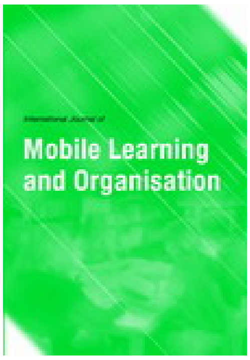

International Journal of Mobile Learning and Organisation

ISSN online: 1746-7268 - ISSN print: 1746-725X
https://www.inderscience.com/ijmlo

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Pitsanu Chaichitwanidchakol, Witcha Feungchan

DOI: 10.1504/IJMLO.2023.10048607

Article History:

Received:	29 December 2021
Accepted:	16 April 2022
Published online:	01 December 2023

Design and implementation of a breathing interaction system for autistic Thai children

Pitsanu Chaichitwanidchakol

Department of Computer Science and Information Technology,
Faculty of Science,
Udonthani Rajabhat University,
Udon Thani 41000, Thailand
Email: pitsanu.ch@udru.ac.th

Witcha Feungchan*

Department of Computer Engineering,
Faculty of Engineering,
Khon Kaen University,
Khon Kaen, 40002, Thailand
Email: witcha@kku.ac.th
*Corresponding author

Abstract: Hyperbaric oxygen therapy (HBOT) is utilised to treat a variety of abnormal symptoms and assist children with autism improve their development in a variety of areas. The goal of this study is to help children with autism practise breathing at a pace that is near normal in order to deliver more oxygen to the brain. As a result, breathing interactions with two VR games were created specifically for autistic youngsters. First, an ASD breathing game allows a child to interact with real-time respiration rate, the practitioners could assist the child to breathe near the norm. Second, an ASD underwater exercise game allows a youngster to practise breathing skills while underwater and in the water. It involves an interactional breathing pattern. Both games employ virtual reality (VR) technology to aid in teaching proper breathing techniques. The findings of the game test show that autistic children's usage of breathing interaction patterns is successful.

Keywords: pervasive learning; virtual reality; VR; bio interaction; breath interaction; virtual feedback; simulation; autism; respiratory; hyperbaric oxygen therapy; HBOT; hypoxic-ischemic encephalopathy; HE.

Reference to this paper should be made as follows: Chaichitwanidchakol, P. and Feungchan, W. (2024) 'Design and implementation of a breathing interaction system for autistic Thai children', *Int. J. Mobile Learning and Organisation*, Vol. 18, No. 1, pp.74–100.

Biographical notes: Pitsanu Chaichitwanidchakol is an Assistant Professor at the Faculty of Science (Computer Science), Udonthani Rajabhat University. Udonthani 41000, Thailand. He completed his PhD in Computer Engineering at the Khon Kaen University, in 2021. He has published many publications in the area of human computer interaction, video game design and ubiquitous computing.

Witcha Feungchan is an Assistant Professor at the Faculty of Engineering (Computer Engineering), Khon Kaen University, Khon Kaen, 4002, Thailand, where he has been a faculty member since 2002. He completed his PhD in Electronic Systems Engineering at the University of Regina, Canada, in 2009. He has contributed in many publications in the areas of video games design, serious games, ubiquitous computing, VR and educational technology. He has also collaborated actively with multidisciplinary teams in engineering, computer science and education.

1 Introduction

Autistic spectrum disorder (ASD) is a congenital disease of the brain. The specific cause has yet to be determined. It is influenced by a variety of factors. Cerebral hypoxia or ischemia is one of the variables that contribute to autism. Injury to brain cells occurs because of HE. Although uncommon, this sort of damage can occur during delivery (Raurale et al., 2020) and, if it occurs, it can result in irreversible brain damage and even death. For those who survive, it can lead to autism (Lechpammer et al., 2016). Autism creates problems in three areas: communication, social interaction, and behaviour. Meanwhile, this sickness cannot be treated fully as a result. The treatment strategy focuses on promoting growth while also minimising improper conduct, which can help autistic individuals live their lives as normally as possible. Many areas of the brain in children with autism have decreased blood flow, as found in previous studies. Such a decrease may cause an anomaly to occur. HBOT is a technique that permits the brain tissue to get more oxygen. Brain cells are thus able to function more efficiently. Statistically, assisting youngsters to develop a sense of language in all categories, social interactions, eye contact, and cognition increased significantly (Rossignol et al., 2009).

To get more oxygen to the brain, children undergoing treatment should be taught proper breathing methods. Breathing quicker than normal does not result in additional oxygen being delivered to the body; the blood carbon dioxide level is too low. Palpitations, disorientation, numb hands and feet, and other symptoms may occur. If breathing at a normal rate, more oxygen will be delivered to the brain as a result (Mintun et al., 2001).

To teach autistic children to breathe properly, a practitioner (an instructor/researcher at the autistic research centre) finds it difficult to explain and demonstrate a respiratory concept via verbal and visual, especially for youngsters who have communication or dyschronometria issues. Using an incentive spirometer to learn about breathing lack of attraction and motivation for youngsters, and it is not a suitable metaphor for the human respiratory system. Therefore, using interactive media such as video games and VR as a learning tool is a good solution. Interactive media allows users to explore the content in many possibilities (time, metaphors, animations and 3D objects). Appropriate interactions for autistic children are those that can meet their needs (Yang and Chen, 2009). Common interactions may not be entirely applied to autistic youngsters because of different disabilities, personal characteristics, and levels of autism. For example, interaction with smartphones by speaking is surely functional for common people and some autistic children who can speak. However, it is not practical for those who are not able to speak (Grynszpan et al., 2005; Ur Rehman et al., 2021). Therefore, using biological features (such as ECG, brainwave, or breathing) (Fedotchev et al., 2019; Cerasa et al., 2021) for interactions is appropriate for this study since these features come directly from an autistic child's body, making the interaction suite for a wide range of autism (Sarker et al., 2018). According to ASD interactivity framework (Chaichitwanidchakol, 2021), using breathing interaction could be an appropriate approach for this solution. For this study, computer interaction patterns through breathing are presented and used for teaching autism to breathe properly.

This research aims to design a breathing interaction to help autistic children practice breathing at a near-standard level for further oxygen intake. An appropriate interaction by breathing for these children is designed in the form of VR games. In this study, two games were designed by using a breathing interaction. The first one is the balloon game (an analogy to human lungs because they bloat while inhaling and flatten while exhaling), which can help children see the lungs more clearly and more easily understand how they work than an incentive spirometer. VR is implemented in this game to immerse children into the virtual environment as if the situation is occurring. The balloon game displays a real-time respiratory rate, helping the practitioners to suggest the child breathe correctly according to the standard rate. To verify a breathing concept with autistic children, the second game is used to assess the ability of children to control their respiratory. This second VR game simulates in the water scenarios to learn the basic underwater breathing exercises by using a breathing interaction. The second game also helps the children learn about the breathing concept in water before attending water therapy class. Three autism volunteers participated in the experiment at Autistic Research Centre Khon Kaen University under the supervision of the practitioners, a psychologist, and the researchers. Each volunteer played both games four times.

To investigate the feasibility and effectiveness of applying a breathing interaction system for autism through the VR games. The researchers pursued the following research questions:

- Can a breathing interaction game help autistic children improve their respiratory rate?
- Can a breathing interaction game assess the ability of autistic children to control their respiratory based on the given scenarios?

2 Related works

2.1 Autism spectrum disorder

ASD is a group of conditions caused by brain abnormalities that cannot specify which part of the brain is the actual cause, causing disabilities in language and social development. The severity of the condition depends on language development, IQ, and additional abnormalities. Autism is in the pervasive developmental disorders (PDDs) group. Symptoms are apparent during childhood, typically manifesting in abnormal language and social development, behaviours, and interests.

ASD cannot be completely cured. Therefore, therapy involves focusing on the improvement of children's development and reducing inappropriate behaviours in order to help autistic people be able to live as normal a life as possible similar to other people.

2.2 Hypoxic-ischemic encephalopathy

HIE is a condition wherein the brain functions incorrectly due to a lack of oxygen or blood during the neonatal period (birth asphyxia) (Raurale et al., 2020), thus causing brain pathology. Typically, the brain tolerates the lack of oxygen for up to approximately five minutes. A newborn who has asphyxia will also have brain ischemia. If the infant is treated correctly and immediately after the lack of a small amount of blood, brain tissue necrosis will not happen. If asphyxia is allowed to become more severe or is not treated quickly, tissue necrosis will occur in many areas of the brain, causing cerebral oedema and increased pressure in the skull. This leads to brain necrosis and loss of brain cell functionality. Those who survive brain necrosis may become autistic (Lechpammer et al., 2016).

2.3 Hyperbaric oxygen therapy

HBOT is treatment by giving special oxygen. This can be done by letting a patient breathe 100% pure oxygen in a hyperbaric chamber with more than 1 ATA of pressure. Breathing under HBOT treatment causes the body to receive 2–3 times more oxygen levels than breathing with pure oxygen in a normal atmosphere. This alternative treatment must be done along with internal medicine and surgical treatment (Chungpaibulpatana et al., 2008).

HBOT treatment for autism can be done by increasing 100% of oxygen level to brain cells at 1.3 ATA of pressure. The brain and body receive more oxygen than normal, causing the brain cells to awaken and function more effectively. Typically, this phenomenon cannot occur while breathing in a normal atmosphere, which contains only 21% oxygen.

2.4 Breathing

Breathing is the means to bring air containing oxygen into the body through the mouth or nose, which is then distributed to the brain and parts of the body, as well as the release of carbon dioxide from the body through the lungs. The two types of breathing comprise inspiration, which involves the inhalation of air into the lungs, and expiration, which involves the exhalation of air out of the body through the lungs. Humans have survival instincts, enabling them to breathe since birth; it is a basic human function that cannot be denied. Those who cannot breathe will die in 8–10 minutes. Different ranges of human age have different standard respiratory rates, as shown in Table 1.

Table 1 Standard respiratory rate by Age Ranges

Age	*Respiratory rate (breaths per minute)*
Infant	30–60
Toddler	24–40
Preschooler	22–34
School-aged child	18–30
Adolescent	12–16

Source: Yock-Corrales and Starr (2010)

2.5 Interaction for autistic children

By searching related works, there are six patterns of interactions for autistic children, as shown in Table 2. Therefore, a breathing interaction was proposed as the seventh pattern.

Table 2 Patterns of interactions from related works

Interaction	*Related work(s)*
Touch interaction	Dehkordi and Rias (2014), Iyer and Kalbande (2014), Kamaruzaman and Jomhari (2015), Nouwen et al. (2016)
Mouse/keyboard interaction	Hassan et al. (2011), Weilun et al. (2011), Chang et al. (2012Z), Kamaruzaman and Jomhari (2015)
Motion interaction	Bartoli et al. (2013), Garzotto et al. (2014), Roglic et al. (2016), Mir and Khosla (2018)
Sound interaction	Alqahtani et al. (2011), Heni and Hamam (2016)
Emotional expression interaction	Heni and Hamam (2016)
Dramatic element interaction	Barakova et al. (2007), Barakova (2011), Pipitpukdee and Phantachat (2011), Peca (2016), Mei and Guo (2018)
Breathing interaction	Proposed in this study

According to these six interaction patterns in Table 2, all interactions can be employed for autism in many approaches. Each interaction provides a different experience and serves various purposes:

- Touch interaction: A user can interact with the system via touch (fingers, hand, or stylus). This interaction allows a user to directly manipulate the UI elements on a touch screen. This interaction is widely used on mobile platforms such as smartphones, tablets and smart watches.
- Mouse/keyboard interaction: This interaction serves as a general input on computer platforms. Most computer games or software provides this basic interaction for a user to interact with the system.
- Motion interaction: This interaction relies on motion detection mechanisms to capture a user's body movements (Chaichitwanidchakol and Feungchan, 2020), eye movements, or gestures. Examples of motion sensors are cameras, gyroscopes, accelerometers, magnetometers, and ultrasonic sensors.
- Sound interaction: A microphone is the main input device for sound interaction. Sound interaction could be speech, utter, or other human-made sounds. For example, a serious game that utilises sound interaction to help autism learn how to correctly pronounce the vocabulary (Chaichitwanidchakol and Feungchan, 2021).
- Emotional expression interaction: This interaction focuses on a user's emotional expression based on various approaches such as facial expression, voice, vital signs, and bio information.
- Dramatic element interaction: This interaction requires special hardware to interact with a user. For example, using special purposed smart toys or robots to interact with autism in attractive ways.

- Breathing interaction: Using bio information to interact with autism is effective and effortless. A user's breathing is an input for the interaction, while the responses could be any proper feedback. This interaction is intuitive for autism, who just naturally breathe to provide the input (respiratory rate, pattern, and time interval). The interaction feedback can be visual, video, sound, or haptic feedback based on the design purposes. In this study, video feedback is displayed based on real-time breathing information from the biosensors. In short, the breathing interaction is the most appropriate approach to deal with the autism respiratory matter.

After exploring the six interaction patterns, the researcher could not find the existing interaction to answer the research questions. Therefore, this study proposed breathing interaction to fill in the gap and aim to solve the respiratory issue in autism by using interactive breathing VR games.

2.6 Virtual reality therapy

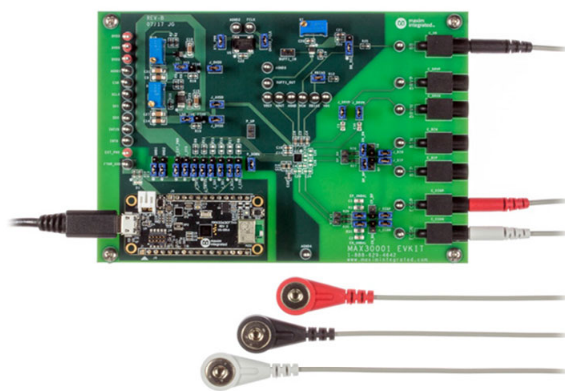
VR is a tool used to create a virtual environment combined with the real environment via a computer system in 3D views. However, additional equipment for viewing the 3D virtual world and interacting with the system is required to use VR technology. The gadget for interacting with the VR system is in the form of glasses, a head-mounted display, and a joystick with a motion sensor. Furthermore, VR technology enables the user to have a 360-degree stereoscopic view, so virtual images can be observed from wherever the user walks or faces. VR technology is commonly used in the video game industry. One example is a shooting game in which the user can interact via a joystick or the virtual scenery. In fact, VR technology is being used in various industries such as medical, educational, and entertainment media. The study of the design of immersive VR system to improve communication skills in individuals with autism (Raurale et al., 2020) uses VR in communication skill development, and the results show that the usage of VR can help to improve children's learning. The fully immersed VR with a well-designed virtual environment is suitable for autistic children to avoid real-world distractions (Yu, 2021).

3 Methodology

3.1 Breathing interaction design

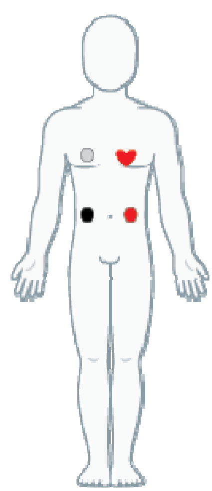
According to a literature review about autism interactions, those six interaction patterns could not be used to solve autism respiratory issues. The researchers discovered that bio information (breathing) is suitable to naturally interact with autism. Breathing interaction is the means to interact by detecting types of respiration (inspiration or expiration). Typically, humans can verify the breathing of others by watching the expansion and flattening of their chest. For a computer system, a portable respiration sensor (Kano et al., 2018), another respiratory rate measurement device (Liu et al., 2019), or bioimpedance converters. This study uses manual counting and a bio impedance for respiratory rate measurement. The manual counting method is used in observation sessions by the practitioners. This experiment uses a MAX30001 EVKIT experiment board (MAX30001 – Maxim Integrated, 2019) as shown in Figure 1, it can provide input to the games and accurately measure the user's respiratory rate. Max30001 EVKIT allows the researchers to interface with the computer games, it requires less effort than other methods. This board provides many bio-information such as heart rate, ECG signal, and respiratory rate. The volunteers need to attach an ECG electrode pad on three positions of their body (three lead), as shown in Figure 2. The respiration result is shown in Figure 3. This study assumes that autistic children possess the ability to interact with the application or the game by breathing without further learning. The goal of breathing interaction is to track breathing and verify that the body is inhaling or exhaling.

Figure 1 MAX30001 Evkit experiment board (see online version for colours)



Source: MAX30001 – Maxim Integrated (2019)

Figure 2 ECG Electrode installation positions (see online version for colours)



After detecting inhalation or exhalation from the board, the actions must be defined for interaction. For example, a player can control the flying level of his/her avatar to avoid the obstacles in a game by flying up while inhaling and gliding down while exhaling.

Figure 3 Graph displaying respiration types in the MAX30001 evaluation system (see online version for colours)

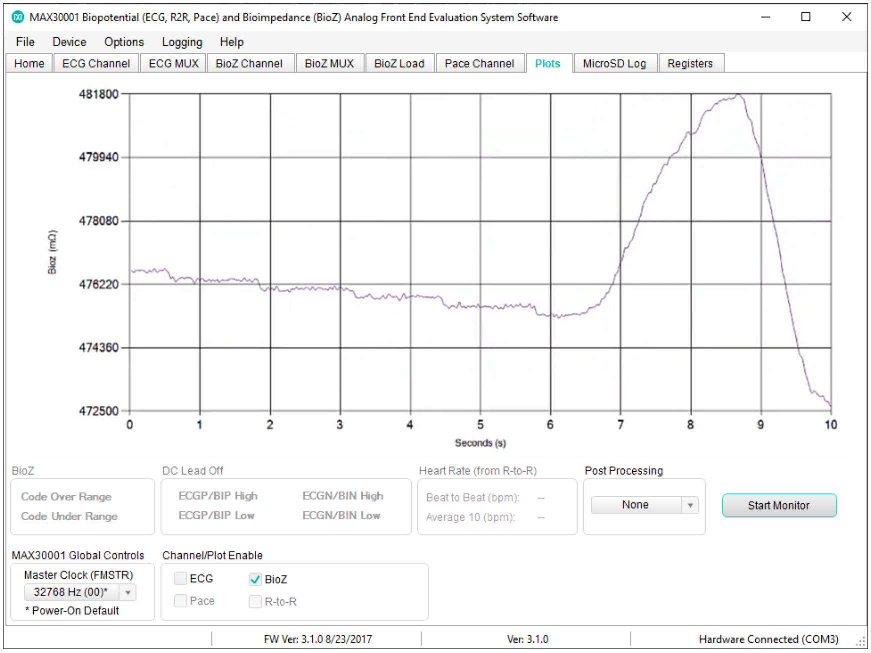
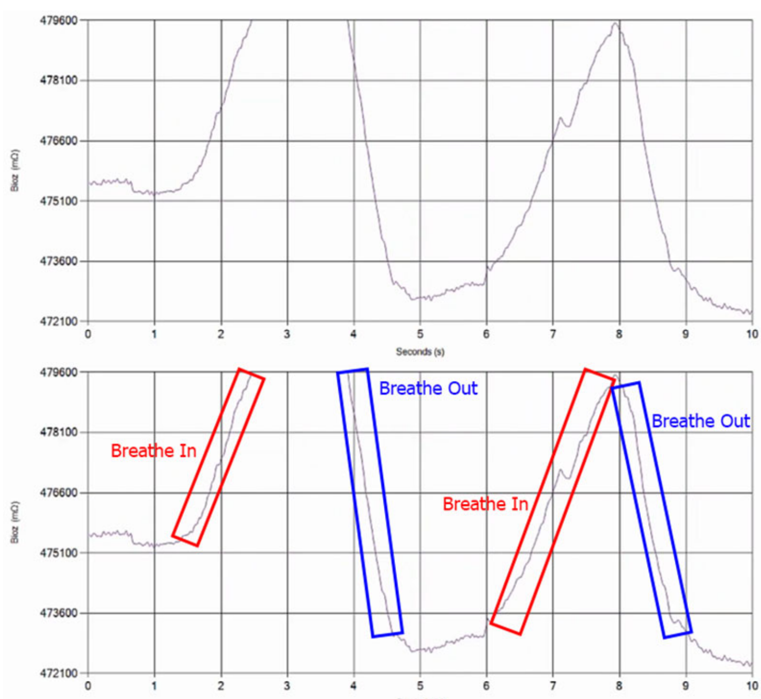


Figure 4 Graph displaying respiration types (see online version for colours)

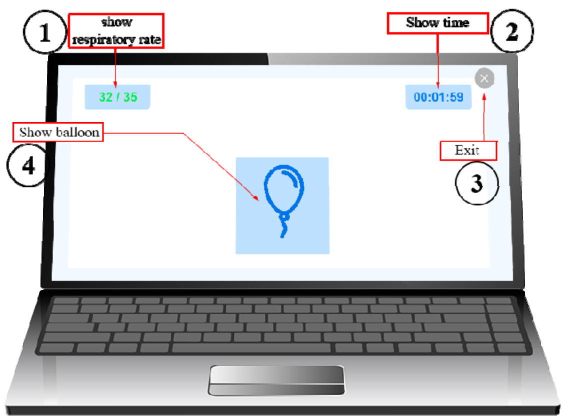


After installing ECG electrode pads on the volunteer's body, the MAX30001 EVKIT experiment board is connected to the computer, and then the experiment begins. The respiration result is shown on a graph. Inhalation causes the BioZ value read from the board to increase, while exhalation causes the BioZ value to decrease. The graph shape is like an upside-down bell curve. Figure 4 shows the parts where the volunteer breathes in and out.

3.2 Game design

The ASD breathing game is a VR game for helping autistic children to practice breathing at the standard level, while the ASD underwater exercise game is a VR game for teaching autistic people correct breathing while underwater and above water. Both games use breathing interaction to interact with the game.

Figure 5 Design of the ASD breathing game interface (see online version for colours)



3.2.1 ASD breathing game for practicing breathing in standard level

Breathing interaction is used in this game for helping the player to practice breathing in and out rhythmically:

- Gameplay: The ultimate goal of this gameplay is a player has to breathe near-standard respiratory rate as much as possible to obtain a high score as a reward. This positive reward could be used to motivate a player to adapt his/her respiratory rate. This game use breathing interaction combined with VR. The virtual balloon in the game represents the player's lung. If the player breathes in, the balloon inflates. If the player breathes out, the balloon deflates. The game will calculate the respiratory rate and display it in the game HUD. If the player breathes at the appropriate rate according to age range, the respiratory rate will be displayed as a blue number. On the other hand, the respiratory rate will be displayed as a red number if the player breathes inappropriately (slower or faster) according to his/her age range. The player can practice breathing continuously for five minutes under the practitioner's supervision.

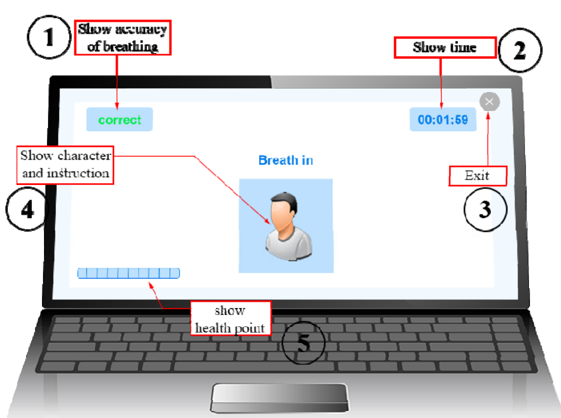
- Game interface design: As shown in Figure 5, the design consists of the following:
  - respiratory rate display
  - time display
  - exit game button
  - balloon display.

3.2.2 ASD underwater exercise game for practicing breathing underwater and above water

Breathing interaction is used in this game for teaching the player how to breathe underwater and above the water, as well as when to breathe in and out:

- Gameplay: A player has to control breathing rhythm according to game scenarios correctly. An underwater breathing exercise lesson is applied to create the gameplay mechanism. There are two scenarios in this VR game, switching back and forth. The first one is the above water scenario in which the player can breathe in and out without losing health points. The second scenario is an underwater scene in which the players need only to breathe out or hold their breath. The player's health point will be deducted when incorrect breathing occurs. The game is over when the player loses three health points. This game is used to test the player's ability to control his/her breath. Moreover, the player can learn underwater breathing skills from this game and should be able to use them later in real situations.
- Game interface design: As shown in Figure 6, the design consists of the following:
  - accuracy of breathing display
  - time display
  - exit game button
  - character and instruction display
  - health point display.

Figure 6 Design of the ASD underwater exercise game interface (see online version for colours)



4 Experimental setup

4.1 Experiment design

In this experiment, each volunteer is assigned to test playing two VR games using breathing interaction. For the first game, the volunteer needs to breathe in and out normally to control the balloon. The respiratory rate of the volunteer is displayed in the game HUD and external display. The practitioners need to guide the volunteer on how to breathe correctly according to the standard respiratory rate. However, the experiment requires minimal intervention from the practitioners during the test. This game takes five minutes to complete (the respiratory rate is shown in a unit of times per minute). Within four sessions, this game could lead the volunteers to breathe at a near-standard respiratory rate.

For the second game, the volunteer needs to test playing for underwater breathing exercises in two scenarios. The practitioners teach the concept of underwater breathing and show how to respond to situations correctly. This game takes approximately five to seven minutes to complete each session. The volunteers need to breathe correctly according to the simulated situations. They should understand the concept of in water breathing after four test sessions.

The practitioners and researchers observe testers' behaviour during the test and record the test data. After completing all sessions, a practitioner fills out the questionnaires to complete the test.

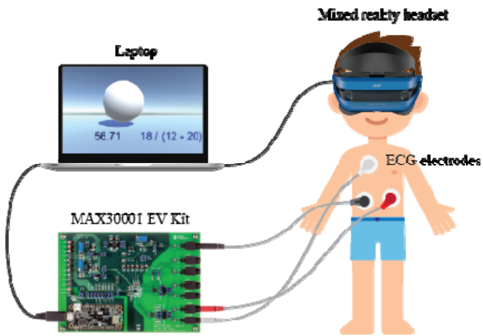
4.2 Sampling

The samples were selected from autistic students at the Autistic research centre Khon Kaen University. Researchers, practitioners, and a psychologist select the sample within the institute based on these criteria; moderate to high autism level, age 7–15 years, and gender. According to Table 1, the standard respiratory rate by age range for this sample group are school-age (18–30) and adolescent (12–16). All participants must be male because of equipment attachment placed on the upper body, which is inappropriate for females. A parent must approve a volunteer before participation. After the screening process, only three volunteers were recruited. Khon Kaen University's institutional review board (IRB00001189) granted approval for this study.

4.3 Experimental environment

In this experiment, volunteers had to sit in place and not move their bodies. Each volunteer needed to put on the mixed reality headset and attach three ECG electrode pads to three assigned positions on the body. The headset was connected to a laptop, while the electrode pads were connected to the MAX30001 EV Kit experiment board, which was connected to the laptop. The complete equipment installation is shown in Figure 7. The experiment was conducted in a sensory room at the autistic research centre, an ideal environment for testing and observation. A psychologist recommended testing in the afternoon during their free schedule.

Figure 7 Equipment installation for the ASD breathing game and ASD underwater exercise game (see online version for colours)



4.4 Data collection and analysis

This experiment collects data from three sources; inside the games, researcher, and practitioners. The triple sources confirm the reliability of collected data that should be the same among the three sources. The results are compared right after finishing all sessions to verify the correctness of data collection. The testing session will be investigated and re-tested when the problem arises. All the collected data were analysed by descriptive statistics.

Participant observation and non-participant observation approaches were used to collect the participants' behaviour. The practitioners use both approaches during the experiment while the researchers use only non-participant observation. The practitioners and researchers collect the participants' behaviour in three periods; before the testing session, during the test, and after. The behaviour data is used to analyse the behaviour adaptation trend (positive behaviour) for each participant.

5 Result

5.1 Game development

The ASD breathing game and ASD underwater exercise game were developed on Windows OS using breathing interaction and mixed reality toolkit library for displaying in the headset.

Development results of the ASD breathing and ASD underwater exercise game interface on Windows OS

The ASD breathing game and ASD underwater exercise game were run on a test laptop with Windows OS. From the interface design in the last section, the developed game interfaces are as below.

5.1.1 The ASD breathing game

The ASD breathing game has a balloon (white circle), as shown in Figure 8, which animates according to the player's breathing; the balloon bloats if inhaling and flattens if exhaling. The number on the left will count down from 60 seconds, and the respiratory rate will be calculated after the time is up and displayed on the right. If the player breathes inappropriately, the number on the right will be red, as shown in Figure 9. Conversely, the number on the right will be blue if the player breathes appropriately, as shown in Figure 10.

Figure 8 ASD breathing game display (see online version for colours)

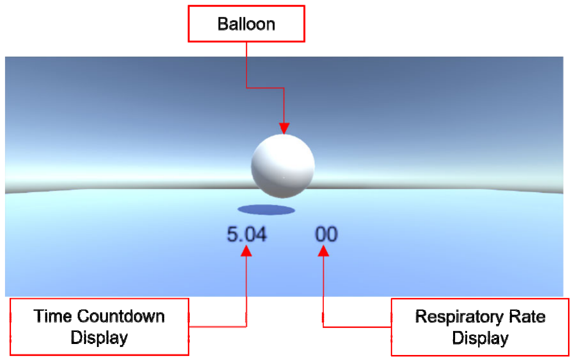


Figure 9 ASD breathing game display while breathing inappropriately (see online version for colours)

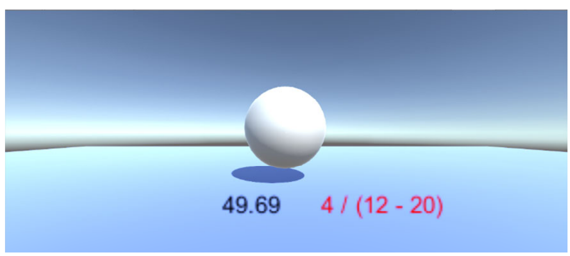
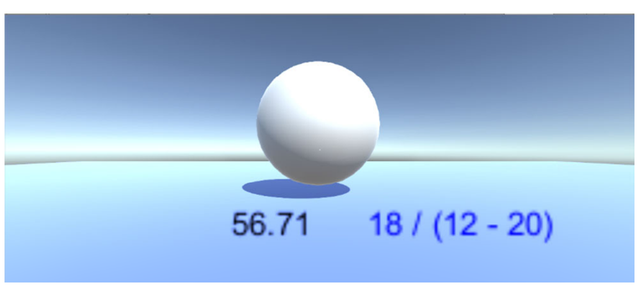


Figure 10 ASD breathing game display while breathing appropriately (see online version for colours)



5.1.2 The ASD underwater exercise game

The ASD underwater exercise game animates the above water scene Figure 11 and the underwater scene Figure 12, switching back and forth. In the above water scene, the player can breathe in and out freely, while in the underwater scene, the player must not breathe in. If the player does, one health point (heart) is lost, as shown in Figure 13.

Figure 11 Above water scene in the ASD underwater exercise game (see online version for colours)

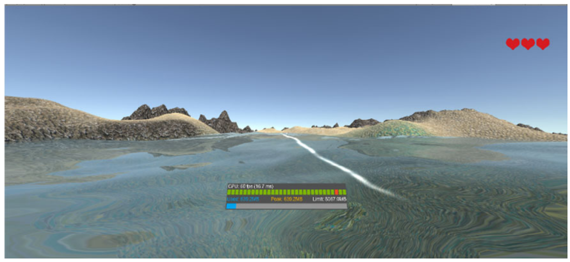


Figure 12 Underwater scene in the ASD underwater exercise game (see online version for colours)

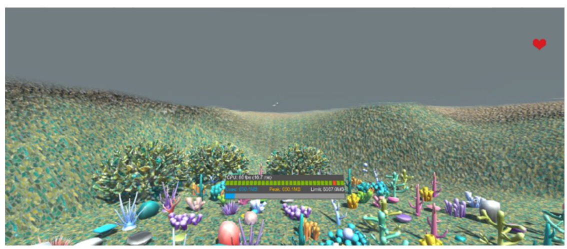
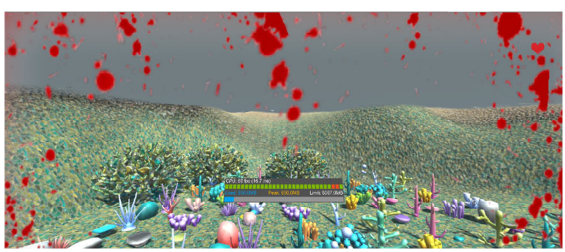


Figure 13 Underwater scene while inhaling in the ASD underwater exercise game (see online version for colours)



5.2 Interaction and game testing

5.2.1 Images during the test session

During the test session with volunteers, the caretaker and researcher observed and recorded the results beside them, as shown in Figures 14–17.

Figure 14 Equipment preparation for testing the ASD breathing game and ASD underwater exercise game (see online version for colours)

Figure 15 A volunteer with the test equipment (see online version for colours)

Figure 16 A volunteer playing the ASD breathing game (see online version for colours)

Figure 17 A volunteer playing the ASD underwater exercise game (see online version for colours)

5.2.2 Experiment results

In the ASD breathing game test, each volunteer was assigned to test four rounds. In each round, the respiratory rate was measured five sessions (1 minute per session), so each testing round took five minutes. There were some issues in the early rounds of testing, such as some volunteers refusing to equip the test gadgets or having abnormal breathing. Besides, most volunteers breathed faster than the standard rate, so the caretaker needed to advise them several times to change their breathing. The game evaluated a participant's breathing rate and compared it with the standard respiratory rate by age range Table 1. If the participant's breathing rate falls in the standard range, he will get one point in that session. The results in Table 4 and Figure 18 show that 66% of volunteers could breathe correctly more than half of the testing times (2.5 sessions) on average, while volunteer C could perform above average.

Table 4 Correct breathing times in the ASD breathing game

Volunteer	*Testing round*				*Average (Time)*	*Standard deviation*
	1	*2*	*3*	*4*		
A	1	2	2	3	2	0.82
B	2	1	4	3	2.5	1.29
C	3	3	4	4	3.5	0.58
Total	2	2	3.3	3.3	2.7	0.77

For the ASD underwater exercise game, each volunteer was assigned to test for four rounds. Each round contained 20 sets of breathing tests. The participant will get one point on each test if he can correctly breathe according to the scenarios. Each test consisted of above water breathing, in which the volunteer could breathe in and out freely, and underwater breathing, which only allowed the volunteer to breathe out. The results in Table 5 and Figure 19 show that only volunteer C could breathe more than 50% correctly (10 sets) and perform better than average.

Figure 18 Comparison graph for correct breathing times in the ASD breathing game (see online version for colours)

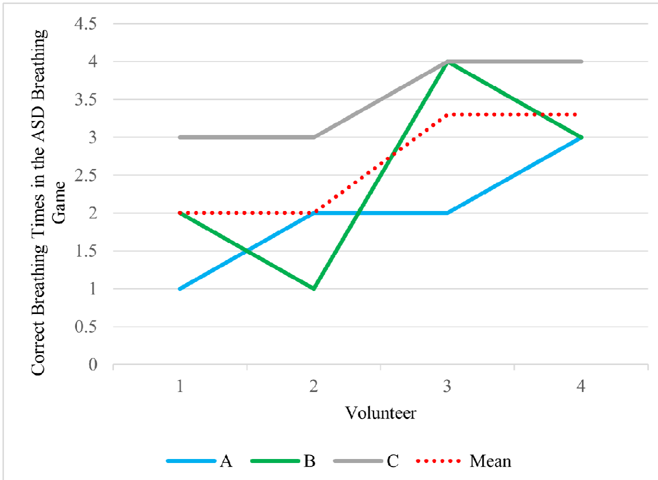
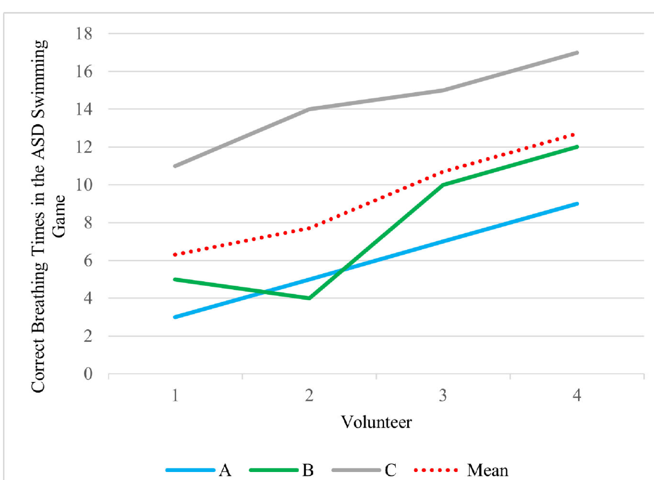


Table 5 Correct breathing times in the ASD underwater exercise game

Volunteer	*Round*				*Average (sets)*	*Standard deviation*
	1	*2*	*3*	*4*		
A	3	5	7	9	6.0	2.58
B	5	4	10	12	7.8	3.86
C	11	14	15	17	14.3	2.50
Total	6.3	7.7	10.7	12.7	9.3	2.87

Figure 19 Comparison graph of correct breathing times in the ASD underwater exercise game (see online version for colours)



The results in Tables 4 and 5 show that the test results for volunteers A and B do not reach half and are lower than the average. However, the results tend to be better since all volunteers improved their performance continuously in the subsequent rounds.

The results showed that all volunteers could use a breathing interaction with these games. All participants had improved respiratory rates, though still not meeting the standard level. Two-thirds of participants understood breathing control for underwater exercise. The practitioners can use these games to train autistic children in both respiratory rate training and underwater breathing exercises.

According to the results from collected data, the researchers found the answers to explain the breathing interaction with autism via VR games.

1. Standard respiratory rate: the ASD breathing game help participants improve their breathing performance. According to the data trend, all participants' have near-standard respiratory rate.
2. Underwater breathing concept: after four rounds of testing, all participants understand the underwater breathing concept. They can correctly breathe in water and underwater in the fully immersed VR game.
3. Breathing interaction: the breathing interaction can be used by all participants without any issues. They can naturally interact with both games.
4. Learning curve: All participants found that they used minimum effort to learn how to play both games. The learning curve of both games is very low that appropriate for autism.

5.2.3 Participant observation results

The observation process is decomposed into three parts; before the experiment, during the experiment, and after the experiment. Before conducting the experiment, information about the personalities of each volunteer was gathered for behavioural analysis, as shown in Table 6. The researchers and the practitioners use this information to make an individual plan to deal with each participant. However, the experiment went smoothly without any issues. During the experiment, volunteers' behaviours were also observed and recorded for analysing changes in behaviours after each round of the test, as shown in Table 7. After the experiment, all participants showed positive behaviour illustrated in Table 8.

The volunteers' behaviours during the experiment, as recorded by participant observation, are shown in Table 7. The researchers use thematic analysis to discover themes by analysing word and sentence structures. There are two key themes expressed in different words:

- Respiratory rate: fast, slow, near-standard.
- Respiratory concept and control: understand, perform, poor, moderate, better, correct, inflate, deflate.

The results can be described as follows:

- Volunteer A has autism at a moderate functioning level. During the experiment, this participant constantly tried to remove the gadgets, causing results that were poorer than expected. In the ASD Breathing game, volunteer A breathed too fast, resulting in a poor score. However, after four rounds of the experiment, this volunteer showed improvement in every round, even if the results failed to reach half and were less than the average. During the ASD underwater exercise game, the child always tried to remove the VR glasses, but this behaviour decreased significantly in the fourth round. The results for volunteer A were not very good because he was unlikely to understand the instructions, so the researcher needed to provide them again before the test and during the test in the fourth round.

- Volunteer B has autism at a moderate functioning level and breathes fast. In the ASD Breathing game, this volunteer continuously improved his performance. In the third round, the child understood that his breathing could control the balloon to inflate or deflate. During the ASD Underwater Exercise game, this volunteer needed to adapt to the game rules in the first two rounds. In the third round, however, he was able to understand how to breathe above water and underwater.
- Volunteer C has autism at a high functioning level, so he can speak understandably and understand instructions quickly. In the ASD breathing game, this volunteer understood how to control the balloon to inflate or deflate by using breathing. However, this child was easily bored. In the third round, after two times of testing, the volunteer began to get bored but continued playing until he finished the last round. During the ASD underwater exercise game, the volunteer began to understand the rules after the second round, and continuously improved his performance until he breathed mostly correctly in the last round.

5.2.4 Behaviours of the volunteers before and after the experiment

After the experiment, behaviour changes were also tracked for the analysis of positive behaviours among volunteers. There are two key themes expressed in different words:

- Respiratory rate: fast, natural.
- Behaviour: refuse, allow, positive, negative, fun, quit, difficult, familiar.

Table 8 shows behaviours before and after testing, which can be described as follows:

- Volunteer A refused to wear the VR glasses and constantly tried to remove gadgets. Besides, this volunteer breathed incorrectly and too quickly. After testing, the volunteer was unlikely to remove the glasses or electrode pads. His breathing was slower, but still faster than the standard rate. The overall performance of this participant is acceptable in both attention and learning. He can understand all the concept of breathing but take more time than the other two volunteers.
- Volunteer B had no issues with equipment or breathing fast, and loved playing games. After testing, his breathing behaviour could be controlled to a certain level, causing him to breathe slower. He can understand the concept of breathing and perform well in all sessions. However, his performance was inconsistent due to the short attention issue. He often loses his focus during the test.
- Volunteer C felt anxious and excited about the experiment. Before testing, the volunteer kept asking about breathing. His breathing was at a normal level. After testing, his anxiety tended to decrease after becoming more familiar with the equipment and games, causing his breathing to improve and ask fewer questions.

This participant has the highest level of attention among all participants. He performed better than the other volunteers and fully understood the breathing concept.

Table 6 Behaviours of three volunteers for the ASD breathing game and ASD underwater exercise game

Volunteer		*Behaviours*
A	Level: moderate functioning	Characteristics • Attention deficit disorder (ADD): unable to focus on anything for a long time, inability to stay still • Less communication with language • Able to follow simple instructions • Ability to adhere to data; requires constant instruction by the mother about what to do each day before going to school • Cries when displeased
B	Level: moderate functioning	Characteristics • Attention deficit disorder (ADD): unable to focus on anything for a long time, inability to stay still • Drowsiness due to medication • Significant communication with language, but incoherently at times • Loves computers and technology • Loves positive reinforcement like snacks or games • Stops talking and run away when displeased
C	Level: high functioning	Characteristics • Intermittently has a short and long attention span • Experiences drowsiness due to medication • Tends to be fanciful; likes to talk and ask about topics of interest, such as 'What is autism?', 'Will I get over the autism?' • Talks with a loud voice and makes an angry face when displeased • Loves positive reinforcement, especially fighting video games • Loves drawing and can memorise multiplication tables very well

According to the results, all participants changed their breathing rate converse to near-normal respiratory rate. They illustrated the positive behaviour and fully supported the experiment without any problems. Only the A participant misunderstood the underwater breathing concept at first. Then, he could understand the concept during the third session, proving the game supported the learning concept. The practitioners and researchers agreed that these breathing interaction games can assess the ability of autistic children to control their respiratory based on the given scenarios. At the end of the test, the practitioners asked some questions to the participants to confirm their understanding. All participants understood the breathing concept in both respiratory rate and respiratory control.

Table 7 Participant observation results for ASD breathing game and ASD underwater exercise game testing

Volunteer	*Experiment*	*Behaviours during the experiment*
A		*ASD Breathing*
	Session 1	Cannot perform very well; breathes too fast; usually removes electrode pads from his body
	Session 2	Can perform better; breathes slower than the previous round
	Session 3	Can perform better; breathes slower than the previous round
	Session 4	Can perform moderately; breathes quite fast, but slower than the first round
		ASD Underwater exercise
	Session 1	Performs poorly due to breathing too fast; always tries to take off the VR glasses
	Session 2	Can perform better, but still breathes too fast; always tries to take off the VR glasses
	Session 3	Can perform better than the previous round, but still tries to take off the VR glasses
	Session 4	Can perform better than every previous round; less focused on attempting to take off the VR glasses
B		*ASD Breathing*
	Session 1	Performs poorly; breathes too fast
	Session 2	Performs poorly; breathes too fast
	Session 3	Can perform moderately; understands how the balloon inflates and deflates
	Session 4	Can perform moderately; understand how the balloon inflates and deflates
		ASD Underwater exercise
	Session 1	Performs poorly due to several factors, mostly from breathing too fast
	Session 2	Performs poorly; still breathes too fast
	Session 3	Can perform better and understands how to breathe above water and underwater
	Session 4	Can perform much better, but still breathes fast
C		*ASD Breathing*
	Session 1	Can understand how the balloon inflates and deflates
	Session 2	Can perform better than the first round; can understand how the balloon inflates and deflates
	Session 3	Performs quite poorly because the volunteer concentrates too much, causing abnormal breathing; wants to quit playing before the fourth round because of boredom
	Session 4	Can perform better
		ASD Underwater exercise
	Session 1	Performs poorly and breathes inconsistently during the game
	Session 2	Performs quite poorly, but starts to understand the game rules
	Session 3	Can perform better; can breathe more correctly
	Session 4	Can perform better than the previous round; breathes correctly in almost all sets

Table 8 Behaviours of volunteers before and after playing the ASD breathing and ASD underwater exercise games

Volunteer		*Behaviours before the experiment*		*Behaviours after the experiment*
A	1	Refused to wear VR glasses; usually try to remove it	1	Allowed to wear VR glasses more easily
	2	Did not understand breathing system; never tried to control his breathing	2	Still breathed fast
	3	Short attention span	3	Needed the practitioners to instruct how to control breathing because he did not quite understand the game
B	1	Loved playing games	1	Could control breathing at a certain level
	2	Breathed fast, and laughed sometimes	2	When losing the game, he said it was too difficult and wanted to quit
	3	Did not understand the breathing game; had many questions during the breathing	1	Had more natural breathing
C	1	Too much concentration on the game, causing hesitation and poor performance	2	Was more familiar with the game environment and had fewer questions
	2	Constantly had questions about breathing	3	Had fun with the game; even tried to swing his arms to swim along with the game
	3	Too much concentration on breathing; unnatural breathing		

5.2.5 Results from the survey

A survey in this study was evaluated by the practitioners. There are two parts to the survey. The first part is about satisfaction with the games, while the second part contains questions about volunteer's behaviours toward the ASD breathing and ASD underwater exercise games, which can be concluded as follows:

- Satisfaction: The score on the five-point score system was 3.77 (75.4%), which can be interpreted as very satisfied.
- Effectiveness: Volunteers could use breathing interactions to control the games.
- Learnability: Some volunteers understood how to breathe above water and underwater.
- Cognition: The topic with a lower evaluation score involved the game improving the concentration of the volunteers. Apparently, four rounds of testing were not sufficient to improve concentration; changes in concentration may occur after ten rounds of testing.

6 Discussion

The primary goal of this work was to investigate the feasibility and effectiveness of applying a breathing interaction framework to help the autisms improve their respiratory rate and learn the breathing concept through VR games. The experiment showed that all participants accomplished both improving their respiratory rate and understanding the concept of breathing.

According to a literature review, the researchers could not find any similar works. This study is original and contributes to autism research by using a breathing interaction framework for autism. The related works to this study are (Paredes et al., 2018; Charoensook et al., 2019; Mulaffer et al., 2019); however, none of these related works focused on improving the respiratory rate via an interactive breathing game.

The comparative results of three volunteers show that volunteer C had the highest performance in both games. The first reason is that he has autism at a high functional level, allowing him to have better skills and concentration than the others. Another reason is that volunteer C could quickly understand the instructions, allowing him to play the games better. The practitioner confirmed the result and agreed about the relationship between volunteer C's autism level and the game result. The other volunteers with a moderate functioning level of autism had a short attention span, which meant more time was needed to adapt. Both volunteers A and B breathe too fast. As a result, they did not pass the ASD breathing game. For the ASD underwater exercise game, volunteer A did not understand the game rules, while volunteer B could not control his breathing correctly. Thus, these volunteers also failed to pass the second game. The practitioner believed that these two volunteers had less performance in breathing due to their moderated level of autism. However, their performance got better in the later testing session.

From the four rounds of testing from two games, all three volunteers tended to improve their performance in subsequent rounds, but the performance of volunteers A and B was insufficient to meet the standard level. The practitioner and researchers agree that more sessions of games may be required to adjust their behaviours. Furthermore, positive behaviours of three volunteers were presented, such as fewer attempts to remove the equipment and lower respiratory rates. According to the psychologist's observation, she did not find any sign or evidence of negative behaviours from all participants.

According to the results, applying a breathing interaction to a game is effective for autism because they can interact naturally with effort. During the ASD breathing game, all volunteers were at least able to understand how to control the balloon by breathing. ASD underwater breathing exercise game, volunteers B and C could understand how to control the game, but volunteer A needed additional time to understand. Using breathing interaction with the appropriate game designs could benefit autism. Researchers uploaded these two games as examples of a breathing interaction framework on GitHub (GitHub – polokung/ASD-breathing-game); researchers or developers can extend these games in their projects. A breathing interaction can be used in other applications such as practising meditation, virtual swimming, and breathing technics.

The limitations of this work are the number and diversity of participants. This study can recruit only the participants from autistic research centre. For equipment installation issues, the researchers had to exclude some participants with skin sensitive problems from the sample group after the first screening procedure by the practitioners. The levels of autism in this study are moderate and high function autism. Consequently, there are only three participants suited for this experiment.

The practical implications of this current study are three main approaches, as shown below:

- Using the ASD breathing game: This game can be used in a respiratory class as a learning and practising tool. This interactive breathing game also helps the practitioners to collect the users' data for progress tracking and individual lesson planning. Moreover, this game could help the doctor in treatment once it was approved to be used in clinical practice.
- Using the ASD underwater exercise: This game can be used in the swimming and water therapy class to teach the breathing concept before going to a swimming pool. The game will evaluate a user's performance to ensure that the user understands the underwater breathing concept in various scenarios. This game could help to reduce the dangers and the risks in this class.
- Using the breathing interaction framework: A breathing interaction framework can be utilised to develop other interactive breathing games and applications such as performing meditation, reducing stress, reducing pain, laboured breathing, and relieving asthma. Developers can employ this framework as a guideline to design and implement their interactive breathing games or applications.

7 Conclusions

Breathing interactions were implemented in the development of two VR games:

1. ASD breathing for improving the respiratory rate of autistic children.
2. ASD underwater exercise for testing breathing skills to survive above water and underwater.

The results showed that breathing interactions can be used by autistic people and are understandable for them. Furthermore, ASD underwater exercise can help teach children that they can breathe freely while above water, but must not breathe while underwater.

ASD breathing and ASD underwater exercise games were tested by the three volunteers and evaluated with standard respiratory rates as well as correct breathing skills while above water and underwater. The test results with the three volunteers can be divided into two parts as follows:

- The first part involves interactions: ASD breathing and ASD underwater exercise games use breathing interactions for control. The experiment showed that all volunteers could use this interaction to control both games. Even if some volunteers did not meet the goal, all volunteers showed consistent improvement.
- The second part involves behaviours: In ASD breathing, most volunteers could adjust their breathing behaviour. After 2–3 rounds of the game, their respiratory rates decreased greatly compared to the first round. In ASD underwater exercise, which teaches breathing skills above water and underwater, most volunteers could perform well and understood that they must not breathe in while underwater or they would suffocate.

The practitioner satisfied the ASD breathing and ASD underwater exercise games with a score of 3.77 on the five-point score system, which can be interpreted as very satisfied. In summary, ASD breathing and ASD underwater exercise game can be used for practising breathing skills and improving the respiratory rates of autistic people. The practitioner offered an additional opinion that the games could also be used as a guideline for developing other skills for autistic children in the future.

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