or did not rotate were not counted. As a result of the comparison of friction on different measuring planes, the success rates for those measuring planes were found to be 1) 16% for Kent paper, 2) 48% for newspaper, and 3) 80% for Japanese paper.

5.3 Comparison of materials

In the comparison of materials, the mass, the forces acting on spinning tops, and the success rates of the tops to remain standing were examined using spinning tops made of different materials. We spun spinning tops of the same shape but different materials (spinning tops 1–3 in Fig. 4-2) 50 times on a sheet of Japanese paper placed on a horizontal surface. The rotation of the spinning tops was recorded using a superhigh-speed camera (HSV-500C^3) and the success rates of the tops to remain standing after they stopped rotating were determined. The cases in which the spinning tops moved away from the center of the measuring plane or did not rotate were not counted. Table 5-1 shows the position of the center of gravity l [mm], the mass M [g], the moments of inertia I_{xx} and I_{yy} [g・m^2], the rotational speed n [rpm], the rotation time t [s], and the success rate [%] obtained by calculation and the comparison of materials.

5.4 Comparison of shapes

In the comparison of shapes, the mass, the forces acting on spinning tops, and the success rates of the tops to remain standing were examined using spinning tops of different shapes. As in the comparison of materials**,** we spun all tops 50 times on a sheet of Japanese paper placed on a horizontal surface. The rotation of the spinning tops was recorded using a superhigh-speed camera (HSV-500C^3) and the success rates of the tops to remain standing after they stop rotating were measured. Table 5-2 shows the position of the center of gravity l [mm], the mass M [g], the moments of inertia I_{xx} and I_{yy} [g・m^2], the rotational speed n [rpm], the rotation time t [s], and the success rate [%] obtained by calculation and the comparison of shapes.

Table. 5-1 *Results of comparison of materials*

Tops	l [mm]	M [g]	I_{xx}[g・m^2]	I_{yy}[g・m^2]	n [rpm]	t [s]	Success rate[%]
①	12.12	19.48	561	680	1363	2.00	64
②	12.12	19.94	575	696	1224	3.43	62
③	12.12	2.45	71	86	3000	9.78	80

Table 5-2. *Results of comparison of shapes*

Tops	I_{xx} [g・m^2]	I_{yy} [g・m^2]	n[rpm]	t[s]	success rate [%]
①	561	680	1363	2.00	67
②	575	696	1224	3.43	62
③	71	86	3000	9.78	80
④	56	77	3333	11.12	76
⑤	74	86	2727	10.09	96
⑥	446	630	1579	11.20	76
⑦	281	454	1364	10.84	100
⑧	8143	9863	600	6.77	64
⑨	6183	8721	682	9.24	96

6. DISCUSSION

6.1 Discussion on comparison of materials

Table 5-1 shows that the success rates of spinning tops 1 and 3 to remain standing are higher than that of spinning top 2. This seems to be due to the fact that the rotational speed increases and the effect of nutation decreases as the material mass decreases.

When different materials are used, the changes in the properties of the materials do not affect the success rates of the tops to remain standing, but only the change in material mass affects the rotational speed and moment of inertia. As the mass decreases, the rotational speed increases and the rotation is stabilized. At the same time, there are cases in which spinning tops hit the wall and are flicked off because of the decreased moment of inertia. It is therefore necessary to clarify the relationship between the rotational speed and the moment of inertia, which are affected by the changes in the mass.

6.2 Discussion on comparison of shapes

The height of the center of gravity and the moment of inertia of a spinning top largely affect the success rate of the top to remain standing after it stops rotating. Because the taper angle θ_t' and the height of the center of gravity are inversely proportional to the moment of inertia I, it is impossible to improve the success rate of the spinning top by adjusting only the taper angle θ_t'.

The success rate increases when the height of the center of gravity of the spinning top is lowered by decreasing the height of the ground contact axis h_4. The rotation is considered to be stabilized because the moment of inertia I_{xx} significantly decreases as the taper angle θ_t' increases. The taper angle θ_t' is a reliable index for determining the success rate.

The success rate increases when the moment of inertia increases along with the increase in the mass. Similarly to the results of comparing the materials, the mass and moment of inertia are inversely proportional to the rotational speed and rotation time. As a result, the change in the size does not affect the success rate, and only the change in the mass affects the rotational speed and moment of inertia.

6.3 Effects of ratio of moment of inertia

The ratio of moment of inertia is obtained using Eqs. (3) and (4). Figure 6-1 shows the relationship between the success rate and the ratio of moment of inertia. The success rate increases with the inertia moment ratio. In addition to the height of the center of gravity and the moment of inertia, the ratio of the moment of inertia is useful in evaluating the stability of rotation.

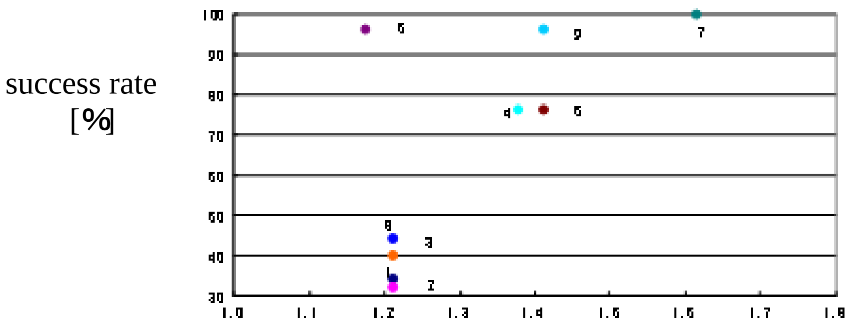


Figure 6-1. *Ratio of moment of inertia and success rate*

6.4 Effects of angular acceleration

The angular acceleration of spinning tops is obtained from Eq. (3). Figure 6-2 shows the relationship between the success rate and the angular acceleration. In this figure, the success rate is higher when the negative value of the angular acceleration is closer to zero.

6.5 Effects of speed of stand-up motion

The speed of the stand-up motion of a spinning top is obtained using Eq. (2) and compared with the success rate. The success rate increases as the speed of stand-up motion decreases. This result shows that the success rate is higher when it takes a longer time for a spinning top to stand up, namely, when the period of precession is longer.

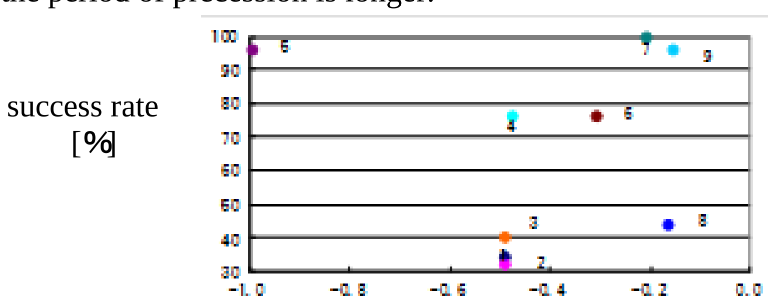


Figure 6-2. Angular acceleration of rotation and success rate

*6.6 Effects of diameter of ground contact axi***s**

Spinning top 8 has the same taper angle as spinning top 6, but it has a larger diameter of the ground contact axis. As a result, the height of the center of gravity is lower and the success rate significantly increases. The success rate of spinning top 8 is high without showing any proportional relationship with *what?*. This may be because the effects of torque acting on the spinning top when it stops rotating are reduced by the small height of the center of gravity and the large ground contact area. Let us first focus on the small height of the center of gravity. The torque of centrifugal force acting on the axis of rotation is expressed as $T=I_{yy}\Omega\omega\sin\theta$. The torque of gravity acting on the spinning top is expressed as $N=Mgl\sin\theta$. Because the torque N includes the height of the center of gravity l as part of the function, this torque decreases as the height of the center of gravity is decreased. Also, because spinning top 8 has a large ground contact area, the frictional force acting on the ground contact area is large enough that the spinning top does not fall over.

6.7 Issues to be resolved and future prospects

The spinning tops that do not fall over after they stop rotating are largely affected by the moment of inertia. The stability of rotation can be evaluated by obtaining the ratio of I_{yy} to I_{xx}. Also, the deflection of the axis of rotation decreases when the convergence of angular acceleration is moderate.

The measurement in this study was not quantitatively accurate because we spun the spinning tops with our fingers and, as a result, the rotational speed varied widely.

Friction is a very important factor in the rotation of spinning tops. In this study, we measured the coefficient of friction and substituted it into each theoretical equation to examine the success rates of the tops to remain standing after they stop rotating, as well as the forces acting on them. However, in the actual rotation of a spinning top, the ground contact area comes into contact with the measuring plane at a point. Therefore, the coefficient of friction varies widely depending on the surface roughness as well as the presence of an oxide film, an adsorbed film, and contamination. The conditions also change as the ground contact area of the spinning top becomes worn.

In the future, we will address the above issues, set appropriate values of the coefficient of friction and rotational speed, and clarify the effects of the moment of inertia, torque, and precession on the success rate of spinning tops.

7. MEASUREMENT OF A EFFECTIVENESS

7.1 Survey for measuring effectiveness

Spinning tops with a large handle axis easily fall over owing to the large deflection caused by the effects of the moment of inertia. Therefore, ideal spinning tops that do not fall over should have a handle axis of small diameter and length.

However, in order for people to easily hold a spinning top with their fingers, the diameter and length of the handle axis must be sufficiently large. In the design of spinning tops that do not fall over as welfare devices used by the elderly, it is necessary to evaluate both the spinning tops themselves and their functions, as shown in Fig. 7-1. Although the spinning tops themselves are evaluated by experiments and analysis, their functions must be evaluated by measuring their effectiveness (Fig. 7-2).

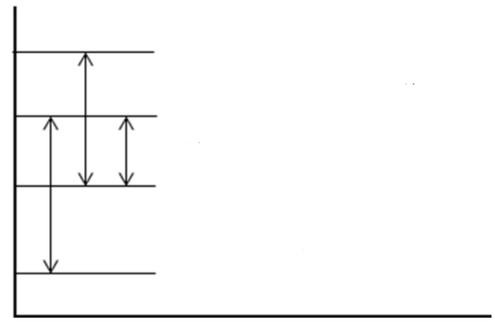


Figure 7-1. *Design of handle axis*

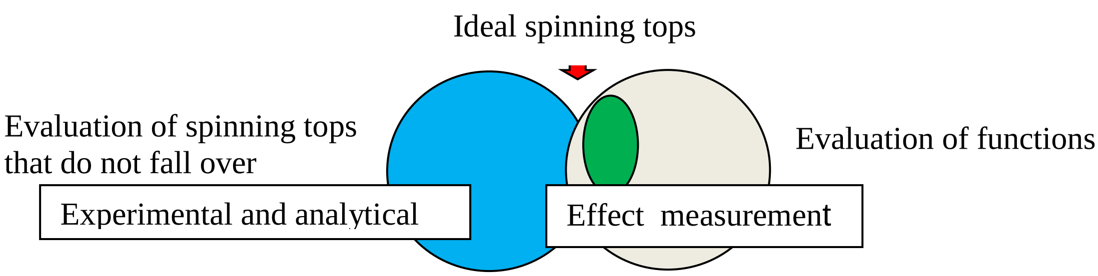


Figure 7-2. *Design of ideal spinning tops*

To determine the effectiveness of the spinning tops designed and developed in this study, we requested the elderly to use these spinning tops. The following four points were examined.

1.Do the spinning tops that do not fall over provide the chance for discovery and fun?
2.Are the product elements of the spinning tops, such as ease of holding, size, and design quality, appropriate?
3.Can the continuous use of the spinning tops that do not fall over be expected?
4.Can the spinning tops that do not fall over be used as welfare devices?

In February 2017, we asked 28 elderly people (20 males and 8 females) aged 62 to 72 years to use the spinning tops that do not fall over. The questionnaire sheet consisted of 10 items concerning the four points described above. Each item was rated on a three-point scale.

Figure 7-3 shows the spinning tops used in the measurement of effectiveness. Table 7-1 shows the dimensions of those spinning tops. Table 7-2 shows the questionnaire items used in the measurement of effectiveness and the obtained responses

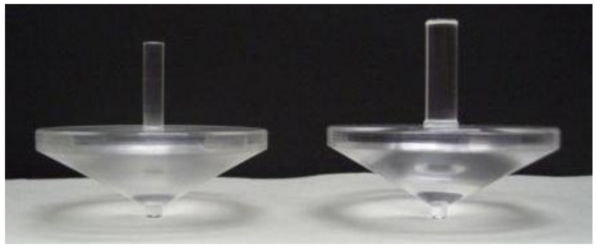


Figure 7-3. *Spinning tops used in measurement of effectiveness*

Table 7-1. *Dimensions of spinning tops*

	d_1[mm]	d_2[mm]	d_3[mm]	h[mm]	h_1[mm]	h_2[mm]	h_3[mm]	h_4[mm]
⑩	3.0	49.0	3.5	38.0	18.0	4.0	13.0	3.0
⑪	3.0	49.0	3.5	42.0	22.0	4.0	13.0	3.0

Table 7-2. *Questionnaire items used in measurement of effectiveness and responses (scores: ◎, 3; ○, 2; △, 1).*

Questionnaire items	Men (N=20)	Women (N=8)	Men and Women (N=28)	
	Indicate the full score	Indicate the full score	Total score	Average score
1. Were you surprised when you saw the motion of the spinning tops?	33	32	65	2. 32
2. Were they easy to spin?	28	26	54	1. 93
3.Were they easy to hold with the fingers?	28	24	52	1. 86
4. Were you satisfied with the rotation time?	28	24	52	1. 86
5. Was the size appropriate?	26	25	51	1. 82
6. How was the design quality?	25	24	49	1. 75
7. Was the weight appropriate?	26	21	47	1. 68
8. Would you like to try spinning them repeatedly?	29	28	57	2. 04
9. Would you tell other people about them?	29	30	59	2. 11
10. Did you enjoy playing with them?	27	27	54	1. 93

*7.2 Discussion on measurement of effectivene*ss

As shown by the results of the questionnaire (Table 7-2), the spinning tops that do not fall over provided many chances for discovery and fun to the elderly. Also, the score for the question "Would you like to try spinning them repeatedly?" was high, which means that the continuous use of spinning tops can be expected. In addition, the spinning tops were highly evaluated as a communication tool that encourages the elderly to share the fun with others.

The action of spinning a top using the fingers, the visual excitement caused by following the motion of a spinning top, and the thought-provoking surprise significantly stimulate the brain. Also, the continuous use of spinning tops can be expected. From the above results, spinning tops are considered effective welfare devices.

However, the scores for product elements including the design and functions were low. The score for the question "Did you enjoy playing with them?" was not very high.

The reason for these low scores is probably be the lack of visual appeal of the spinning tops used. The popular spinning tops that are familiar to us are colorful ones such as Edogoma, whereas the spinning tops we manufactured are colorless (PMMA).

We will carry out further analysis to better understand the properties of the spinning tops that do not fall over. Our goal is to improve the quality of those spinning tops as welfare devices that can be continuously used by the elderly. To this end, we would like to make the spinning tops more appealing by improving their ease of holding, size, and ease of spinning as well as improving their design quality including their color and compactness.

8. CONCLUSION

1. We propose the use of spinning tops, which have long been familiar to Japanese, as welfare devices for encouraging the elderly to use their fingers in their daily lives. To promote the continuous use of spinning tops as rehabilitation devices, we developed the motion theory of a special type of spinning top that does not fall over. Moreover, we designed and manufactured such a type of spinning top.

2. The principle of motion of spinning tops that do not fall over after they stop rotating had not been established. Therefore, we formulated theoretical equations to describe the principle of motion. Spinning tops of different dimensions and materials were manufactured to examine the theoretical equations and compare the success rate under various conditions.

3. The results of comparison experiments, as well as the relationship between the theoretical equations and the success rate of spinning tops that do not fall over, were shown in this study. The issues to be resolved and future prospects were also discussed.

4. A questionnaire survey was conducted to evaluate the effectiveness of the spinning tops developed and designed in this study and to identify points of improvement in their application as welfare devices for the elderly.

The spinning tops that do not fall over after they stop rotating are significantly affected by the moment of inertia. The stability of rotation can be evaluated by obtaining the ratio of I_{yy} to I_{xx}. Also, the deflection of the axis of rotation decreases when the convergence of angular acceleration is moderate. In future studies, we will set appropriate values of the coefficient of friction and rotational speed and clarify the effects of the moment of inertia, torque, and precession on the success rate of spinning tops.

9. REFERENCES

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