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Practical Feedback Method for Mobile CPR Support Systems Considering Noise and User's Attention

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Abstract: In this study, with the aim of improving bystander CPR support using a smartphone and a smartwatch, we evaluated six feedback methods considering practical situations. Since CPR is sometimes required to be conducted in a noisy place, each method was evaluated with 50 dB and 80 dB noise environments, which correspond to a silent office and a noisy construction site, respectively. Also, considering the requirement for a bystander to maintain the safety of him/herself and in order to give appropriate care to the patient, the capability of noticing change in patient condition during CPR was evaluated. From the evaluation results, the best feedback method is a method that uses voice, a metronome sound and a graphic display on a smartphone and vibration and graphic display on a smartwatch if both a smartphone and a smartwatch are available. For only a smartphone, the result shows that feedback using only voice is better in the loud environment, while feedback using voice and clicking sounds is the best in the quiet environment. Moreover, with regard to the subjective feeling, feedback using only a smartwatch is worse than other methods, and it is recommended to be used in conjunction with a smartphone.

Keywords: cardiopulmonary resuscitation (CPR) support, smartwatch, smartphone, cognitive load, evaluation in practical situation

1. Introduction

In the situation of an emergency rescue, starting treatment for basic life support (BLS) in a short time is quite effective for increasing the survival ratio of patients and for preventing serious after effects. For this, an on-site person in the proximity of the patient, namely a "bystander", is essential to give such treatments. Especially, in the case of a cardiac arrest, which is called an out of hospital cardiac arrest (OHCA), the survival ratio of a patient decreases rapidly with respect to the minutes taken to start cardiopulmonary resuscitation (CPR). There are some reports that have shown that a shorter delay in starting CPR improves the survival ratio with statistical difference, and this is at around four minutes [1], [2]. On the other hand, in the case of Japan, the average response time of an ambulance is currently more than eight minutes, and this response time is increasing year by year according to a report by the Japanese Fire Defense Agency [3]. Thus, an ordinary person, who could be a bystander if the occasion arises, is required to be able to do CPR in an emergency situation.

Most people learn the CPR method in a school and/or when they get a driver's license. However, many of them do not have a chance to have successive training. This causes hesitation to do CPR when faced with an emergency situation. From the result of our original survey, few people answered that they can perform CPR to a patient with confidence in an emergency situation, while many people are willing to perform it if they can.

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To solve this problem, some CPR support systems have been developed. Some studies have tried to develop a designated CPR support device [4], [5]. PocketCPR [6] and Q-CPR [7] are examples of designated devices that are already available commercially. Also, along with the development of mobile devices, some studies try to support CPR by using a smartphone and a smartwatch, by recognizing a user's CPR activity with its embedded inertial measurement unit (IMU) [8], [9], [10], [11]. Since these devices are much more regularly carried by people than specialized devices, these could be expected to contribute to significantly increasing the possibility of bystander CPR. However, most of the previous studies of these devices evaluated effectiveness in a static setting. Namely, evaluations are held in a silent room, such as in a laboratory, with a doll that does not move.

Considering an actual situation, CPR has to be given to a patient not only in silent places but in very loud places, such as a busy road, a factory, or a construction site where an accident occurs. Thus, the system's feedback is required to be effective in noisy situations. Also, a bystander giving CPR is required to pay attention to his/her surroundings, namely not exclusively concentrate on CPR, in order to maintain their own safety in an accident environment. It is also important for giving appropriate care to the patient, such as moving a patient's body into the recovery position when he/she regains consciousness, which is recommended by the BLS guideline [12]. Thus, considering the practicality of CPR support systems, the feedback method must be evaluated with more practical situations. There are some studies that focus on the effect of the feedback method, such as Ref. [13], but they still conduct experiments in a lab setting.

Thus, in this study, we evaluate CPR feedback methods on a smartphone and a smartwatch with two types of noise condition, 50 dB and 80 dB. Also, the performance is evaluated with the number of times that a subject notice for a patient's body movement during performing CPR and their delay as well with the ratio of correct compressions which are within the correct pressure and tempo defined in the guideline. The noise of 50 dB corresponds to the noise level of a silent office, and 80 dB is the level of a very noisy construction site. The body movements of the patients are generated by tablet PCs placed at the head and right hand position of a CPR training mannequin. As feedback methods we evaluate voice, click sounds like that from a metronome, and the graphic display on a smartphone as well as vibration and graphical feedback on a smartwatch.

2. CPR Support System in Experiment

To conduct our experiment, we developed our original CPR support system. Our system gives feedback along the criteria described in the guideline of Japan Resuscitation Council (JRC) for basic life support (BLS) [12]. The method of recommended CPR in the guideline is as follows;

- Compression pressure is sufficiently strong so that the patient's chest sinks more than 5 cm,
- and compression tempo is more than 100 times per one minute [*1]

2.1 Detection of CPR Activity

Figure 1 shows the data flow of our system. The tri-axial acceleration of the user's wrist during CPR is obtained by a smartwatch worn by the user. Then the accelerometer data are sent to a smartphone via Bluetooth communication. After calculating resultant acceleration, r, by

$$r = \sqrt{A_x^2 + A_y^2 + A_z^2} \quad (1)$$

where A_x, A_y, and A_z are each axis of accelerometer data and applying low pass filter ($f_c = 5$ Hz), its amplitude and tempo are

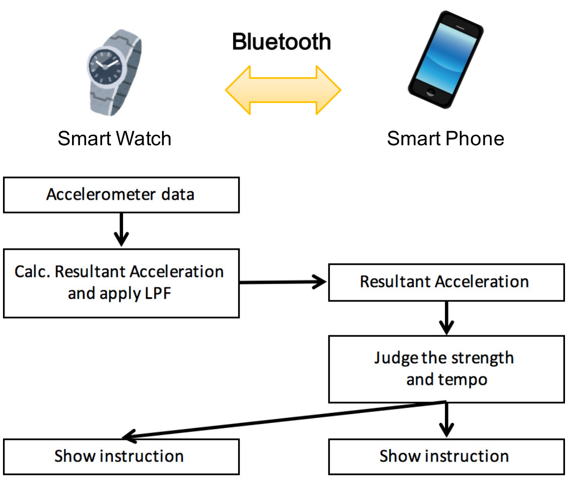

Fig. 1 Data flow of our experiment system.

[*1] These criteria have been changed in that the upper limit has increased from 5 cm to 6 cm for the pressure and from 100 to 120 bpm for the tempo. The change was announced in October 2015 and published in February 2016. However, we had created our system before the announcement and used the old criteria in this study.

calculated on the smartphone. The amplitude is obtained by detecting the gap of upper peak and lower peak with a peak detection technique. The tempo is obtained as the average of the time between five upper peaks. The correctness of CPR is judged by the amplitude and tempo. If these do not exceed certain thresholds, the system gives feedback to the user. The feedback on the smartwatch is initiated by a command sent from the smartphone via Bluetooth.

The threshold of tempo is set as 3 seconds for 5 peaks considering the guideline. To set a suitable threshold for amplitude, we conducted a preliminary experiment. In the experiment, accelerometer data were obtained from wrist-worn sensors, WAA-006 by ATR-Promotions, worn on both wrists while the wearer was performing CPR on a CPR training mannequin, JAMY-P by Yagami. The mannequin gives a click sound if the chest is compressed correctly. With respect to the click sound, we distinguished the correct and incorrect compression, while observing accelerometer data. As the result, we set the threshold of amplitude at 800 mG.

Then, to confirm that our system detects the correctness of the CPR properly, we conducted another experiment with four subjects. All subjects are male university students aged between 22 to 24 years old. We asked them to wear the same accelerometers on both wrists and compress the chest of the mannequin. We did not instruct the method of CPR in detail to the subjects. Thus, the subjects put their hands in a different order, some of them put their right hand over their left hand whilst other subjects placed them in the opposite order. As same as in the preliminary experiment, we distinguished the correctness of compression by the click sound from the mannequin. The accuracy of detecting correct and incorrect pressure was evaluated by comparing the system output referring the sound. The accuracy of tempo detection was also evaluated by the gap of the number of compressions counted by the system and by hand.

The results of pressure and tempo detection are shown in **Table 1** and **Table 2**, respectively. The results show that our system can accurately detect compression pressure and tempo. Moreover, only one accelerometer worn on either wrist gives almost same result as using one on both wrists. Thus, we conclude that the same algorithm works properly on a smartwatch on either wrist of the subject. We implemented the algorithm described in the previous section on a smartphone, Xperia X3 by SONY, and a smartwatch, moto360 by Motorola.

2.2 Feedback Method

In choosing a feedback method, there are various options.

Table 1 Accuracy of pressure detection.

	Precision	Recall	F_1-Score
Both wrist	0.95	0.92	0.93
Right wrist	0.93	0.93	0.93
Left wrist	0.95	0.94	0.94

Table 2 Accuracy of tempo detection.

	The number of detected compression
Both wrist	100 ± 2
Right wrist	100 ± 2
Left wrist	100 ± 2

However, CPR is a very high-load physical activity. Ordinary people get out of breath when doing CPR after a couple of minutes. It is impractical for one subject to conduct many trials with different conditions. Thus, we carefully minimized the number of feedback methods compared in our experiment.

For choosing the feedback methods used in our experiments, we firstly considered the practicality of the devices usage situation. Assuming that a bystander only uses a smartphone for CPR is considered to be practical because a smartphone can work by itself and most people use smartphones without a smartwatch. Meanwhile, although smartwatches are becoming more common, it is generally used as a secondary device for a smartphone (e.g., it only gives a notification and brief summary of an email that is received by a smartphone). Thus, we assume that a smartwatch is used with a smartphone, and not alone. So, we mainly considered cases of using only a smartphone and using both a smartphone and a smartwatch. We omitted the case of using only a smartwatch and decided to have another experiment if the CPR performance is significantly improved when adding a smartwatch on the same feedback on a smartphone.

Next, we considered the I/O devices on a smartphone and a smartwatch. A smartphone has a display and a speaker, and they can give feedback by visual and audio. However, when using only a smartphone, it must be placed on a patient's chest and held in place by the user's hand in order to obtain acceleration data with the internal accelerometer. In this case, the display is hidden making it difficult to display visual information to a user. So we omit the use of a smartphone's display when only a smartphone is used. Another candidate for feedback from a smartphone is vibration. However, as with the display, the smartphone is firmly held by the user's hand and the vibration is expected to be difficult for the user to feel. Moreover, vibration on a smartwatch is expected to be more effective. Thus, we leave the evaluation of the vibration for those cases using the smartwatch. Thus, we consider to only use audio feedback when using only a smartphone.

Since CPR is a periodic activity, we can choose two types of methods for audio feedback. The first is to give a user explicit information on how to improve his/her action. The second method is to give a correct reference, tempo and rhythm in this case, continuously. For giving explicit information, we use voice feedback. If a user's current pressure is weak, the system emits the phrase "Please increase your pressure". If user's current tempo is slow, the system emits the phrase "Please increase your tempo". In addition, if both pressure and tempo are correct, the system emits the phrase "Please continue as is". For giving reference tempo with audio feedback, the system provides a periodic click sound like a metronome. Because of the difficulty of giving feedback for changing pressure with a click sound, we use voice feedback as well as the click sound, in which voice feedbacks are given when the pressure is weak or the tempo is slow as introduced above, while periodical click sounds are continuously given by 100 bpm. As a result, we set conditions of voice feedback that uses only voice and metronome feedback that uses both a voice and the click sound for the cases using only a smartphone.

For feedback on a smartwatch, we referred to the method of Ref. [11], which uses the display and vibration, namely visual and tactile feedback. Reference [11] pointed out the lack of loud speaker and accordingly could not use audio feedback with the smartwatch. For this reason, we omit the audio feedback on a smartwatch, and leave it to a smartphone. When using both a smartphone and a smartwatch, the smartphone can be placed freely because the user's CPR activity is captured by the accelerometer on the smartwatch. Thus, the display on a smartphone is used in all cases of using both a smartphone and a smartwatch. For visual feedback on the display, similar expressions of Ref. [11] are used on both the smartwatch and the smartphone. A green square in the center is displayed if the user's pressure is correct and switches to red if the pressure is too weak, while blinking the frame between black and blue with 100 bpm, as shown in **Fig. 2**.

As described above, the smartwatch is used with a smartphone in an ordinal case, and we displayed graphical feedback on the smartphone always when using a smartwatch. Also, the vibration and the display on a smartwatch are always used at the same time. As a result, **Table 3** summarizes feedback methods in our experiment.

In Table 3, the condition symbol of "No" means there is no instruction method with neither smartphone nor smartwatch. "V" means voice instruction with a smartphone placing near the shoulder of the patient mannequin on the floor, as shown in **Fig. 3**. "M" means with both voice and metronome instructions with a smartphone at the same place as the one of condition "V". "W+G" means graphical instruction shown in Fig. 2 and vibration instruction with a smartwatch worn by a subject, as well as graphical instruction on a smartphone at the same place of "V" and "M" condition. In this case, there is no voice or no metronome instruction on the smartphone. In "W+G+V" condition, voice instruction on the smartphone is added to "W+G" condition. Finally, metronome instruction on the smartphone is added to "W+G+V" condition for "W+G+M" condition.

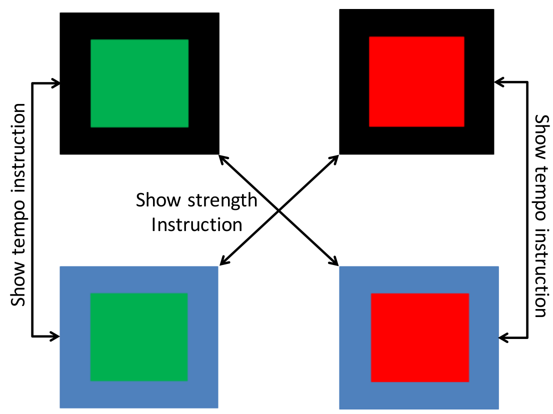

Fig. 2 Instruction using graphic.

Table 3 Instruction methods in experiment.

Condition Symbol	Smartwatch	Smartphone
No	–	–
V		Voice
M		Voice and metronome
W+G	Graphic and vibration	Graphic
W+G+V		Graphic and voice
W+G+M		Graphic, voice and metronome

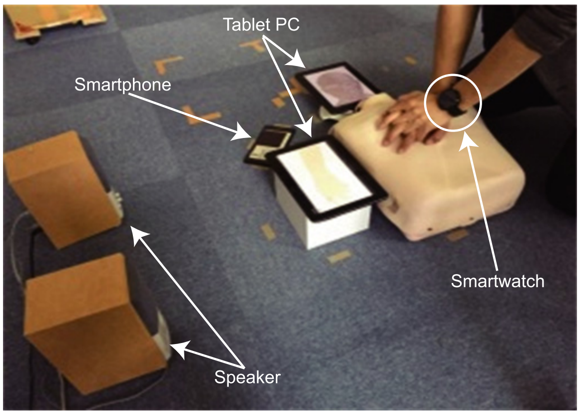

Fig. 3 Photo of an experiment scene.

3. Experiment Method

A photo of the experiment environment is shown in Fig. 3. In the experiment, we tried to compare the six conditions of feedback methods in Table 3 under two types of noise conditions, 50 dB and 80 dB noise. As a result, twelve trials were conducted for one subject.

The noise of 50 dB is very silent, such as an office room where no one speaks. On the other hand, 80 dB is very loud, such as at a construction site, on a busy road, or in an amusement arcade. 80 dB of noise gives a subject a high cognitive load that is expected to prevent him/her from concentrating on CPR. The noises were produced with speakers connected to a computer by playing recorded construction sounds. The level was confirmed by a sound pressure meter which is placed around the head position of the subject before the experiment.

For the order of each trial, the first two trials were of no feedback conditions, whilst 50 dB and 80 dB of noises were randomly ordered. Then, the remaining ten trials were randomly ordered. This is because most of the subjects were not expected to get used to CPR and a couple of the initial trials were expected to be highly affected by the effect of the experience. To flatten the effect under feedback conditions, the first trials were used for the subject to get used to CPR and the experiment. In addition, the feedback method in each latter trial was not explained to the subject in each trial.

In each trial, we asked the subject to perform CPR for one minute. The correct compression ratio (CCR), the number of responses against changes (NOR), and the average delay of responses against changes (ADR) were obtained in one trial as objective criteria. The CCR is calculated by dividing the number of correct compressions by the total number of compressions. The total number of compressions is counted by an experimenter. The number of correct compressions is obtained by a counter embedded in the mannequin's chest, which we originally developed as it increments the count when the mannequin's chest sinks more than 5 cm.

As described above, the BLS guideline [12] suggests that a patient's body should be moved to a recovery position after recovering the patient's heart beat and breath when he/she gets consciousness and starts body movements while doing CPR. In this

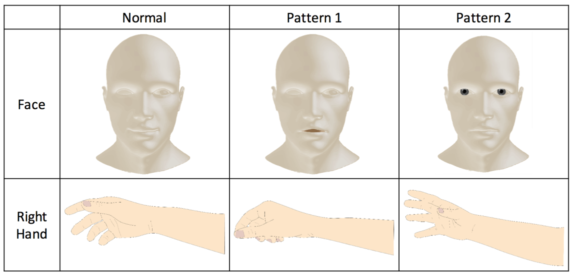

Fig. 4 Pictures of the face and right hand of mannequin in the experiment.

experiment, we also evaluated the subject's noticing of the patient's body movement for simulating this situation. The face and hand of a mannequin are displayed by tablet PCs, and the pictures of them changed 10 times in one trial and 20 times in total for simulating the patient's body movement in the early stage on recovering consciousness. The pictures displayed for the face and hand are shown in **Fig. 4**. On each change, the normal picture changed to pattern1 or pattern2, the changed picture stayed a couple of seconds at random, and then the picture returned to the normal one. Each change randomly occurred. When a subject noticed the change, the subject says "face" or "hand", and the experimenter touches the corresponding tablet. The number of touches and the delay from the change were measured by a program on the tablet.

After the trial, we asked the following questions with an inquiry sheet to obtain the subjective feeling of each feedback method.

Question 1 Regarding the instruction of pressure strength, please evaluate the understandability using a 10-point scale. (10: very understandable, 1: could not understand at all)

Question 2 Regarding the instruction of pressure strength, please evaluate the easiness of improving your motion using a 10-point scale. (10: very easy to improve, 1: could not improve at all)

Question 3 With regards to tempo instruction, please evaluate the understandability using a 10-point scale. (10: very understandable, 1: could not understand at all)

Question 4 With regards to tempo instruction, please evaluate the easiness of improving your motion using a 10-point scale. (10: very easy to improve, 1: could not improve at all)

Question 5 Please evaluate the easiness of considering the patient and the surroundings while doing CPR using a 10-point scale. (10: very easy to consider, 1: could not consider at all)

Question 1 asks understandability of pressure feedback. Question 2 asks about the easiness of changing the subject's motion with pressure feedback. Question 3 asks about the understandability of tempo feedback. Question 4 asks about the easiness of changing the subject's motion with tempo feedback. Question 5 asks about the easiness of paying attention to a patient and the surroundings. Note that only Question 5 was asked for the first two trials because they were without feedback. Also, we asked for a short written comment for the trial by free writing.

4. Result

We conducted our experiment with thirty-two subjects. The ages of the subjects ranged from 20 to 45. **Figures 5** to **12** show

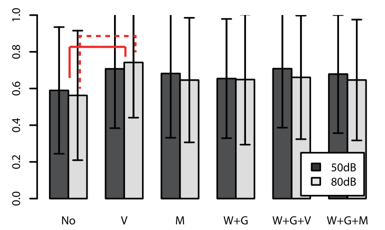

Fig. 5 The correct compression ratio (CCR).

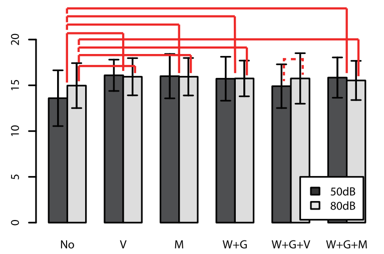

Fig. 6 The number of total responses (NOR).

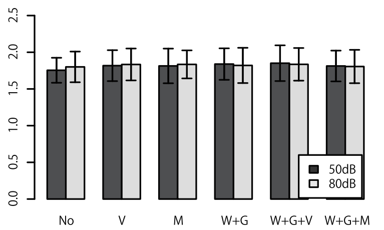

Fig. 7 The average delay of responses (ADR).

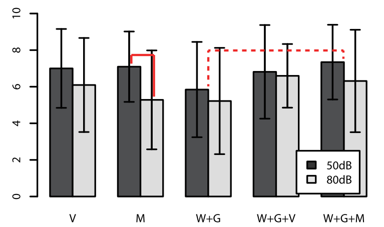

Fig. 8 Question 1.

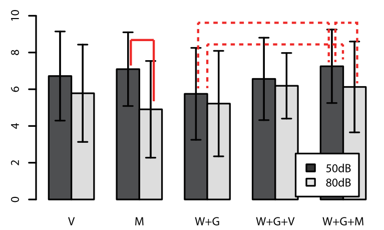

Fig. 9 Question 2.

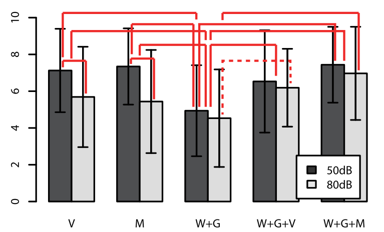

Fig. 10 Question 3.

the results. Each figure shows the average value of the correct compression ratio (CCR), the number of total responses (NOR), the average delay of responses (ADR), and the questions with bar plot, and standard deviation is shown by the error bars.

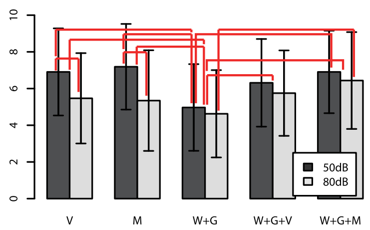

Fig. 11 Question 4.

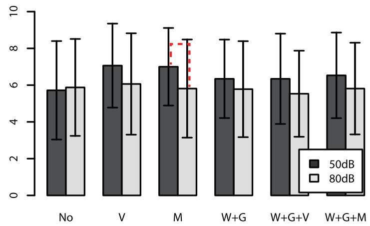

Fig. 12 Question 5.

First of all, the Shapiro-Wilk test is applied for each result with 0.05 of p-value for confirming if each result follows normal distribution or not. The result showed that one or more results (all results in some cases) rejected the test. Thus, we decided to use a non-parametric test for analyzing the result.

Then, we applied the Friedman test, which is a non-parametric method to detect differences in the multiple results, similar to repeated measures ANOVA, on each result along the trial order with 0.05 of p-value in order to confirm the effect of the order. We expected to have some statistical difference between the no feedback condition and certain feedback conditions, because the no feedback conditions of 50 dB and 80 dB were always placed first. The test showed that the results of CCR and NOR have significant differences ($p = 0.024$ and $p = 7.63 \times 10^{-6}$, respectively). For CCR, a post-hoc test by the Steel-Dwass test with 0.05 of p-value didn't give any significant difference. For NOR, the same post-hoc test gave significant differences between the first and the sixth ($p = 0.0016$), the first and seventh ($p = 0.0026$), the first and nineth ($p = 0.0017$), and the first and the eleventh ($p = 5.17 \times 10^{-4}$). Thus, we conclude the result with no instruction, which is represented as "No" on Fig. 6, in NOR needs to be carefully examined, and the other result can be examined without specific consideration.

Then, since there is no method of non-parametric test that can be applied to two-way data, the Wilcoxon signed-rank test with 0.05 of p-value is applied between the result of 50 dB and 80 dB without consideration of each instruction method. The result showed the objective criteria, CCR, NOR, ADR, did not have a significant difference. On the other hand, all of the subjective criteria from Q1 to Q5 have significant differences ($p = 6.80 \times 10^{-6}$ in Q1; $p = 1.16 \times 10^{-6}$ in Q2; $p = 5.34 \times 10^{-4}$ in Q3; $p = 4.48 \times 10^{-6}$ in Q4; $p = 5.73 \times 10^{-6}$ in Q5). Thus, we conclude the noise level has an effect on subjective impression, while it doesn't affect to objective CPR performance.

For more detail, the same test is applied between the noise levels on each instruction method. The result showed that metronome instruction in Q1 and Q2, and voice and metronome instruction in Q3 and Q4 have a significant difference as shown in Figs. 5 to 12 ($p = 0.0032$ in metronome in Q1; $p = 5.88 \times 10^{-4}$

Table 4 Selected Subjects' comments for each instruction.

	50 dB	80 dB
No	I couldn't understand tempo.	I could concentrate at patient's condition because of no instruction
V	I could concentrate because there is no instruction preventing it I could understand that I can keep going with the instruction	I could pay attention to subject with sound only instruction I couldn't hear almost all of the instruction (can hear some of them) I couldn't concentrate because of noise
M	It was easy to listen to the instruction I felt the sound was slow	I couldn't understand what it says I couldn't listen to the sound
W+G	I couldn't understand the correctness, but could concentrate I couldn't afford to see watch's display I was worried because of only the display	The tempo can be understand with blinking of the display without metronome I couldn't pay attention to a patient because I need to pay attention for the display I think there was no meaning for the display I didn't see the display at all
W+G+V	It is easy to understand the voice instruction because of no metronome It is easy to understand the combination of the metronome and vibration I couldn't feel the vibration and I didn't refer it I refer only the voice, and didn't refer to the display	It was difficult to understand the voice instruction but the display support to guess The noise is very loud and difficult to understand what it said I couldn't afford to feel the vibration The voice instruction is enough and I didn't see the display
W+G+M	The instructions are enough I rarely see the display and did CPR only with the sound I couldn't understand the vibration The metronome sound is enough	The sound is difficult to understand, but I can guess with the display I needed to concentrated to the display for tempo Only the sound is enough I couldn't listen to the metronome

metronome in Q2; $p = 0.028$ in voice in Q3; $p = 0.0033$ in metronome in Q3; $p = 0.015$ in voice in Q4; $p = 0.0039$ in metronome in Q5). In addition, no significant difference is given in Q5, but metronome instruction has marginal difference with $p = 0.0655$. Thus, the results prove that voice and metronome instruction is highly affected by noise level with regard to the subjects' feelings, while the effect on voice instruction is less than on the metronome for instructing CPR pressure strength.

The Friedman test with 0.05 of p-value is also applied along the instruction methods without consideration of noise level. The result showed that all results except ADR and Q5 have a significant difference ($p = 4.63\times10^{-5}$ in CCR; $p = 8.18\times10^{-4}$ in NOR; $p = 1.88\times10^{-4}$ in Q1; $p = 0.0029$ in Q2; $p = 3.99\times10^{-7}$ in Q3; $p = 3.60\times10^{-5}$ in Q4). In addition, Q5 has a marginal difference with $p = 0.095$. The Steel-Dwass post-hoc test showed the significant differences between no instruction and voice in CCR ($p = 0.026$), no instruction and voice in NOR ($p = 0.029$), no instruction and metronome in NOR ($p = 0.0020$), no instruction and watch in NOR ($p = 0.0199$), no instruction and watch with metronome in NOR ($p = 0.036$), voice and watch in Q3 ($p = 0.0041$), metronome and watch in Q3 ($p = 0.0043$), watch and watch with voice in Q3 ($p = 0.0051$), watch and watch with metronome in Q3 ($p = 4.41\times10^{-6}$), voice and watch in Q4 ($p = 0.023$), metronome and watch in Q4 ($p = 0.0095$), watch and watch with voice in Q4 ($p = 0.046$), and watch and watch with metronome in Q4 ($p = 3.74\times10^{-4}$). Q1 (and Q5) didn't give any significant difference by post-hoc test. The CCR has only a difference between no instruction and voice, the result implying that the voice instruction while CPR gives better CCR performance. Moreover, while the no instruction condition must be dealt with carefully due to the effect of trial order as mentioned above, almost all instructions (except watch with voice) ease subjects care for patient and surroundings. Moreover, in Q3 and Q4, watch instruction has a significant difference from all of the other methods, the watch instruction is subjectively less effective than the others about instructing CPR tempo.

The Friedman test is also applied under the condition of 50 dB and 80 dB noise separately. Under the 50 dB noise condition, there are significant differences on NOR ($p = 1.31\times10^{-4}$), Q1 ($p = 0.0073$), Q2 ($p = 0.011$), Q3 ($p = 4.88\times10^{-4}$), Q4 ($p = 2.16\times10^{-4}$), and Q5 ($p = 0.011$), and CCR has a marginal difference ($p = 0.078$). The post-hoc test gives a significant difference between no instruction and voice instruction in NOR ($p = 0.0061$), no instruction and watch in NOR ($p = 0.0073$), no instruction and watch and watch with voice in NOR ($p = 0.028$), no instruction and watch with metronome in NOR ($p = 0.018$), voice and watch in Q3 ($p = 0.0074$), metronome and watch in Q3 ($p = 0.0018$), watch and watch with metronome in Q3 ($p = 0.0015$), voice and watch in Q4 ($p = 0.013$), metronome and watch in Q4 ($p = 0.0033$), and watch and watch with metronome in Q4 ($p = 0.029$). Q1, Q2 and Q5 didn't gives significant difference (as well as CCR). Under the 80 dB noise condition, the test gives significant differences on CCR ($p = 8.73\times10^{-4}$), Q1 ($p = 0.020$), Q2 ($p = 0.030$), and Q4 ($p = 0.0092$). The post-hoc test gave significant difference only between watch and watch with metronome in Q4 ($p = 0.0064$) and Q5 ($p = 0.038$). From these results, almost all instructions (except watch with voice) ease the subjects' care for a patient and surroundings under the silent (50 dB) condition, but not under the loud (80 dB) conditions. Also, watch instruction is less effective for instructing CPR tempo, while the difference decreases under loud condition. In either case, watch with metronome instruction has a better subjective effect for the tempo instruction.

The comments given by subjects after each trial are shown in **Table 4**.

5. Discussion

As described above, we could get the results of

- while surrounding noise doesn't affect the users' objective performance of CPR, it affects the user's ability to understand and ease of changing their CPR actions, especially with voice and metronome instructions;
- any instructions are effective in improving the subjects' attention to their surroundings;
- and while the types of instructions do not affect to the objective performance, instruction only with smartwatch is not as effective as the others.

Before the experiment, we expected that the metronome condition was always better than voice, because the metronome condition is the one that just adds click sounds to the voice condition. However, while the average score of metronome instruction under 50 dB is better than voice instruction, under 80 dB condition it is worse in CCR and from Q1 to Q4 although there is no significant difference. The comments of “I could pay attention to subject”, suggest that the click sound and voice information can get complicated for a subject to understand as it is using two audio sources simultaneously. This is supported by a comment that says “It is easy to understand the voice instruction because of no metronome”.

On the other hand, the smartwatch with metronome instruction gets higher or almost the same as the smartwatch with voice instruction under both 50 dB and 80 dB conditions. Considering a comment of “the sound is difficult to understand, but I can guess with the display”, the visual and audio information compensates each other and, this helps to prevent confusion for the subject.

Only the smartwatch instruction has a worse impression than the others for both 50 dB and 80 dB conditions. It is clear that users found it difficult to feel vibration and to see the display from the comments “I couldn’t afford to see watch’s display” and “I couldn’t feel the vibration”. This supports the theory that a smartwatch should be used with a smartphone for CPR instruction.

From the above, we conclude that with regard to the objective performance of CPR there is no significant difference in the type of instruction method, but any instruction method (except watch and voice instruction) is implied to improve the easiness of the surroundings. That is, giving some instructions during CPR is considered to be effective in assisting a person to notice the change in the patient’s condition and to give appropriate care after the patient’s recovery. Also, from the view point of subjective impression, the best feedback method is with the watch-metronome feedback if both a smartphone and a smartwatch are available under both silent and noisy environments. In case of only having a smartphone, metronome feedback is the best in the silent environment, and only voice instruction is the best under a loud noise environment.

6. Conclusion

With the increased practicality of on-site CPR support using a smartphone and a smartwatch, we evaluated the feedback methods of these devices. While existing studies evaluated their systems within a lab setting, we consider the practicality of the evaluation situation, with elements such as noise and safety. Six feedback methods, (1) no feedback, (2) voice on a smartphone, (3) voice and periodic click sound on a smartphone, (4) vibration on a smart watch and graphics on both a smartphone and a smartwatch, (5) vibration and graphics on a smart watch and graphic and voice on a smartphone, (6) vibration and graphic on a smart watch and graphic, voice, and click sound on a smartphone, are evaluated in 50 dB and 80 dB noise environments, which correspond to the environments of a silent office room and a noisy construction site. Also the subject’s awareness of the patient’s body movement are analyzed as well as the correctness of compression movements.

From the result, we could not find significant differences in the objective performances with the different instruction methods, correct compression ratio (CCR), the number of total response (NOR), and the average delay of responses (ADR), except between no feedback and voice feedback for CCR. On the other hand, the feedback method using only a smartwatch does not give a good subjective impression to the user. Overall, the result shows that the best feedback method is a combination of each feedback method, vibration and graphic on a smart watch and graphic, voice, and click sound on a smartphone if both a smartphone and a smartwatch are available. Meanwhile, if only a smartphone is available, feedback using only voice is the best in a noisy environment and metronome feedback is recommended in a silent environment.

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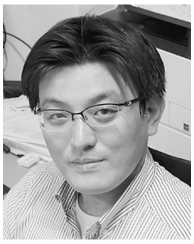

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