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在虛擬實境中藉由觸覺流動進行呼吸引導

Tactile Motion for Breath Guiding in Virtual Reality

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口試委員會審定書

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Tactile Motion for Breath Guiding in Virtual Reality

本論文係黃琬庭君（學號 R07922024）在國立臺灣大學資訊工程學系完成之碩士學位論文，於民國 109 年 7 月 27 日承下列考試委員審查通過及口試及格，特此證明

口試委員：

（指導教授）

系 主 任

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中文摘要

現今壓力已成為日常生活中的普遍問題，壓力可能導致失眠等健康問題。許多呼吸法可以幫助使用者放鬆並釋放壓力。在本論文中，我們用虛擬實境幫助使用者放鬆，為了能不干擾使用者享受放鬆的場景及音樂，嘗試用觸覺指令樣式引導使用者呼吸，因此設計一震動椅墊和觸覺指令樣式的設計介面。我們透過多個實驗探索要如何設計腹式呼吸及左右交替呼吸的觸覺指令樣式，並提出有關觸覺指令樣式設計的注意事項，它們對於觸覺指令樣式的設計非常重要。我們還發現腹式呼吸時吸氣的觸覺指令樣式的震動方向對於每個人來說都不一樣，且如果他們不能接受某種震動樣式，那麼比起給他們不喜歡的觸覺指令樣式，不如在該動作時不要震動比較好。因此，在進行有觸覺引導的實驗之前，我們都會為他們客製化觸覺指令樣式。接著，我們評估在不同組合的引導模式下使用者的偏好，結果顯示，有觸覺指令的組合是大多數人的首選。最後我們提出引導呼吸的系統，用虛擬實境提供放鬆的場景及音樂，一開始會有視覺、聽覺及觸覺引導，一分鐘後視覺引導會消失，再一分鐘後聽覺引導會消失，只剩下觸覺來引導呼吸，在最少干擾放鬆的音樂和場景之下引導使用者呼吸。因為這是他們第一次採用這種呼吸法，還不太熟悉，所以暫時還看不到進行這種呼吸法的效用，但 SUS 分數為 66.7，已非常接近可接受的 70 分，未來仍需再做一些改進，讓觸覺回饋之呼吸引導系統更容易使用。

關鍵字：觸覺指令、呼吸引導、腹式呼吸、左右交替呼吸、虛擬實境

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ABSTRACT

Nowadays, stress has become a common problem in everyday life. Stress may cause health problems such as insomnia. Many breathing techniques can help users relax and release stress. In this thesis, we use virtual reality to help users relax. In order not to interfere with the immersion of relaxing scene and music, we try to use tactile instruction to guide breathing, so we design a tactile chair cushion and an interface for designing tactile instruction pattern (TIP). We also conducted multiple studies to explore the TIPs that can guide users to do diaphragmatic breathing and Nadi Shodhana Pranayama. And put forward some design considerations for TIP, they are important when designing TIPs. We also found the direction of TIP for inhalation of diaphragmatic breathing is not the same for everyone, and if they cannot accept the vibration patterns, it is better not to provide vibration for that action than give the TIP that they dislike. So, we personalize the TIP for every participant before studies with tactile instruction. Next, we find the user's preferences of multi-modal instruction, the results show the combinations with tactile instruction are preferred by most people. Finally, we proposed a breath guiding system that uses virtual reality to provide relaxing scene and music. At first, there are

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visual, audio, and tactile instructions. After one minute, we remove the visual instruction. After another minute, we remove the audio instruction, leaving only tactile instruction. The system can guide users breathing with less interference, and won't affect relaxing music and scenes. Because this is the first time they use these breathing techniques, so we cannot see the effect of these breathing techniques just yet. The SUS score 66.7 is in marginal high, which is very close to acceptable, we still need some improvement to make the system easier to use.

Keywords: tactile instruction, breath guiding, diaphragmatic breathing, Nadi Shodhana Pranayama, virtual reality

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Chapter 1 Introduction

The current pace of life is fast, and it causes great pressure unconsciously. Stress not only affects health, but also causes toxins in the body to accumulate, and personal performance may also decrease. Too much stress may also lead to Dysautonomia or Generalized Anxiety Disorder. Studies showed that yogic breathing can alleviate anxiety, depression, and stress [1, 2]. Different breathing techniques have different effects, such as the 4-7-8 breathing exercise proposed by Andrew Weil [3], this breathing exercise is a natural tranquilizer for the nervous system, it helps to reduce stress, calms the body and mind, and makes it easier to fall asleep. Another example is Nadi Shodhana Pranayama, it can activate the brain and the parasympathetic nervous system, a study showed that it rapidly alters cardiopulmonary responses and improves simple problem solving [4]. Naik et al. [5] randomly divided 100 volunteers into 2 groups, one group is control group, another is slow breathing group. Slow breathing group practiced slow breathing exercise training 30 minutes a day, 5 times a week for 12 weeks. Results showed that slow breathing exercise can reduce stress and improve cardiovascular parameters.

Nowadays, Virtual Reality (VR) is blooming. There are many applications that help

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users to train deep breathing meditation or guide users breathing to help users relax, such as Deep VR, TRIPP, Guided Meditation VR (Fig 1.1). They use visual and audio cues to guide breathing. Tactile cues are another sense that can be used to guide breathing.

Fig. 1.1 Applications that guide users breathing: (a) Deep VR, (b) TRIPP, (c) Guided Meditation VR

In this thesis, we design a tactile chair cushion. It can be placed on different chairs, and the vibrators can also be easily placed on other types of soft chair cushions. We put vibrators on a chair cushion instead of on a chair because the chair cushion is easy to store when you don't want to use it. We conducted experiments to find the optimal SOA models for different body positions, and the effects of different back tilt angles of the chair that may change the pressure between skin and vibrators. Then, we invented an interface to design tactile instruction pattern (TIP). Next, we invited 5 users and 3 yoga teachers to design the TIPs for breathing. After that, we analyzed the TIPs that they designed, and extract some elements from them. We then conducted studies to understand which TIPs

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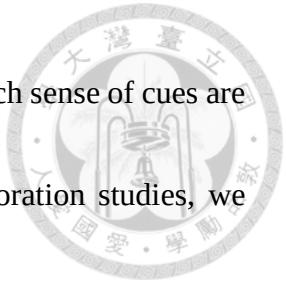

that each of them felt the most intuitive to guide their breath, and which sense of cues are suitable to guide the users in breathing exercises. After these exploration studies, we proposed a breath guiding system that uses VR to provide relaxing scene and music. At first, we add visual, audio, and tactile instruction on top of the original relaxing scene to guide breathing. After one minute, we remove the visual instruction, and after another minute, we remove the audio instruction, leaving only tactile instruction, and also scene and music that can help users relax. Then, we conducted user studies to find out how much help is needed under different difficulty breathing techniques if we only provide tactile instruction to users and the effectiveness of the system.

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Chapter 2 Related Work

2.1 Guided Breathing with Tactile Instruction

Some studies used a device that can change size to guide breathing (Fig. 2.1). In Breathe with Touch [6], they used the inflation and deflation of a shape-changing airbag to simulate human breathing movements. Uratani et al. [7] put airbags into a teddy bear abdomen, one for leading respiration. Relaxushion [8] developed a cushion device that expands and shrinks as if it is breathing to overwrites users breathing rhythm.

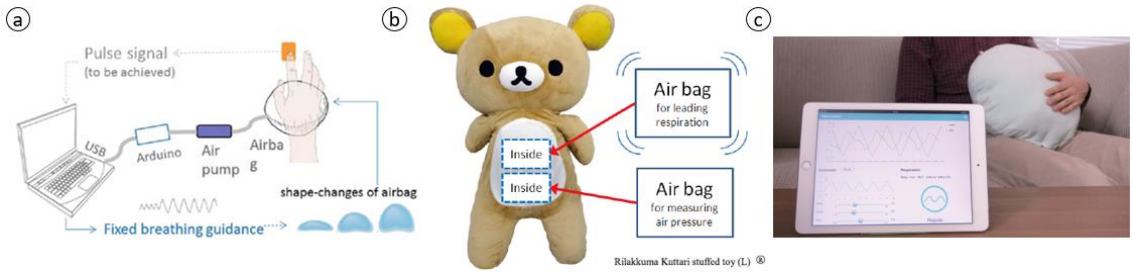

Fig. 2.1 Device that change size to guide breathing: (a) Breathe with Touch [6]. (b) Uratani et al. [7]. (c) Relaxushion [8].

Sato et al. [9] placed two actuators on the back and used them to coach chest breathing (Fig. 2.2). The results show that the participants could perform best while inhaling with upward moving stimulation and they like it the best. They suggest that

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guiding one phase is sufficient for controlling the respiration cycle. It is because they only have two phases in the cycle, inhalation and exhalation, no breath-holding phase. Just Breathe [10] proposed guided slow breathing intervention for drivers. They compared the effectiveness and impact of haptic and voice guidance methods in slowing drivers' breathing rate. The results showed that both haptic and voice guidance can reduce drivers' breathing rate, though most participants preferred haptic guidance. The haptic guidance they used is shown in Fig. 2.3. Breath Booster! [11] used the same device as Just Breathe [10], but explore the effects of high-paced breathing on autonomic arousal, and proved that guided fast breathing interventions can boost energy and focus. They chose a simple pattern that swipes up and down the user's whole back as their tactile guidance to guide drivers to breathe fast while driving. Three papers mentioned above used phantom illusion or apparent motion illusion to create the smooth vibration pattern.

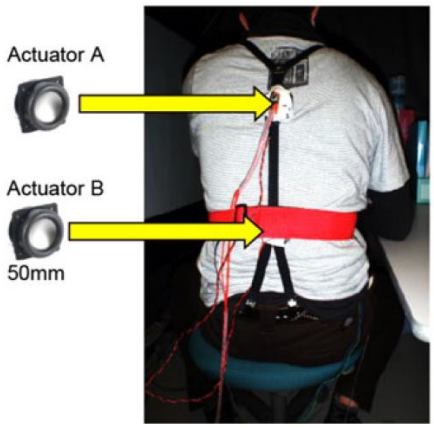

Fig. 2.2 Device used in Sato et al. [9].

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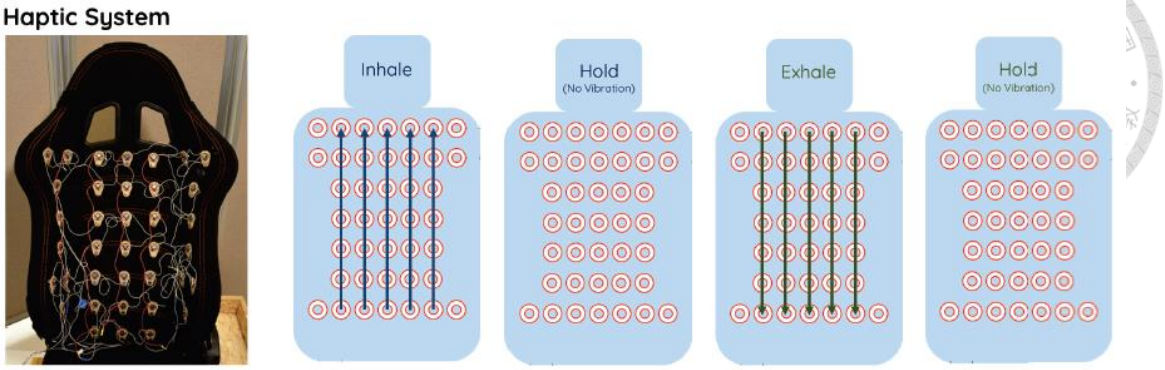

Fig. 2.3 The haptic guidance in Just Breathe. [10]

Other studies or applications use vibrations of mobile devices to create tactile sensations to guide breathing. Bumatay et al. [12] control the vibration of the mobile phone's motor to vibrate deeply when the time for inhaling and exhaling then fade off slowly. They also used audio guidance, so the users won't get confuse which step is now after they accidentally zone out (Fig. 2.4). Apple watch uses tactile and visual instructions to guide breathing, it only has two stages, inhalation and exhalation, so it vibrates from slow to fast when inhaling, and no tactile feedback for exhalation.

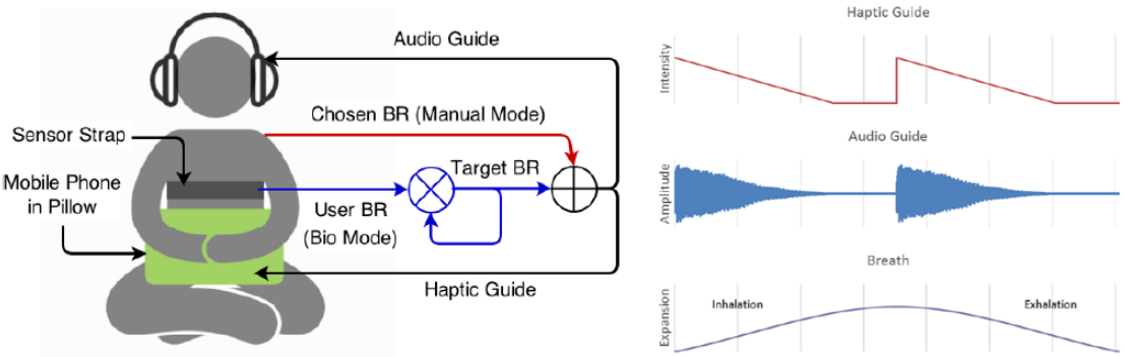

Fig. 2.4 System in Bumatay et al. [12].

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2.2 Tactile Illusion

A tactile illusion is an illusion that influences our tactile sensation. In 1957, Bekesy [13] was inspired by the working mechanism of the audition system. He observed that when two vibrators vibrate together, an imaginary vibration source will be generated between the physical vibrator (Fig. 2.5(a)). Earlier in 1917, Burtt [14] wondered whether the sense of touch is the same as sight and hearing that when two similar stationary stimuli in quick succession in different places yield an impression of movement. After the experiment, he found that when two vibrators started to vibrate within a certain time interval, and distance and intensity of the two vibrators were under certain conditions, can produce an impression of movement from one point to the other in the direction of the actual temporal succession (Fig. 2.5(b)). But he has not investigated in detail on how to set the parameters that affect the impression of movement. Sherrick et al. [15] asked the subject to adjust the time interval between the start of two vibrators, also called Stimulus Onset Asynchrony (SOA), until it felt like actually moving a vibrator smoothly from the first stimulus to the second (Fig. 2.5(b)), and find the SOA with the longest uninterrupted feeling. Afterward, there are also many studies using different experimental methods to find suitable SOA value under different layout of vibrators [16, 17, 18].

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Tactile Brush [17] combines the findings of the above two types of illusions and present an algorithm that uses a low-resolution grid of vibrating actuators to produce high-resolution tactile strokes on skin. As long as the starting point, endpoint, intensity, frequency, and the time required to complete the stoke are given, it can compute the intensity, frequency, and time controls for each vibrator. Many studies placed these actuators on the back of the chair [17, 19, 20, 21], attached to the handle [18], gloves, tablet [22] or vast [23] to provide tactile feedback for games [17, 19, 22], VR [20] and AR [22]. It can also be used to "read" English letters [24]. Tactile illusion can be used in lots of scenarios, it can also enhance user's tactile sensation. With apparent motion illusion, we can easily create smooth vibration patterns.

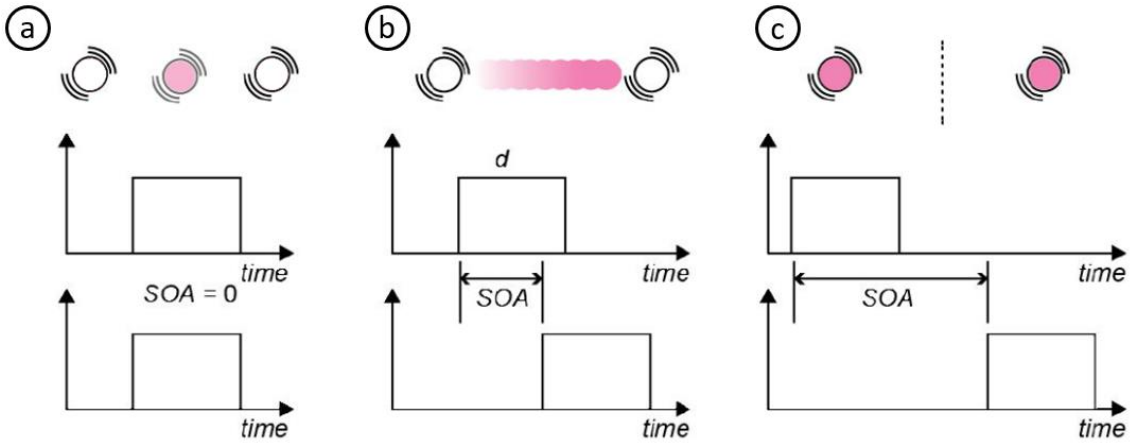

Fig. 2.5 Vibrotactile illusions: (a) Phantom illusion. (b) Apparent motion illusion. (c) Discrete vibrations. [18]

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Chapter 3 Design Consideration

To design tactile chair cushion and TIPs for breathing, the following aspects need to take into considerations.

3.1 Distance Between Two Vibrators

Kirman [16] found through experiment that the distance between two vibrators had no major influence on producing the impression of movement, as long as the distance between the vibrators is not too large to make the continuous motion. In Tactile Brush [17], to provide high-resolution tactile strokes on actuator grids, when the stroke passes through two vibrators, the two vibrators vibrate simultaneously with different amplitudes to generate a virtual actuator, so the movement can be smoother and without any discontinuity. Our distance between the upper and lower vibrators is approximately 4 centimeters. It is the shortest distance we can place.

3.2 Tactile Stimuli Used and Body Location

Kirman [16] paired multiple durations and SOAs and asked the participants to rate

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the sense of continuity. The results of the optimal SOA function was different compared to the results of Sherrick and Rogers [15]. Although the trend of the function is the same, the optimal SOA value for each duration is relatively low. The difference in these results are due to the differences between the tactile stimuli used and the body location placed. Kirman [16] applied the vibrators to the fingertip, and Sherrick and Rogers [15] applied them to the thigh. Tactile Brush [17] uses C-2 tactors. The location of tactors is at the upper back. Their relation between duration and SOA of the tactile stimuli function is *SOA = 0.32 * duration + 47.3*. Hand-to-Hand [18] uses voice coil actuators and they are held in hand. The optimal SOA model is *SOA = 0.38 * duration + 58.8*. If duration = 1000 milliseconds (ms) is used, the difference between the two SOAs is 71.5ms. If duration increases, the difference in the optimal SOA values will also increase. We use Arduino vibration motor modules. The location of our vibrators is on the inner Bladder Meridian of the back. They almost cover the entire back. So, we will find the optimal SOA model for the upper back, and lower back respectively.

3.3 Duration and SOA

Stimulus Onset Asynchrony (SOA) is the time difference between the start of two

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vibrators. It is a very important parameter for continuous tactile motion. If the SOA is too small, it feels like there is only one vibrator vibrating (Fig. 2.5(a)). If the SOA is too large compared to duration, it feels like the two vibrators vibrate separately (Fig. 2.5(c)). Only with optimal SOA can feel the impression of movement (Fig. 2.5(b)).

3.4 Pressure Between Vibrators and Body

Gunther et al. [25] embedded transducers in a one-size-fits-all design nylon suit, so the suit is loose-fitting, if they didn't use anything to tie the transducers to users, the users won't feel the vibrations. Therefore, they used elastic straps at each transducer point to tie the transducers to users. When they conducted the initial experiment, they found that if the straps are too tight, the vibrations will be felt in the bone structure, resulting in a deeper, more diffuse sensation. On the other hand, if the straps are relatively loose, the transducers rest comfortably on the skin, the vibrations are perceived superficially on the skin.

3.5 Design of Tactile Instruction Pattern (TIP)

TIP should be distinguishable and consistent with intuition. Different actions need

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to have different TIPs. Otherwise, users will not be able to determine which step it is now after they accidentally zone out. The TIP for the latter action should not be the same as the end of the TIP of the previous action. Otherwise, the users will think that the next action has started, but it has not. The TIP for each action must be completed to a stop, so the vibration for TIP of the next action won't stick with the previous one, making it impossible to tell when it has switched to the next action. The TIPs should not interfere with the user's breathing. If they cannot accept the vibration patterns, it is better not to provide vibration for that action than give the TIP that they dislike. If provide users the TIPs that they dislike, it might have the opposite effect. Different participants prefer different direction for inhalation and exhalation of diaphragmatic breathing. It is better to personalize it before use. If they are given the wrong direction, they won't feel being guided.

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Chapter 4 Implementation

In this chapter, we introduce our tactile chair cushion and TIP design interface.

4.1 Tactile Chair Cushion

We use 16 Arduino vibration motor modules, 8 vibrators on the left side, another 8 vibrators on the right side. The location is roughly on the inner Bladder Meridian, 3.8 centimeters away from the middle of L-shaped chair cushion, and the distance between the upper and lower vibrators is placed side by side, roughly 4 centimeters. The highest vibrators are 40 centimeters from the bottom of the back of the L-shaped chair cushion, not too high, so there is no skeletal leakage of vibrations into the ear, it won't result in undesirable sonic artifacts [25]. The vibrators are placed in small pockets and glued to the L-shaped chair cushion with Velcro (Fig. 4.1). We control Haptic Maker (Fig. 4.2) to trigger the on-off of vibrators via Unity. We connect the Arduino NANO to the computer through a USB connection, which can not only read the signal from Unity but also power the Arduino. The PWM shield is powered by a 5V 2A power supply. We didn't use the Bluetooth module.

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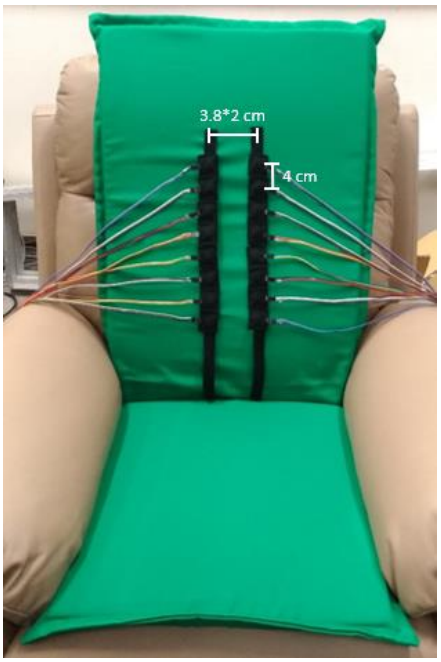

Fig. 4.1 Tactile chair cushion.

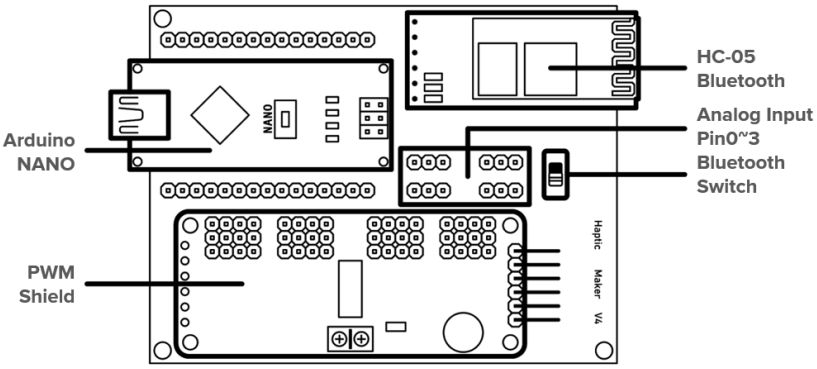

Fig. 4.2 Illustration of Haptic Maker.

4.1.1 Duration and SOA

According to the design consideration described in Chapter 3.3, if we want to feel the impression of movement, the SOA cannot be too large or too small. We conducted a study to find the optimal SOA model for our system.

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Method

We took the experimental method of Tactile Brush [17] as reference. We utilized a two-alternative forced-choice (2AFC) paradigm combined with one-up one-down adaptive procedures to determine SOA thresholds [26, 27]. The SOA thresholds were determined for two durations (500ms and 1000ms) and two positions (upper back, and lower back). We will find the upper threshold and lower threshold respectively. When measuring the upper threshold of SOA, the initial value of SOA equals duration. Participants were asked whether they could feel individual discrete actuators. If the answer is "Yes", the SOA value decreases. If the answer is "No", the SOA value increases. When measuring the lower threshold of SOA, the initial value of SOA equals 0. Participants were asked if they felt actuators merged as one. If the answer is "Yes", the SOA value increases. The SOA value decreases when the answer is "No". Each experiment series started with a SOA step-size of 20ms, and after the first two reversals, the step-size decreased to 5ms. The experiment terminated after a total of eight reversals. An average SOA threshold was computed from the last four reversals. The order of these 8-test series (2 durations, 2 positions, 2 thresholds) for each participant is random.

doi:10.6342/NTU202002260

Participants

We recruited 12 participants (8 males and 4 females) between 21 and 25 years old (mean=23.17 years old, SD=1.19) to be our subjects in this experiment. Most people have used massage chairs before. Half of them like to use the massage chairs, and the other half have no special feeling for massage chairs.

Results

The results of our upper- and lower-SOA threshold values for two durations and two positions, averaged across 12 participants with standard error bars is shown in Fig. 4.3. We used ANOVA to determine the significant effects of thresholds and duration. There is significant difference between the upper- and lower-SOA threshold values ($F=67.5$, $p<0.001$). Duration is also a significant factor ($F=33.0$, $p<0.001$). The range of SOA that generates continuous tactile motion increases when the duration increases.

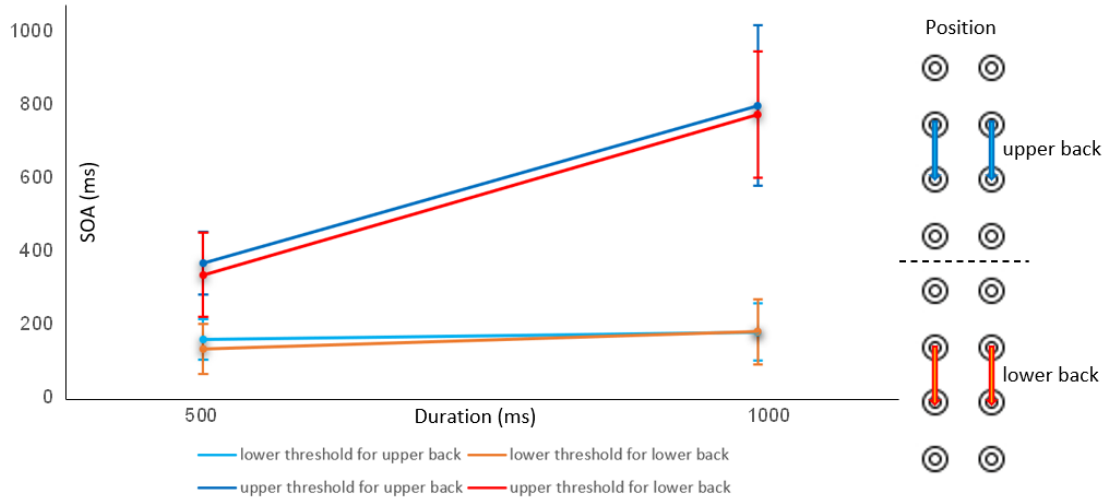

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Fig. 4.3 The results of upper- and lower-SOA thresholds.

There are no significant differences between both upper threshold of the upper back and upper threshold of the lower back, and lower threshold of the upper back and lower threshold of the lower back. So, we average them both and find the upper- and lower-SOA thresholds for the whole back. Then, we computed an average of the upper- and lower-SOA thresholds and fit a straight line through them. The lines are optimal SOA model for robust apparent tactile motion at the back. As long as the SOA of two vibrators is computed using the equation, the user perceives continuous motion. The optimal SOA model for back is *SOA = 0.474 * duration - 4* (Fig. 4.4).

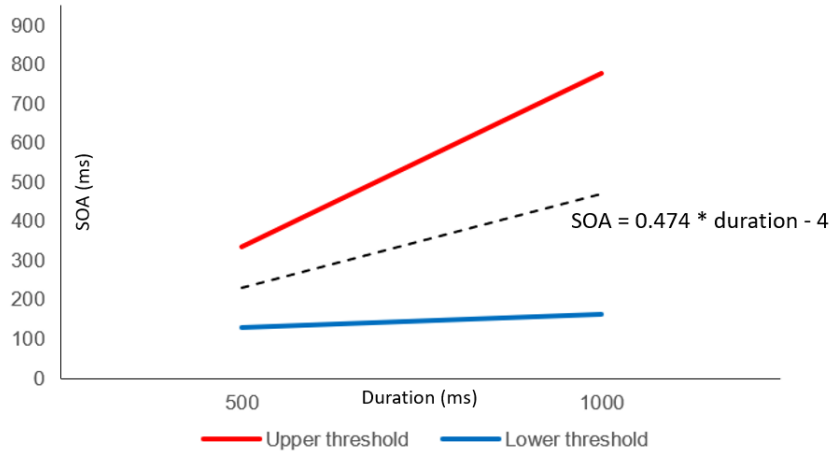

Fig. 4.4 The optimal SOA model for back.

4.1.2 Pressure

According to the design consideration described in Chapter 3.4, the pressure should

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be appropriate, not too large, or too small to feel the best vibrations. We conducted a study to see if placed on chairs with different back tilt angles would affect the pressure, and if so, which angle is the best back tilt angle for our device.

Method

We used an electric reclining sofa sell-by NITORI. When the seatback is in the upright position, it is roughly 100 degrees. When the seatback is tilted all the way back, it is about 140 degrees. We considered three interfaces: *Sitting Upright* (100 degrees), *Half Lying* (120 degrees), *Lying Down* (140 degrees). For these three interfaces, we asked participants to use a 7-point scale (1: No feeling, like sitting on a normal chair cushion, 7: There are noticeable bumps) to answer the questions: "Do you obviously feel the vibrators?" (pressure level). If his or her answer is not 1, we will ask them: "Do the vibrators make you pain?". Then, we vibrated the vibrators and asked participants: "Do you feel the vibrations in the bone structure?". Afterward, we asked them to use a 7-point scale (1: Very uncomfortable, 7: Very comfortable) to rate the comfort level.

Participants

We recruited 12 participants (8 males and 4 females) between 22 and 30 years old

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(mean=24.25 years old, SD=2.67) to be our subjects in this experiment.

Results

The results are shown in Table 4.1. There is no significant difference found in both pressure level and comfort level. All of the participants who did not answer 1 on the pressure level said that although they could feel the existence of the vibrators, they did not feel pain or discomfort due to the vibrators. None of the participants reported that they feel vibrations in their bone structure in any interfaces. Therefore, when the seatback tilts within 140 degrees, the pressure is not too large.

	Sitting Upright	Half Lying	Lying Down	ANOVA
Pressure level	2.17 (1.27)	2 (1.21)	2.25 (1.22)	F=0.16, p=0.85
Comfort level	4.06 (1.24)	4.25 (1.61)	4.5 (1.4)	F=1.88, p=0.16

Table 4.1 The results of study on pressure.

4.2 TIP Design Interface

Our interface for TIP design is shown in Fig. 4.5. The main part for TIP design is on the right. Those that are circled by light blue has 8 groups of 2x8 tactile array, each group is separated by a bar. Each icon is matched to the corresponding position of the vibrator on the chair cushion. It is used to design which vibrators vibrate at the same time. The

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darker background is the vibrators that are selected to vibrate at that time. The part that is circled by purple shows the duration of each group of vibrators. The unit is milliseconds. Those that are circled by red indicates how to connect to the next group of vibrators. *Con.* means continuous. The system will automatically calculate SOA based on the optimal SOA model obtained from Chapter 4.1.1. *Dis.* means discrete. The user needs to specify the interval between the previous group of vibrators stopping and the next group of vibrators starting to vibrate. The value 0 indicates the moment the previous group of vibrators stops, the next group of vibrators starts to vibrate. The part that is circled by green is the visualize of the vibration. When the vibrators vibrate, the icon in the corresponding position will change to light blue, so the user can also see which vibrators are vibrating. The buttons below are shortcuts to make the design of TIP more convenient. These buttons mainly refer to the TIPs that designed by users in exploration study 1 (see in Ch 5.1), most of them design the patterns that vibrates from bottom to top or from top to bottom. So, we add *Top Down* and *Bottom Up* buttons. When pressed, it will automatically set the part that is circled by light blue in Fig. 4.5. Fig. 4.5 is the result of pressing *Bottom Up*. In some of the TIPs that users defined, they only vibrate one side, so we add *Only Left* and *Only Right* buttons. After pressing these buttons, it will deselect

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the selected vibrators icon on the other side. Enter the value in the text field behind the *Set All Duration* button and press *Set All Duration*, the place that is circled by purple will become that value. If most durations of each group of vibrators are the same, using this feature can speed up the design speed, only need to change a few places that are not this value. The usage of *Set How Long* is similar to *Set All Duration*. The input value is the total vibration time of 8 groups of vibrators. Some total vibration time is unreachable, we will use the duration that can make the closest total vibration time. Press *Count How Long* can see the real total vibration time. All units are also milliseconds. Press *Play* can play this pattern, it needs to enter how many times to play first in the text field above. Press *Stop* to stop the vibration. Enter a file name in the text field above *Load* and *Save* before pressing them. *Save* will save the pattern currently designed with the file name that enters in the above text field and close the *Event*. *Load* is to read the pattern that saved with the file name and show it on the interface. *Clear* is to set everything back to its default state. *Close* is to turn off the *Event* that is currently open, it won't save the content. If the pattern requires more than 8 groups to conduct, open the next Event and can continue to design. The left part of the interface is mainly to connect multiple Events. Therefore, can fully experience the whole set of TIP for breathing. The user name can be entered in the text

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field at the top, and the saved file will add the user name before the file name. It is easier to distinguish the designer of TIPs. The main part has 16 *Event* buttons. After pressing one of them, the interface on the right will open. After pressing *Save* on the right, the file name will be written under the clicked *Event* button. It can be known which *Event* has been designed so far. The usage of *Play*, *Stop*, *Load*, *Save*, *Clear* at the bottom are the same as those on the right, but deal with the content on the left side of the interface. For example, when pressed *Play*, it will start to play from *Event1* to the last *Event* that has been designed.

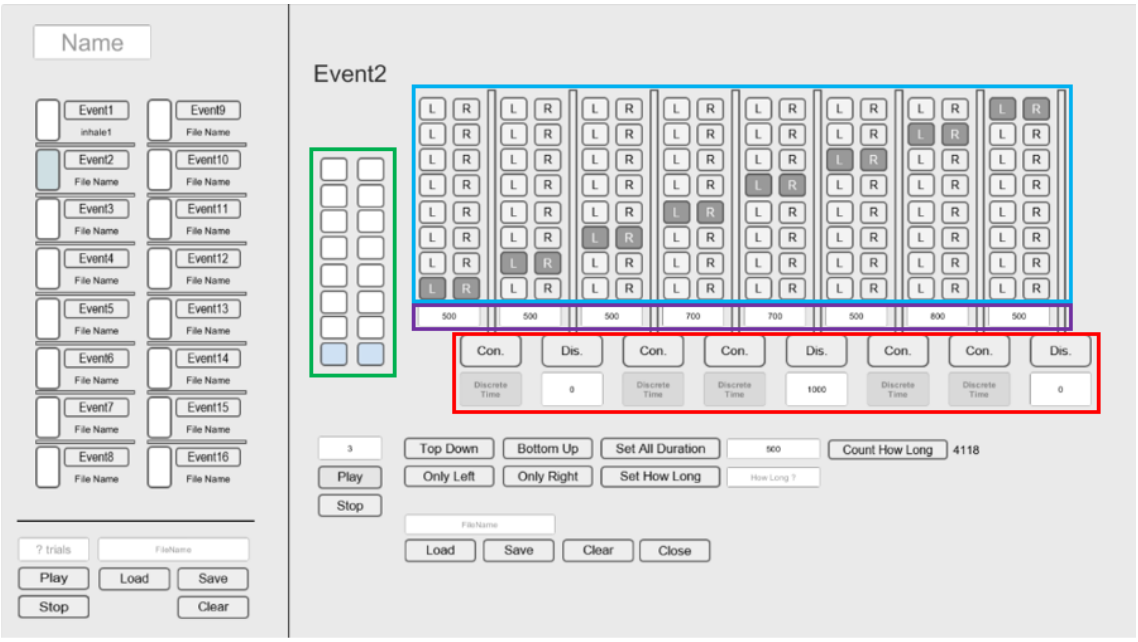

Fig. 4.5 TIP design interface.

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Chapter 5 Exploration Study

After the procedure of designing and implementing the tactile chair cushion, we need to find suitable patterns for breath guiding. Thus, we conducted studies to understand which TIP users and experts will think of when talking about certain breathing techniques. Then, we extracted some elements from the results of the previous studies and conducted studies to understand which TIP most people like the most. Hereafter, we used audio, visual, and tactile instructions to guide participants to do diaphragmatic breathing, and find out which combination of guidance users preferred the most and felt most suitable for breath guiding.

5.1 Exploration Study 1: User Defined Patterns

In this study, we recruited 5 participants (3 males and 2 females). They only know that when doing diaphragmatic breathing, the belly expands when inhale, and the belly shrinks when exhale. They are not experts in any breathing techniques. We want to investigate which TIP will come to their mind for each command of the diaphragmatic breathing: inhale, breath-holding, and exhale.

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Procedure

In the beginning, we asked the participants if they knew diaphragmatic breathing, and asked them to say anything about diaphragmatic breathing. As long as he or she mentions something similar to the abdominal expands when inhale, and the abdominal shrinks when exhale, he or she can conduct this study. Then, we explain how to design TIPs with the TIP design interface and what variables can be adjusted. They can also draw on a schematic diagram of 8x2 tactile array (Fig. 5.1) to explain their ideas. After that, we guided the participants to design the TIPs for diaphragmatic breathing. We asked them following questions in order to guide them: "What kind of tactile instruction patterns do you think is like inhalation of diaphragmatic breathing?", "What kind of tactile instruction patterns do you think is like exhalation of diaphragmatic breathing?", "What kind of tactile instruction patterns do you think is like breath-holding of diaphragmatic breathing? And how long?", "Vibrate on both sides or only one side? If one side, which side?". After they answer any of the above questions, we asked them why they think the patterns are like this to understand their ideas better. After the TIP is conducted, we asked them to follow the TIP to do diaphragmatic breathing and feel whether this TIP is the same as they thought. We will adjust the TIP until the participants are satisfied.

Fig. 5.1 Schematic diagram of 8x2 tactile array.

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Results

The results of all five TIPs are shown in Fig. 5.2. Inhalation is represented by medium turquoise, exhalation is expressed in tomato red and breath-holding is indicated by purple. These are the design ideas they gave, including "faster", "slower". Blue indicates the duration of each vibrator that the participants are satisfied with. Black dots represent the start of *Event1*. Where there is no connection, we connect it with black lines to show the execution order. The TIP of diaphragmatic breathing designed by the first participant is shown in Fig. 5.2(a). She thinks that the TIP for inhalation of diaphragmatic breathing is like vibrates from bottom to top and should slow down in the last half because the inhalation speed slows down due to almost full inspiratory capacity. The TIP for exhalation is the same but in the opposite direction. There is no vibration for breath-holding, and it lasts 1 second after both inhalation and exhalation. Inhalation and exhalation only vibrate one side. The TIP of diaphragmatic breathing designed by the second participant is shown in Fig. 5.2(b). When inhaling, the top 4 vibrators vibrate from top to bottom. When exhaling, the bottom 4 vibrators also vibrate from top to bottom. The total time for exhalation should be longer than inhalation. The TIP for breath-holding after inhaling is to vibrate the fourth vibrator counted from above for 1 second. There is no vibration for breath-holding after exhaling, and it also lasts 1 second. Inhalation and exhalation only vibrate one side. If this breath vibrates the left side, the next breath should vibrate the right side. The TIP of diaphragmatic breathing designed by the third participant is shown in Fig. 5.2(c). She thinks that the TIP for inhalation is to vibrate from bottom to top for 4 seconds. The speed from fast to slow. The TIP for exhalation is to vibrate from top to bottom for 7 seconds. The speed is also from fast to slow. There is no

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vibration for breath-holding after inhalation, and it lasts 3 seconds. No breath-holding after exhalation. She originally thinks that both sides should vibrate together, but she feels the intensity of vibration is too large, so she changes to vibrate only one side. The TIP of diaphragmatic breathing designed by the fourth participant is shown in Fig. 5.2(d). He thinks that the TIP for inhalation of diaphragmatic breathing is like vibrates from bottom to top and the speed is from slow to fast. The TIP for exhalation is like vibrates from top to bottom and the speed is from fast to slow. Because he feels the vibration of lower vibrators is less obvious, so slower is better. Both sides vibrate together. There is no vibration for breath-holding, and it lasts 1.5 seconds after both inhalation and exhalation. The TIP of diaphragmatic breathing designed by the fifth participant is shown in Fig. 5.2(e). When inhaling, vibrates from bottom to top, and begins to slow down where the dash is drawn. When exhaling, vibrates from top to bottom, and also begins to slow down at the point the dash is drawn. Both sides vibrate together. There is no vibration for breath-holding, and it lasts 1.5 seconds after both inhalation and exhalation. After he feels the TIP that he designed, he thinks it is kind of fast in the middle, so we slow down the speed in the middle.

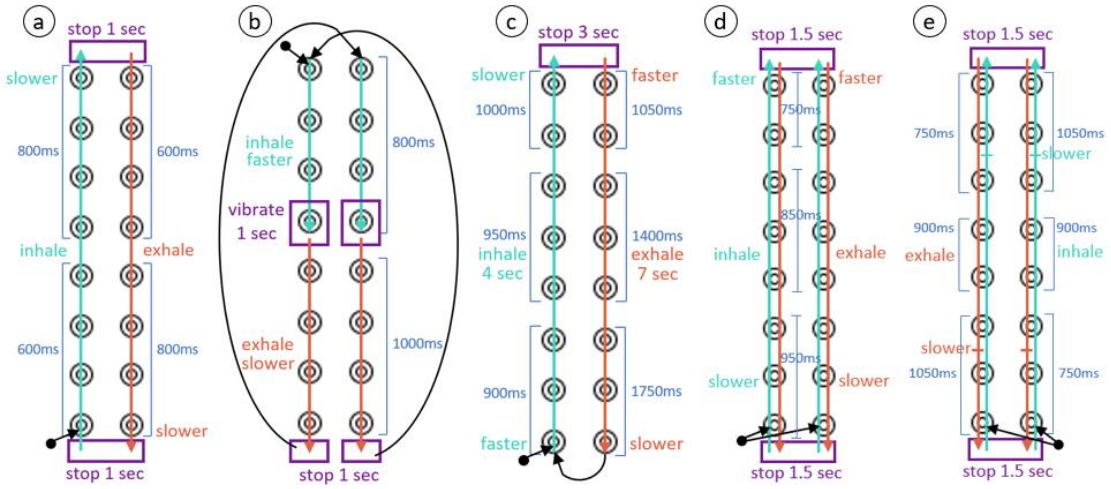

Fig. 5.2 The results of user defined TIPs.

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5.2 Exploration Study 2: Expert Defined Patterns

With the TIP designed by ordinary users, we think some are not the correct way for diaphragmatic breathing, such as inhalation speed should slow down due to almost full inspiratory capacity. When doing diaphragmatic breathing, it is important to breathe smoothly and at the same speed. Thus, we invited three yoga teachers (1 male and 2 females) and asked them to design the TIP of diaphragmatic breathing that they usually teach their students. After we experience the TIPs made by the users, we felt that the inhalation and exhalation that only vibrate one side seems to guide Nadi Shodhana Pranayama, breath with left and right nose respectively. Therefore, we also asked the yoga teacher to design the TIP for Nadi Shodhana Pranayama.

Procedure

First, the purpose and contents of the experiment were introduced. Second, we let them experience several basic vibration patterns: continuous block vibration, two sides discrete top-down, two sides continuous top-down, two sides continuous bottom-up, one side continuous top-down, one side continuous bottom-up, an upper small circle with

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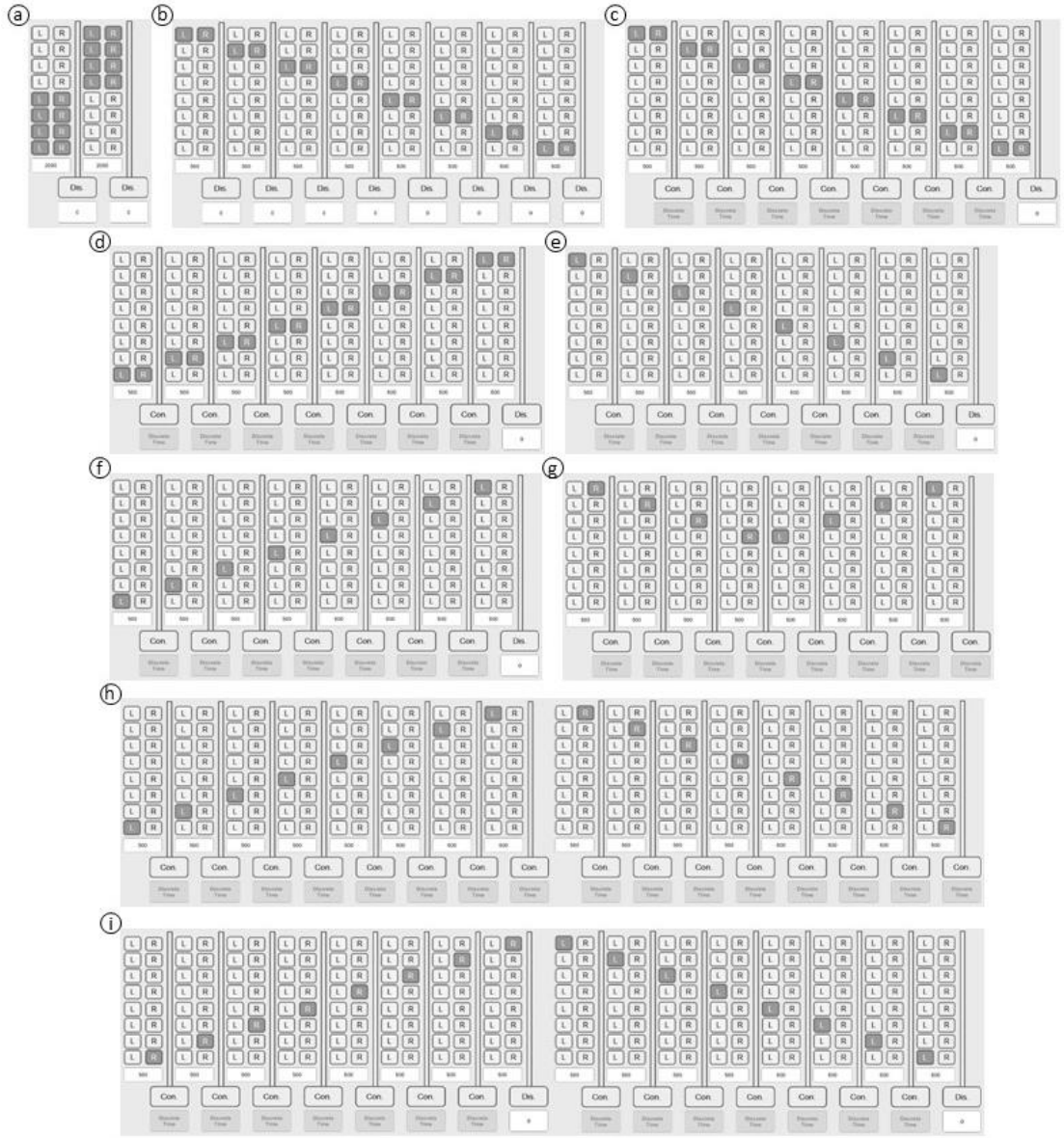
right side top-down, left side bottom-up, a large circle with left side bottom-up, right side top-down and a large circle with right side bottom-up, left side top-down (Fig. 5.3). Third, we then explain how to design TIPs with TIP design interface, and what variables can be adjusted. Fourth, we assisted them in designing the TIPs for diaphragmatic breathing and Nadi Shodhana Pranayama.



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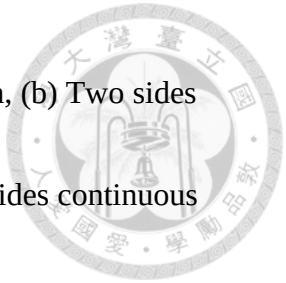

Fig. 5.3 Basic vibration patterns: (a) Continuous block vibration, (b) Two sides discrete top-down, (c) Two sides continuous top-down, (d) Two sides continuous bottom-up, (e) One side continuous top-down, (f) One side continuous bottom-up, (g) Upper small circle, (h) Large circle with left side bottom-up, right side top-down, (i) Large circle with right side bottom-up, left side top-down.

Results

The TIPs of diaphragmatic breathing that designed by the three yoga teachers are shown in Fig. 5.4. Colors represent the same thing in exploration study 1. Fig. 5.4(a) was designed by the first yoga teacher. She thinks that when inhaling, the air is stacked from the bottom, so the direction of the TIP for inhalation is from bottom to top, the direction for exhalation is the opposite. The main focus when diaphragmatic breathing is the abdomen, so the vibration is limited to the lower half, where the abdomen is. There is no vibration for breath-holding. Each breathing step lasts for 2 seconds. If lengthen or shorten each breathing step, only need to change the duration. Fig. 5.4(b)(c)(f)(g) was designed by the second yoga teacher. All his TIPs for inhalation and exhalation are the same. He thinks that when inhaling, air flows from the nose to the abdomen, so the

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direction of the TIP for inhalation is from top to bottom. When exhaling, air flows from the abdomen to the nose, so the direction is from bottom to top. The vibrators at the place of the abdomen keep vibrating. In addition to the feeling of air flowing to the abdomen, it also allows the users to focus on the expansion and contraction of the abdomen. Fig. 5.4(b) only has inhalation and exhalation, without breath-holding. Fig. 5.4(c) has 1 second breath-holding time after both inhalation and exhalation, but there is no vibration for it. Apart from this, he also designed two other TIPs for breath-holding. As shown in Fig. 5.4(f), the TIP for breath-holding after inhalation is vibrating the bottom four vibrators and no vibration for breath-holding after exhalation. As shown in Fig. 5.4(g), the TIP for breath-holding after inhalation is adding row by row from the bottom row until all the vibrators are vibrating within 0.5 seconds, and the rest of breath-holding time vibrates all the vibrators (Fig. 5.5). Fig. 5.4(d)(e) was designed by the third yoga teacher. She thinks that the TIP for inhalation of diaphragmatic breathing is like vibrates from bottom to top, and the TIP for exhalation is like vibrates from top to bottom. She had felt both sides vibrate together, but she thought it was too heavy, so only vibrates the left side when inhaling and only vibrates the right side when exhaling. Fig. 5.4(e) add the TIP for breath-holding. She said that when she teaches, only the last breath at the end of the breathing

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exercise has breath-holding, so the students can perceive their breathing more. There is no vibration for breath-holding.

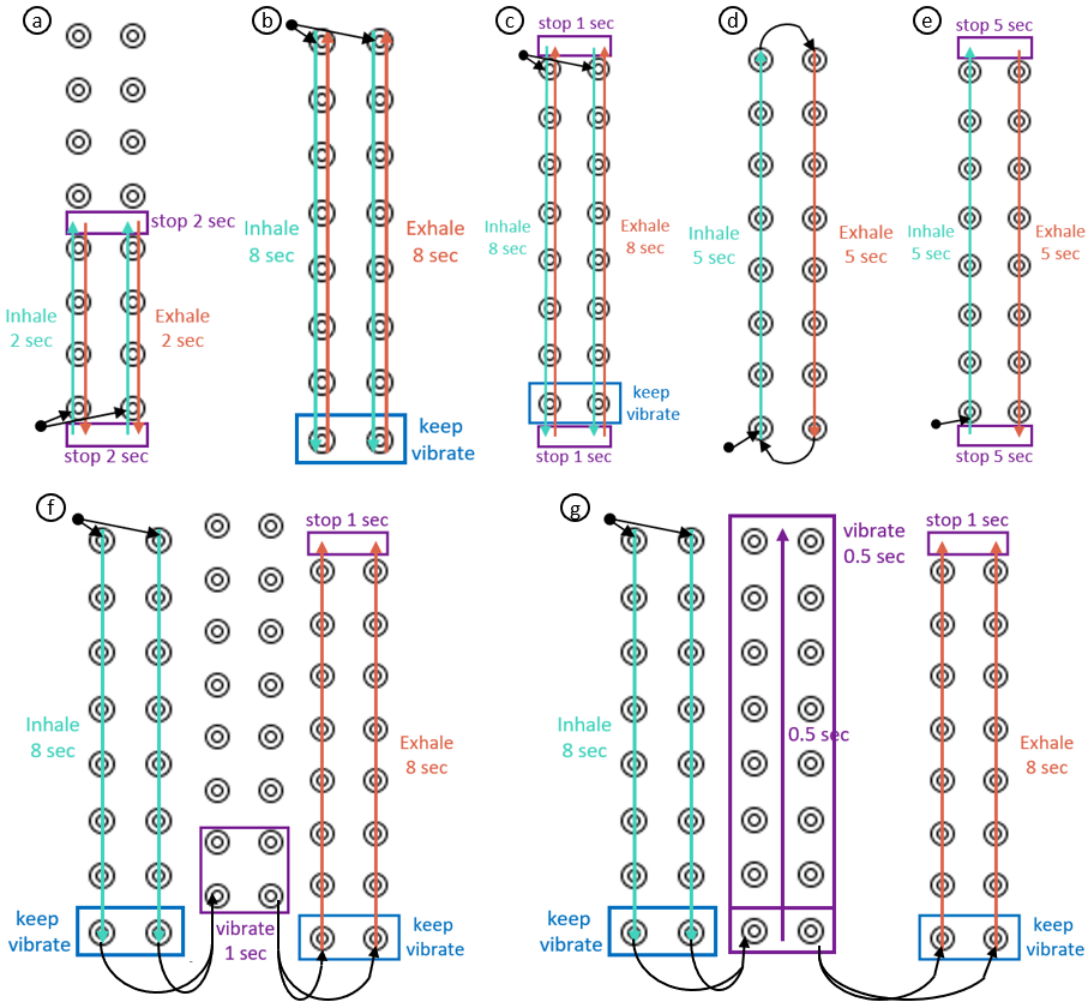

Fig. 5.4 The results of expert defined TIPs of diaphragmatic breathing.

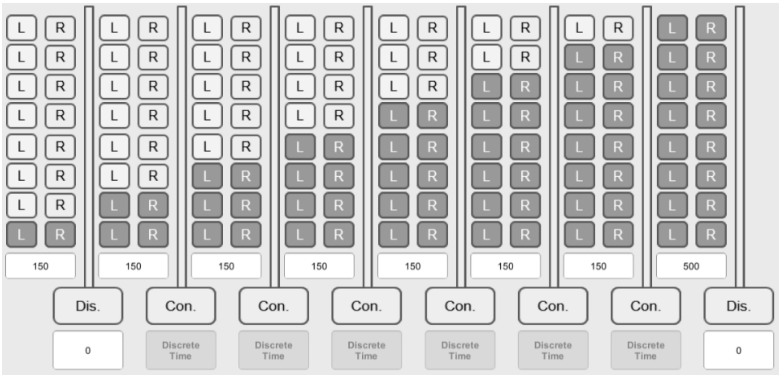

Fig. 5.5 The TIP for breath-holding that designed by the second yoga teacher.

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The TIPs of left inhale and left exhale in Nadi Shodhana Pranayama, also known as Alternate Nostril Breathing, are shown in Fig. 5.6. Fig. 5.6(a) was designed by the first yoga teacher. The basic vibration range for inhalation and exhalation is two rows (Fig. 5.7), she thinks it feels fuller. The direction of the TIP for inhalation is from bottom to top, and the direction of the TIP for exhalation is from top to bottom. Which side of the nostril is used for inhalation and exhalation, vibrate that side of vibrators. Also no vibration for breath-holding. The TIP of Nadi Shodhana Pranayama designed by the second yoga teacher is shown in Fig. 5.6(b)(c). The direction of the TIP for inhalation is from top to bottom, and the direction of the TIP for exhalation is from bottom to top. The TIP shown in Fig.5.6(b) is more ordinary. It simply divides the TIPs for inhalation and exhalation of diaphragmatic breathing that he designed into half. Which side of the nostril is used for inhalation and exhalation, vibrate that side of vibrators. Fig. 5.6(c) is special, it's like zigzag. It vibrates sequentially on the left and the right sides, which can outline the three-dimensional shape of chakra. Which side of vibrator vibrates at the top row is the side of the nostril used to inhale or exhale. Fig. 5.6(d)(e) are designed by the third yoga teacher. She doesn't like too much vibration, so her designs have very few vibration parts. Which side of the nostril is used for inhalation and exhalation, vibrate that side of

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vibrators. As shown in Fig. 5.6(d), when inhaling, vibrates the fifth vibrator counts down from the top for 1 second, then stops for 0.1 seconds, then vibrates the third vibrator counts down from the top for 1 second, then stops for 0.1 seconds, and then vibrates the top vibrator counts down from the top for 1 second, finally change to exhale after 0.1 seconds. The vibration for exhalation is the same, but with reversed order. Fig. 5.6(e) only vibrates the fourth vibrator counts down from the top, vibrates for 0.9 seconds, and stops for 0.1 seconds. Inhale or exhale for how many seconds just vibrate it for that many times. The TIP for inhalation and exhalation is the same. Used the no vibration of breath-holding to know when to change to the next step of breathing.

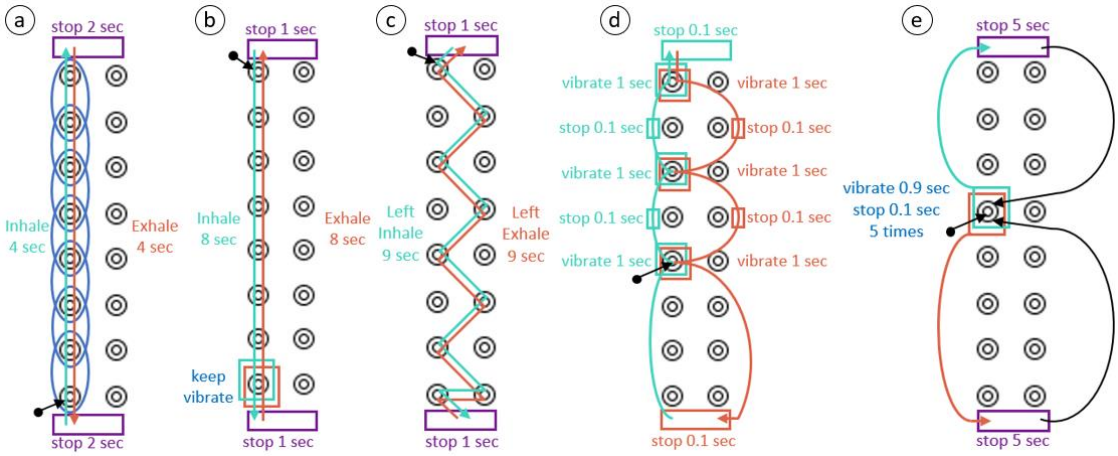

Fig. 5.6 The results of expert defined TIPs of Nadi Shodhana Pranayama.

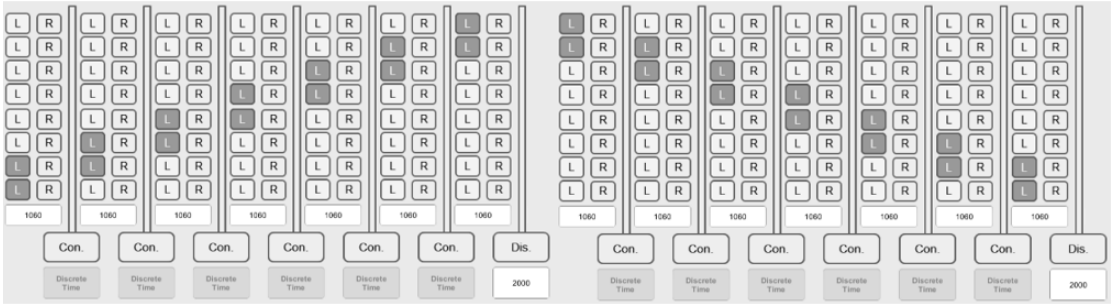

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Fig. 5.7 The TIP of Nadi Shodhana Pranayama that designed by the first yoga teacher.

Discussions

Although we can see that every participant has their own ideas when designing the TIPs, none of them designed exactly the same. Most of the TIPs designed for inhalation and exhalation are straight up or down, and with only small changes. For example, the TIP of Nadi Shodhana Pranayama that designed by the first yoga teacher, it's basic vibration range is two rows. And the second yoga teacher designed TIPs that keeps vibrating at the bottom vibrators. The third yoga teacher and the third user in study 1 are more sensitive and don't like vibrations that are too strong, so the TIPs for diaphragmatic breathing changed from two sides vibrates together to only vibrates one side. This problem can be solved by changing the vibration motor modules to speaker modules, speaker modules can adjust the amplitude directly to reduce the intensity, we listed as future work. Only the second yoga teacher and the second user in study 1 had designed TIPs for breath-holding. It may be that they haven't come up with better ideas on the TIPs for breath-holding, or they really don't like vibration when breath-holding. And all of the TIPs that they designed can change the total length by changing the duration of each group of vibrators.

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5.3 Exploration Study 3: Find Intuitive Tactile Instruction Patterns

After we explore the TIP that users and experts think of when talking about diaphragmatic breathing and Nadi Shodhana Pranayama. We extracted some elements from the results that we think are appropriate and interesting and conducted this study to understand the preferences and intuitiveness for these TIPs.

Experiment Design

Many TIPs for inhalation that participants designed are from bottom to top or from top to bottom, their reasons for the design are both reasonable. So, for the direction of TIP for inhalation, we have from bottom to top (*Up*) and from top to bottom (*Down*) to choose from. And we find the TIPs that designed by second yoga teacher interesting, it keeps vibrating the bottom row of vibrators, adding a terminal point for inhalation at the abdomen. So, we add the terminal point to the TIP of inhalation for users to choose from. If the direction of TIP for inhalation is *Up*, the keep vibrating row is the top row (*Top*), and if the direction is *Down*, the keep vibrating row is the bottom row (*Bottom*). We also

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find the TIP of Nadi Shodhana Pranayama that designed by the first yoga teacher interesting, the basic vibration range for inhalation and exhalation is two rows, the vibrations feel fuller. So, we also add one row and two rows of basic vibration range for users to choose from.

The options of TIP for breath-holding is shown in Fig. 5.8. Most TIPs for breath-holding are no vibration (Fig. 5.8(a)), therefore it is an option for breath-holding. The TIPs for breath-holding after inhalation that second yoga teacher designed are vibrating the bottom four vibrators and adding row by row from the bottom row until all the vibrators are vibrating within 0.5 seconds, and the rest of breath-holding time vibrates all the vibrators. We modify them a little and add them to the options for breath-holding. 2x2 vibrators vibrate when breath-holding both after inhalation and exhalation, and the position of the vibration depends on the TIP for inhalation and exhalation (*2x2 Continuous Vibration*). If the direction is from top to bottom then the bottom 2x2 vibrators vibrate when breath-holding (Fig. 5.8(b)). On the other hand, if the direction is from bottom to top then the top 2x2 vibrators vibrate (Fig. 5.8(c)). For *2x8 Continuous Vibration*, we preserved the TIP for breath-holding after inhalation that second yoga teacher designed: adding row by row from the bottom row until all the vibrators are

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vibrating within 0.5 seconds, and the rest of breath-holding time vibrates all the vibrators (Fig. 5.8(f)). But we change the TIP for breath-holding after exhalation to vibrates from bottom to top within 0.5 seconds, then only vibrates the top 2x2 vibrators for the rest of breath-holding time (Fig. 5.8(g)). We think the TIPs for breath-holding are too less, so we come up with two other TIPs. One is *2x2 Pulse Vibration*, it's like heartbeats, the heartbeat has two sounds in each heart cycle: "lubb" and "dupp". The first sound "lubb" is longer, it is the sound of the mitral valve and tricuspid valve closed. The second sound "dupp" is shorter, it is the sound of the aortic valve and pulmonary valve closed. It followed by a pause about twice the time of "lubb" and "dupp". Mitral valve and tricuspid valve are lower than aortic valve and pulmonary valve, thus we start this TIP at the lower row than to the higher row, we test a lot of combination and find longer vibration of 0.25 seconds and shorter vibration of 0.15 seconds then stop 0.6 seconds is the best combination. The position of the vibration also depends on the TIP for inhalation and exhalation. If the direction is from bottom to top, we used the top 2x2 vibrators for breath-holding (Fig. 5.8(d)). On the other hand, if the direction is from top to bottom, we used the bottom 2x2 vibrators (Fig. 5.8(e)). The other TIP is *2x8 Pulse Vibration*. It's kind of like the combination of *2x8 Continuous Vibration* and *2x2 Pulse Vibration*. The TIP for

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breath-holding after inhalation is the same as *2x8 Continuous Vibration* in the first 1 second. Then similar to *2x2 Pulse Vibration*, the bottom four rows of vibrators vibrate for 0.25 seconds then the top four rows of vibrators vibrate for 0.15 seconds then stop for 0.6 seconds, and then repeat the pattern of this seconds until breath-holding end (Fig. 5.8(h)). The TIP for breath-holding after exhalation is simpler, the first 0.5 seconds is the same as *2x8 Continuous Vibration*, then only vibrate the top row for 0.5 seconds, after that it's the same as the top *2x2 Pulse Vibration* (Fig. 5.8(i)).

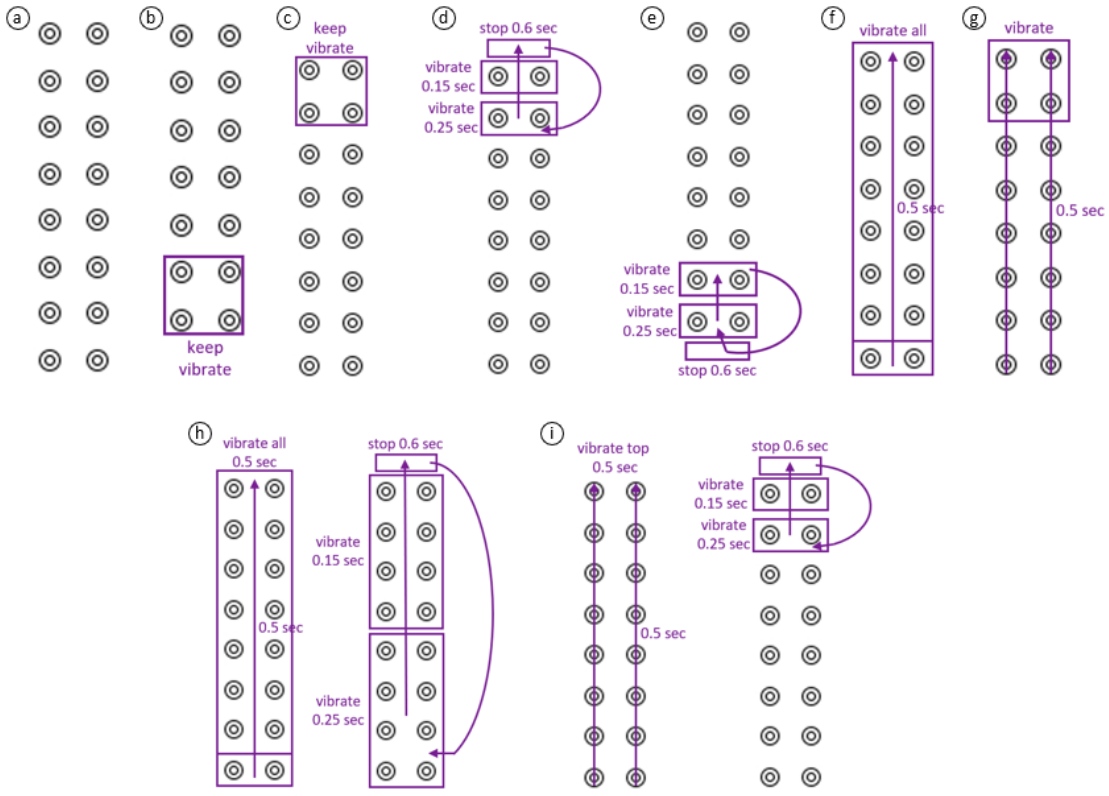

Fig. 5.8 TIPs for breath-holding: (a) *No Vibration*, (b)(c) *2x2 Continuous Vibration*, (d)(e) *2x2 Pulse Vibration*, (f)(g) *2x8 Continuous Vibration*, (h)(i) *2x8 Pulse Vibration*.

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Task

The task in this study is to follow the TIP to do diaphragmatic breathing and use a 7-point scale (1: Dislike it very much, 7: Like it very much) to rate the preference of each option for TIPs. After experiencing all the options in this section, sort the options by preference. Then, we will go on to the next section with the most favorite TIP chose in this section.

Participants

We recruited 12 participants (9 males and 3 females) between 21 and 26 years old (mean=23.08 years old, SD=1.38) to be our subjects in this experiment. Most people have used massage chairs before. 7 of them like to use massage chairs, and 5 of them have no special feeling for massage chairs. Nobody practices diaphragmatic breathing on their daily basis.

Procedure

At the beginning of the experiment, we used video [28] to teach participants diaphragmatic breathing. After they watched the video, we said the main point again: abdominal expands when inhale, and the abdominal shrinks when exhale. Then the

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participants experience options from *Inhale Direction / Keep-Vibrating Row*: *Up/No*, *Up/Top*, *Down/No*, *Down/Bottom*. All of them are 4 seconds inhalation time and 4 seconds exhalation time (4040), exhalation direction is opposite from inhalation direction. After they choose their favorite TIP, we go on to the options of the *Basic Vibration Range*: *One Row*, *Two Rows*. Then, we add 4 seconds of breath-holding time in between (4444), they also need to choose a favorite from *No Vibration*, *2x2 Continuous Vibration*, *2x2 Pulse Vibration*, *2x8 Continuous Vibration*, *2x8 Pulse Vibration*. The TIP for inhalation and exhalation is the favorite one they chose before. Then, the breath-holding time becomes 8 seconds (4848) to see if their preference for these TIPs change because of the length of breath-holding. All of the order of options are counterbalanced.

Results

The results of the *Inhale Direction / Keep-Vibrating Row* are shown in Table 5.1. Although 3 people like the option *Up/No* the most, it's value for the order is less than *Up/Top*, because the participants that think the direction for inhalation should be *Down* may put the *Up/No* last because they think it's too boring. In addition, one participant said the keep vibrating row can distract his attention from the dislike of the wrong direction.

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The results of the *Basic Vibration Range* are shown in Table 5.2. Two-thirds of people like *Two Rows* better. They think it feels more like massage, and it feels more comfortable. The results of *4 Second Breath-Holding* and *8 Second Breath-Holding* are shown in Table 5.3 and Table 5.4. We can see that none of the participants like *No Vibration* the most when breath-holding is 8 seconds, because they think it's too boring, and don't know if it is the end of the study or just breath-holding. At *4 Second Breath-Holding* only one participant like *No Vibration*, this may mean that in exploration study 1 and 2, users and experts didn't design TIPs for breath-holding is because they have not yet come up with ideas about how to design the TIP for breath-holding.

	Up / No	Up / Top	Down / No	Down / Bottom	ANOVA
Order	2.17 (1.27)	2.42 (0.9)	2.83 (1.03)	2.58 (1.31)	F=0.55, P=0.65
Preference	3.67 (1.23)	3.67 (0.89)	4.17 (1.03)	3.92 (1)	F=0.64, P=0.6
How many people like the most	3	1	4	4	N/A
Order	2.29 (1.08)		2.71 (1.16)		F=1.2, P=0.28
Preference	3.67 (1.05)		4.04 (1)		F=1.26, P=0.27

Table 5.1 The results of *Inhale Direction / Keep-Vibrating Row*.

	One Row	Two Rows	ANOVA
Order	1.33 (0.49)	1.67 (0.49)	F=1.38, P=0.27
Preference	5.17 (0.83)	5.25 (0.97)	F=0.08, P=0.78
How many people like the most	4	8	N/A

Table 5.2 The results of *Basic Vibration Range*.

	No Vibration	2x2 Continuous Vibration	2x2 Pulse Vibration	2X8 Continuous Vibration	2x8 Pulse Vibration	ANOVA
Order	3 (1.13)	3.67 (1.44)	3.17 (1.4)	2.5 (1.57)	2.67 (1.5)	F=1, P=0.42
Preference	4.33 (0.89)	4.92 (1.51)	4.33 (1.3)	3.83 (1.53)	4.08 (1.78)	F=1.24, P=0.31
How many people like the most	1	5	3	2	1	N/A

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Table 5.3 The results of *4 Second Breath-Holding*.

	No Vibration	2x2 Continuous Vibration	2x2 Pulse Vibration	2X8 Continuous Vibration	2x8 Pulse Vibration	ANOVA
Order	2.42 (1.24)	3.58 (1.51)	3.42 (1.16)	2.83 (1.64)	2.75 (1.42)	F=1.15, P=0.35
Preference	4.17 (0.94)	5.08 (1.73)	4.33 (1.56)	4.08 (1.44)	4.08 (1.78)	F=1.29, P=0.29
How many people like the most	0	5	3	3	1	N/A

Table 5.4 The results of *8 Second Breath-Holding*.

Discussions

After analyzing the results, we think it's unreasonable for the participants to rate the direction that they don't like and put them all together to compare. And we can see that the preference of each participant for the direction of TIP for inhalation and exhalation of diaphragmatic breathing is different. Thus, next time we do this kind of studies, we should give them *Up/No* and *Down/No* first to find out which direction he or she likes for inhalation. Then add a row of vibrators that keep vibrating to see if he or she likes it or not, some people think it's too annoying, but others think it's more comfortable and has the sense of transformation when changes from inhalation to exhalation. For *Basic Vibration Range* we chose *Two Rows* to use in the following studies because two-thirds of people like it the most. Although 5 people like *2x2 Continuous Vibration* for breath-holding the most, we got many feedbacks that when it's almost the end of inhalation and exhalation, the pattern feels the same as breath-holding, so they don't know when to hold

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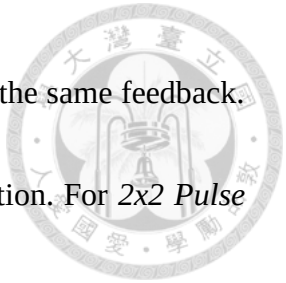

their breath, even some participants like this TIP the most had given the same feedback. It violates the distinguishable that we talk about in design consideration. For *2x2 Pulse Vibration*, some participants think it counts time for them, so they like it. Others think to count the time is unnecessary and disturbing. Most participants that like *2x8 Continuous Vibration*, *2x8 Pulse Vibration* the most don't like all of them, some like the TIP for breath-holding after inhalation better, some like the TIP for breath-holding after exhalation better. Lots of participants gave the feedbacks that these two TIPs are too complex, hard to remember what these TIPs are for.

5.4 Exploration Study 4: Find the Preference of Multi-modal Instructions

After the participants completed the previous study to choose their favorite TIPs, we give them that TIP for tactile instruction for diaphragmatic breathing in this study. In this study, we have two other instructions for diaphragmatic breathing, visual and audio. We use these instructions alone or together to see which combination the users think is good for guiding them to do the breathing exercise. The scene is milky way, and the background music is music that helps relax. There are 4 seconds for each breathing step (4444).

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Experiment Design

For visual instruction we used a light blue balloon (Fig. 5.9), it expands to guide the users to inhale, and it shrinks to guide the users to exhale. When breath-holding, the size of the balloon stays the same. The word under the balloon also tells users what instruction is now. For audio instruction, when each breathing step begins, the sound will say which step is now. The 7 interfaces used in this study are *Audio*, *Visual*, *Tactile*, *Audio+Visual*, *Audio+Tactile*, *Visual+Tactile*, and *Audio+Visual+Tactile*. We always give participants *Audio+Visual+Tactile* first, so that they can learn each kind of instructions.

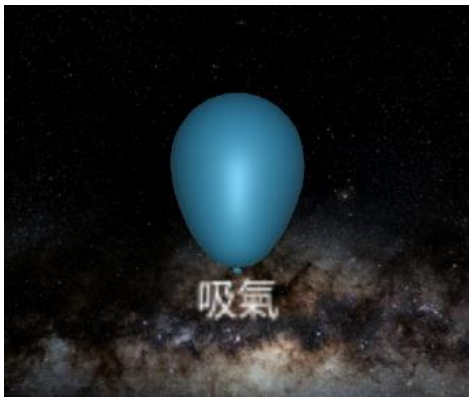

Fig. 5.9 Visual instruction.

Task

The task in this study is to follow the combination of instructions to do diaphragmatic breathing, each interface will guide the participants to breathe 4 times. Then the participants should rate the preference using a 7-point scale (1: Dislike it very

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much, 7: Like it very much) for each interface and answer the following questions: "Have you kept up with the breathing guidance?", "Have you forgotten what to do at any of the instructions?" After experiencing all the interfaces, sort them by preference.

Participants

We recruited 12 participants (9 males and 3 females) between 21 and 26 years old (mean=23.08 years old, SD=1.38) to be our subjects in this experiment. Most people have used massage chairs before. 7 of them like to use massage chairs, and 5 of them have no special feeling for massage chairs. All of them have used VR before. Nobody practices diaphragmatic breathing on their daily basis.

Procedure

First, we introduced the three instructions to participants. Then, the participant is asked to put on the head-mounted display. We measured their brainwaves with Lookxid Link, so we will check if the values of brainwaves have been read. Before each interface, we read the brainwaves for 10 seconds as the reference value. Then, we give them *Audio+Visual+Tactile* first to let them get familiar with those instructions. The order of

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the other six interfaces are counterbalanced. After they sort the interfaces by preference, we asked them why they like the interface the most, and why they dislike the interface the most.

Results

The results are shown in Table 5.5 to Table 5.8 and Fig. 5.10. We can see in Table 5.5, 7 people like tactile instruction the most, they think the tactile is like massage and can help them relax, but there is no significant difference between them because still, some people think it's not easy to remember what the instructions are for, so they put the tactile instruction last. Four participants reported they forgot what the instructions mean in tactile instruction. In Table 5.6, *Audio+Tactile* and *Visual+Tactile* are significantly better than *Audio+Visual*, many people think audio and visual instructions don't need to appear together, one is enough to guide them. In Table 5.7 we compared different amounts of instructions, we pick out the best one in one instruction and two instructions to do the comparing. Participants prefer the combination of two instructions better than one instruction along. Because with two instructions, one can make up for the lack of another guide. We can see also in Table 5.8 and Fig. 5.10, there are significant difference in

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preferences and order. Most of the combination of two instructions are better than one instruction alone. Half of the participants like *Audio+Tactile* the most, because they think visual cue is redundant, and with audio cue, they won't forget what step is now.

	(1) Audio	(2) Visual	(3) Tactile	ANOVA
Order	2 (0.74)	1.67 (0.78)	2.33 (0.89)	N/A
How many people like the most	3	2	7	F=1.38, P=0.27

Table 5.5 The results of order for one instruction.

	(1) Audio+Visual	(2) Audio+Tactile	(3) Visual+Tactile	ANOVA	Tukey Post-hoc
Order	1.33 (0.65)	2.42 (0.67)	2.25 (0.75)	N/A	-
How many people like the most	1	6	5	F=5.67, P<0.05	1-2, 1-3

Table 5.6 The results of order for two instructions.

	(1) One	(2) Two	ANOVA	Tukey Post-hoc
Order	1.17 (0.39)	1.83 (1.39)	N/A	-
How many people like the most	2	10	F=8.8, P<0.05	1-2

Table 5.7 The results of order for different amount of instructions.

	(1) Audio	(2) Visual	(3) Tactile	(4) Audio+Visual	(5) Audio+Tactile	(6) Visual+Tactile	ANOVA	Tukey Post-hoc
Preferences	3.83 (1.47)	3.58 (1.44)	4.42 (1.73)	3.92 (1.24)	5.42 (1.08)	4.92 (1.51)	F=6.52, P<0.001	1-5, 2-5, 2-6, 4-5
Order	3.17 (1.53)	2.17 (1.47)	3.42 (1.78)	2.75 (1.22)	4.92 (1.38)	4.58 (1.38)	F=5.23, P<0.001	2-5, 2-6, 4-6
How many people like the most	1	0	1	0	6	4	N/A	-
Relation	31% (0.32)	8% (0.23)	9% (0.43)	26% (0.37)	30% (0.32)	21% (0.3)	F=1.31, P=0.27	-
Attention	1% (0.39)	-1% (0.39)	-13% (0.34)	-36% (0.23)	-16% (0.42)	-12% (0.37)	F=1.99, P=0.09	-

Table 5.8 The results of exploration study 4.

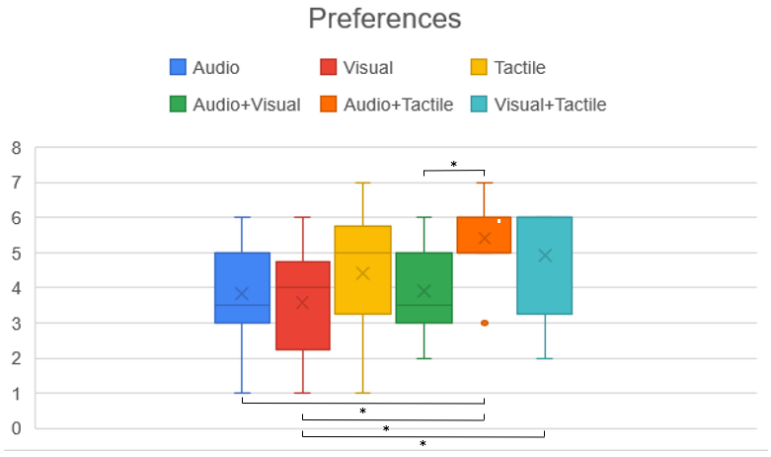

Fig. 5.10 The results of preferences for all interfaces.

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Discussions

We received many feedbacks on pros and cons of each instruction. The participants that like *Audio* said they can easily receive the messages passively and don't need too much effort to translate the meaning. Others who don't like it said with only sound, they don't know when is about to change to the next step, the sudden appearance of the sound frightens them a little, and also affects the background music. Some people think the cue of the balloon is intuitive, and have word under it, so it's easy to understand. Some people disagree and think the balloon looks fake, and they don't like the way it presented. Others think when doing breathing exercise, they want to close their eyes or see the starry sky, the balloon interfere with relaxation. The pros of *Tactile* are it feels like massage and can help to relax, it can really guide the breathing and it's more interesting and comfortable. The cons for *Tactile* are it's not easy to translate the meaning of TIP and it needs more time to learn. So, with the help of *Audio* or *Visual*, the shortcomings of *Tactile* can be compensated. That why most people like the combination of two instructions better.

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Chapter 6 Evaluation

After we explore the TIP for each step of breathing and know the preference of multi-modal instruction, we conducted several user studies to learn more about them.

Participants

We recruited 16 participants (11 males and 5 females) between 21 and 31 years old (mean=23.88 years old, SD=2.53) to be our subjects in user studies. Only 4 of them have never used massage chairs before. 7 of them like to use massage chairs, and 9 of them have no special feeling for massage chairs. All of them have used VR before. Nobody practices diaphragmatic breathing on their daily basis.

6.1 User Study 1: Determine Personalize TIP for Inhale and Exhale

Experiment Design

The options for the TIP of inhalation is the same as *Inhale Direction / Keep-Vibrating Row* in exploration study 3 (as described in Ch 5.3), the directions of TIP for

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exhalation is the opposite of *Inhale Direction*, and the *Keep-Vibrating Row* is the same as TIP for inhalation. In exploration study 3 two thirds of people like *Two Rows* in *Basic Vibration Range* better, so in this study, we all use *Two Rows*.

Task

The task in this study is to follow the TIP to do 4040 diaphragmatic breathing and use a 7-point scale (1: Negative, 7: Positive) to rate the effectiveness (can it successfully guide breathing), efficiency (how much effort and resource need to learn and remember) and satisfaction of each option for TIPs. Then choose the one they like the most.

Procedure

At the beginning of the experiment, we used video [28] to teach participants diaphragmatic breathing. After they watched the video, we said the main point again: abdominal expands when inhale, and the abdominal shrinks when exhale. Then, we let them experience *Up/No* and *Down/No*, the order is counterbalanced. If the participants said they like *Up/No* better, we then let them experience *Up/No* and *Up/Top*, and ask them to choose the one they like. If the participants said they like *Down/No* better, we then let

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them experience *Down/No* and *Down/Bottom*, and ask them to choose the one they like. The order is also counterbalanced.

Results

The results are shown in Table 6.1. Half of the participants think the direction for inhalation should be *Up* and another half think the direction should be *Down*. 7 out of 8 participants that like *Up* don't like the top row keep vibrating. 5 out of 8 participants that like *Down* don't like the bottom row keep vibrating.

	Up / No	Down / No	Up / No	Up / Top	Down / No	Down / Bottom
Effectiveness	4.06 (1.48)	4.13 (1.82)	4.5 (1.77)	3.5 (1.77)	5 (1.51)	4.63 (1.19)
Efficiency	4.75 (1.65)	4.75 (1.61)	4.88 (1.96)	4.25 (1.67)	5.38 (1.3)	5 (0.93)
Satisfaction	3.94 (1.29)	3.88 (1.75)	4.38 (1.19)	3.38 (1.3)	4.75 (1.58)	4.5 (1.51)
How many people like the most	8	8	7	1	5	3

Table 6.1 The results of user study 1.

Discussions

We changed the way participants choose their favorite TIP and do the rating. Because in exploration study 3, we found there will be a situation that many people like that TIP, but its ratings are lower than the one that fewer people like. In this study, the problem has solved. And we can see that the preference of each participant for the

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direction of TIP for inhalation and exhalation is different, both have their own supporters, and if they are given the wrong direction, they think it feels weird. But for *Keep-Vibrating Row* it is not really necessary.

6.2 User Study 2: Determine Personalize TIP for Breath-Holding

Experiment Design

The options for the TIP of breath-holding is *No Vibration* and *2x2 Pulse Vibration*. The other options in exploration study 3, *2x2 Continuous Vibration*, *2x8 Continuous Vibration*, and *2x8 Pulse Vibration* are removed because as mention in the discussion of exploration study 3, *2x2 Continuous Vibration* violates the design consideration for TIP design. *2x8 Continuous Vibration* and *2x8 Pulse Vibration* are too complex and the front of the TIP of breath-holding after exhalation is similar to the TIP of inhalation or exhalation, only it's faster. So, we also removed these TIPs.

Task

The task in this study is to follow the TIP to do 4848 diaphragmatic breathing and

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use a 7-point scale (1: Negative, 7: Positive) to rate the effectiveness (can it successfully guide breathing), efficiency (how much effort and resource need to learn and remember) and satisfaction of each option for TIPs. Then choose the one they like the most.

Procedure

We asked the participants to experience *No Vibration* and *2x2 Pulse Vibration* with the TIP of inhalation and exhalation selected in user study 1 and ask them to choose the one they like. We then ask why he or she like that TIP the most. The order is counterbalanced.

Results

The results are shown in Table 6.2. 2 out of 5 participants that chose *No Vibration* said they cannot endure *2x2 Pulse Vibration*. One said the pattern let him want to spit out the air, it has the opposite effect for breath-holding. Another thinks it feels like a person poking him, which was very disturbing. So, as we said in design consideration, the TIP should not interfere with the user's breathing, if they cannot accept the patterns, it's better to give them *No Vibration*. The good comment for *2x2 Pulse Vibration* is the same as exploration study 3.

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	No Vibration	2x2 Pulse Vibration
Effectiveness	4.13 (1.54)	4.69 (1.35)
Efficiency	4.81 (1.28)	5 (1.55)
Satisfaction	4 (1.55)	4.44 (1.41)
How many people like the most	5	11

Table 6.2 The results of user study 2.

6.3 User Study 3: Evaluate Effectiveness of Personalize TIP for Breath Guiding

After the participants completed previous studies and chose their favorite TIPs, we give them that TIP for tactile instruction for 4-7-8 breathing and Nadi Shodhana Pranayama in this study. When practicing Nadi Shodhana Pranayama, it's best to use the time ratio of 4:16:8:0 to practice [29]. But it's hard for most people to hold their breath for 16 seconds then exhale for 8 seconds, so we use 2840 in this study.

Experiment Design

We come up with a system that guides the users breathing. There always has relaxing background music and the milky way as the background scene. First, the audio, visual, and tactile instructions appear together for nearly one minute. Then we take off visual instruction, it remains audio and tactile instructions. After another one minute, audio

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instruction disappeared, leaving only tactile instruction. If the participants forget what the tactile instruction means, he or she can press space to call back the audio instruction, the audio instruction will last for 1 breath and disappeared again. All the instructions for 4-7-8 breathing are the same as in exploration study 4 (as described in Ch 5.4). But when the audio instruction is called back, a canvas with icons that are circled by green in Fig. 4.5 will appear. It may help the participants to learn the TIP better. The visual instruction for Nadi Shodhana Pranayama has two balloons (Fig. 6.1), one for left nose, the other for right nose, when breathing with left nose, the balloon on the left will change its size. The word in the middle of two balloons will specify which nose to use. The audio sound is the same as the word in the middle of two balloons, it will specify which nose to use. The tactile instruction divides the TIPs into left side and right side. Which side of the nostril is used for inhalation and exhalation, that side of vibrators vibrate.

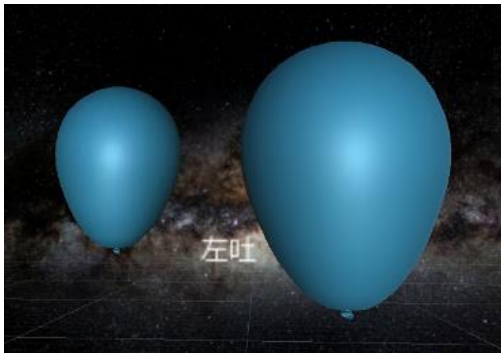

Fig. 6.1 Visual instruction for Nadi Shodhana Pranayama.

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Task

The task in this study is to follow the instructions to do the breathing exercise for ten minutes and answer the following questions: "Have you kept up with the breathing guidance?", "Have you forgotten what to do at any of the instructions?", and "Do those instructions disturb you?"

Procedure

First, we teach participants the steps of 4-7-8 breathing are inhale through the nose for 4 seconds, then hold the breath for 7 seconds, next exhale from the mouth for 8 seconds. Second, we introduced the system to them, and tell them to press the space whenever they forget what the tactile instruction means to call back the audio instruction. Next, the participant is asked to put on the head-mounted display. We measured their brainwaves, so we will check if the values of brainwaves have been read. Then, we tie Mindfield eSense Skin Response to their fingers and check if it works properly. Next, 4-7-8 breathing exercise for ten minutes starts. After they take their head-mounted display off and answered the questions, we teach participants that the steps of 2840 Nadi Shodhana Pranayama are inhale with left nose for 2 seconds, then hold the breath for 8

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seconds, next exhale with right nose for 4 seconds, then inhale with right nose for 2 seconds, next hold the breath for 8 seconds, and then exhale with left nose for 4 seconds. Use a finger to block the nose that is not for breathing. Then, we tell them to press the space with the hand that we tied eSense Skin Response. Next, the participant is asked to put on the head-mounted display again. We check again if the values of brainwaves and skin responses have been read. Next, Nadi Shodhana Pranayama exercise for ten minutes starts. After they have done the study, we asked them to fill out the System Usability Scale (SUS).

Results

Two participants called back the audio instruction when practicing 4-7-8 breathing. They called back 1 and 2 times respectively. Four participants called back the audio instruction when practicing Nadi Shodhana Pranayama. They called back 1, 1, 2, and 3 times respectively. Because Nadi Shodhana Pranayama is harder, so more people need the audio cue to help them and need them more times. The results of the brainwaves are shown in Fig. 6.2, a color represents a participant's brainwave movement in attention and relaxation. The brainwaves of the tenth participant failed to record properly. Most of the data are on II quadrant, which may mean that participants are relaxed and about to fall

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asleep, so their attention decreased. None of the participants are in meditation state, both attention and relaxation increased (I quadrant), when doing the breathing exercise, it needs more practice to enter the meditation state. The results of the skin response are shown in Fig. 6.3, a color represents a participant's result. The horizontal axis is time, the vertical axis is stress level. More people can get used to 4-7-8 breathing quickly, so their stress level increased in the front, decreased in the end. But still, some people's stress level rises, and more people's stress level rises in Nadi Shodhana Pranayama. It may because it is their first time doing these breathing exercises, and it's not easy for them to keep up, so they didn't feel relax. It needs practice to get familiar with these breathing techniques and see the effectiveness of these breathing techniques. The results of the SUS are shown in Fig. 6.4. The average SUS score is 66.72 (SD=13.31). The results of every item in SUS are shown in Fig. 6.5, we can see that the score for "I think that I would like to use this system frequently.", "I think that I would need the support of a technical person to be able to use this system.", "I needed to learn a lot of things before I could get going with this system." are relatively low. The SUS score is much better than ok and close to good, we still need to improve the TIPs for our system so that users want to use it more and require less effort to memorize and translate them.

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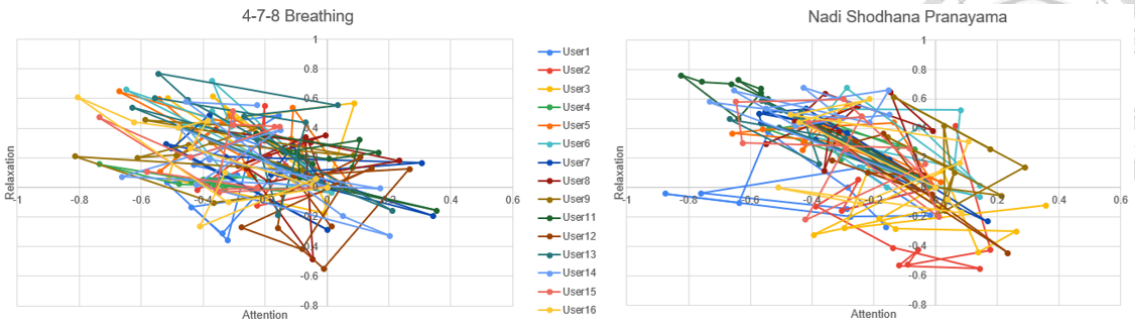

Fig. 6.2 The result of brainwaves in user study 3.

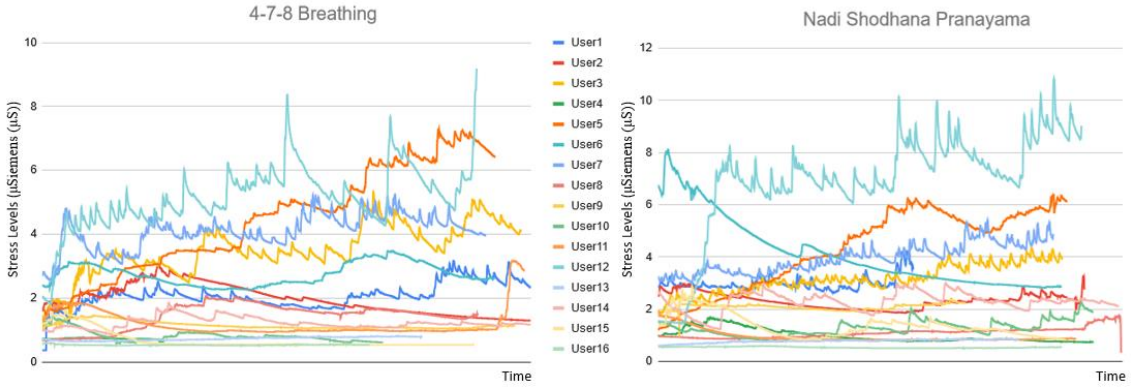

Fig. 6.3 The result of skin response in user study 3.

Fig. 6.4 The results of SUS.

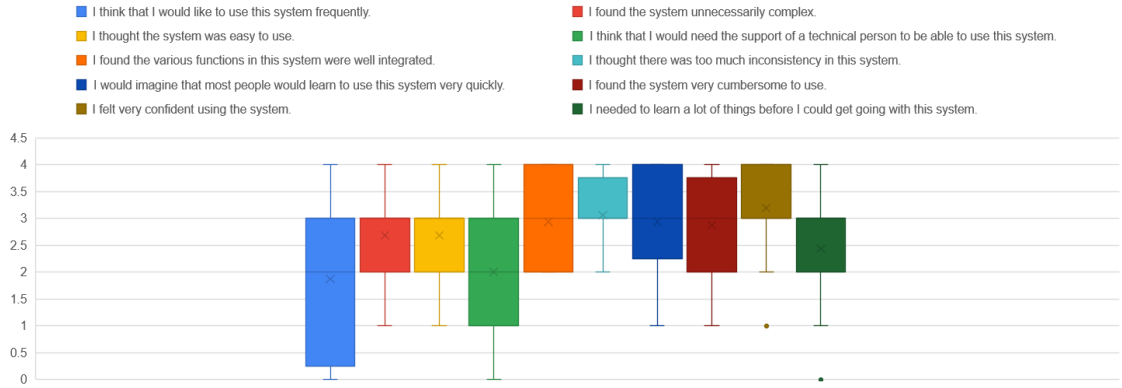

Fig. 6.5 The results of every item in SUS.

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Most people said that they cannot keep up with the guidance because of the difficulty of the breathing techniques. In 4-7-8 breathing, they said the length for breath-holding and exhale is too long, but they still know what step it is now due to the tactile instruction. In Nadi Shodhana Pranayama, they said the length for breath-holding is too long and only has 2 seconds to inhale, the air is not enough for the following steps. And due to stuffy nose so cannot do it properly. In 4-7-8 breathing, a participant said the audio instruction disturb her a little and is a little bit too long. A participant said the visual instruction is useless. No other participants said that any instruction disturbs them. But in Nadi Shodhana Pranayama a participant said that due to the relatively short inhalation time, the interval between each step of TIP feels small, which is a little bit unclear. So, the tactile instruction kind of disturb her, we may need to do a study on TIPs for relatively short breathing steps in the future to solve this problem. In 4-7-8 breathing, every participant said with this system they won't forgot what the instructions mean, because they can call back audio instruction and we removed instructions one by one until only tactile instruction was left, so it won't like in exploration study 4 that many participants said when the tactile instruction appeared, they had forgotten what the instruction means. But in Nadi Shodhana Pranayama a participant said to press the space while doing this

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breathing is not that easy, only concentrate on breathing is hard enough. So, she thinks the audio instruction disappeared again after 1 breath is too short. It is because Nadi Shodhana Pranayam is harder than 4-7-8 breathing, it needs more time to learn it.

Discussions

We can see in the results that only practice the breathing exercises once with our system cannot see the effect yet. But we still got a lot of feedbacks of pros and cons of our system. In the future, we should divide the participants into two groups, one does the breathing exercises with our system, the other does the breathing exercises by themselves every day for about two weeks, and see which group of participants can enter the meditation state and feel the effectiveness of the breathing techniques faster. Other feedbacks are listed below. A participant said is good to only left the tactile instruction and can call back audio instruction when he needed, because he thinks with the audio instruction he cannot be relaxed, but he still needs the audio instruction when he forgot what the tactile instruction is about. A participant said there is a gap between the TIP of exhalation and inhalation, it is because we need to allow the users to distinguish when the exhalation changes to inhalation, as we said in design consideration. A participant thinks in Nadi Shodhana Pranayam the TIP vibrates different sides is very intuitive.

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Chapter 7 Conclusion and Future Work

In this thesis, we design a tactile chair cushion and explore on TIPs that can guide breathing. We invented an interface that helps designing TIPs faster and more efficiently. Then we conducted several studies to find the intuitive TIP for breath guiding. We can see in our results that the preference of each participant for the direction of TIP for inhalation and exhalation of diaphragmatic breathing is different, and if they cannot accept the vibration patterns, it is better not to provide vibration for that action than give the TIP that they dislike. We also carry out a study to find the preference of multi-modal instruction, the results show when only one instruction is used to guide breathing, more people prefer tactile instruction. Last but not least, we propose a system that can guide users breathing with the least interference. Although, we do not see much effect of participants using this system to do the breathing exercise only once. The SUS score 66.72 is much better than ok and close to good, we still need some improvement to enter acceptable. We listed future works below to enhance the tactile instruction for breath guiding. First, change the vibration motor modules to speaker modules, so the users can change the intensity of vibration. Second, find a more suitable TIP for relatively short

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breathing steps. Third, we can conduct a study similar to user study 3, and asked the participants to come several days to do the breathing exercise and see when they can enter the meditation state and can feel the effectiveness of the breathing techniques. We can divide the participants into two groups, one does the breathing exercise with our system, the other does the breathing exercise by themselves, and see which can see the effectiveness of the breathing techniques faster. Last, we can explore the design of TIPs on other breathing techniques.

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REFERENCE

[1] Brown, R.P. and P.L. Gerbarg, *Sudarshan Kriya yogic breathing in the treatment of stress, anxiety, and depression: part I—neurophysiologic model.* Journal of Alternative & Complementary Medicine, 2005. **11**(1): p. 189-201.

[2] Brown, R.P. and P.L. Gerbarg, *Sudarshan Kriya Yogic breathing in the treatment of stress, anxiety, and depression: part II—clinical applications and guidelines.* Journal of Alternative & Complementary Medicine, 2005. **11**(4): p. 711-717.

[3] Weil, A., *Breathing: The master key to self healing*. 1999: Sounds True.

[4] Kinabalu, K., *Immediate effect of 'nadi-shodhana pranayama'on some selected parameters of cardiovascular, pulmonary, and higher functions of brain.* Thai journal of physiological sciences, 2005. **18**(2): p. 10-16.

[5] Naik, G.S., G. Gaur, and G. Pal, *Effect of modified slow breathing exercise on perceived stress and basal cardiovascular parameters.* International journal of yoga, 2018. **11**(1): p. 53.

[6] Yu, B., Feijs, L., Funk, M., & Hu, J., *Breathe with touch: a tactile interface for breathing assistance system*. in *IFIP Conference on Human-Computer Interaction*. 2015. Springer.

[7] Uratani, H. and M. Ohsuga, *Relaxation Effect of a Respiration-Leading Stuffed Toy.* Advanced Biomedical Engineering, 2018. **7**: p. 100-106.

[8] Ban, Y., Karasawa, H., Fukui, R., & Warisawa, S. I., *Relaxushion: controlling the rhythm of breathing for relaxation by overwriting somatic sensation*, in *SIGGRAPH Asia 2018 Emerging Technologies*. 2018. p. 1-2.

doi:10.6342/NTU202002260

[9] Sato, T. G., Ohsuga, M., Boutani, H., & Moriya, T., *Tactile phantom sensation for coaching respiration timing.* IEEE transactions on haptics, 2015. **8**(1): p. 119-125.

[10] Paredes, P. E., Zhou, Y., Hamdan, N. A. H., Balters, S., Murnane, E., Ju, W., & Landay, J. A., *Just breathe: In-car interventions for guided slow breathing.* Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies, 2018. **2**(1): p. 1-23.

[11] Balters, S., Murnane, E. L., Landay, J. A., & Paredes, P. E., *Breath Booster! Exploring In-car, Fast-paced Breathing Interventions to Enhance Driver Arousal State*. in *Proceedings of the 12th EAI International Conference on Pervasive Computing Technologies for Healthcare*. 2018.

[12] Bumatay, A. and J.H. Seo. *Investigating the role of biofeedback and haptic stimulation in mobile paced breathing tools*. in *International Conference on Augmented Cognition*. 2017. Springer.

[13] v. Békésy, G., *Sensations on the skin similar to directional hearing, beats, and harmonics of the ear.* The Journal of the Acoustical Society of America, 1957. **29**(4): p. 489-501.

[14] Burtt, H.E., *Tactual illusions of movement.* Journal of Experimental Psychology, 1917. **2**(5): p. 371.

[15] Sherrick, C.E. and R. Rogers, *Apparent haptic movement.* Perception & Psychophysics, 1966. **1**(3): p. 175-180.

[16] Kirman, J.H., *Tactile apparent movement: The effects of interstimulus onset interval and stimulus duration.* Perception & Psychophysics, 1974. **15**(1): p. 1-6.

[17] Israr, A. and I. Poupyrev. *Tactile brush: drawing on skin with a tactile grid display*.

doi:10.6342/NTU202002260

in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 2011.

[18] Pittera, D., M. Obrist, and A. Israr. *Hand-to-hand: an intermanual illusion of movement*. in *Proceedings of the 19th ACM International Conference on Multimodal Interaction*. 2017.

[19] Israr, A., Poupyrev, I., Ioffreda, C., Cox, J., Gouveia, N., Bowles, H., ... & Williams, T., *Surround Haptics: sending shivers down your spine*, in *ACM SIGGRAPH 2011 Emerging Technologies*. 2011. p. 1-1.

[20] Israr, A., Schwemler, Z., Mars, J., & Krainer, B., *VR360HD: a VR360 player with enhanced haptic feedback*. in *Proceedings of the 22nd ACM Conference on Virtual Reality Software and Technology*. 2016.

[21] Zhao, S., Schneider, O., Klatzky, R., Lehman, J., & Israr, A., *FeelCraft: crafting tactile experiences for media using a feel effect library*. in *Proceedings of the adjunct publication of the 27th annual ACM symposium on User interface software and technology*. 2014.

[22] Israr, A., Zhao, S., McIntosh, K., Kang, J., Schwemler, Z., Brockmeyer, E., ... & Mahler, M, *Po2: augmented haptics for interactive gameplay*, in *ACM SIGGRAPH 2015 Emerging Technologies*. 2015. p. 1-1.

[23] Israr, A., Zhao, S., Schwalje, K., Klatzky, R., & Lehman, J., *Feel effects: enriching storytelling with haptic feedback.* ACM Transactions on Applied Perception (TAP), 2014. **11**(3): p. 1-17.

[24] Geldard, F.A., *Cutaneous coding of optical signals: The optohapt.* Perception & Psychophysics, 1966. **1**(11): p. 377-381.

doi:10.6342/NTU202002260

[25] Gunther, E. and S. O'Modhrain, *Cutaneous grooves: composing for the sense of touch.* Journal of New Music Research, 2003. **32**(4): p. 369-381.

[26] Leek, M.R., *Adaptive procedures in psychophysical research.* Perception & psychophysics, 2001. **63**(8): p. 1279-1292.

[27] Levitt, H., *Transformed up-down methods in psychoacoustics.* The Journal of the Acoustical society of America, 1971. **49**(2B): p. 467-477.

[28] YouTube. How to practice diaphragmatic breathing in yoga? June 2020. https://www.youtube.com/watch?v=nkQqYEK2tJ4

[29] HEHO. Illustrated Nadi Shodhana Pranayama, allows you to be calm and sleep well. June 2020. https://heho.com.tw/archives/60102

doi:10.6342/NTU202002260