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Body-Part Motion Synthesis System and Its Evaluation for Discovery Learning of Dance

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SUMMARY This paper reports an assessment of the feasibility and the practicality of a creation support system for contemporary dance e-learning. We developed a Body-part Motion Synthesis System (BMSS) that allows users to create choreographies by synthesizing body-part motions to increase the effect of learning contemporary dance choreography. Short created choreographies can be displayed as animation using 3DCG characters. The system targets students who are studying contemporary dance and is designed to promote the discovery learning of contemporary dance. We conducted a series of evaluation experiments for creating contemporary dance choreographies to verify the learning effectiveness of our system as a support system for discovery learning. As a consequence of experiments with 26 students who created contemporary dances, we verified that BMSS is a helpful creation training tool to discover new choreographic methods, new dance movements, and new awareness of their bodies.

key words: *motion, dance, choreography, discovery learning, synthesis*

1. Introduction

Our goal is to develop useful tools for the education, creation, and appreciation for dance using 3D motion data captured from performances by professional dancers. We have been developing interactive simulation systems for dance using dance-motion archives. Automatic composition for ballet and contemporary dance using the motion clips of the whole body have already been developed in our project [1], [2]. Our research approach focuses on creating and composing choreographies for dance.

This paper assesses the feasibility and practicality of a creation support system for contemporary dance e-learning. We developed a Body-part Motion Synthesis System (BMSS) that allows users to create choreographies by synthesizing body-part motions to increase the effect of learning contemporary dance choreography. The system targets students who are studying contemporary dance and is designed to promote the discovery learning of contemporary dance. Discovery learning is a concept that argues that learning is more effective when learners discover something for themselves rather than being spoon-fed by a teacher.

We improved BMSS and conducted a series of experiments with 26 students who were majoring in dance at university to verify the effectiveness of our software as a discovery learning tool. The students created short dance pieces using three different versions of BMSS and explained their creative process. This paper describes the concept of BMSS, its improvement, and the results of our experiments.

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2. Related Works

There are some works using dance notations and application software [3], [4]. By using them, one can simulate already captured or strictly described dance animation. However, it is difficult to compose original dances by describing the movement of each body part. Our approach easily creates new dance motions by selecting the already provided motion clips.

There have been human animation systems using motion clips with a GUI [5] and a tangible interface [6]. However, they are difficult to use for choreographic composition because most preview animations after editing sequences. Though motion control systems with touch inputs have recently been developed as real-time systems [7], it is difficult to compose creative and effective choreographies because their motions are limited.

Other studies addressed motion synthesis using music, such as synthesizing dance motions based on emotions and the contents of a piece of music [8] or the automatic synthesis of dance motions based on musical features [9]. These studies generated natural motions by connecting or synthesizing multiple motions automatically based on rules. However, we support creation that targets contemporary dance without rules such as style or traditional manners and generate unexpected motions that are helpful for dances rather than natural motions.

Our proposed system allows users to select each motion clip of specific body parts and synthesize them in real time. Therefore, different varieties of dance movements can be created based on the selected timing and the combination of body-part motions. Our approach does not create a complete connection and the physical reality of dance, instead it creates unexpected motions and conceptual sequences. We generate rough but unique dance motions so that users can refine and create their own choreographies.

3. Concept

3.1 Analytic-Synthetic Choreography

The basic concept of our approach segments dance movements into elemental motions and synthesizes these segments to create novel movements. We call this method analytic-synthetic choreography.

From the standpoint of dance education, university students tend to be taught more expressive than structural methods. It is easier for students to make dances based on their own feelings or some kind of stories than from original movements or unique concepts. Especially in Japan, structural methods are seldom taught in choreographic learning courses. However, structural methods are also required to achieve creative works in recent contemporary dance trends. This is the reason we employed analytic-synthetic choreography as a structural method.

We target choreographers and dancers who are specializing in contemporary dance. Users can generate short choreographies with BMSS and use them as references for dance creation, learning, and training. The short created choreographies can be displayed as animation using 3DCG characters to provide an opportunity to develop new ideas for choreography creation. Occasionally, impossible and unnatural motions are created because the application does not support the collision detection of body parts or contact with the floor, but users do not have to completely reproduce real movements in 3DCG characters. Users can incorporate various arrangements and ideas in their created motions without using our application by adopting such techniques as horizontal inversion and devising motions of the hands and feet to simplify balance.

3.2 Discovery Learning

BMSS is designed to promote the discovery learning of contemporary dance. Regarding the process of learning, it refers to the unique individual experiences by which concepts evolve in the mind of learners rather than being transmitted ready-made [10].

Discovery learning is quite controversial because its educational effects depend on the fields of learning, the learning purpose, and the personality of the learners. The method enhances motivation, interest, satisfaction, and the development of both intellectual capacities and problem-solving skills [11].

Contemporary dance can be described as an artistic endeavor without any shared or standard choreographic vocabulary. Since no traditional or canonical manner of contemporary dance choreography exists and students are required to discover their own paths, discovery learning is an absolutely appropriate method with which to study it.

We identified three requirements for BMSS as an e-learning tool for contemporary dance choreography that promotes discovery learning. First, the system must encourage students to find novel contemporary dance movements for creating original dances. Second, the system must promote in students the understanding of contemporary dance movements for themselves. Third, the system must provide students with the opportunity to learn a novel choreographic method, analytic-synthetic choreography, as a structural method. We tested these three requirements with evaluation experiments.

4. BMSS

4.1 System Overview

Figure 1 shows our concept of body-part motion synthesis. Short choreographies about five seconds long are created by synthesizing body-part motion clips. After selecting a base motion, body-part motions and their synthesis timings are interactively or automatically selected.

BMSS has been improved from BMSS1 to BMSS3. BMSS1 was developed in 2010 on a laptop PC. Each motion clip is adapted to each key on a keyboard and previewed with a stick figure [12]. BMSS2, the second version, runs on a tablet with touch inputs and was developed in 2012 [13]. Though the number of motion clips is identical to BMSS1, the number of body-part categories was increased and motion blends are also acceptable in it. In addition, a humanoid model was implemented to preview each motion. Our third version, BMSS3, also runs on a tablet and supports automatic synthesis. Since the motion clips and their synthesis timing are automatically selected by the system, the number of motion clips tripled in BMSS3 [14].

Figure 2 illustrates an example of a short choreographic motion with a stick figure created by using BMSS1. Figure 3 illustrates an example of a short choreographic motion with a humanoid figure created by motion blends of BMSS2.

Figure 4 shows the GUI of BMSS3. The created choreographies are previewed in 3DCG space. Favorite choreographies can be saved, and some are composed and played as a dance sequence. Users can control the camera view or

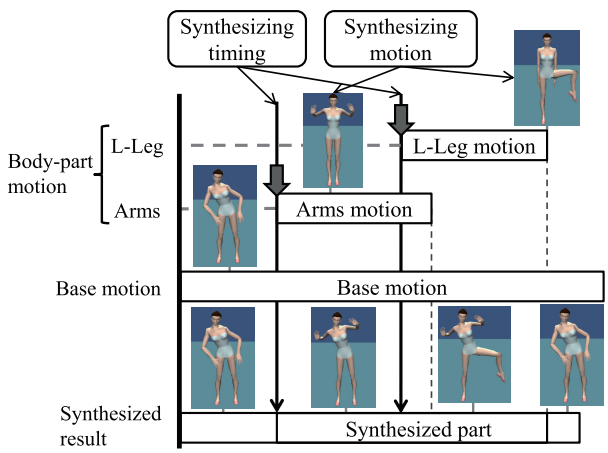


Fig. 1 Concept of body-part motion synthesis.

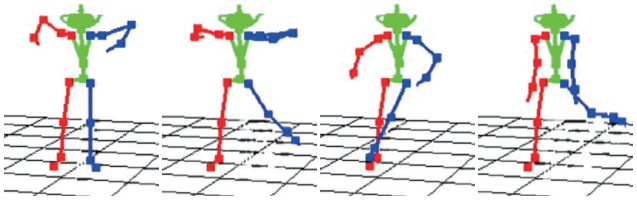


Fig. 2 Example of created motion by BMSS1.

Fig. 3 Example of created motion by BMSS2.

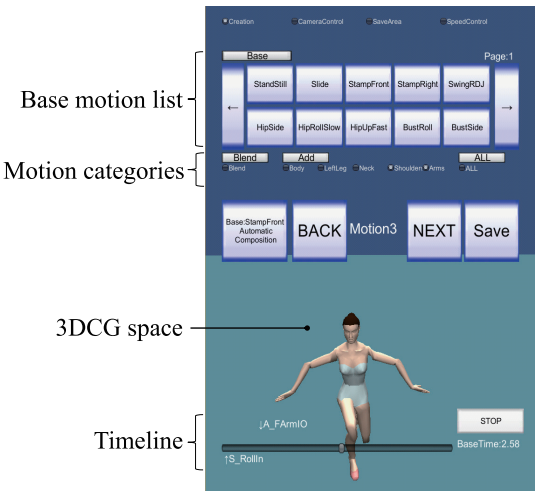


Fig. 4 GUI of BMSS3.

the playback speed of the animation.

4.2 Motion Clips and Body-Part Categories

We captured the basic motions of contemporary dance performed by a professional dancer. To capture the motion data, we used an optical motion capture system. We have already archived 128 kinds of basic motion clips of contemporary dance. Each clip consists of simple and uncombined movements.

Each motion's potential for synthesis is analyzed and separated into three main categories: Base, Blend, and Body-part. The Body-part category includes the subcategories of body parts, such as Body, Neck, L-Leg (Left-Leg), Shoulders, and Arms. The number of motion clips included in each category of each BMSS is shown in Table 1. Figure 5 illustrates the human structure and the groups of body joints for BMSS.

The Base category's motion clips are the whole-body

Table 1 Categories and the number of motions.

category name		BMSS1		BMSS2		BMSS3	
Base			15		10		40
Blend			0		6		6
Body-part	Body	10	25	5	24	10	72
	Neck			3		10	
	L-Leg	5		5		13	
	Shoulders	10		3		7	
	Arms			8		32	
total			40		40		118

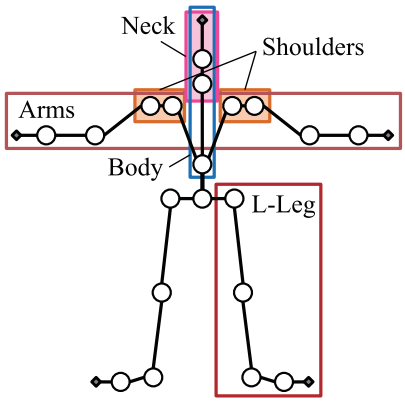


Fig. 5 Human structure and the groups of body joints.

movements that form the basis of the created choreographies. Motions that involve the whole body, like standing or one-leg balance, are assigned to this group. The motion clips of the Blend category are the whole-body movements that can be blended with the base motion clips. This group mainly consists of hip movements like jumping and twisting, which are made more effective by blending them with other motions. The motion clips of the Body-part category are the body-part movements that replace the body-part movements of the base motion clips. Only left-leg motions are prepared as replaceable leg motions, since unnatural motions such as floating in the air can be generated when both leg motions are replaced. Therefore this system does not allow users to synthesize right-leg motions. The created motions can be danced as horizontally inverted motions without the system because most dancers can perform such motions during a performance.

4.3 Methods of Motion Synthesis

There are two types of synthesis methods, Replace and Blend. In BMSS1, only the Replace method is used, while in BMSS2 and BMSS3, both Blend and Replace methods are used.

In the Replace method, the motion clips of the body parts can replace the corresponding part of the base motion as shown in Fig. 6(a). Users can add more body-part motions in the synthesized motion. This method is intuitive and users can easily imagine the result.

In the Blend method, the selected motion clip of the whole body is blended to a base motion as shown in

Fig. 6(b). In this mode, for each joint in every frame, the vector of the blend motion is added to that of the base motion. For example, when rolling hip and bending knee motions are selected, a bending knee motion with a rolling hip can be created. This method is effective against unnatural motions by just replacing body-part motions.

4.4 Automatic Synthesis

It took a long time to create complex choreographies with BMSS1 or BMSS2 because the synthesizing motions and their timings were determined by the users. In addition, since the corresponding buttons to each body-part motion had to be displayed to fit within the screen or keyboard, the number of motions was limited. To resolve these problems, BMSS3 supports the automatic synthesis of choreographies to reduce the time needed to create them. Based on the motion categories selected by the users, body-part motions, which are synthesized to the base motion and their synthesis timings, are randomly selected.

Figure 7 illustrates how to select the motion clips. First, the number of them that are synthesized to the base motion clip is randomly determined based on the upper limit of the categories selected by the users. Next, the motion categories are selected from the Blend or Body-part categories. Then

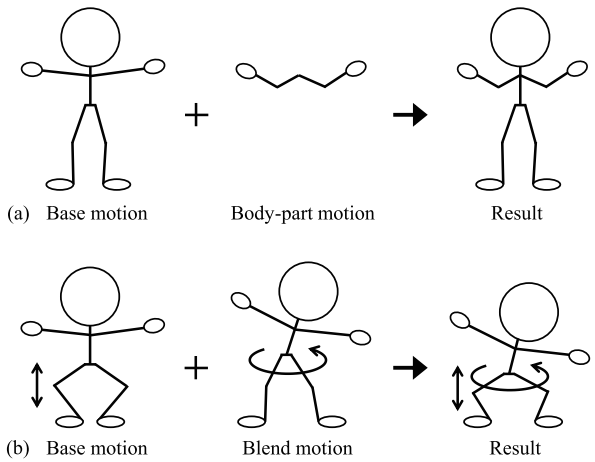


Fig. 6 Two methods of motion synthesis.
(a) Motion synthesis by replacing a body-part clip.
(b) Motion synthesis by blending two whole-body clips.

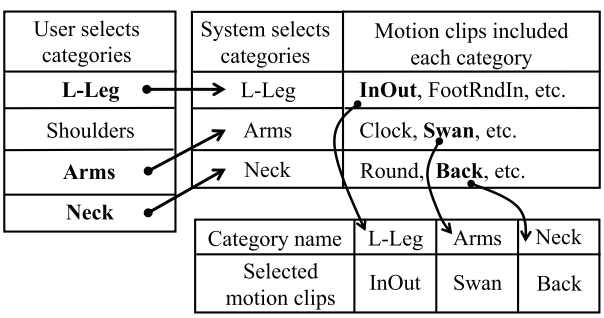


Fig. 7 Procedure of selecting motion clips.

one motion clip is selected from each category.

This feature allows many variations of choreographies to be created each time. In addition, it can create variegated choreographies by increasing the number of motion clips and adjusting the timing of the synthesis.

5. Experiments

5.1 Hypotheses

We conducted a series of experiments with 26 students to verify the following four hypotheses:

1. BMSS is useful for students to create their own original dance.
2. BMSS is useful for students to understand contemporary dance movements.
3. BMSS is helpful for students to learn a new choreographic method of contemporary dance by themselves.
4. To create original dances, BMSS2 is more useful than BMSS1, and BMSS3 is more useful than BMSS2.

The first three hypotheses correspond to the three requirements for BMSS as an e-learning tool that promotes discovery learning described in Sect. 3.2. The first hypothesis also addresses the usefulness of the analytic-synthetic choreography method, which BMSS uses. The second hypothesis also concerns the usefulness of the 3DCG animation displayed by BMSS on the screen. The third hypothesis also suggests that the analytic-synthetic choreography is worthful per se for discovery learning. The fourth hypothesis addresses improvement of the software.

5.2 Participants

We conducted three experiments and changed the participants in each one. Eight students used BMSS1 in the first experiment in 2010, 10 used BMSS2 in the second experiment in 2012, and eight used BMSS3 in the third experiment in 2014.

All 26 students were majoring in dance at the University of Tsukuba in Japan, which has a research field of dance, which is rare in Japan. Half were undergraduates and the other half were graduate students. They consisted of 23 females and three males.

The years of dance experience varied from 3 to 23 with an average of 14.5 years. The number of times the participants had previously created contemporary dance choreography ranged from 0 to 10 with an average of 3.3.

5.3 Method

Our experiments were conducted by one set of four or five participants in a gymnastic studio, and the experiment time per set was 90 minutes.

First, the participants were briefly taught how to operate the software, but its two concepts were not explained to them. The analytic-synthetic choreography and discovery

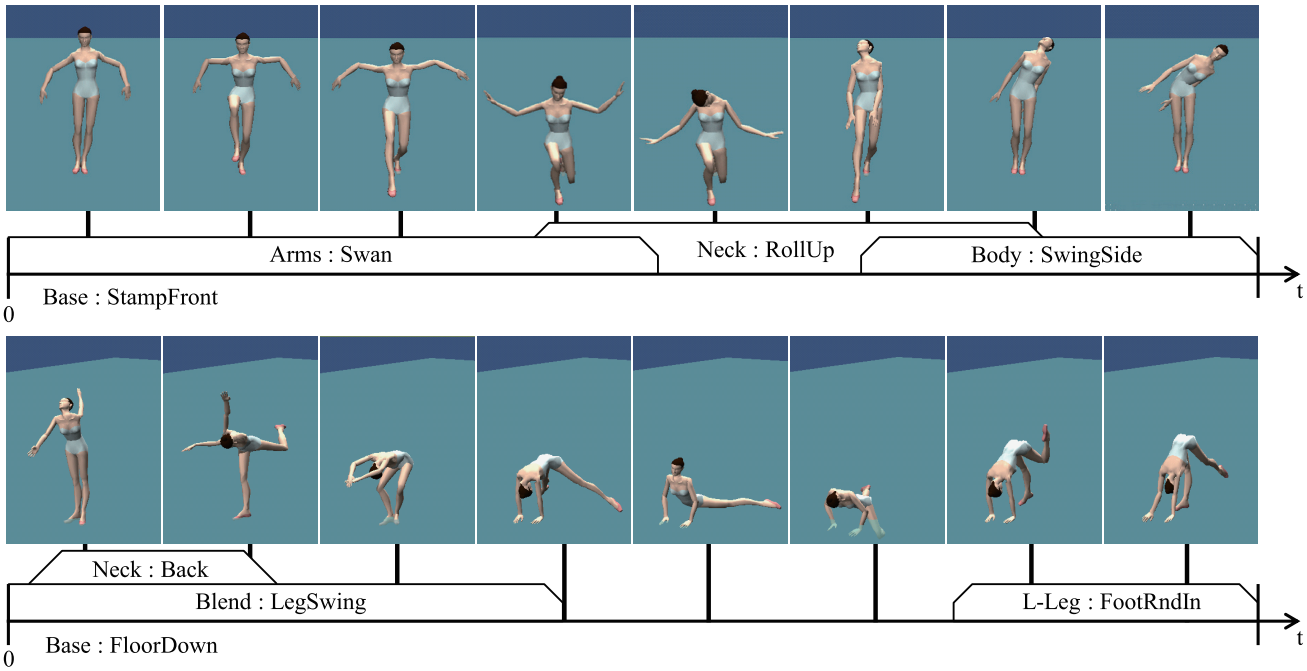


Fig. 8 Examples of created sequence by a student.

learning concepts were intentionally concealed, because we wanted to test how much contemporary dance choreography the students would learn by themselves.

Next they freely tried to make short movements using the software with 3DCG animation by selecting and saving movements that might serve as seeds or hints of their own choreographies.

Then they created their own dance sequences (about 30 to 60 seconds) by connecting and refining the short movements simulated by the software. They were also requested not to copy the movements but to refine them as their original choreographic works. They were allowed to freely add such techniques as iteration, inversion, or speed changes. After rehearsal they performed their dance sequences in front of a video camera. The short 3DCG movements made by the software and incorporated into their sequences were also recorded. At the end of the experiment they filled out questionnaires.

Figure 8 illustrates examples of short choreographic motions created by a student using BMSS3. The base motion of the first one is StampFront and arm motions (Swan) are replaced at the early point, and then a neck motion (RollUp) and a body motion (SwingSide) are replaced to the base motion from the halfway point. In the second one, the base motion is FloorDown, and a whole-body motion (LegSwing) is blended and a neck motion (Back) is replaced to the base motion at the early point, then a left-leg motion (FootRndIn) is replaced at the last phase.

6. Results and Discussion

6.1 Creation of Dance

The duration of the performances by the students, which varied from 13 to 72 seconds, averaged 33.3 seconds.

To test the first hypothesis, the students answered questionnaires about the usefulness of the system for creating contemporary dance. They selected the level of usefulness from four levels, as illustrated in Table 2.

In terms of contemporary dance creation, 23 of 26 students (88%) chose “effective enough” and no one chose “not so effective”. The numerical analysis suggests that the software is useful as an e-learning tool to create contemporary dance.

The students were also requested to explain their above subjective choices. Several typical reasons for “effective enough” are excerpted below. The responses were translated from Japanese. The version of BMSS is shown in brackets.

- “When I create movements only with my body, they tend to be a combination of trite motions, but the software creates fresh movements” (BMSS1).
- “I got inspiration and new ideas from the animation displayed when I combined several movements randomly” (BMSS2).
- “It was easier to think about the transition of body movements using the tablet” (BMSS3).

Judging by the analysis of the responses, the first hypothesis was verified by our experiments.

6.2 Understanding of Movements

To test the second hypothesis, the students also answered questions about the usefulness of the system for understanding dance movements in questionnaires. They selected the level of usefulness from four levels, as illustrated in Table 3.

In terms of understanding movements, eight students (31%) chose “effective enough”, 14 (54%) chose “effective

Table 2 Evaluation about creation of dance.

option	BMSS1	BMSS2	BMSS3	total
effective enough	6	9	8	23
effective if reformed	0	1	0	1
not so effective	0	0	0	0
don't know	2	0	0	2

Table 3 Evaluation about understanding of movements.

option	BMSS1	BMSS2	BMSS3	total
effective enough	2	3	3	8
effective if reformed	6	4	4	14
not so effective	0	0	0	0
don't know	0	3	1	4

if reformed", and no one chose "not so effective". Numerical analysis suggests that the software is basically useful as an e-learning tool for understanding dance movements.

The students also explained their choices. Several typical reasons for "effective enough" are excerpted below:

– "Because you can understand the movements by breaking them down" (BMSS1).
– "It is helpful when I dance by myself because it offers so many motions as dance elements" (BMSS2).
– "If you don't know much about contemporary dance, seeing the movements provides a big hint" (BMSS3).

On the other hand, we identified two typical reasons for "effective if reformed": the reality of dance movements and the software's user interface. Many students using BMSS1 were not satisfied with the representation of the 3DCG animation because of the stick figure. However, after BMSS1, we implemented a humanoid model and complaints decreased. Some students commented on the reality of dance movements:

– "The connection of the motions is not very clear" (BMSS2).
– "The system's reality was not convincing and a novice might have difficulty understanding the movements properly" (BMSS3).

In BMSS2 and BMSS3, the synthesized motions became more complex and difficult to recognize, since the number of synthesizing body-parts increased and motion blend was supported.

Some students commented on the motion clips and the BMSS interface:

– "The material of the motions is similar. Motion clips should be added based on difficulties or genres" (BMSS2).
– "Ideally, the horizontal inversion of motions and simpler editing of the saved motions are recommended" (BMSS3).

Judging by the numerical analysis of the responses, the second hypothesis was basically verified, but improvements to the user interface and a clear display of the motions were identified.

6.3 Discovery Learning

The student ratings for the creation of dance and understanding movements already suggest that the software worked as a discovery learning tool. However, to satisfactorily test the third hypothesis, we scrutinized student responses to the following open question: "What did you learn about creating contemporary dance choreography through this experiment?"

All 26 (100%) students described something they learned through the experiments. Twenty one (81%) of 26 students believed that they learned a new choreographic method of contemporary dance, although their Japanese expressions varied. Several typical responses are excerpted below:

– "I saw that contemporary dance movements consist of various body-part motions" (BMSS1).
– "It was very interesting, because I could choreograph by a method I had never tried before" (BMSS2).
– "I realized that the combination and permutation of movements gave me an infinite number of original choreographies" (BMSS3).

These responses show that the students learned the concept of analytic-synthetic choreography, even though it was not explained explicitly during the experiments. Although five students did not expressly describe a new choreographic method, they also unconsciously achieved creation using the analytic-synthetic method.

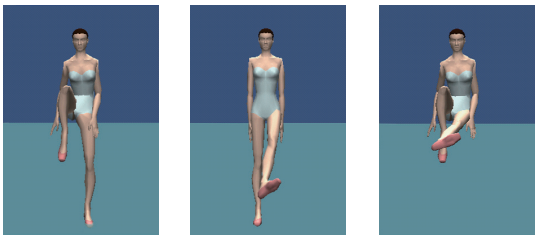
Another open question was posed in the questionnaire: "If the software created some unexpected movements, please write about them with concrete descriptions." Twenty (77%) students wrote about the unexpected movements. In other words, almost 80% discovered new contemporary dance movements using the software by themselves.

Judging by the numerical analysis of the responses, BMSS worked as a discovery learning tool of contemporary dance choreography. Our third hypothesis was verified.

6.4 Difference among Versions

To test the fourth hypothesis, the numbers of the three groups were compared. The "effective enough" ratio for dance creation increased from BMSS1 (75%) to BMSS2 (90%) and BMSS3 (100%), although the difference between BMSS2 and BMSS3 was less clear. The "effective enough" ratio for understanding movements slightly increased from BMSS1 (25%) to BMSS2 (30%) and BMSS3 (38%).

BMSS1 and BMSS2 had the same number of motion clips as the elemental dance movements, but there is a difference of usefulness between them for dance creation. The difference was probably caused by the synthesis method and the number of synthesized body-parts. Since motion blend was supported in BMSS2, the possibility of creating unexpected motions might be increased. From the recorded videos and the recreated CG animation of BMSS2, many



(a) (b) (c)

Fig. 9 Example of unnatural motion created by BMSS3.

complex motion syntheses were found that are impossible to create by BMSS1.

Another difference came from the improvement of the usability of the software. BMSS1 runs on a notebook PC with keyboard operation, and BMSS2 runs on a tablet with touch operation. The tablet has an advantage of choreographic practice, because users can simulate movements composed by the software while holding and looking at the tablet. Actually, most students who used BMSS2 and BMSS3 rehearsed their original dance sequences by holding the tablet during the experiments. In addition, using the software is much easier by the touch operation than the keyboard operation.

Both BMSS2 and BMSS3 were run on a tablet, but there is a difference of usefulness between them for understanding movements. The difference was probably caused by the improvement of the algorithm. As mentioned above, automatic motion synthesis was incorporated in BMSS3 and the number of motion clips was tripled from BMSS2 (40 clips) to BMSS3 (118 clips). One reason might be that the automatic synthesis reduces the time to create choreographies. Since users do not have to consider motions for synthesis or the synthesis timing by automatic motion synthesis, they can create choreographies more easily with our system.

The fourth hypothesis was verified by our experiments. We also realized that our software must be improved to add constraints for creating performable motions because the possibility of generating unnatural motions was increased. Figure 9 shows an example of unnatural motion created by BMSS3. By replacing a left-leg swing motion (Fig. 9(b)) to a right-foot stomping motion (Fig. 9(a)), the body is unnaturally floating in the air as shown in Fig. 9(c).

7. Conclusion

In this study, we developed a system that creates short choreographies by synthesizing many body-part motions to support choreography creation. We conducted evaluation experiments for creating contemporary dance choreographies to verify the learning effect of BMSS as a support system for discovery learning. As a consequence of experiments with 26 students who created contemporary dances, we verified that BMSS is a helpful creation training tool to discover new choreographic methods, new dance movements, and new awareness of their bodies. In addition, we compared evaluations of the three systems and verified that the utility of supporting dance creation was improved.

In future work, the difficulty levels of the created choreographies will be varied from novice to expert to reflect user skills. Our application will be improved to generate choreographies by removing physically unnatural motions with some appropriate conditions. However, some created motions are unnatural but interesting by choreographers. We will analyze what is helpful and adapt some useful constraints by collaborating with choreographers.

Acknowledgments

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