# Walking Pace Induction Application Based on the BPM and RhythmValue of Music

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**Abstract.** Walking has been attracting attention as an important means for prevention and improvement of lifestyle diseases, such as high blood pressure and diabetes. However, walking at a continuous pace with high load can be challenging, and health benefits cannot be expected when walking with low load. A walking pace support system is necessary in order to achieve effective walking. Hence, we are developing BeatSync, a smartphone application that realizes the induction of a natural and accurate walking pace by the rhythm of music. This application can select songs from a user's music library. However, some songs, such as songs with a fast (slow) rhythm or complex beats, are not suitable for walking pace induction. In the present paper, we consider the speed and clarity of music rhythm to be an important factor in selecting a song that is suitable for walking pace induction and make an index and clarify its effect on walking pace induction. In the present study, BPM is used as an index of rhythm speed, and RhythmValue (RV) is proposed as an index of rhythm clarity. In order to verify the effectiveness of the index, we conducted walking pace induction experiments using 30 songs with different speeds and clarities (two sets of 15 songs) with 14 participants. As a result, the experiments confirmed that the proposed index can distinguish songs that are suitable or unsuitable for walking pace induction and can select songs that are suitable for walking pace induction.

**Keywords:** Music · Walking pace induction · BPM · RhythmValue · Smartphone application

## 1 Introduction

In recent years, walking activity has been highlighted as a major solution to prevent lifestyle diseases, such as high blood pressure and diabetes [13]. However,

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walking at a continuous pace with high load can be challenging, and health benefits cannot be expected when walking with low load [4]. It is important to walk the correct route at the right pace in order to improve an individual's health.

A number of walking support systems have been developed to solve this problem [7,9,16]. In a previous study, we developed a walking support system based on heart rate prediction [7,16]. This system suggests a walking route and pace for each walker according to his/her request (target calorie usage, walking time, etc.) and conditions (gender, age, exercise habit, etc.). However, the system only provides suggestions, such as "Please walk at 5.2 km/h." Therefore, it is difficult for the user to adjust to the walking pace. It is necessary to have a support method for the user to adjust to the walking pace presented by the system. Several studies have already developed walking pace adjustment systems [9,11,19,20]. In order to adjust walking pace, there is a method of advising increased or decreased walking speed through a screen and/or voice of a smartphone, but this method cannot accurately adjust the speed of the walker to the target speed. Moreover, in this method, walkers need to watch their smartphones while walking, which may lead to accidents.

Therefore, we decided to use music to induce walking pace in a natural, accurate, and fun manner. Several studies have shown that music affects body movement [1,3,5,6,8,14,15,18]. Fraisse and Noorden et al. reported that people tend to prefer to match their body movements to music [1,18]. Hence, we are developing an application called BeatSync [12] (Fig. 2), which realizes natural and accurate walking pace induction by adjusting the walking pace to the rhythm of music. This application can select a song from the user's music library. However, there are some songs that are not suitable for walking pace induction. For example, when a song's rhythm is too fast (slow) or complex, it will be difficult to adjust the walking pace of the user to the pace of the music. For the induction of the walking pace, it is necessary to select a song of appropriate rhythm speed and clarity.

In the present paper, we consider the speed and clarity of the rhythm of the song are major factors affecting walking pace induction. Therefore, BPM is used as an index of rhythm speed, and RhythmValue (RV) is proposed as an index of rhythm clarity. Hence, we consider that the selection of songs that are suitable for walking pace induction becomes possible by these two indexes. In order to investigate the effectiveness of the indexes, a walking pace induction experiment was conducted using 30 songs with different speeds and clarities (two sets of 15 songs) with 14 participants. As a result, it was confirmed that a song suitable for walking pace induction could be selected by the proposed index. Concretely, it was confirmed that for a BPM of 90–120, walking pace induction is possible regardless of RV, and, at other BPM values, the range in which walking pace induction is possible narrowed as RV decreases.

## 2 Previous Research

This section describes applications and research about walking support systems.

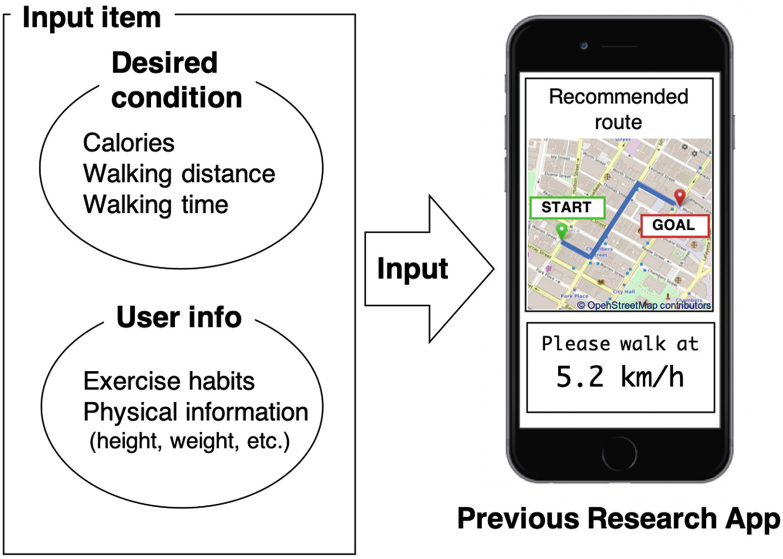


**Fig. 1.** Previous research application (created by the author based on [7]).

### 2.1 Existing Walking Support Systems

RunKeeper[1] and iSmoothRun[2] are currently used as walking support applications. In these applications, the heart rate meter and the smartphone are connected by Bluetooth, and the heart rate is displayed on the smartphone. Therefore, if the heart rate becomes too high, the walking speed can be reduced in order to lower the heart rate. However, in these systems, when a heart rate meter is not attached, it is not possible to confirm the heart rate. Furthermore, even when a heart rate meter is attached to the user, the present heart rate is displayed, but the future heart rate cannot be predicted. Therefore, the Runkeeper app can only decrease the walking pace when the heart rate becomes too high.

On the other hand, we are developing a walking support system based on heart rate prediction using smartphones [7,16]. This application predicts the heart rate while walking using walking pace, road gradient, and user information (height, weight, exercise habits, etc.) and shows the walking route and walking pace that are suitable for conditions such as time limit, target calorie usage, and maximum heart rate (Fig. 1). However, realizing an interface to accurately adjust the user's walking pace has been problematic. Hence, it is necessary to induce a walking pace through some method.

[1] Runkeeper https://runkeeper.com/.
[2] iSmoothRun http://www.ismoothrun.com/.

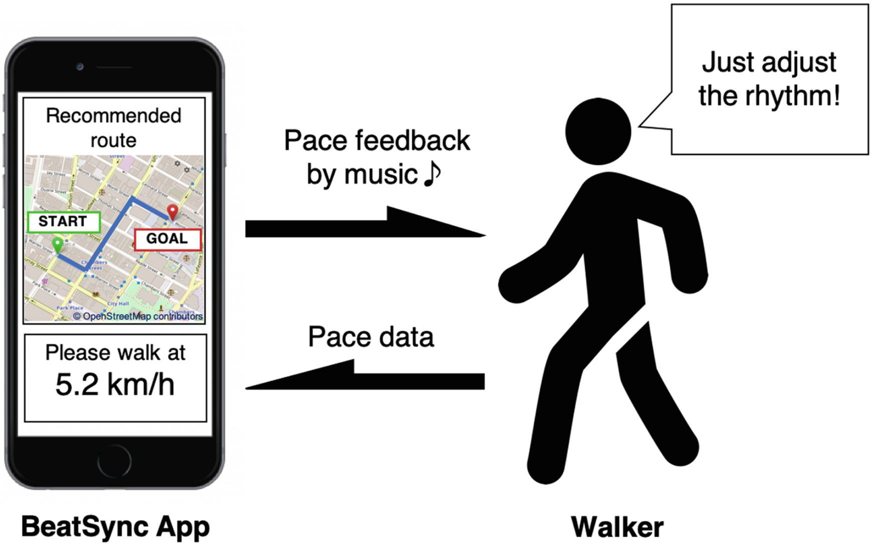


**Fig. 2.** Image of the BeatSync application.

### 2.2 Walking Pace Induction System

Watanabe et al. developed a walking pace induction system using a shoe-shaped interface [19]. They clarified that constant-walking-pace induction is possible by generating vibrations in the instep of the foot using a shoe-type device and changing the pace of these vibrations. However, this method requires special devices and is not widely adopted.

MPTrain [11] and the IM4Sports music system [20] can be induced to the target walking pace by following the rhythm of the music. These are systems that select the song of the optimum speed in proportion to the heart rate and goal before the music ends and choose the next song. However, in order to change the song itself, the induction was either delayed, or many songs had to be retained.

Tajadura-Jimenez et al. reported that modified walking sounds change one's own perceived body weight and affects the user's walking pattern [17]. Walk-In Music [9] uses this effect and generates music based on the walking pace and induces the walking pace. Walk-In Music has the advantage whereby there is no need to prepare songs. However, the generated music is composed of monotonous drum sounds, and so is not preferable to the user. Nagashima reported that boredom and habituation to monotonous rhythms reduce the attentiveness of participants [10]. We considered that it is important to use the user's preferred song rather than monotonous sounds, such as a drum, to induce the walking pace.

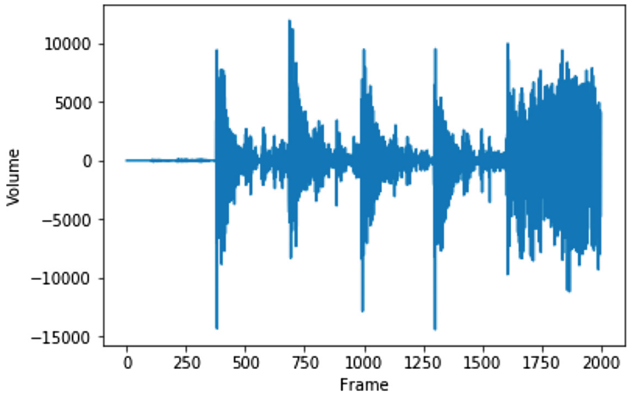


**Fig. 3.** Volume component for each frame of the song (first 2,000 frames).

Therefore, we proposed a method by which to induce a walking pace using only a single (or a few) song(s) by controlling the reproduction of the speed of music, which can be easily used by everyone [12] (Fig. 2). Concretely, an application capable of inducing a walking pace with a limited number of songs by using the "Superpowered" library with less deterioration of tone quality, even by changing the reproduction speed of music (time stretching processing), was developed for smartphones usable by everyone. As a result of the walking induction experiment using song data prepared in advance by six participants using this application, the walking pace of all participants could be adjusted in the range of 102 to 120 steps per minute. However, in this experiment, it seemed easy to adjust the walking pace to the rhythm of a song, because the musical piece was close to the walking pace of the examinee and the beats were clear. In the real environment, it is preferable to use a song that the user likes, but the speed and clarity of the rhythm are different for all songs. Hence, it is not always easy to adjust the walking pace to the music.

Therefore, in the present study, the speed and clarity of rhythm are made to be an index and are used as parameters for song recommendation. The number of beats per minute (BPM) is an index that indicates the speed of the rhythm. However, there is no index for the clarity of rhythm. Therefore, we index the clarity of song rhythm (degree of clarity of the periodic beat) as the Rhythm-Value (RV). By indexing, the system can choose a suitable song for walking pace induction.

## 3 Proposed Index

This section describes how to index the speed and clarity of the rhythm of a song.

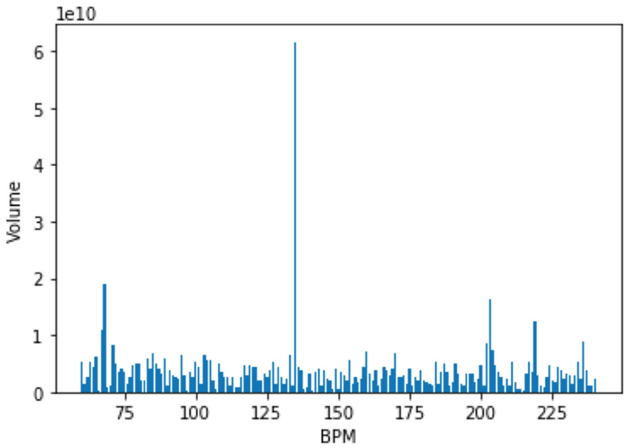


**Fig. 4.** Volume component for each BPM (BPM 60–240).

### 3.1 Indexing the Speed of Rhythm: uBPM

Regarding the speed of the rhythm of a song, there is an index called BPM, which indicates the number of beats per minute. Many songs have a specific BPM that can be obtained by analyzing the frequency of audio waveform data of songs. In the present paper, a song's specific BPM is described as the unique BPM (uBPM). Here, uBPM is calculated as follows:

- Step 1-1: Divide a song's waveform data into frames. The volume (effective value) of each frame is then obtained (Fig. 3).
- Step 1-2: Calculate the volume increment between adjacent frames.
- Step 1-3: Calculate the volume component for each BPM by analyzing the frequency component of the volume increase (Fig. 4).
- Step 1-4: The BPM with the largest volume component is defined as uBPM.

In Step 1-1, in order to reduce the calculation amount, the song's waveform data is divided into frames (one frame includes 512 samples, approximately 0.01 s), and the volume (effective value) of each frame is obtained. In Step 1-2, the volume increment between adjacent frames is calculated. This is because most of musical instruments have the common feature that the volume increases rapidly at the moment of sound emission. On the other hand, the appearance of the volume decreases differently depending on the type of instrument. In Step 1-3, the volume increment is analyzed by analyzing the frequency component in order to determine the volume component for each BPM. Since the uBPM of many songs is within the range of 60–240, the volume component is calculated for each BPM in this range. In Step 1-4, the BPM of the largest volume component of BPM 60–240 is selected as the uBPM. The waveform shown in Figs. 3 and 4 is the analysis result of "original smile" by SMAP, a J-POP song.

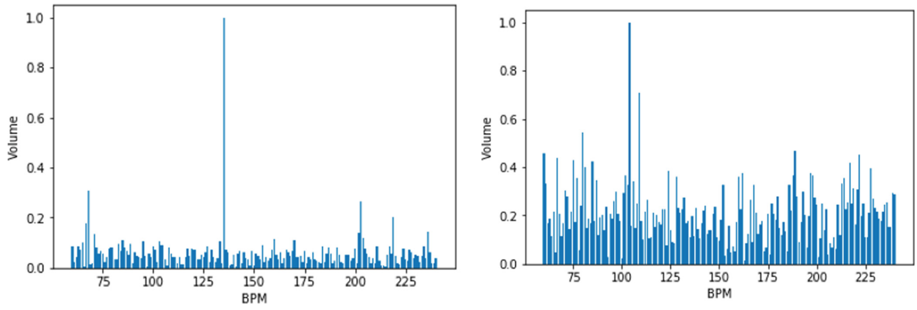


**Fig. 5.** Volume component for each BPM of songs with clear rhythms (left) and songs with complex rhythms (right). Left: SMAP Original Smile (J-POP), RV: 94, Right: Beethoven's 5th Symphony, RV: 79.

### 3.2 Indexing the Clarity of Rhythm: RV

Currently, since the clarity of the rhythm has no index, we devise a method to index the clarity. The rhythm of music consists of the size of the periodic volume (beat strength), and it is easy to walk when the rhythm of song is clear.

**Summary of Indexing.** Between songs with clear and complex rhythms, a difference appears in the volume component for each BPM of the song obtained in the previous section in Step 1-3. Figure 5 shows the volume component per BPM in songs with clear or complex rhythms. The volume components of each BPM are normalized to be 1 at the maximum in order to index different songs by the same standard. In songs with clear rhythm, the volume component of uBPM becomes much larger than other BPM volume components (Fig. 5 left). In contrast, in songs with complex rhythms, the volume components of BPMs other than the uBPM become large (Fig. 5 right). In the present study, we use this tendency as an indicator of the clarity of rhythm. RhythmValue (RV) is defined as the clarity of the rhythm indexed by 0–100. The closer RV is to 100, the clearer the rhythm is. The closer RV is to 0, the less clear the rhythm is.

**Process of Indexing.** To calculate RV, we first determine the volume components for each BPM beforehand (Steps 1-1 to 1-3 of the previous section), then apply the process of indexing, Steps 2-1 to 2-3 shown below.

– Step 2-1: Normalize each BPM volume component to a maximum of 1.
– Step 2-2: Calculate the average of the normalized volume components ($VOL_a$) excluding uBPM.
– Step 2-3: Output values up to 0–100 using Eq. (1) below.

$$RV = (1 - VOL_a) \times 100 \tag{1}$$

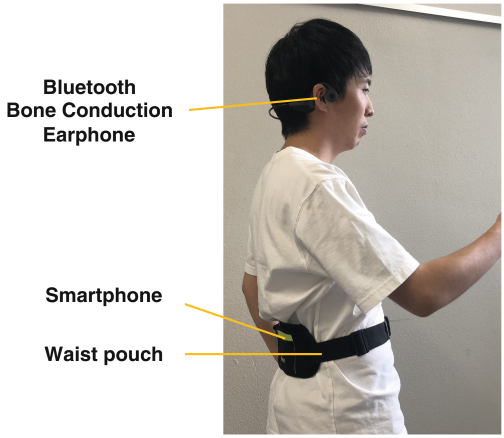


**Fig. 6.** Experimental situation.

In Step 2-1, in order to make it possible to compare songs with different sound levels, the volume components for each BPM obtained are normalized to be 1 at maximum (Fig. 5). In Step 2-2, calculate the average of the volume components ($VOL_a$) excluding uBPM. Since the volume components are normalized in Step 2-1, the magnitude of volume components other than uBPM can be expressed in the form normalized by 1 at maximum by calculating the average value. $VOL_a$ approaches 0 if the rhythm of the song is clear and approaches 1 if the rhythm is complex. In Step 2-3, Eq. (1) is used to give index values of up to 0–100.

## 4 Evaluation Experiment

Evaluation experiments are conducted to confirm the effectiveness of uBPM and RV and their effects on the induction of walking pace. This section describes the experiments and experimental applications.

### 4.1 Summary of the Experiment

The purpose of this experiment is to clarify the effect of differences in uBPM and RV on the induction range of walking pace. If the uBPM and RV of a song with a large walking pace induction range can be specified, these values can be used for song selection in the walking pace induction. An experiment was carried out with 14 participants (men and women) in their 20's in a flat place without a slope. A walking pace induction experiment (5 to 15 min) and a survey (1 min) were conducted using one song. This experiment was approved by the Ethics Review Committee (Approval Number 2018-I-8) at Nara Institute of Science and Technology. In order to express the differences among songs, 15 categories were created based on uBPM (five categories) and RV (three categories) (Table 1). Two songs are selected for each category, and a total of 30 songs are used (Table 2).

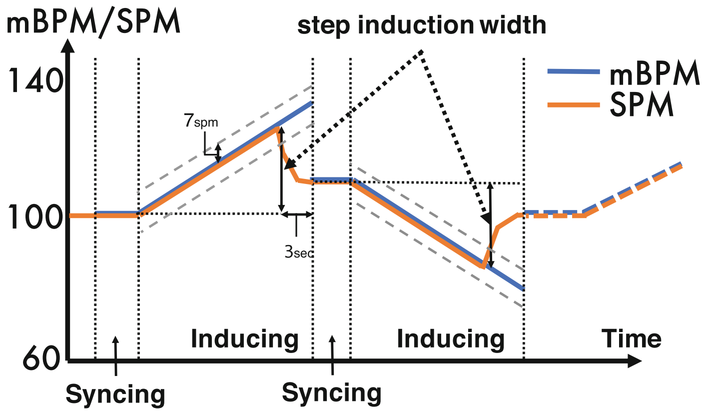


**Fig. 7.** Image of walking pace induction.

The experiment took a long time (150–450 min) because it was necessary to repeat the set of the walking pace induction experiment and the survey for 30 songs. Since walking for a long time may cause exhaustion, the maximum number of songs per day was limited to six (up to 90 min), and sessions were divided into several days according to the participant's convenience. The contents of the experiment were explained to the participants before the experiment, and the application for the validation, Bluetooth bone-conduction earphones, and waist pouches were distributed (Fig. 6). A Bluetooth bone-conduction earphone was used to ensure safety by enabling people to listen to ambient sounds while walking and listening to music. In addition, a waist pouch was distributed to enable people to walk empty handed and to cope with unexpected accidents such as falls.

### 4.2 Details of Walking Induction Experiment

The playing speed of music is dynamically changed during the walking pace induction experiment. In the present paper, the BPM of the music being played is described as mBPM (Music BPM)[3]. Figure 7 shows an image of walking pace induction. First, mBPM is played according to the walking pace (steps per minute: SPM), and then the paces of the song and the walking speed are synchronized (Fig. 7 Synchronizing). The number of steps per minute (SPM) is then induced by slowly varying mBPM (Fig. 7 Inducing). In this experiment, 1 mBPM is changed every two seconds. The induction ends when the walking pace does not follow the pace of the music (more than seven differences between mBPM and SPM) for more than three seconds continuously. The difference in mBPM from the beginning of induction to the point at which it becomes impossible to follow is defined as the step induction width. The upper and lower limits

[3] mBPM can be different from uBPM since the music playback speed can be changed.

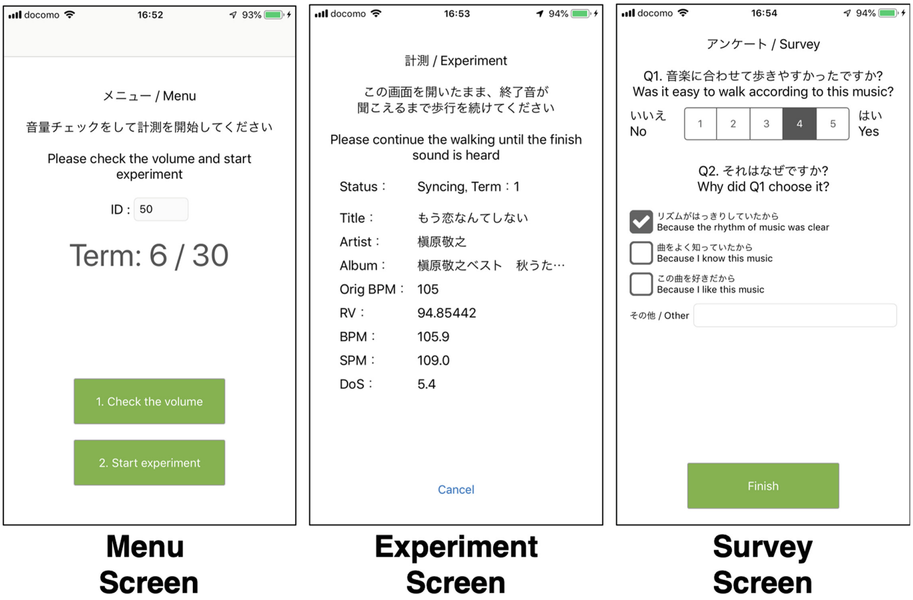


**Fig. 8.** Screenshot of the application used for the experiment.

of the inducible walking pace are different depending on the user, but it is possible to simply compare the inducible range of the walking pace by using step induction width.

We considered that the clearer the rhythm, the easier it is to adjust to the rhythm of the song, and the wider the step induction width is. Furthermore, in the survey carried out at the end of each set, it was confirmed that it was easy to walk with music, as well as the reason thereof.

### 4.3 Details of the Survey

The participants answered the survey after each walking pace induction experiment (Fig. 8 Right). The survey was based on whether it was easy to walk with the music, as well as the reason thereof. The survey items are as follows.

**Table 1.** uBPM and RV categories.

| RV | uBPM | | | | |
|---|---|---|---|---|---|
| | 60–90 | 90–120 | 120–150 | 150–180 | 180–210 |
| Less than 80 | A | D | G | J | M |
| 80–90 | B | E | H | K | N |
| 90–100 | C | F | I | L | O |

**Table 2.** Songs used in the present study.

| Song name | uBPM | RV | Category | Song name | uBPM | RV | Category | Song name | uBPM | RV | Category |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Song-1 | 74 | 74 | A | Song-11 | 164 | 82 | K | Song-21 | 106 | 94 | F |
| Song-2 | 78 | 86 | B | Song-12 | 166 | 95 | L | Song-22 | 136 | 79 | G |
| Song-3 | 74 | 93 | C | Song-13 | 199 | 71 | M | Song-23 | 130 | 82 | H |
| Song-4 | 106 | 67 | D | Song-14 | 190 | 88 | N | Song-24 | 135 | 94 | I |
| Song-5 | 106 | 86 | E | Song-15 | 194 | 96 | O | Song-25 | 177 | 79 | J |
| Song-6 | 105 | 95 | F | Song-16 | 74 | 79 | A | Song-26 | 160 | 88 | K |
| Song-7 | 135 | 71 | G | Song-17 | 74 | 89 | B | Song-27 | 170 | 92 | L |
| Song-8 | 130 | 88 | H | Song-18 | 75 | 93 | C | Song-28 | 186 | 75 | M |
| Song-9 | 135 | 93 | I | Song-19 | 100 | 76 | D | Song-29 | 200 | 82 | N |
| Song-10 | 156 | 79 | J | Song-20 | 100 | 88 | E | Song-30 | 194 | 94 | O |

- Was it easy to walk with music?
  - Five levels: 1 to 5 (1: Difficult to walk, 5: Easy to walk)
- Q2 Reason for selecting Q1.
  - A1 The rhythm was clear
  - A2 I know this song well
  - A3 I like this song
  - A4 The rhythm was not clear
  - A5 I didn't know this song well
  - A6 I don't like this song
  - A7 Other (free description)

If the answer to Q1 is 4 or 5, the selectable answers to Q2 will be A1, A2 and A3. Furthermore, when the participant chooses 1 or 2 as an answer to Q1, A4, A5 or A6 become selectable. If the answer to Q1 is 3, A1–A6 can not be selected. Then, A7 is always descriptive.

### 4.4 Experimental Application

The developed verification application is equipped with the function of walking pace synchronization, induction, induction finish decision, and a survey for carrying out the experiment of the previous section (Fig. 8). The application was developed as an iOS app and implemented in the Swift programming language. For the playback of music and change of the mBPM, the Superpowered library (see Footnote 2), which can only change the reproduction speed while maintaining the sound height (pitch) without damaging tone quality, as far as possible, is used. The user's walking pace (SPM) is detected in real time using acceleration. During the walking pace induction experiment, mBPM and SPM are recorded every second. For each set of experiments, the application works as follows. When the application is started, a menu screen (Fig. 8 Left) is displayed first. Users tap "Start Experiment" to go to the experiment screen (Fig. 8 Center). When walking starts in this state, a walking pace induction experiment is started. When the walking pace induction experiment ends, the survey screen (Fig. 8 Right) is displayed. After responding to the survey, the menu screen (Fig. 8 Left) is displayed again.

## 5 Results

This section describes the experiment results and discusses the proposed index.

### 5.1 Walking Experiment Results and Discussion

Although there was difference in individual results, the difference in the step induction width was generated by the difference between uBPM and RV of the songs. Table 3 shows the average step induction width of all participants tabulated for the uBPM and RV of each song. In all uBPM categories, the step induction width increases as RV increases. For example, when the uBPM category is 60–90 and the RV category is less than 80 or 90–100, the step induction widths are 13.89 and 20.21, respectively. Furthermore, in all RV categories, when the uBPM category is 90–120, the step induction widths become the largest. As shown in Table 3, in each uBPM category, the step induction width increases as the value of RV increases. Since RV represents the clarity of the beat of the song, we considered that the higher the value of RV, the easier it was to walk with the rhythm of song. Moreover, in any RV category, the category of uBPM 90–120 has the largest step induction width. Ishizaki et al. reported that the listener feels uncomfortable when the playback speed of the music is changed greatly [2]. Therefore, the maximum step induction width was observed when the category of uBPM was 90–120, which is closest to the general walking pace of around SPM100. In addition, as the uBPM category moves away from 90–120, which is close to the walking pace, i.e., as the playback speed greatly changes from the original speed of the song, the effect of RV appears remarkably. Compared with songs having clear rhythms, songs having complex rhythms with small RV were found to be difficult to induce the walking pace when the playback speed was changed.

Therefore, when these results are applied to BeatSync app, songs will be recommended a priory from the RV category 90–100 and uBPM category 90–120 according to Table 3, and then the surrounding categories are recommended. Moreover, it is also feasible to use a new index, which is calculated by multiplication of RV and uBPM for the song recommendation.

### 5.2 Survey Results and Discussion

Table 4 shows the results of the survey (Q1). Similar to the results shown in Table 3, we found that the closer the uBPM category is to 90–120, the easier walking in rhythm is. When uBPM and SPM are close to each other, there was little sense of incongruity and walking to the rhythm of music was easier, because the reproduction speed of music does not change greatly from the speed particular to the song. Therefore, when the uBPM category is 90–120, it is easy to walk in rhythm, regardless of RV. In categories other than uBPM category 90–120, the effect of RV is remarkable. When the RV category was 90–100, the uBPM category was 60–180, and the answer (answer is over 3) for which music was easier to walk was obtained. However, when the RV category was less than

**Table 3.** Average (Standard Deviations) of the step induction width for 14 participants.

| RV | uBPM | | | | |
|---|---|---|---|---|---|
| | 60–90 | 90–120 | 120–150 | 150–180 | 180–210 |
| Less than 80 | 13.89 (7.51) | 21.27 (11.65) | 18.46 (9.02) | 16.79 (12.73) | 14.01 (7.08) |
| 80–90 | 15.16 (7.36) | 21.86 (14.03) | 19.79 (12.06) | 19.58 (10.34) | 16.63 (7.41) |
| 90–100 | 20.21 (13.60) | 23.20 (17.69) | 20.22 (9.72) | 19.79 (12.45) | 19.57 (9.50) |

**Table 4.** Average (Standard Deviations) of Survey Q1 (Ease of walking with rhythm of music) [1: Difficult to walk - 5: Easy to walk].

| RV | uBPM | | | | |
|---|---|---|---|---|---|
| | 60–90 | 90–120 | 120–150 | 150–180 | 180–210 |
| Less than 80 | 3.00 (1.05) | 3.86 (0.89) | 2.68 (1.19) | 2.36 (1.13) | 2.21 (1.10) |
| 80–90 | 3.43 (1.07) | 4.00 (1.05) | 3.29 (1.27) | 3.04 (1.29) | 2.61 (1.23) |
| 90–100 | 3.86 (0.89) | 3.96 (1.00) | 3.79 (1.07) | 3.46 (1.26) | 2.89 (1.13) |

80, the response that it was easy to walk with music was obtained only for a limited range, where the uBPM category was 60–120. Table 5 shows the results of Q2 (Reason for Q1) of the survey. In Q2, the reason for Q1 was selected from specified items. Table 5 shows the item, the number of items selected, and the results of average the step induction width of the all participants and all songs for the selected item. A difference of approximately 5.7 steps appears on the step induction width depending on whether the song is known or unknown. In other words, the range of steps that can be induced by a known song is larger than that of an unknown song. It seems to be easy to walk in accordance with music, because the rhythm of the song is grasped in advance. However, in this experiment, the effect of the song preference on the step induction width was not observed.

**Table 5.** Results of Survey Q2 (reason for choosing Q1).

| Item (reason of Q1) | Number of selections (out of 420) | Average step induction width |
|---|---|---|
| The rhythm was clear | 164 | 20.4 |
| I know this song well | 91 | 21.2 |
| I like this song | 23 | 21.9 |
| The rhythm was not clear | 95 | 15.7 |
| I didn't know this song well | 75 | 15.5 |
| I don't like this song | 6 | 22.7 |
| Average of all songs | – | 18.7 |

## 6 Conclusion

We have developed a walking support application called BeatSync, which runs on a smartphone, with the aim of inducing walking pace naturally and accurately to a target by focusing on the rhythm of music. This application uses song data stored in the smartphone, however these songs depend on the individual, so there are songs that are suitable or not suitable for walking pace induction. Then, in the present paper, we considered that the speed and clarity of the rhythm of the song greatly affected the walking pace induction, and made an index using these characteristics. Specifically, we used BPM as an index of the rhythm's speed and proposed the RhythmValue (RV) as a new index of the rhythm's clarity. Furthermore, a walking experiment and survey were carried out with 14 participants using two sets of 15 songs (total 30 songs) with different BPMs and RVs. The results of these experiments confirmed that the proposed index can discriminate songs that are suitable or unsuitable for walking pace induction and can select songs that are suitable for walking pace induction. Concretely, it was confirmed that for a BPM of 90–120, walking pace induction was possible regardless of RV, and, at other BPM values, the range in which the walking pace induction was possibly narrowed as RV decreased.

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