Identification of Motion Features Affecting Perceived Rhythmic Sense of Virtual Characters through Comparison of Latin American and Japanese Dances

(南米人と日本人の踊りの比較による仮想キャラクタへのリズム感知覚に影響を及ぼす動作特徴の同定)

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Abstract Physical motion features that cause a difference in the perceived rhythmic sense of a dancer were identified. We compared the rhythmical movements of Latin American and Japanese people to find such features. A 2-D motion capture system was used to measure rhythmical movement, and two motion features were identified. The first was the phase shift of the rotational angles between the hips and chest, and the second was the phase shift between the hips' rotational angle and horizontal position. A psychophysical study demonstrated whether these features affected the perceived rhythmic sense of a dancer. The results showed that both motion features significantly affected perceived sense, and one of them also affected how a viewer guessed the home country or area of a dancer. Consequently, the rhythmic sense of a virtual character can be controlled easily by adding and removing features to and from the character's synthesized motion.

Key words: dance motion, virtual character animation, rhythmic sense

1. Introduction and Motivation

A dance motion reflects the profile of a dancer such as the rhythmic sense, home country, personality, biological features (i.e., gender and age), dancing skills, and so on. In particular, the rhythmic sense of a dancer has a great effect on the dance motion as people can perceive it just by observing the motion. In this paper, we try to identify physical motion features that affect the perceived rhythmic sense of a dancer. Once the motion features are identified, the rhythmic sense of a virtual character can be controlled just by removing/adding the features from/to its synthesized motion. This research particularly deals with rhythmical movement because it is one of the most primitive dances and does not have any special choreography.

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It is generally said in Japan that Japanese do not have as a good rhythmic sense as people from other countries. On the other hand, it is also said that Latin American people are very good dancers and their movements very rhythmical. We believe that physical motion features that cause the differences between the dance motions of Latin American and Japanese people are closely related to the perceived rhythmic sense of a dancer. Therefore, at first, we compare the rhythmical movements of Latin American and Japanese people to find the motion features. Then we carry out a psychophysical study to confirm whether the identified motion features affect the perceived rhythmic sense of a dancer. In the study, participants evaluate 3-D human figure animations of rhythmical movement synthesized with combinations of the motion features.

3-D motion capture technology has been widely applied to produce highly realistic human figure animations. Several research works have aimed at editing captured motion while preserving the natural quality of the original motion to overcome the spatial constraints of motion capture studios[1]. It has been pointed out that motion editing or control can be hierarchically prescribed from script-based specifications at the highest level of control to direct adjustment of each joint position and angle at the lowest[2]. The higher level of control can reduce the user's load, in which the captured motion data can be edited only by changing the motion impression parameters such as emotion[2], gender[3], age[4] and so on. The home country/area of a human figure also affects the impression of the animation, but it has not been well investigated. Once it becomes one of the controllable motion impression parameters, captured motion data can be edited more flexibly. As the first attempt to investigate the home country/area of a human figure motion, this paper focuses on dance because we believe that it reflects the home country/area of a person more than other types of motions. Furthermore, once Latin American and Japanese dance animations are synthesized, they can be used as instructional materials for dance education in Japanese dance schools, by which the students can efficiently learn the way of dancing to have better rhythmic senses.

2. Related Work

Computer graphics (CG) researchers consider that a motion can be decomposed into style (e.g., gender, age, and so on) and content (e.g., walking, dancing, and so on). The style of a motion is one of the vital components of character animation[5]. Realistic motions contain natural fluctuations in which motion styles are reflected[6]. Once human motions are decomposed into styles and contents, a novel character animation can be synthesized with an arbitrary combination of them (i.e., a motion with different styles while performing the same task). The synthesized animation still contains the natural fluctuations, and thus appears to be realistic[1,3,7,8]. In the context of our research, style and content are rhythmic sense and rhythmical movement, respectively.

Many researchers in various fields such as CG, biomechanics, psychology, or evolution have analyzed human motions, and found motion features for classifying different motion styles. Human locomotion is the most popular target. Several motion features in human locomotion have been found to classify different profiles of walkers such as gender[3,9], age[4], effort[10], and emotions[2,11]. Other types of motions have also been investigated. Amaya et al.[12] and Pollick et al.[13] extracted motion features for classifying emotions of people from drinking and knocking motions, respectively. Yamamoto et al.[14] analyzed skiing motions and recognized the skills of skiers.

Dance motion has also been analyzed. Emotions

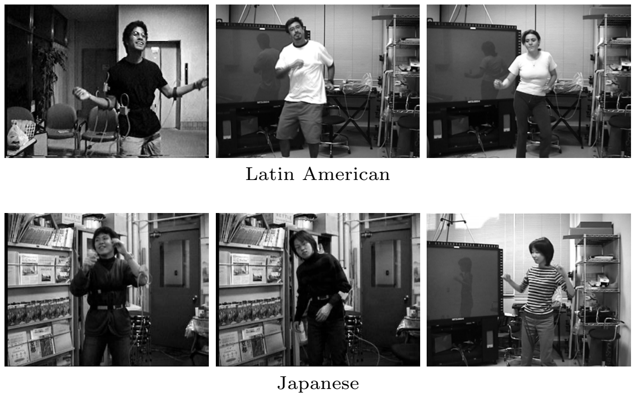


Fig. 1 Rhythmical movement of non-professional dancers.

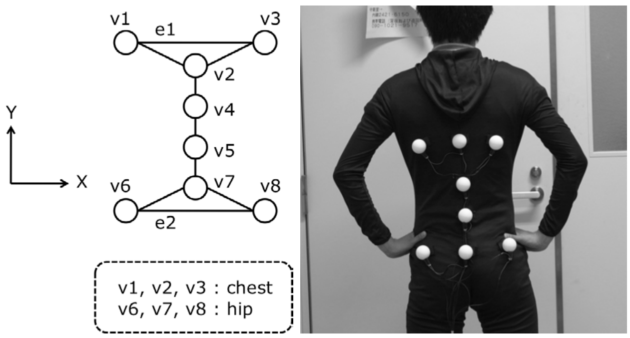
[15,16], impressions[17], and attractiveness[18] were extracted from dance motions. On the other hand, in this paper, we try to extract motion features related to the rhythmic sense of a dancer. Most of the previous studies have analyzed formal dances such as ballet, modern dance, and traditional dance. Our study focuses on casual dance, in particular, on rhythmical movements.

3. Comparison of Latin American and Japanese Rhythmical Movement

A simple motion capture system is used in comparison of Latin American and Japanese rhythmical movements. The system consists of a flexible black suit on which visual markers (small white balls) are attached, a video camera, and a PC. The rhythmical movement of a dancer who wears the suit is captured by the camera in a dark room, while the light bulbs inside of the white balls are turned on. The captured images are binarized, each marker is extracted, and the trajectories of the markers are traced. The motion capture system can only measure 2-D motion of the markers parallel to the camera image plane. However, this is sufficient for our purpose because people can recognize the style of a motion from a sparse set of 2-D moving light points[3,19].

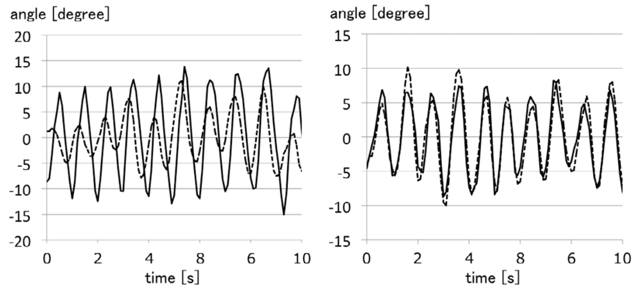
3.1 Deciding marker location for motion capture system

It is important to know where the markers should be located on a body to effectively extract the motion features that differentiate Latin American rhythmical movement from Japanese. We at first observed both Latin American and Japanese rhythmical movements. Nine Latin American and twelve Japanese people were recruited for the observation. All of the participants were 20-30 years old and non-professional dancers. Dance is a hobby of all Latin American participants, while their dances are not as good as ones of profes-



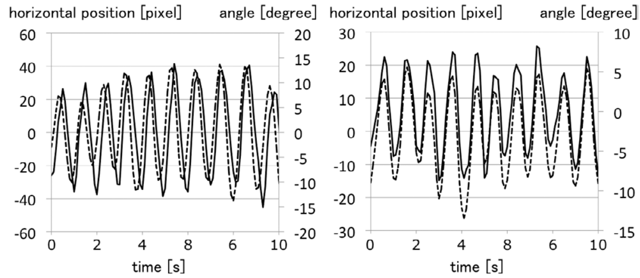
(a) (b)

Fig. 2 Marker configuration: (a) diagram, (b) overview.



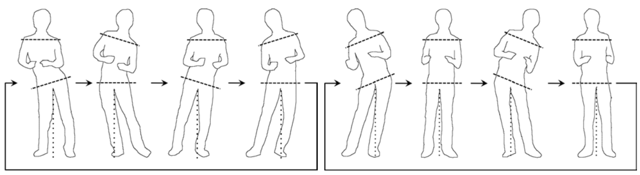
(L) (J)

Fig. 4 Measured time series of rotational angles of hips and chest (solid line: hips, broken line: chest).



(L) (J)

Fig. 5 Measured time series of hips' rotational angle and horizontal position (solid line: rotational angle, broken line: horizontal position).



(L) (J)

Fig. 6 Illustration of Latin American and Japanese rhythmical movements (broken line indicates rotational angles of hips and chest, and dotted line indicates hips' horizontal position).

sional dancers. In contrast, all Japanese participants are almost beginners of dancing. In the experiment, each participant danced to a modern R&B song[20] which is often used in casual dance parties in Japan (**Fig. 1**). Each dance motion was recorded with a video recorder.

We observed the recorded videos and noticed that there were differences between Latin American and Japanese rhythmical movements around their chests and hips. Therefore we decided to put 8 vision markers on these parts of the body as shown in **Fig. 2**. **Fig. 2**(a) shows a diagram of our marker configuration. We assigned $v_i(i = 1, 2, ..., 8)$ to each marker, and e_1 and e_2 to the edges which connect v_1 and v_3, and v_6 and v_8, respectively. **Fig. 2**(b) shows the overview of the suit.

3. 2 Measurement and analysis of rhythmical movement

We measured rhythmical movement with the 2-D motion capture system. Six Latin American and five Japanese people were recruited for the experiment. All of the participants were 20-30 years old and were not professional dancers. Each participant wore the suit and danced to the same piece of music used in the previous experiment. Their rhythmical movements were recorded by the video camera. Each captured image sequence was processed afterwards as described above. **Fig. 3** shows an example of binarized image sequences of Latin American and Japanese rhythmical movements.

3. 3 Result

We plotted the time series of the positions and rotational angles of all the participants' hips and chests, and observed them to compare the motions of Latin American and Japanese participants. As a result, we found two motion features which were different between Latin American and Japanese rhythmical movements. In this paper, we did not take into account other motion features. **Fig. 4** shows the time series of the rotational angles of chest and hips. **Fig. 4**(L) and (J) show the data of a Latin American participant and of Japanese one, respectively. The rotational angle of the chest (or hips) is represented as the angle between the x-axis of the captured image and e_1 (or e_2) on the image plane. **Fig. 5** shows the time series of hips' rotational angle and its horizontal position. **Fig. 5**(L) and (J) show the data of a Latin American participant and of Japanese one, respectively. The horizontal position is represented as the x-coordinate value of v_7 on the image plane. **Fig. 6** shows the illustration of Latin American and Japanese rhythmical movements.

Fig. 4 shows the first motion feature. We regarded the rotational angle as a sinusoidal wave, as suggested in a previous work[21]. We found that phases of the two sinusoidal waves of the Latin American motion were shifted around $1/2\pi$ rad, while there was almost no

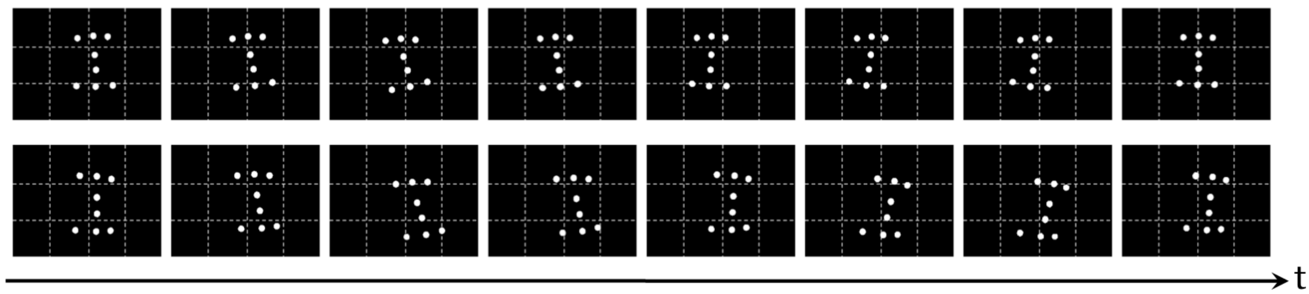


Fig. 3 Binarized captured sequences (grid lines are added by the authors): (upper) Latin American, (lower) Japanese.

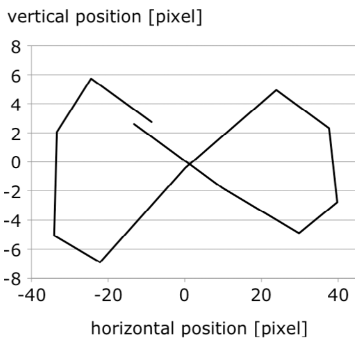


Fig. 7 Measured hips' trajectory.

phase shift in the data of the Japanese participant. We refer to the first motion feature as "hip-chest phase shift (HCPS)".

We also regarded the hips' horizontal position as a sinusoidal wave in **Fig. 5**. Then we found that phases of the two sinusoidal waves (i.e., hips' rotational angle and its horizontal position) of the Latin American participant were shifted around $1/2\pi$ rad, while there was almost no phase shift in the Japanese participant's data. This is the second motion feature. We refer to it as "hips' angle-position phase shift (HAPPS)".

These two motion features could also be found in the data of the other participants: HCPS could be found in 83 % of Latin American and 80 % of Japanese motion data, and HAPPS could be found in 67 % of Latin American and 80 % of Japanese motion data. Therefore, we argue that they distinguish Latin American rhythmical movement from Japanese. On the other hand, we found that the hips' trajectory appeared to be in the shape of the infinity symbol "∞", in both the Latin American and Japanese rhythmical movements as shown in **Fig. 7**. This motion feature will be used in the synthesis of the rhythmical movement in Sec. 4.1.

4. Evaluation of Motion Feature by Synthesis of Virtual Character Animation

We conducted a psychophysical study to evaluate the effect of each motion feature on the impression of rhythmical movement. For the study, we synthesized a human figure animation performing rhythmical movements based on the combination of the extracted motion features. Then participants were asked to report the perceived rhythmic sense as well as home country/area of the figure. At last, we determined whether the extracted motion features were salient for judgments of the perceived sense of rhythm and home country/area.

4.1 Synthesis

We generated a 3-D stick figure animation (**Fig. 8**) because its form does not affect the perceived motion styles[22]. The stick figure model consisted of 15 vertices and 14 edges that connect them. We determined the initial positions of the vertices and the lengths of the edges based on the dimensions of a physical human body, which were manually measured in advance. The 3-D world coordinate system was defined as shown in **Fig. 8**. The rotational angle of the shoulder $\alpha_{shoulder}$ represents the angle of a line which connects $v_{R-shoulder}$ and $v_{L-shoulder}$ from the x-axis, and that of the hips α_{hip} represents the angle of a line which connects v_{R-hip} and v_{L-hip} from the x-axis (**Fig. 8**(c)).

Rhythmical movements with different combinations of the two motion features were synthesized as follows. At first, we computed the rotational angles of the shoulder $\alpha_{shoulder}$ and the hips α_{hip} which are related to the first motion feature, HCPS. Suppose that A_{hip} and $A_{shoulder}$ represent the maximum rotational angles of the hips and the shoulder, respectively, t represents the time, and f represents the frequency, α_{hip} and $\alpha_{shoulder}$ are computed as:

$$\alpha_{hip}(t) = A_{hip} \sin(2\pi f t), \quad (1)$$

$$\alpha_{shoulder}(t) = A_{shoulder} \sin(t'), \quad (2)$$

$$t' = \begin{cases} 2\pi f t + 1/2\pi, & \text{for Latin American, (3a)} \\ 2\pi f t. & \text{for Japanese.} \quad \text{(3b)} \end{cases}$$

Equations (1), (2) and (3a) represent a phase shift of

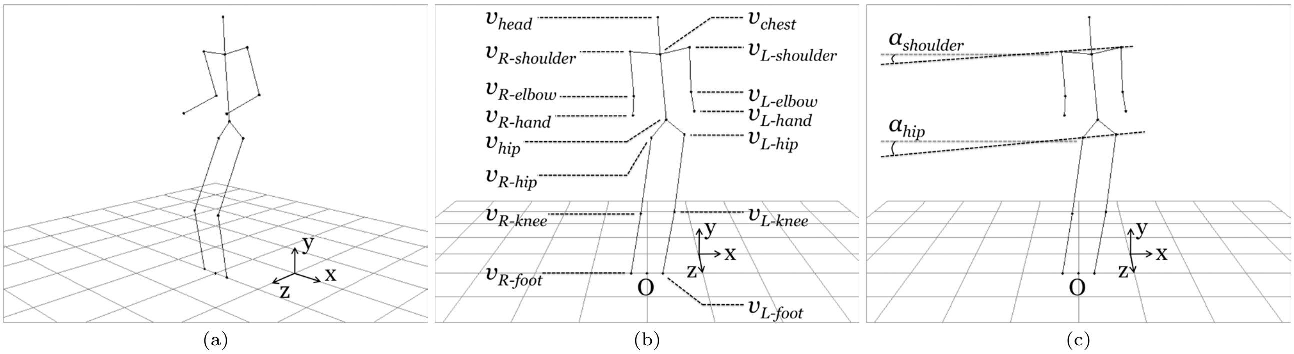


Fig. 8 Synthesized stick figure model: (a) overview, (b) model's vertices, (c) defined rotational angles.

$1/2\pi$ rad between the rotational angles of the hips and the shoulder (or the chest) in the Latin American rhythmical movement. On the other hand, no phase shift in the Japanese rhythmical movement is represented by Equations (1), (2) and (3b).

The second motion feature HAPPS is represented as the phase shift between the hips' rotational angle α_{hip} and its horizontal position. Suppose that the x- and y-coordinate values of the model's hips v_{hip} are represented as (x_{hip}, y_{hip}) and the amplitude of the hips' horizontal translation is X_{hip}, the hips' horizontal position x_{hip} is represented as:

$$x_{hip}(t) = X_{hip} \sin(t'). \tag{4}$$

Equations (1), (3a) and (4) represent a phase shift of $1/2\pi$ rad between the hips' rotational angle and its horizontal position in the Latin American rhythmical movement. On the other hand, no phase shift in the Japanese rhythmical movement is represented by Equations (1), (3b) and (4).

The hips of the model moves in the shape of the infinity symbol "∞". This can be represented as:

$$y_{hip}(t) = Y_{offset} + Y_{hip} \sin(2t' - \pi), \tag{5}$$

where Y_{hip} represents the hips' vertical maximum displacement, and Y_{offset} represents the initial y-coordinate value of v_{hip}. Equations (3), (4), and (5) represent the trajectory of the infinity symbol.

The z-coordinate values of the vertices of the model are fixed. We fix the positions of v_{R-foot} and v_{L-foot} on the ground, and define x- and y-coordinate values of v_{R-knee} and v_{L-knee} as the midpoint between v_{R-hip} and v_{R-foot}, and between v_{L-hip} and v_{L-foot}, respectively. v_{hip}, v_{R-hip}, v_{L-hip}, and v_{chest} configure a rigid body. Therefore, once the position of v_{hip} and α_{hip} are computed based on the above equations, the positions of these vertices are determined. The other vertices

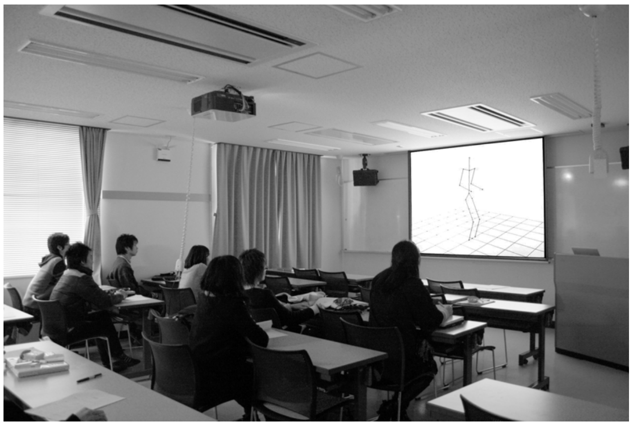


Fig. 9 Group participating in psychophysical study.

Table 1 Combination of the proposed motion features for synthesized rhythmical movements.

motion	1st feature (HCPS)	2nd feature (HAPPS)
1	Japanese	Japanese
2	Japanese	Latin American
3	Latin American	Japanese
4	Latin American	Latin American

configure another rigid body. Therefore their x- and y-coordinate values are determined, once position of v_{chest} and $\alpha_{shoulder}$ are computed.

4. 2 Data collection

18 participants (13 males and 5 females, aged 21 to 28) took part in a psychophysical study. All participants were naïve to the purpose of the experiment and had normal or corrected to normal vision. Note that all participants were Japanese and this paper evaluated the perception of the participants of a particular nationality/cultural background. Participants viewed the stimuli (synthesized rhythmical movements) on a large projected screen in a lecture room (**Fig. 9**). We used a two-way, repeated measures design where the conditions were HCPS (×2) and HAPPS (×2). So we synthesized four types of rhythmical movements. Each motion was designed with different combination of the proposed motion features as shown in **Table 1**. For example, in motion 2, HCPS was Japanese while HAPPS was Latin

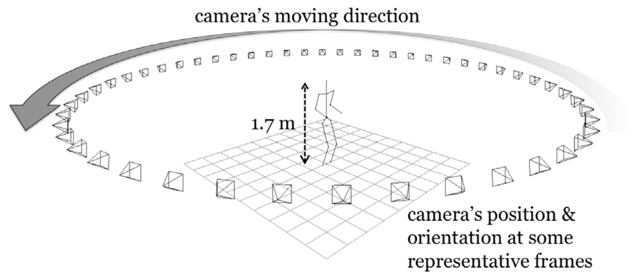


Fig. 10 Camera's path.

Table 2 Values assigned to the parameters of the synthesized stick figure model.

Y_{offset}	A_{hip}	$A_{shoulder}$	X_{waist}	Y_{waist}	f
1.0 m	5 deg	5 deg	0.13 m	0.025 m	0..8 Hz

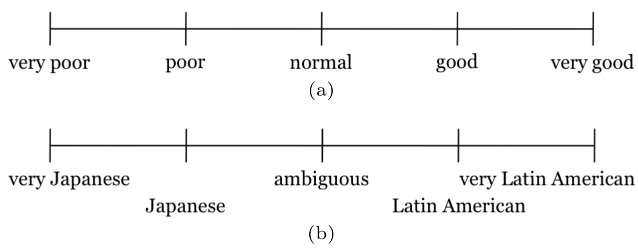


Fig. 11 Presented five-point scale: (a) for sense of rhythm, (b) for home country/area.

American.

The purpose of the study is to confirm whether the identified motion features affect the perceived rhythmic sense of a dancer. However, the motion features might affect not only the perceived rhythmic sense but also the perceived home country/area (i.e., Latin America or Japan) of the dancing stick figure. Therefore the participants were asked to report the perceived rhythmic sense as well as home country/area of the synthesized model.

A grid ground plane was added to the scene and the virtual camera moved around the model at 50 seconds/cycle (**Fig. 10**). In the evaluation, the height of the model was 1.7 m (**Fig. 10**), and the parameters (A_{hip}, $A_{shoulder}$, X_{hip}, and Y_{hip}) were determined based on the measured data in the previous experiment. In particular, we applied the data of a Latin American participant to the parameters to ensure that the synthesized motion looked natural. **Table 2** shows the assigned values for the parameters. f was determined according to the speed of the R&B music used in the previous experiments.

The movies of the four synthesized motions were sorted randomly in two different playlists. The two groups of participants each viewed one of the sets of the movies on a large projected display. Note that our large display ensured consistent viewing angles so that recognition performance was above chance. They were asked to answer two questions according to a five-point scale (**Fig. 11**) by taking only motion into account when making the judgments. Participants sat near to one another, but were not allowed to discuss their decisions. The movies were all displayed for 3 minutes, one after another.

4.3 Result

We averaged the participants' ratings over the two repetitions for each combination of the motion features. **Fig. 12**(a) shows the result of the judged sense of rhythm. A two-way ANalysis Of VAriance (ANOVA) with repeated measures showed main effects of HCPS ($F_{1,17} = 7.3, p < 0.05$) and of HAPPS ($F_{1,17} = 17.2, p < 0.001$). **Fig. 12**(b) (or (c)) shows the averaged ratings of Latin American and Japanese HCPS (or HAPPS). It can be seen that the rhythmical movements with the Latin American HCPS (or HAPPS) were considered to have significantly better sense of rhythm than those with the Japanese HCPS (or HAPPS). There was no interaction between HCPS and HAPPS.

Fig. 13(a) shows the result about the home country/area. A two-way ANOVA with repeated measures showed the main effect of HCPS ($F_{1,17} = 48.6, p < 0.001$) while we found that HAPPS had no effect ($F_{1,17} = 1.0, p > 0.34$). **Fig. 13**(b) (or (c)) shows the averaged ratings of Latin American and Japanese HCPS (or HAPPS). It can be seen that the rhythmical movements with the Latin American HCPS were rated overall as Latin American, and those with the Japanese HCPS as Japanese. On the other hand, HAPPS did not affect the perceived home country/area of the motions. There was no interaction between HCPS and HAPPS.

5. Discussion

We have extracted two motion features, HCPS and HAPPS, that affect the perceived rhythmic sense of a dancer. We have also confirmed that a motion feature, HCPS, affects the perception of the home country/area (particularly, Latin America and Japan) of a dancer.

This information is useful in CG motion design. When a designer would like to make the rhythmic sense of a dancing virtual character better, he (or she) only has to apply a phase shift of $1/2\pi$ rad to both/either HCPS and/or HAPPS. When the both features or only HCPS are changed, the virtual character is perceived as Latin American. On the other hand, by changing HAPPS only, the designer can make the rhythmic sense better irrespective of the perceived home country/area

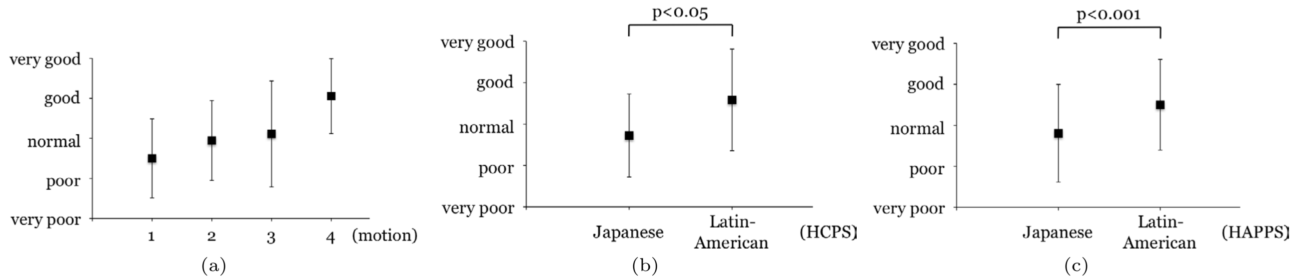


Fig. 12 Averaged participants' ratings with standard deviations of the selected degree of the sense of rhythm: (a) of all conditions, (b) of Latin American and Japanese HCPS, (c) of Latin American and Japanese HAPPS.

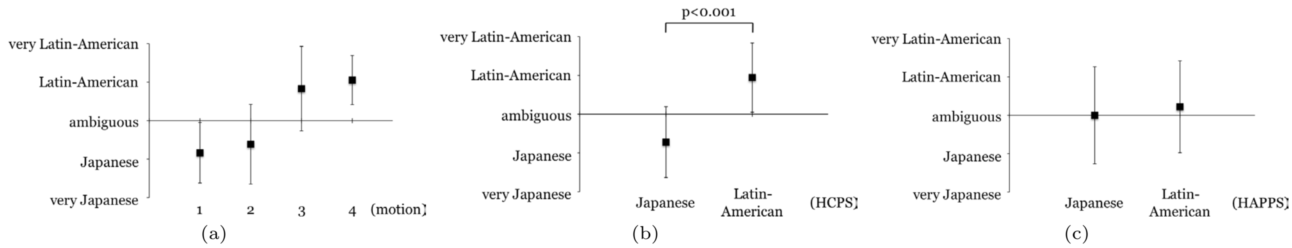


Fig. 13 Averaged participants' ratings with standard deviations of the selected home country/area: (a) of all conditions, (b) of Latin American and Japanese HCPS, (c) of Latin American and Japanese HAPPS.

of the character.

Folklore researchers have also investigated similar issues and indicated that isolated movements of different body parts in dance motion were related to the perceived rhythmic sense of the dancer[23]. Compared to their qualitative research, the novelty of this paper is that the isolated movements are quantitatively revealed as the HCPS and HAPPS. Therefore, we believe that the results of this paper will contribute not only to CG but also to other research fields such as Folklore, Ethnology, and Cultural Anthropology. We will collaborate with researchers of these fields for further investigation of the effect of the phase shift on the impression of human figure motions.

6. Conclusion

This paper compared the rhythmical movements of Latin American and Japanese people for finding motion features closely related to the perceived rhythmic sense of a dancer. We constructed a 2-D motion capture system to measure the rhythmical movements. By analyzing the measured motion data, we found two motion features: HCPS and HAPPS. We carried out a psychophysical study to confirm whether these features affected the perceived rhythmic sense of a dancer. In the study, participants evaluated stick figure animations synthesized with different combinations of the motion features. The result showed that both the motion features significantly had an effect on the perceived rhythmic sense of the figure, while HCPS also affected the perceived home country/area of the figure.

As a future work, we will investigate other motion features that affect other impressions of a dance motion (e.g., joyfulness, angry, happiness, gracefulness, etc.) for efficient higher-level control of virtual character animations.

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