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An Evaluation Study of preferences between combinations of 2D-look shading and Limited Animation in 3D computer animation

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Abstract

3D computer animation has become popular all over the world, and different styles have emerged. However, 3D animation styles vary within Japan because of its 2D animation culture. There has been a trend to flatten 3D animation into 2D animation by using 2D-look shading and limited animation techniques to create 2D looking 3D computer animation to attract the Japanese audience. However, the effect of these flattening trends in the audience's satisfaction is still unclear and no research has been done officially. Therefore, this research aims to evaluate how the combinations of the flattening techniques affect the audience's preference and the sense of depth. Consequently, we categorized shadings and animation styles used to create 2D-look 3D animation, created sample movies, and finally evaluated each combination with Thurston's method of paired comparisons. We categorized shadings into three types; 3D rendering with realistic shadow, 2D rendering with flat shadow and outline, and 2.5D rendering which is between 3D rendering and 2D rendering and has semi-realistic shadow and outline. We also prepared two different animations that have the same key frames; 24fps full animation and 12fps limited animation, and tested combinations of each of them for the evaluation experiment. The result of the study showed that people prefer 24fps to 12fps, and 2.5D rendering to the other renderings. It also presented a cultural difference in which Japanese spectators tend to like 2D rendering more than 3D rendering, but spectators of other nationalities tend to like 3D rendering more than 2D rendering. 2D-look 3D animation is beneficial in some degree for Japanese audience; however, there seems to be room for exploring new styles between 2D and 3D to attract more audience.

Keywords: CG Animation, Evaluation, Animation Styles

1. Introduction

1.1. Background

『FROZEN』(2013) made more than 25-billion-yen at the Japanese box office and became one of the highest-grossing film in Japan, at the same time『STAND BY ME DORAEMON』(2014) made 8-billon-yen at the box office [1]. In spite of being big hits of 3DCG animation, Japanese academy award wining films are all 2D animated [2]. This shows that 3D animated films are still on their way to being recognized in Japan, and is why techniques to create 2D looking 3DCG animation have been studied by Japanese researchers and 3d animators. There are two techniques for creating 2D looking 3DCG animation. One is a rendering method called *toon shader*, which creates pictures that look like 2D cell animation out of 3DCG objects. The other method deals with the animation's frames per second, instead of the usual frame rate of 24fps, it is shortened to 8~12fps to add the feeling of limited animation. For an example, 『Rakuen Tsuiho –Expelled from Paradise』(2014) got internationally recognized at SIGGRAPH because of using a combination of these two methods, and merging 3D objects with 2D backgrounds. [3]

1.2. Related Research

There are researches about how to create 2D looking 3DCG, and how to apply the techniques. There are two keys in order to create the 2D look: rendering and animation style.

The 2D look rendering is known as non-photo realistic rendering, and there has been studies about creating different styles for being used in technical illustration. [4] This paper focuses on a style that imitates Japanese 2D cell animation. Mitsuru Kaneko defined that the key elements of 2D cell-look are outlines, flat coloring, and the independent shadow without the environment light effect. [5] This 2D cell-look rendering technique is called toon-shader. Researchers are trying to enhance it so it looks closer to actual 2D cell by improving shadow-casting method. [6] Also, the technique to get refined outlines is still a recurrent topic on the field all over the world [7]. These flat shading and outlines are the key visual elements in order to create 2D cell-look 3DCG animation. However, 2D cell-animation have unique characteristics not only in their visual look but also in their motion style as limited animation.

Toshihiro Konma mentioned that the limited animation style is a strong characteristic of 2D cell animation because there are people who prefer the limited style compared to 24fps fully

animated style [8]. There are previous researches about how to create the 2D feeling by emphasizing the timing of animation [9] and creating cartoony effects such as speed lines [10]. In this case, the author thinned out frames from motion captured character movement and used them for creating the limited animation style. Similarly, Maki Kitamura created an auto filter in order to transform the motion captured character movement into 2D-look by dropping frames intentionally [11]. These studies aimed to create limited animation from motion capture data, however John Lasseter implied that motion capture data is too realistic and it does not fit with stylized animation. [12] Because of this, recent 3DCG films such as『Saint Seiya Legend of Sanctuary』(2014) [13] and『STAND BY ME DORAEMON』(2014) [14] have been animated by hand. Although, this paper suggested that limited animation style in 3DCG is still in an experimental phase, and is not yet certain if motion capture is an appropriate tool for increasing quality and productivity.

These techniques are expected to expand the expression in 3DCG, however, we need to make sure how these techniques will be applicable practically.

2D cell animation has been widely popular in Japan and the flattening 3DCG animation seems to be an appropriate approach. However, two related researchers have cast doubt on this assumption.

Koji Mikami researched the efficiency of producing 3DCG animation. [15] They measured productivity in both 2D animation and 2D-look 3DCG and the result showed that there was no significant difference between them. On the other hand, the research done by Masami Sano shows that more than 80% of the audience who had no advanced knowledge of 3DCG accepted 3DCG animation as regular "anime" even without toon shading. [16]

These researches put in evidence that creating 2D animation by using 3DCG does not have a significant change on its production in terms of productivity and familiarity. However, they don't evaluate the audience's satisfaction regarding the flattening methods of 3DCG, which is why a study in the matter is required.

1.3. Research Goal

To flatten 3DCG animation into 2D, 2D look shading and limited animation style are applied on 3D objects. However, whether it increases audience's satisfaction or not has not been verified. Therefore, this research aims to evaluate how the combination of the flattening techniques affects the audience's preference and the sense of depth.

2. Sample Movies

2.1. Categorizing animation styles

3DCG animation feature films are normally animated on 24 fps, which is called *full animation*. 『009 RE: Cyborg』, released in 2012, took a different approach. It imitated the limited animation feeling by shortening the frame rates. Since then, several films were also made in this limited animation style. Thus, we categorized animation styles into the commonly used 24fps full animation and 8~12fps limited animation, used in Japanese feature animated films. (Figure 1)

Animation studios in the United States, such as Walt Disney Animation, make full animation. They draw 24 images per second, which is the same frame rate as a live film, and are able to show smooth movements. On the other hand, Japanese 2D animation uses limited animation, which consists of lower number of images, around 8 to 12 per second. Therefore the motion becomes slightly rougher compared to full animation.

One of the biggest Japanese animation studios, Studio Ghibli, uses 12 images per second but repeats each image twice in order to complete the 24fps. [17] However, they also use 8fps for slow movements, and 24 fps for fast ones.

This research focuses on feature films, so we categorized animation styles as 24fps, used by Walt Disney Studios, and 12 fps, used by Studio Ghibli.

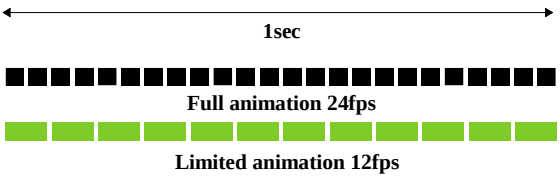


Figure 1 24fps and12fps

2.2. Rendering Techniques Classification

While 3DCG animation in the U.S. tends to render images realistically based on physical calculation, in Japan, animation has a different look because of the influence of the 2D animation culture. Based on past Japanese 3D animated feature films, we categorized shading into 3 types; 3D rendering with realistic shadow, 2D rendering with flat shadow and outline, and 2.5D rendering which is between 3D rendering and 2D rendering and has semi-realistic shadow and outline.

- 3D rendering: commonly used in 3D animated feature film in the U.S., which has realistic shading.

Examples:
『Oblivion Island: Haruka and the Magic Mirror』(2009)
『FRIENDS; Naki on the monster island』(2011)

- 2D rendering: characterized by flat shades and outline.

Examples:
『Appleseed』(2004)
『Expelled from paradise』(2014)

- 2.5D rendering: positioned between 3D rendering and 2D rendering, has realistic shadow and also outline.

Examples:
『Appleseed SAGA Exmachina』(2007)
『After School Midnighters』(2012)

2.3. Creating sample movies

We used Autodesk Maya and Adobe After Effects to create the sample movies. The same character is used in all of the sample movies in order to focus on the combination of shadings and animation styles. The character's movements are "walking" and "jumping", because those movements are often presented in animation textbooks as basic human motions.

In animation, the frame that defines the transition of movement is called a key-frame, and the frames between each key-frame are called in-between. In this experiment, we animated 24 fps and 12 fps with the same key-frames and different in-betweens. Richard Williams's *The Animator's Survival kit* [18] was used as reference to animate 24fps, and also Tadashi Ozawa's *Anime sakuga no kihon* [19] to animate 12fps. Also, we applied the 12 principles of animation by Ollie Johnston and Frank Thomas where necessary in order to animate in-between frames. [20]

To reproduce three different types of shading, we used multi-pass rendering. We split and rendered one movie into several layers on 3D software, and created the final look by compositing those layers. We then divided in seven layers (Figure 2), and created 3D rendering (Figure 3), 2D rendering (Figure 4) and 2.5D rendering (Figure 5).

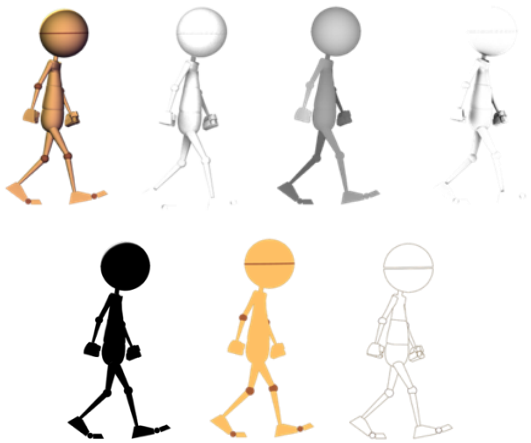


Figure 2 Render Layers

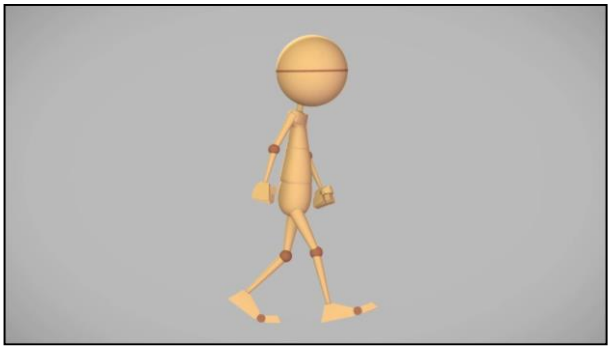


Figure 3 3D rendering

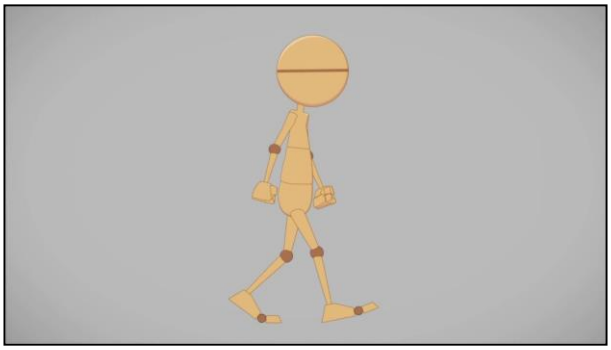


Figure 4 2D rendering

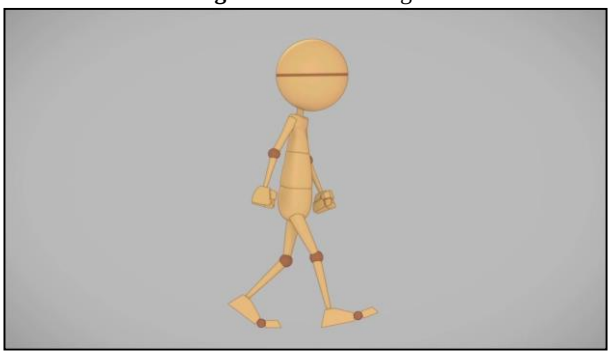


Figure 5 2.5D-Rendering

3. Evaluation Experiment

3.1. Approach

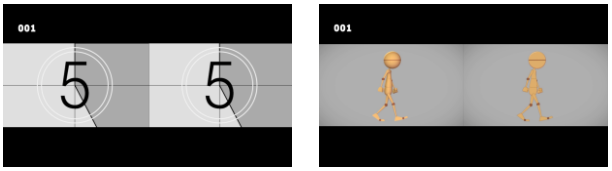


Figure 6 Test movie

We created sample movies with each combination of three different types of shading (3D rendering, 2D rendering, 2.5D rendering) and two types of animation styles (24 fps full animation and 12fps limited animation). To evaluate how the combination of the flattening techniques affect the audience's preference and the sense of depth, we used Thurston's method of paired comparisons that enable to measure different stimulus on the same scale by repetitive comparison of the pair of the stimulus.

In this experiment, we put two stimulus side by side to make it easier to compare. (Figure 6) To balance out the order effect, we included reversed position order as well.

In the experiment, we divided subject group into Japanese and other nationalities. We tested these two groups and experimented the effect of cultural difference, types of movement, camera movement, and camera angle.

① Overall average scale value of the combination of shading and animation style.
② The scale value of different types of movement (Walk and Jump)
③ The scale value of different camera movements (follow camera and fixed camera)
④ The scale value of different camera angles (side view and

perspective view)

⑤ The scale value of each flattening method

3.2 Experiment

Figure 7 Experiment environment

We gathered 58 people from 21 to 34 years old (average 23.8 years old) as test subjects, of which 44 people were Japanese (11 female and 33 male) and 14 people were from other nationalities (6 female and 8 male). The second group included test subjects form France, Brazil, Morocco, Colombia, China, Australia, the Netherlands, and Germany. As pictured above, we projected the movie on a 100-inch screen by a projector. The subjects evaluates the stimulus at the optimal visual distance, which is 2.5~3m away from the screen. The experiment took about one hour including breaks. The experiment was split into 6 sections as shown in Table1. There were short breaks between each section and long breaks after section No.2 and section No.4.

Each section consisted of 30 paired comparisons of the combinations, which had 3 types of shadings and 2 types of animation styles and calculated by ${}_6P_2=30$ including reversed position order.

Table 1 Test objects

	Motion	Camera Angle	Camera Move
1	Walk	Side View	Follow Camera
2	Walk	Perspective View	Follow Camera
3	Walk	Side View	Fixed Camera
4	Walk	Perspective View	Fixed Camera
5	Jump	Side View	Fixed Camera
6	Jump	Perspective View	Fixed Camera

4. Results

The following sections show the result of the experiment, with scale values of each combination calculated according to Thurston's method and a visualized graph of each. The results are shown in following order ① Overall result of each combination ② The result of different character motions ③ The result of different camera movements ④ The result of different camera angles ⑤ The result of each flattering method

4.1. Overall average of each combination

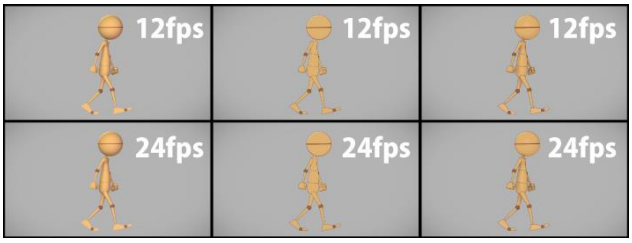


Figure 8 Combinations of Renderings and Frame rates

The following result shows the effect of the audience's sense of depth and preference between six types of combination which includes 24fps 3D rendering, 24fps 2D rendering, 24fps 2.5D rendering, 12fps 3D rendering, 12fps 2D rendering, 12 fps 2.5D rendering (Figure 8).

ⅰ. Overall result of Japanese subjects

Table 2 Scale Value

Flatness	Depth	Preference
24fps 3D	1.294	0.196
24fps 2D	-0.789	0.454
24fps 2.5D	0.082	0.697
12fps 3D	0.752	-0.998
12fps 2D	-1.762	-0.150
12fps 2.5D	-0.540	-0.116

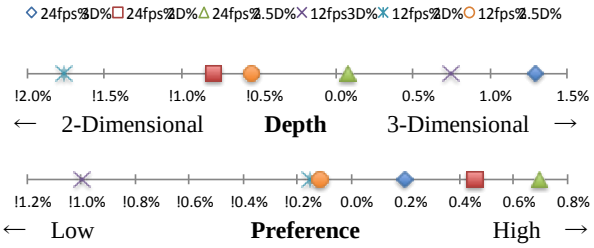


Figure 9 Visualized scale values

Japanese subjects felt depth in the following order; 24fps 3D rendering, 12fps 3D rendering, 24fps 2.5D rendering, 12fps 2.5D rendering, 24fps 2D rendering、12fps 2D rendering. Also, they preferred the combinations in the following order; 24fps 2.5D Rendering, 24fps2D Rendering, 24fps3DRendering, 12fps2.5D Rendering, 24fps2D Rendering, 12fps3D Rendering.

The preference of 12fps 3D rendering got a significantly low preference. There were Japanese subjects who noted that they felt uncomfortable looking at the combination of 12fps and 3D rendering after the experiment.

ⅱ. Overall results of foreign subjects

Table 3 Scale Value

Combination	Depth	Preference
24fps 3D	1.889	0.229
24fps 2D	-0.968	0.153
24fps 2.5D	0.371	0.760
12fps 3D	1.038	-0.522
12fps 2D	-1.493	-0.812
12fps 2.5D	-0.432	-0.228

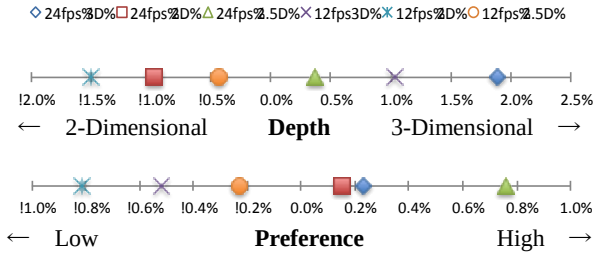


Figure 10 Visualized scale values

In the non-Japanese subjects' case, they showed almost the same tendency of the feeling of depth as the Japanese subjects. However, the preference rank of the combinations was different from the Japanese group. They preferred the combinations in decreasing order; 24fps 2.5D rendering, 24fps 3D rendering, 24fps 2D rendering, 12fps 2.5D rendering, 12fps 3D rendering, 12fps 2D rendering. These subjects preferred 3D rendering over 2D rendering as opposed to the Japanese subjects.

4.2 The results of different character motions

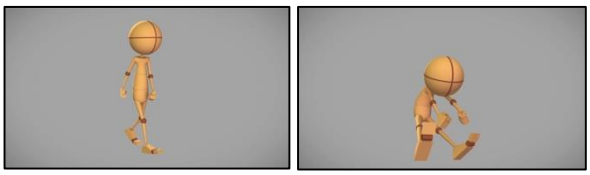


Figure 11 Walk (left) and jump (right)

The following results show the effect on the audience's sense of depth and preference in six types of combinations of different character motions. We tested "walk" and "jump" to see if the character motions influenced the results.

ⅰ.The results of "walk" in Japanese subjects

Table 4 Scale Value

Combination	Depth	Preference
24fps 3D	1.266	0.235
24fps 2D	-0.870	0.486
24fps 2.5D	0.208	0.745
12fps 3D	0.744	-1.108
12fps 2D	-1.944	-0.200
12fps 2.5D	-0.483	-0.110

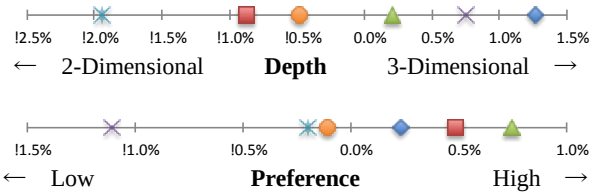


Figure 12 Visualized scale values

ⅱ. The result of "Jump" in Japanese subjects

Table 5 Scale Value

Combination	Depth	Preference
24fps 3D	1.351	0.119
24fps 2D	-0.628	0.391
24fps 2.5D	-0.172	0.601
12fps 3D	0.768	-0.778
12fps 2D	-1.398	-0.049
12fps 2.5D	-0.653	-0.130

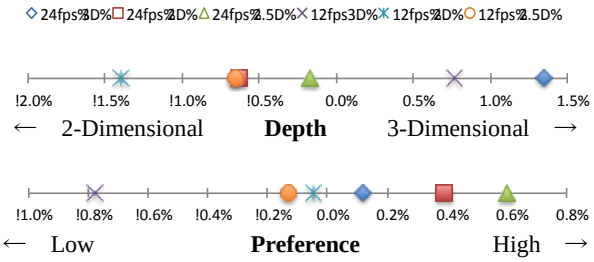


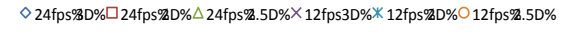
Figure 13 Visualized scale values

As a result, both walk and jump showed almost the same tendency as an overall result at 4.1. The jump showed slightly different results. That is, 24fps 2D rendering and 12fps 2.5D rendering slightly interchange their ranking on the scale of depth, and 12fps 2.5D rendering and 12fps 2D rendering were swapped on the scale of preference.

ⅲ. The result of "Walk" in non-Japanese subjects

Table 6 Scale Value

Combination	Depth	Preference
24fps 3D	1.729	0.195
24fps 2D	-1.043	0.085
24fps 2.5D	0.393	0.782
12fps 3D	1.163	-0.662
12fps 2D	-1.506	-0.793
12fps 2.5D	-0.011	-0.244



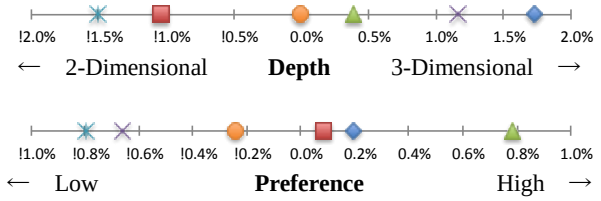


Figure 14 Visualized scale values

ⅳ. The result of "Jump" in non-Japanese subjects

Table 7 Scale Value

Combination	Depth	Preference
24fps 3D	2.209	0.298
24fps 2D	-0.817	0.291
24fps 2.5D	0.326	0.717
12fps 3D	0.787	-0.241
12fps 2D	-1.467	-0.851
12fps 2.5D	-1.274	-0.196

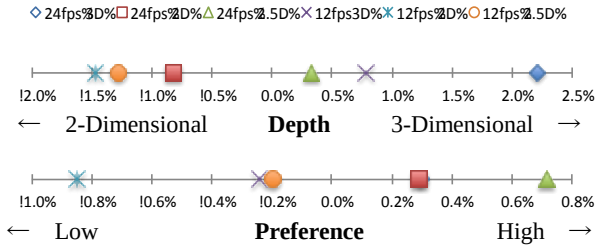


Figure 15 Visualized scale values

Both results were roughly the same as the results shown in 4.1. Only the scale of depth was swapped between 24fps 2D rendering and 12fps 2.5D rendering.

ⅴ Discussion

Overall, the difference of the character movement doesn't give a significant effect on the depth and preference and the results were roughly equal to those presented in 4.1. However, there were several subjects who said that they had a hard time evaluating the jump movement, and had irregular results in 2.5D rendering and 2D rendering. There was a possibility that fast movement may make it difficult to distinguish the difference of the shadow of 2D rendering and 2.5D rendering.

4.3 The result of different camera movements

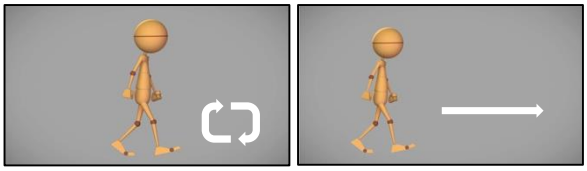


Figure 16 Follow (right) and fixed (right) cameras

To see the effect of the different camera movement, we tested the same movement with both follow camera and fixed camera. (Table 12) Then we calculated average scale value of depth and preference of each combination.

ⅰ. The results with "follow camera" in Japanese subjects

Table 8 Scale Value

Combination	Depth	Preference
24fps 3D	1.285	0.215
24fps 2D	-0.903	0.262
24fps 2.5D	0.180	0.708
12fps 3D	0.904	-0.842
12fps 2D	-1.704	-0.217
12fps 2.5D	-0.568	-0.148

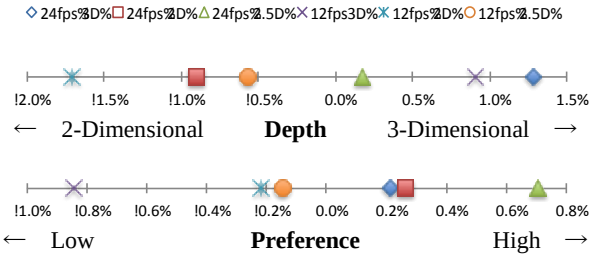


Figure 17 Visualized scale values

ⅱ. The results with "fixed camera" in Japanese subjects

Table 9 Scale Value

Combination	Depth	Preference
24fps 3D	1.246	0.254
24fps 2D	-0.836	0.709
24fps 2.5D	0.237	0.783
12fps 3D	0.583	-1.374
12fps 2D	-2.183	-0.183
12fps 2.5D	-0.399	-0.071

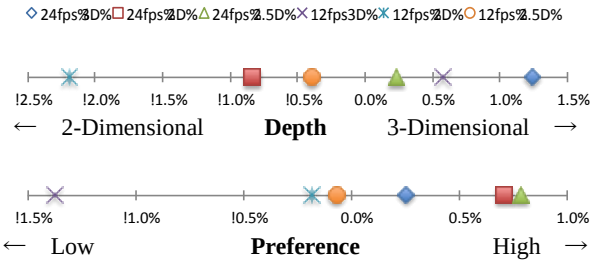


Figure 18 Visualized scale values

Both results of follow camera and fixed camera showed same result of ranking as the overall average. Compare to follow camera, fixed camera had a result of relatively higher preference of 24fps 2D rendering.

ⅲ. The results with "follow camera" in non-Japanese subjects

Table 10 Scale Value

Combination	Depth	Preference
24fps 3D	1.584	0.060
24fps 2D	-1.168	-0.016
24fps 2.5D	0.142	0.849
12fps 3D	1.166	-0.442
12fps 2D	-1.628	-0.851
12fps 2.5D	0.098	-0.183

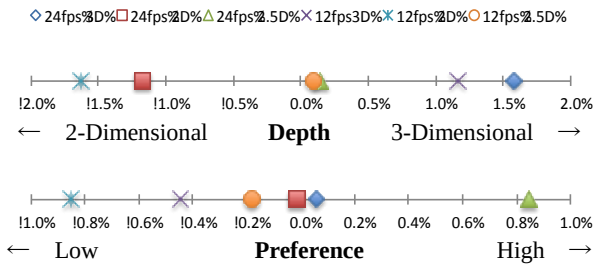


Figure 19 Visualized scale values

ⅳ. The results with "fixed camera" in non-Japanese subjects

Table 11 Scale Value

Combination	Depth	Preference
24fps 3D	1.873	0.330
24fps 2D	-0.918	0.185
24fps 2.5D	0.643	0.715
12fps 3D	1.161	-0.882
12fps 2D	-1.384	-0.736
12fps 2.5D	-0.119	-0.305

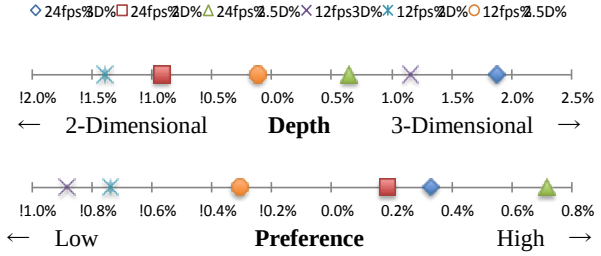


Figure 20 Visualized scale values

Both results showed almost same ranking as the results in 4.1. 12fps 3D rendering and 12fps 2D rendering were swapped in the preference scale for the follow camera.

ⅴ Discussion

Both of the results obtained in follow camera and fixed camera showed basically the same ranking as the overall result at 4.1. Therefore, we concluded that the different camera movement doesn't affect the overall result.

There was a tendency of the fixed camera being preferred for the 2D rendering in both Japanese and non-Japanese subjects. Fixed camera makes the distance to the movement bigger than the follow camera, and simple shading could be preferable in that case because of its visibility.

4.4 Effect by camera angle

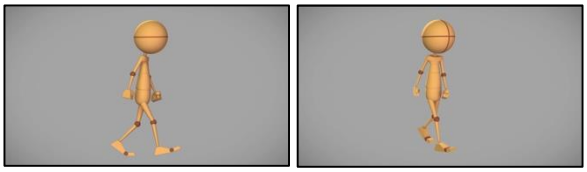


Figure 21 Side view (left) and right view (right)

To see the effect by the camera angle, we calculated average scale value of depth and preference of each combination of renderings on two different camera angles; side view and perspective view. (Table 12)

ⅰ. The result of "Side view" by Japanese subjects

Table 12 Scale Value

Combination	Depth	Preference
24fps 3D	1.245	0.221
24fps 2D	-0.680	0.386
24fps 2.5D	0.051	0.863
12fps 3D	0.782	-0.869
12fps 2D	-1.657	-0.133
12fps 2.5D	-0.409	-0.070

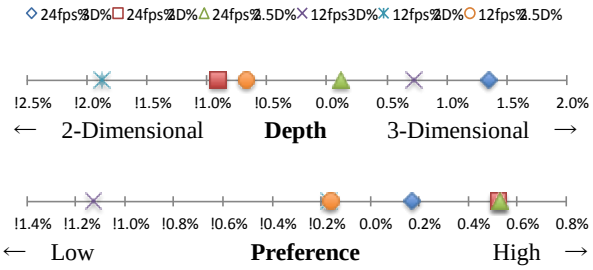


Figure 22 Visualized scale values

ⅱ.The result of "Perspective view" in Japanese subjects

Table 13 Scale Value

Combination	Depth	Preference
24fps 3D	1.343	0.172
24fps 2D	-0.898	0.523
24fps 2.5D	0.112	0.531
12fps 3D	0.721	-1.127
12fps 2D	-1.867	-0.167
12fps 2.5D	-0.671	-0.163

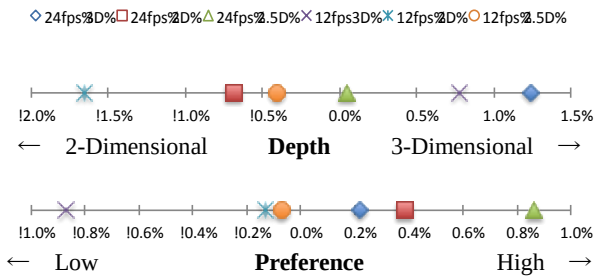


Figure 23 Visualized scale values

Both result of side view and perspective view had the same ranking result in both the depth scale and the preference scale. They also had the same ranking results in the overall average.

The depth scale had no difference between side view and perspective view. The distance of the value of 2D rendering and 2.5D rendering in the preference scale was close in side view but got distant in perspective view.

ⅲ. The result of "Side view" in non-Japanese subjects

Table 14 Scale Value

Combination	Depth	Preference
24fps 3D	1.848	0.164
24fps 2D	-1.023	-0.124
24fps 2.5D	0.692	0.856
12fps 3D	1.076	-0.668
12fps 2D	-1.583	-0.868
12fps 2.5D	-0.670	-0.238

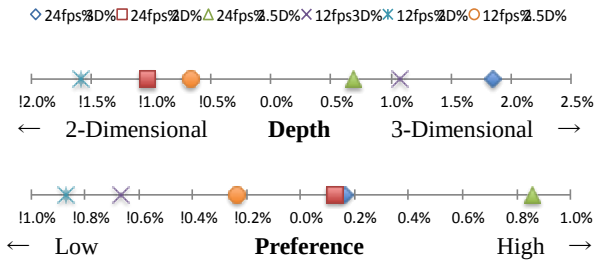


Figure 24 Visualized scale values

ⅳ. The result of "Perspective view" in non-Japanese subjects

Table 15 Scale Value

Combination	Depth	Preference
24fps 3D	1.930	0.295
24fps 2D	-0.912	0.182
24fps 2.5D	0.049	0.665
12fps 3D	1.000	-0.375
12fps 2D	-1.402	-0.757
12fps 2.5D	-0.193	-0.218

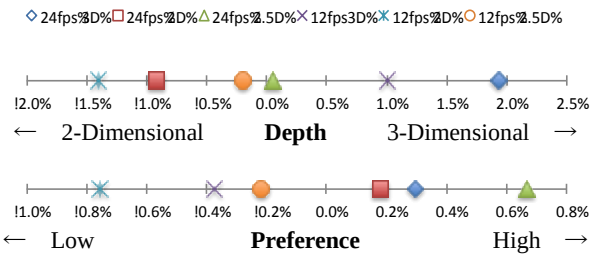


Figure 25 Visualized scale values

Both of the results of side view and perspective view showed almost same ranking as the overall result at 4.1. Furthermore, 12fps 3D rendering and 24 fps 3D rendering got a relatively higher preference in perspective view than the one in side view.

ⅴ Discussion

The results were same as the overall result in 4.1. Additionally, there was almost no effect between the different camera angles. Both groups of subjects gave more distinct answers in perspective view than in side view.

4.5 The results of each method

Lastly, the result of combination had certain tendency and we calculated the result of each items of the combinations.

ⅰ. The result of each method by Japanese subjects

Table 16 Scale Value

Combination	Depth	Preference
3D Rendering	1.023	-0.401
2D Rendering	-1.276	0.152
2.5D Rendering	0.229	0.291
12fps	0.517	-0.421
24fps	-1.195	0.449

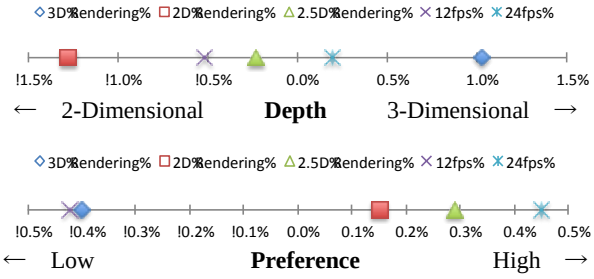


Figure 26 Visualized scale values

ⅱ. The result of each method by non-Japanese subjects

Table 17 Scale Value

Combination	Depth	Preference
3D Rendering	1.463	-0.146
2D Rendering	-1.230	-0.330
2.5D Rendering	0.031	0.266
12fps	0.296	-0.521
24fps	0.431	0.381

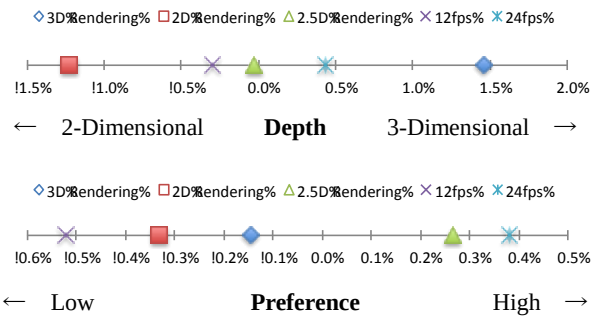


Figure 27 Visualized scale values

If we focus specifically on each item of the combinations, we could see the general result of this experiment. Concerning the animation styles, 24fps is preferred over 12fps. Likewise, the test subjects preferred 2.5D rendering over any other. 2D rendering and 3D rendering show a cultural difference in preferences; Japanese subjects preferred 2D renderings over 3D rendering and non-Japanese subjects favored 3D rendering over 2D rendering. Concerning the effect to the sense of depth, shading has a stronger flattening effect than frame rate, and 24 fps gives extra depth compared to 12 fps.

5. Conclusion

This research evaluated the 2D look of 3DCG animation by testing multiple 3DCG styles made with a series of rendering and movement techniques.

The results of the experiment show that regarding the frame rate there is a general preference of 24fps over 12fps, meanwhile in the rendering techniques, the 2.5D had a higher favorability rating.

Furthermore, there was a tendency of Japanese subjects of preferring the 2D look rather than 3D. On the other hand, non-Japanese subjects preferred 3D more than 2D. Also, in the cases of the change in movements of the character, and the changes of the movements of the camera, as follow camera and fixated camera, there was no significant change in the observed results. In addition, the camera angle changes did not present any major impact. As future research, the influence of the character's type of movement and speed should be studied with more attention. Also, while in this research only one character model was used, different character designs could be tested to observe their effects.

Through the method of evaluation experiments, it was found that the 2D look technique used has a high of preference, and not necessarily has to be 2D for the Japanese viewers to be liked. Rather, a representation between 2D and 3D should be aimed for in the future.

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