DanceVibe: Assistive Dancing for the Hearing Impaired

Chi-Ju Chao[1], Chun-Wei Huang[2], Chuan-Jie Lin[3], Hao-Hua Chu[2], and Polly Huang[1,2(✉)]

[1] GICE, National Taiwan University, Taipei, Taiwan
pollyhuang@ntu.edu.tw
[2] GINM, National Taiwan University, Taipei, Taiwan
[3] CSIE, National Taiwan Ocean University, Keelung, Taiwan

Abstract. Dancing to the rhythm in music comes natural for most of us. This however is a little far-fetched for the hearing impaired. Not being able to hear the music, the hearing impaired rely on visual aid and techniques such as mind counting to dance. To ease the learning process and alleviate the cognitive load in a dance performance, we propose DanceVibe, a wearable device that replays the beats in music via vibrations. In a 35-volunteer user study conducted over 3-month time, we find the system adds to the visual aid in the learning process and is effective enhancing dance performance. The system is particularly useful enabling on-stage performance without the need to memorize and mind count the beats. A word of caution before using DanceVibe and DanceVibe only on stage is that it does require practice and familiarity to the concept of rhythm.

Keywords: Assistive dancing · Wearable computing
Human computer interaction

1 Introduction and Background

For many of us, music is a daily necessity. The reason is simply that music works magic. Listening or moving along the rhythm in music is emotionally soothing and physically liberating [1, 2]. For those who are physically coordinated, performing dance on stage, adding to the music experience, creates a certain sense of self-fulfillment [3].

For the hearing impaired, these benefits of dancing or feeling along the emotions in the music could be far-fetched. The difficulty hearing music makes it hard to grasp the concept of rhythm which is crucial to performing dances. Getting the tones, particularly the volume, pitches, and flow of the sound requires sophisticated hearing aid. Until today, accessibility and affordability of the hearing aids remain an issue that requires continuous effort in well-developed countries [4], not to mention the level of effort required for the developing countries. Seeking alternatives that are potentially more affordable, efforts such as [5–7] investigate how assistive devices that communicate music through *vibrations* could enhance the experience of music appreciation for the hearing impaired.

K. Murao et al. (Eds.): MobiCASE 2018, LNICST 240, pp. 21–39, 2018.
https://doi.org/10.1007/978-3-319-90740-6_2

There is little work done yet to assist dancing despite reports of hearing impaired performing dances publicly [8, 9]. For recreational performances, the dancers rely on visual aids such as video from displays or gestures from assisting staff nearby the stage. For professional performances, the dancers mind-count based on music tempos memorized by heart. The latter case is particularly challenging and the cognitive loads of these dancers are two-fold: the dance moves and the rhythm. Precise recollection of movement timings, just like precise execution of dance moves, might require a human being of exceptional talent to perform [10, 11].

Not only so, music and dance trainings in early childhood are known to benefit one's motor skill development and have long-lasting effect into the adulthood [12]. Dancing to the music, in particular, help perfect the arm and leg coordination [13]. More recent work finds music training has even broader influence to cognitive development, including memory, language, reading ability, and executive function [14].

Feeling the rhythm in the music can be made easy and affordable. Our premise in this work is that – DanceVibe, the proposed system, helps learning and performing dances for the hearing impaired, and therefore lowering the threshold for the hearing impaired to enjoy rhythm and dancing.

DanceVibe consists of two components. The Beat Extraction component pre-processes the music sound wave and captures the rhythm, i.e., timing of the beats, in the music. The rhythm file can be uploaded and later replayed on the DanceVibe gloves or belts. By feeling the vibrations generated by the wearable part of DanceVibe, the users receive continuous cues of the beats in the music. An analogy of the DanceVibe system is how we often convert the music into digital mp3 format today. We then can load the file to a mobile mp3 player and later listen to the music as we go. Unlike the usual mp3 experience, we extract only the beats in the music into a digital file, play the file back on a wearable module that vibrates at the time of the beats, and therefore communicating the rhythm to the listeners. The wearable part of DanceVibe is implemented in two wearable forms: glove and belt to accommodate different stage performance needs.

Thirty-five people of different degree of hearing impairment have volunteered to participate in the user study over 3-month time. In the experiment, each volunteer first learns the dance with the help of an instruction video and DanceVibe in the first phase and performs the dance in three different assistive dance performance settings: (1) DanceVibe and video, (2) video only, and (3) DanceVibe only. Professional dancers are invited to score the volunteers as they dance in the three different settings. The volunteers are also requested to fill out a pre-test questionnaire to inform us of their gender, age, level of hearing impairment, use of hearing aid, and prior experience with music and dancing. They are also asked to fill out a post-test questionnaire to express how they rate the DanceVibe experience subjectively.

The major findings are as follows. (1) DanceVibe adds to the conventional visual-aid-based method. In particular, DanceVibe works the best alongside the dance video. (2) DanceVibe does sustain for stage performances where placement of visual aids is restricted. (3) However, for recreational performances, visual aid is still more effective as we observe that DanceVibe works the best for volunteers who have prior music experience, whereas the visual aid approach does not require prior music experience and works well for all volunteers. This suggests that DanceVibe might not be for all the dancers to be. It does require practice and familiarity to the concept of rhythm. (4) Furthermore, according to the post-test questionnaire, feeling the rhythm via vibration is refreshing and interesting to the volunteers. This indicates the vibration-based user interface could help motivating the music and/or dance training for the hearing impaired. When this is done at the early age, the hearing impaired could potentially develop better motor, language, and execution skills.

To sum up, our contribution includes (1) the design and implementation of DanceVibe, (2) the user study on the effectiveness of DanceVibe, and (3) the analysis revealing the caution one should take before considering DanceVibe as a dance performance aid. In the sections to come, we first describe the design and implementation of DanceVibe. The evaluation is carried out progressively. First, we take on a small-scale trial study, which sets us on track for the formal, large-scale user study, which is described subsequently. Lastly, but not the least, we report the findings from both objective dance scores and subjective user feedback.

2 System Design and Prototype

The DanceVibe system consists of 2 components. The beat extraction component processes the music clip and generates the beat-only playback file. The file is transferred and store on a wearable module which vibrates at the beats and therefore communicates the rhythm to the user.

2.1 Beat Extraction

There are two phases of computation involved in identifying the beats in the music. In the first phase, the system estimates the peaks in the raw sound waves. Figure 1 shows

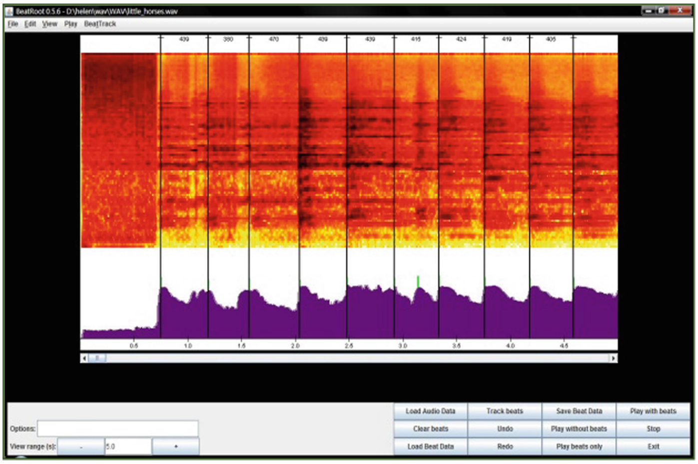

Fig. 1. Raw signals of a music segment. The peaks of the sound wave are the onsets of the beats. The time duration between the peaks are referred to as the inter-onset interval (IOI).

the raw signal of a music segment. The peaks in the plot indicate the onsets of the beats. Identifying timing of the peaks allows estimating of the inter-onset interval (IOI), which enables playback of the beats for the beat player component.

There are two approaches to identify peaks. One is to envelop a wave segment by tracing a pair of consecutive local maximums in the signal amplitude. The other is to exploit time-frequency processing such as the wavelet transform to identify the timing of the energy peaks at the frequency of interest. The challenge is however that both approaches could potentially be erroneous depending on the music, as well as the recording quality.

To mitigate the problem in peak estimation, more recent solutions [15–17] refine the peak estimations by aligning them to the tempo derived from multiple peak estimations in the music. We adopt BeatRoot [18], which is open source and shown outperforming prior works, for the beat extraction function.

2.2 Wearable Vibrator

The vibrator module consists of an 8-bit microcontroller, an IEEE 802.15.4 compliant radio transceiver, and a high-speed motor. Given the simplicity of the vibrating function, we choose the commonly used MSP430 and CC2420 chipsets for the control and communication functions on board. The only caution applied in the hardware design is the choice of the motor. Preliminary testing shows that low-power motors might not provide strong enough sensation when the users are more engaged in dance moves. On the other hand, high power motors can be too bulky to wear which does not serve the purpose of the system well either. The eventual choice, a 20000 RPM high-speed motor, is considerably small and sensible. See the small metal cylinder extending to the left of the main module in Fig. 2. The module is packaged into the glove form initially. After receiving feedback from the preliminary experiment, the belt form is developed. Both forms of DanceVibe are shown in Fig. 3. Note that the glove form can be implemented alternatively using a smart watch. Though, the prototype, using low-end microcontroller, is substantially lower in cost and for the waist belt form, there is no commercially available alternative.

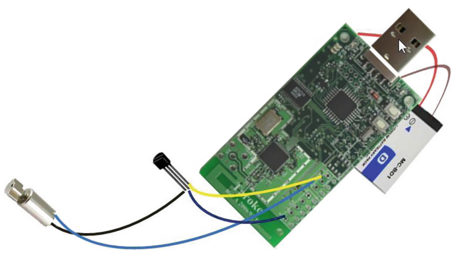

Fig. 2. DanceVibe prototype: (1) The main module contains the MSP430 microcontroller and CC2420, a IEEE 802.15.4 compliant radio, (2) Vibrators are connected to the main module via GPIO.

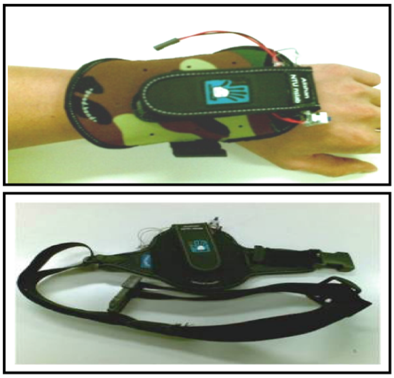

Fig. 3. DanceVibe in two wearing form: (1) Glove (top) and (2) Belt (bottom).

The vibrator is started by a remote controller. Currently, the remote control is implemented as a PC plugged in with the IEEE 802.15.4 radio transceiver. When the user initiates the play function on the PC, it transmits a packet to all Vibrator modules in the area and allows synchronized group dances.

3 Preliminary Study

To validate the design and to try out the prototype, we recruit three users with hearing impairment for a folksong dance lesson in the lab. The three participants, two male and one female, are in their 30s and live an active lifestyle. The dance is typical of folksong dances with 4 simple move sequences and each recurring twice till the end of the music.

The participants are first instructed to put on the DanceVibe glove (Fig. 4, Left). In the learning phase, the glove is on with vibrating beats as the instructor shows each of the move sequences with the music played synchronously. After observing a couple of

Fig. 4. Experimental procedure: (1) Trying out the DanceVibe Glove (Left). (2) Learning to dance by following the instructor's moves (Right).

times, the participants begin to mimic the moves of the instructor (Fig. 4, Right). The practice phase continues for some 5–10 min until the participants are confident dancing by themselves.

In the performing phase, the participants perform the full dance twice (Fig. 5, Left). Once with the music and beats in synchronization. The other with the music and beats off sync. We observe distinctively that the participants dance to the beats communicated from the glove, as opposed to following the music. To conclude the experiment, all of us, including the participants with hearing impairment and the experiment administrators with healthy hearing, dance to the beats and music respectively (Fig. 5, Right).

Fig. 5. Experimental procedure: (1) Dancing alone with the DanceVibe (Left) and (2) Group dancing by all with the DanceVibe (Right).

The three participants are interviewed following the experiment. The major findings are as follows. (1) All of them find the device odd but the experience interesting and fun. (2) The DanceVibe works intuitively and does not distract them visually while learning the dance moves. One participant, who has experience performing to the public, share openly that: (3) the device might be more of stage use where placement of visual aids on stage are often restricted. Dancers on stage rely on mind counts to keep in sync with the music. This can be difficult depending on the music the performers will be dancing to. (4) On the other hand, in the learning phase, visual aids are necessary anyway. It is not clear how much DanceVibe would help. (5) Although the DanceVibe is compact, it would provide more flexibility for costume design if more wear forms are available. The findings are encouraging and the feedback prompts us to implement the belt form DanceVibe.

4 User Study

The objective of the user study is to evaluate the effectiveness and usability of DanceVibe and compare it to the commonly used visual aid approach, i.e., showing of dance video. The test subjects are invited to the lab and instructed to follow an experimental procedure that is substantially extended from the preliminary trial. The sessions are recorded and each subject is asked to complete a pre-test questionnaire for basic information and a post-test questionnaire regarding the experience with DanceVibe.

4.1 User Selection

According to our observation and user feedback from the preliminary trial, it is likely that DanceVibe might be more of use for a certain population but not the others. To enable further analysis on a number of user-specific factors, we recruit volunteers of both gender, varying age, varying degree of hearing impairments, varying level of dance or music experience, and varying level of sports activities. 35 people of hearing impairment participate in the study.

Each volunteer is provided a pre-test questionnaire to complete before the experiment starts. See the questionnaire in Table 1. See also Table 2 for a detailed summary of the 35 volunteers and their attributes. There is a 43% to 57% gender balance in the population. There is also a significant age and hearing impairment severity span. As hearing aid is becoming economically affordable, a majority of the population wear hearing aid and live rather active lifestyles, with some degree of music, dance, and sports experience.

4.2 Procedure

The procedure is similar to the preliminary trial. Each volunteer is instructed to go through 4 stages of the experiment: (1) wear the DanceVibe, (2) learn the dance moves, (3) practice the dance, and (4) perform the dance.

To speed up the learning process, we record the instructor dancing to the music and edit the video so it runs in a karaoke-like style. In the video, captions indicating a sequence of moves are added. Figure 6 shows a user learning to dance by watching the dance karaoke video and feeling the vibrations from the DanceVibe (right wrist). At the bottom of the projection screen, the volunteer sees 8 moves. Translated, they mean move left, step, move right, step, move left, step, step, and stop. The moves are simple by design. This is to lower the learning curve and take the volunteer's cognitive load off from executing the moves, and therefore focusing on feeling the beats from DanceVibe. Note though the learning curve could still be steep for volunteers who has little experience with music or dance.

After learning the moves and the sequence, the volunteers are allowed to practice as many times as they want until they are comfortable for the final test dance. At the final stage, the volunteers are instructed to dances 3 times, first with the karaoke style dance video and DanceVibe, (2) with just the video, and (3) with just the DanceVibe. The test dance performances are video recorded for analysis later. When all 3 test dances are completed, the volunteers are asked to complete the post-test questionnaire (Table 3) and a short interview before receiving the compensation for their time and effort.

Table 1. Pre-test questionnaire.

1. Gender:	□ Male □ Female
2. Age:	□ ≤ 17 □ 18~35 □ 36~64 □ ≥ 65
3. Hearing Impairment:	□ Slight □ Moderate □ Severe
4. Are you wearing any hearing aid?	□ Yes □ No
5. Have you listened to music before?	□ Yes □ No (If no, jump to question 8)
6. Do you listen to music often?	□ Yes □ No
7. How do you listen to music?	□ Just listen □ Turn up the volume □ Sense the vibration □ Visual effect or dance move □ Body or sign language □ Headphone or earphone □ Others ________________
8. Have you danced before?	□ Yes □ No (If no, jump to question 11)
9. Do you dance often?	□ Yes, for____year(s) □ No
10. How do you listen to the music while dancing:	□ Just listen □ Turn up the volume □ Feel the vibration on the dance floor □ Mind count □ Visual aid from friends □ Others ________________
11. Do you do any sports regularly?	□ Yes □ No (If no, skip rest of the questions)
12. Frequency of sports activities:	□ < 1 □ once a week □ twice □ 3 times □ 4 or more
13. Duration of the sports sessions:	□ 30 mins □ 1 hr □ 2 hrs □ 3 hrs or more
14. Preferred sports activities :	□ swimming □ team sport such as baseball/basketball □ running □ yoga/aerobic □ others ________________

4.3 Data Collection and Processing

User experience is multi-facet. Both subjective and objective measures are essential to a well-around understanding of the system. For the subjective user experience, we quantify the feedback provided by the volunteers in the post-test questionnaires. The 5 options, disagree, mildly disagree, neutral, somewhat agree, very much agree, are converted to numerical scores 1 to 5 respectively.

For objective user experience, we find the effectiveness of DanceVibe better captured by evaluating the dance performance. To quantify how well each volunteer dances in different settings, we invite 3 professional dancers to screen the video recordings and score each dance from 1 to 5. To be specific, the screeners are provided the scoring guideline (Table 4). Each video receives 3 scores.

The pre-test questionnaires are mainly to allow further analysis of how a user subgroup respond stronger or weaker to the use of DanceVibe.

Table 2. Summary of the test subjects.

Age	18–35 26(74.2%)	36–64 8(22.8%)	>65 1(2.8%)	Sum 35
Gender				
M	8	6	1	15(42.8%)
F	18	2	0	20(57.1%)
Hearing impairment				
Slight	6	0	0	6(17.1%)
Moderate	5	0	0	5(14.2%)
Severe	15	8	1	24(68.5%)
Wearing hearing aid				
Yes	25	1	0	26(74.2%)
No	1	7	1	9(25.7%)
Prior music experience				
Yes	25	3	1	29(82.8%)
No	1	5	0	6(17.1%)
Prior dance experience				
Yes	20	5	0	25(71.4%)
No	6	3	1	10(28.5%)
Regular sports activity				
Yes	21	6	1	28(80%)
No	5	2	0	7(20%)

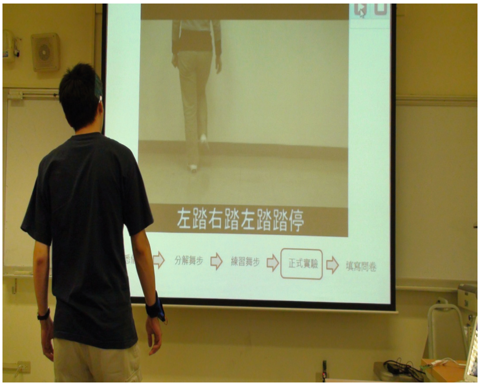

Fig. 6. A volunteer dancing to the instruction video with the DanceVibe glove on his right wrist.

4.4 Hypotheses and Tests

The main hypotheses surround (1) whether different assistive settings, with or without DanceVibe, affects significantly the volunteers' dance performance, (2) whether any of the factors impact significantly the volunteers' dance performance, (3) whether any of

Table 3. Post-test questionnaire.

1. Dancing is fun.				
□ Disagree	□ Mildly disagree	□ Neutral	□ Somewhat agree	□ Very much agree
2. The dance you just learned is not difficult.				
□ Disagree	□ Mildly disagree	□ Neutral	□ Somewhat agree	□ Very much agree
3. It is interesting learning to dance via vibrations.				
□ Disagree	□ Mildly disagree	□ Neutral	□ Somewhat agree	□ Very much agree
4. DanceVibe is helpful learning to dance.				
□ Disagree	□ Mildly disagree	□ Neutral	□ Somewhat agree	□ Very much agree
5. DanceVibe is helpful learning to dance even without the video.				
□ Disagree	□ Mildly disagree	□ Neutral	□ Somewhat agree	□ Very much agree

Table 4. Video scoring guideline.

1: Missing almost all beats
2: Missing more than half of the beats
3: Dancing to about half of the beats
4: Dancing to more than half of the beats
5: Dancing almost all move on beat

the factors impact significantly how the volunteers feel about dancing and using DanceVibe.

For the first main hypothesis (H1), 3 sub-hypotheses (H1-1 to H1-3) are tested to further analyze which pair of assistive settings are more different than the others.

- **H1**: The dance performance is significantly different among the assistive dance settings.
- **H1-1**: The dance performance is significantly different between the DanceVibe and Video vs. the Video only setting.
- **H1-2**: The dance performance is significantly different between the DanceVibe and Video vs. the DanceVibe only setting.
- **H1-3**: The dance performance is significantly different between the Video only vs. the DanceVibe only setting.

For the second main hypothesis (H2), 7 sub-hypotheses (H2-1 to H2-7) are tested to see if any of the volunteer-specific factors are more influential than the others.

- **H2**: The dance performance is significantly different depending on any of the factors.
- **H2-1**: The dance performance is significantly different between the 2 genders.

- **H2-2**: The dance performance is significantly different between the 2 age groups.
- **H2-3**: The dance performance is significantly different between the 3 hearing impairment level groups.
- **H2-4**: The dance performance is significantly different between the 2 groups wearing the hearing aid or not.
- **H2-5**: The dance performance is significantly different between the 2 groups having prior music experience or not.
- **H2-6**: The dance performance is significantly different between the 2 groups having prior dance experience or not.
- **H2-7**: The dance performance is significantly different between the 2 groups having prior sports experience or not.

For the third hypothesis (H3), we perform tests on each of the questions in the post-test questionnaires and check if any of the factors makes a difference. There are in total 5 by 7 sub-hypotheses. In the result, we present only the sub-hypothesis that at least one factor plays a statistically significant role in the subjective feedback.

- **H3**: Any of the questions in the post-test questionnaire is significantly different depending on any of the factors.

We apply commonly used statistical techniques to examine whether multiple data samples are significantly different. Specifically, the T test [19] is used to check if two data samples are from the same distribution and the ANOVA test [20] is used for the cases of 3 data samples or above.

The t-value and f-value represent how far apart the sample means are from each other for the T and ANOVA test respectively. From both tests, the generated p-value reflects the variation of the possible means. The smaller the variation, the more confident the test is about whether the sample means are from the same distribution or not. Typically, we seek a p-value smaller than 0.001 or 0.01. We mark a p-value smaller than 0.001 with *** indicating strong confidence and for p-value smaller than 0.01 with ** indicating moderate confidence.

In case we need to examine if certain factor pairs are correlated (so we can trace back to the root cause), the Chi Square test [21] is applied. When the p-value generated by the test is small, the correlation in the factor pair is statistically significant.

5 Result - Dance Performance

Each volunteer's dance is evaluated by 3 expert dancers. All 35 volunteers dance to the music in 3 different assistive dance settings: DanceVibe and video, video only, and DanceVibe only. Therefore, for each setting, we receive 105 scores for the statistical analysis. Below we present first the results of how well the volunteers dance in the 3 assistive settings (Hypothesis H1) and then analyze how the volunteer might react differently depending on factors such as hearing impairment severity and prior music experience (Hypothesis H2).

5.1 Comparison of 3 Assistive Settings

We pass the scores from each of the 3 settings through the ANOVA and T test. Table 5 shows the outcome of the ANOVA test. An f-value of 10.43 and a p-value of less than 0.001 suggests that some of the 3 settings are significantly different, confirming Hypothesis H1. Furthermore, applying the T test on each pair of settings (see Table 6) shows the 3 settings are significantly different from each other. Every pair shows a p-value of less than 0.001, which confirms Hypothesis H-1.1, H-1.2, and H-1.3.

Table 5. One-Way ANOVA test result.

Source	SS	df	MS	f-value	p-value
3 assistive dance settings	14.76	2	7.38	10.43	<.001
Error	72.13	102	0.70		
Total	86.90	104			

Table 6. Pairwise t-test result.

Test settings	# of Scores tested	t-value	p-value
DanceVibe and Video vs. Video only	105 vs. 105	4.51	<0.001
DanceVibe and Video vs. DanceVibe only	105 vs. 105	7.97	<0.001
Video only vs. DanceVibe only	105 vs. 105	5.87	<0.001

Now we examine quantitatively which of the 3 settings stands the best and which the worst. Table 7 enlists the average score and the standard deviation per assistive dance setting. One can observe that DanceVibe and video together work the best overall. An average score of close to 4 signifies that the volunteers are able to dance the majority of the moves on beat. The video only setting does not quite compare, which suggests that DanceVibe enhances the learning and performance process.

Table 7. Average and standard deviation of the dance scores.

Test settings	# of Scores collected	Average	Standard deviation
DanceVibe and video	105	3.94	0.81
Video only	105	3.56	0.77
DanceVibe only	105	3.02	0.92

The DanceVibe only setting however performs significantly worse than the video only setting. The message is that visual stimulus is more effective than vibrations as it communicates not just the beats but also the moves. Nonetheless, the average score of the DanceVibe only setting suggests that the volunteers on average catches half of the beats in a dance which would have been impossible for the severely hearing impaired. For circumstances that placement of visual aid might be restricted (e.g., stage performance), DanceVibe provides as a sensible alternative that is less intrusive to the environment.

5.2 Impact of Dancer-Specific Factors

To understand whether a certain population benefit more from DanceVibe than the others, we group the scores by a number of factors that we have surveyed in the pre-test questionnaire. For factors that are binary, we apply the t-test and examine the t-value and p-value to see if the difference between the 2 groups are significant. For factors that are trinary or higher, we apply the ANOVA test and examine the f-value and p-value to see if the difference among the groups are significant. Below, we present first the influence of the personal attributes such as gender, age, and hearing impairment level. Next, we discuss the influence of habit related factors such as wearing of hearing aid, experience with music, dancing, and sports activities.

5.2.1 Personal Attributes

Among the 3 personal attributes (Tables 8, 9 and 10), gender's influence to dance performance is minimum, and this is the case for all 3 settings. While the volunteers of varying degree of hearing impairment show some difference in the dance performance, the p-values suggest that the score variation is high and the difference in the average scores is not statistically significant.

Table 8. t-test result for the influence of gender in 3 test settings.

Test settings	Average score		t-value	p-value
	Male	Female		
DanceVibe and video	3.93	3.95	−0.059*	*<0.05
Video only	3.55	4.56	−0.04*	*<0.05
DanceVibe only	2.82	3.18	−1.14*	*<0.05

Table 9. t-test result for the influence of age in 3 test settings.

Test settings	Average score		t-value	p-value
	18–34	35–65+		
DanceVibe and video	4.16	3.29	3.11**	**<0.01
Video only	3.75	3.00	2.74**	**<0.01
DanceVibe only	3.28	2.29	3.07**	**<0.01

Table 10. t-test result for the influence of hearing impairment level in 3 test settings.

Test settings	Average score			f-value	p-value
	Slight	Moderate	Severe		
DanceVibe and video	4.39	3.87	3.85	1.10*	*<0.05
Video only	4.11	3.73	3.39	2.38*	*<0.05
DanceVibe only	3.78	3.2	2.81	3.07*	*<0.05

Age is a factor that incurs a significant difference. Younger volunteers dance better than the older ones. This could be partly that the younger volunteers are generally more agile and fond of physical activities. This could also be contributed by the fact that the hearing aids are growingly affordable and the support from the social welfare system has been strengthened. As a result, the younger generations of the hearing impaired are cared by specialists and wear hearing aids at an early age. We do observe commonly that the young volunteers cite their experience with sound and music in the pre-test questionnaire. To confirm the conjecture, we present how the three factors, age, hearing aid, and music experience, are correlated in Sect. 5.2.3.

Hearing impairment level does not influence the dance performance significantly. The chance is high that hearing aid has compensated the factor for most volunteers as we do observe a high percentage of volunteers participating in the study wearing a hearing aid.

In summary, Hypothesis H2-2 is validated while H2-1 and 2-3 are invalidated. Note that H2 is also validated as one of the H2-x is shown statistically true.

5.2.2 Habit-Related Factors

Influence of the remaining factors are discussed in this subsection. Firstly, we compare the dance scores of the groups with hearing aid vs. not are statistically different (Table 11). This is not entirely surprising, as being able to hear to some degree would have helped in addition to all the other aids. We are particularly interested in the result of the video only setting. Among the 3 settings, the video only setting shows less a difference. This is likely due to the visual nature of the setting. Being able to hear does not matter much. Though in the meantime, rhythm is indeed a non-negligible component in the learning and dancing process. The vibrations serve the purpose of adding to the visual aid and provide as a *richer* reminder to the volunteers.

Table 11. t-test result for the influence of wearing hearing aid in 3 test settings.

Test settings	Average score		t-value	p-value
	Hearing aid	No aid		
DanceVibe and video	4.17	3.25	3.34**	**<0.01
Video only	3.74	3.03	2.52*	*<0.05
DanceVibe only	3.28	2.29	3.07**	**<0.01

Prior music experience is a unique factor. It influences only one setting – the DanceVibe only setting (see Table 12). It appears that, in the 2 other settings, the volunteers are able to keep up with the moves provided the visual cues. This is understandable, as prior visual experience would matter more to the interpretation of the visual cues, rather than prior music expeirence. This suggests also, without the video in the DanceVibe only setting, vibrations are the only cues the volunteers are receiving and prior music experience is crucial interpreting the vibrations, i.e., the rhythm. Having a good sense of rhythm makes a difference when using DanceVibe, and such a sense is typically fostered by prior experience with periodic processes, e.g., listening to music.

Table 12. t-test result for the influence of music experience in 3 test settings.

Test settings	Average score		t-value	p-value
	Music exp	No exp		
DanceVibe and video	4.08	3.27	2.35*	*<0.05
Video only	3.68	2.94	2.25*	*<0.05
DanceVibe only	3.25	1.94	3.68***	***<0.001

Once the sense of rhythm is established, how frequent one practices the skill does not seem to matter much, as we see in Table 13 that the difference between the frequent and infrequent music appreciators is insignificant.

Table 13. t-test result for the influence of music appreciation frequency in 3 test settings.

Test settings	Average score		t-value	p-value
	Frequent	Not frequent		
DanceVibe and video	4.17	3.72	1.31*	*<0.05
Video only	3.82	3.16	1.54*	*<0.05
DanceVibe only	3.28	3.11	0.32*	*<0.05

In summary, Hypothesis H2-4 and H2-5 are validated.

The influence of the dance and sports activities is even less and not statistically significant. See Tables 14, 15 and 16. The reason is likely that the dance moves are simple by choice, so it does not require volunteers to be athletic to learn or perform. How often the volunteers dance and what sports they play are even less influential.

Table 14. t-test result for the influence of prior dance experience in 3 test settings.

Test settings	Average score		t-value	p-value
	Yes	No		
DanceVibe and video	3.93	3.96	−0.10*	*<0.05
Video only	3.64	3.36	0.93*	*<0.05
DanceVibe only	3.05	2.96	0.24*	*<0.05

Table 15. t-test result for the influence of dance frequency in 3 test settings.

Test settings	Average score		t-value	p-value
	Frequent	Not frequent		
DanceVibe and video	4.5	3.82	1.6*	*<0.05
Video only	4.33	3.50	2.12*	*<0.05
DanceVibe only	3.75	2.92	1.69*	*<0.05

In summary, Hypothesis H2-6 and H2-7 are invalidated.

Table 16. t-test result for the influence of prior sports experience in 3 test settings.

Test settings	Average score		t-value	p-value
	Yes	No		
DanceVibe and video	3.91	4.04	−0.37*	*<0.05
Video only	3.55	3.57	−0.03*	*<0.05
DanceVibe only	3.03	3.00	0.08*	*<0.05

5.2.3 Interaction Between Factors

To validate the conjecture that most young volunteers wear hearing aid and therefore more experienced with music, we show in Tables 17, 18 and 19 the percentage of volunteers at different age groups who wear hearing aid, volunteers at different age groups who have prior music experience, and volunteers wearing hearing aid who have prior music experience. The Chi Square test finds a p-value of less than 0.001 for all three factor pairs, indicating statistically significant correlation in all factor pairs.

Table 17. Correlation between age and hearing aid.

Age	18–34 N(%)	35–65+ N(%)	Sum N(%)
Wearing hearing aid			
Yes	25(71.43)	1(2.86)	26(74.29)
No	1(2.86)	8(22.86)	9(25.71)
Chi Square test output: $\chi^2 = 29.07$ p = 4.874E-07 (***<.001)			

Table 18. Correlation between age and prior music experience.

Age	18–34 N(%)	35–65+ N(%)	Sum N(%)
Prior music experience			
Yes	25(71.43)	4(11.43)	29(82.86)
No	1(2.86)	5(14.29)	6(17.14)
Chi Square test output: $\chi^2 = 15.71$ p = 0.0003887 (***<.001)			

Table 19. Correlation between prior music experience and wearing hearing aid.

Prior music exp	Yes N(%)	No N(%)	Sum N(%)
Wearing hearing aid			
Yes	25(71.43)	1(2.86)	26(74.29)
No	4(11.43)	5(14.29)	9(25.71)
Chi Square test output: $\chi^2 = 15.71$ p = 0.0003887 (***<.001)			

Table 20. Post-test questionnaire score average and standard deviation.

Question set	Average	Standard deviation
Q1: Dancing is fun	4.51	0.78
Q2: The dance I just learned is not difficult	4.37	0.59
Q3: It is interesting to feel the beats in music through vibrations	4.31	0.75
Q4: DanceVibe helps learning to dance	4.05	0.90
Q5: Without the video, DanceVibe helps performing dance	3.71	1.04

6 Result – Post-test Questionnaire

Summarized in Table 20 is the result of the post-test questionnaire. We can see that the volunteers in general find that (Q1) dancing is fun, (Q2) the dance they have learned in the experiment is not difficult, and (Q3) feeling the beats in the music via vibration is fun. We see in the standard variable of the scores that while the volunteers are more consistent about the difficulty level of the dance, the opinion on whether dancing or feeling the beats through vibration is interesting is more diverged. This indicates that there is some degree of variability in the volunteers' personal interest about dancing and music, which shows diversity in the volunteers participating in the user study.

More importantly, the users are positive that (Q4) DanceVibe helps in the learning process. This echoes the finding from the dance performance scores. The volunteers do learn better with not just the instruction video but also DanceVibe. Note that in the learning phase of the experiment, the instruction video is always in display. On the other hand, the volunteers agree only partially that (Q5) DanceVibe helps in dance performance. As we see in the testing phase, the volunteers perform the worst wearing only DanceVibe. The volunteers are self-conscious of their performance and their answers to Q4 and Q5 reflect so.

One particular result to present is the relative difference between volunteers who have prior dance performance experience and rely on mind counting to track the beats in the music while dancing. The average score to Q5 in this group of volunteers is 4.22, which is significantly higher than the overall average 3.71. This supports Hypothesis H3 and echoes what one of the volunteers in the preliminary trial has commented. DanceVibe would be helpful to stage performance that placement of visual aid is constrained.

7 Conclusion

In this study, DanceVibe is shown effective assisting dance learning and performing well aside the conventional video-based method. In particular, DanceVibe does sustain for stage performances that placement of visual aids is restricted. One word of caution though is that DanceVibe might not be for all the dancers to be. It does require practice and familiarity to the concept of rhythm.

A surprising finding is that the users do find the form of user interaction, i.e. feeling the rhythm via vibration, refreshing and interesting. This indicates the potential of DanceVibe as an aid in music or dance training for children. Children, relative to adults, are more prone to fun activities. With DanceVibe being fun, children of hearing impairment are more likely to accept music and dance training and therefore develop better motor, language, and execution skills in the long run.

Using vibration as an HCI has potential. To this point, the vibrations communicated are simply the beats extracted from the music. There is a good design space expressing the music through vibration patterns. For example, the power or sudden breakage of beats in the music can be cues for dramatic moves that are more expressive of the ambient emotion. Furthermore, there is an increasing number of performances embracing digital art forms. In these performances, synchronization among dancers and the on-stage projections can be critical. If the vibration feed takes into account how individual dancer reacts slower or faster to the vibrations, fine-grained synchronization might be possible and therefore creating a seamless flow. We are currently looking into these possibilities to enable richer dancing experience for the hearing impaired.

References

1. Salimpoor, V.N., Benovoy, M., Larcher, K., Dagher, A., Zatorre, R.J.: Anatomically distinct dopamine release during anticipation and experience of peak emotion to music. Nat. Neurosci. **14**, 257–262 (2011)
2. Sievers, B., Polansky, L., Casey, M., Wheatleya, T.: Music and movement share a dynamic structure that supports universal expressions of emotion. Psychol. Cogn. Sci. **110**(1), 70–75 (2013)
3. Michal Doron Harari: "To be on stage means to be alive" theatre work with education undergraduates as a promoter of students' mental resilience. Soc. Behav. Sci. **209**(3), 161–166 (2015)
4. Donahue, A., Dubno, J.R., Beck, L.: Accessible and affordable hearing health care for adults with mild to moderate hearing loss. Ear Hear. **31**(1), 2–6 (2010)
5. Goldstein, J.M.H., Proctor, A.: Tactile aids for profoundly deaf children. J. Acoust. Soc. Am. **77**, 258–265 (1985)
6. Darrow, A.A.: The effect of vibrotactile stimuli via the Somatron on the identification of rhythmic concepts by hearing impaired children. J. Music Ther. **26**(3), 115–124 (1992)
7. Nanayakkara, S., et al.: An enhanced musical experience for the deaf: design and evaluation of a music display and a haptic chair. In: Proceedings of the 27th International Conference on Human Factors in Computing Systems, Boston, MA, USA (2009)
8. Berselli, M., Lulkin, S.A.: Theatre and dance with deaf students: researching performance practices in a Brazilian school context. Res. Drama Educ. J. Appl. Theatre Perform. **22**(3), 413–419 (2017)
9. Hill, K.: Delightful! Deaf Dance Competitors Move to The Beat. The Gleaner, 15 May 2016
10. Peltier, C.: Inspirational Deaf Dancer Uses Vibrations to Coordinate His Moves And Proves Anyone Can Do Anything. A Plus. 31 Mar 2016
11. Traynor, R.: The Dance of a Thousand Hands. Hearing Health & Technology Matters, 4 April 2016
12. Costa-Giomi, E.: Does music instruction improve fine motor abilities? Ann. New York Acad. Sci. **1060**, 262–264 (2005)

13. Washburn, A., DeMarco, M., de Vries, S., Ariyabuddhiphongs, K., Schmidt, R.C., Richardson, M.J., Riley, M.A.: Dancers entrain more effectively than non-dancers to another actor's movements. Front. Hum. Neurosci. **8**, 800 (2014)
14. Miendlarzewska, E.A., Trost, W.J.: How musical training affects cognitive development: rhythm, reward and other modulating variables. Front. Neurosci. **7**, 279 (2013)
15. Duxbury, C., et al.: A hybrid approach to musical note onset detection. In: Proceedings Digital Audio Effects Workshop (DAFx) (2002)
16. Bello, J.P., et al.: A tutorial on onset detection in music signals. IEEE Trans. Speech Audio Process. **13**, 1035–1047 (2005)
17. Klapuri, A.: Sound onset detection by applying psychoacoustic knowledge. In: 1999 IEEE International Conference on Acoustics, Speech, and Signal Processing, ICASSP 1999, vol. 6, pp. 3089–3092 (1999)
18. Dixon, S.: Evaluation of the audio beat tracking system BeatRoot. J. New Music Res. **36**, 39–50 (2007)
19. Student: The probable error of a mean. Biometrika **6**(1), 1–25 (1908)
20. Fisher, R.A.: Statistical Methods for Research Workers. Oliver & Boyd, Edinburgh (1925)
21. Pearson, K.: On the criterion that a given system of deviations from the probable in the case of a correlated system of variables is such that it can be reasonably supposed to have arisen from random sampling. Philos. Mag. Ser. 5 **50**(5), 157–175 (1900)