Using Wearable Sensors and Virtual Reality Video for Tai Chi and Qigong Intervention Research (We Sense Tai Chi): Feasibility Study

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Abstract

Background
Tai Chi and Qigong (TCQ) interventions as mind-body exercise have increasingly demonstrated a spectrum of health benefits, but few were assessed using objective measurements, such as wearable sensors. Virtual reality has the potential to improve the experience of recorded Tai Chi classes, but Tai Chi research has not yet used this technology.

Objectives
The current study examined the feasibility and acceptability of using wearable sensors and virtual reality (VR) videos to deliver a remotely delivered TCQ intervention for older adults.

Methods
This 2-week feasibility study enrolled 16 participants who were 50 years or older, with half being experienced in Tai Chi and the other half novices. Participants were instructed to join TCQ intervention classes and wear sensors at home to measure their sleep and heart rate variability. They received a 2-hour in-person group training on how to use wearable sensors and VR headsets and completed questionnaires on demographics, health, stress, physical activity, and sleep quality at pre-intervention and post-intervention stages. Focus groups were conducted for qualitative feedback.

Results
Descriptive analyses were conducted for the feasibility of using wearable sensors and VR and completing the assessments. The completion rate for all the questionnaires and focus group interviews was 100%. The results showed high acceptance and satisfaction among older adults in using wearable sensors and VR headsets for TCQ intervention, with 14 out of 16 participants feeling positive or very positive. However, over one-third of the participants experienced some level of difficulty with the technology.

Conclusions
The study found high acceptability and good feasibility of using wearable sensors and VR for TCQ intervention among older adults. It also suggested the need for more training and consultations to help older adults effectively use the technology in an intervention study.

Keywords
Tai Chi; Qigong; Wearable Sensors; Virtual Reality (VR); Feasibility Study; Older Adults; Mind-Body Exercise; Remote Intervention.

Funding
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Trial Registration
This study was reviewed and approved by the University of Arizona Institutional Review Board (IRB). The "We Sense Tai Chi" study was conducted between February and June 2022, in Tucson, Arizona, United States.

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Introduction

Tai Chi and Qigong (TCQ) are mindfulness-based exercises that have been shown to have an extensive range of health benefits including stress reduction, improved quality of sleep, better coordination and balance, reduced risk for heart diseases, pain reduction, and maintaining cognitive function with aging.[1] However, TCQ research has mostly used self-reported questionnaires to evaluate a variety of health outcomes.[2] Because self-reported questionnaires are subject to response bias, applying more objective measurements in TCQ research is warranted. There are an increasing number of wearable sensors in the market that simultaneously assess multiple health outcomes, including stress and quality of sleep.[3–5] However, research using wearable sensors to track health outcomes with TCQ is lacking, and research on the utility and feasibility of different wearable sensors for remote mindfulness-based interventions in older adults is needed.

The need and possibility of teaching TCQ classes online, either as live classes or recorded videos, have been explored.[6–8] Although a standard online intervention has many advantages for people to learn TCQ from the experts remotely, there are clear limitations when viewing the movements from two dimensions (2D, online) versus three dimensions (3D, in-person). Virtual Reality (VR) is an emerging technology that can allow users to immerse themselves in simulated and interactive environments in 3D. Researchers have seen a positive effect of using VR headsets for physical activity and motor ability of aging communities through the promotion of sensorimotor learning and cortical plasticity. [9,10] There are few research studies on using VR for different mind-body exercise modalities such as Tai Chi and yoga, and the studies were mostly conducted in supervised environments. [11] Currently, there is limited research specifically focused on VR for TCQ interventions in the home setting, making further research necessary to determine whether VR headsets are feasible for remote TCQ interventions in the home. [12,13]

VR presents a plausible and novel method to remotely deliver a 3D TCQ intervention, increasing feasibility and enjoyment for health promotion and well-being in general populations. However, perceived benefits and challenges of using technology to deliver and evaluate TCQ interventions may vary by characteristics of the user.[9,10] In particular, older people are generally viewed as being more resistant and less adaptable to using technology in their daily lives.[14,15] Still, little is known about their views and experiences using technology for health promotion research.

The present feasibility study (We Sense Tai Chi) was conducted with a community sample of adults aged 50 years and older. The study had three main goals. The first goal was to compare the feasibility of using different types of wearable sensors, including needed training, costs, and levels of user-friendliness. The second goal was to compare different types of wearable sensors regarding utility (the number of outcome measurements at different time points) and reliability to assess heart rate variability (HRV), a stress index. The third goal was to examine participants' perceptions on the benefits of receiving the intervention using VR compared to Zoom video conferencing and assess participants' satisfaction and engagement with TCQ intervention with VR vs. Zoom.

Methods

This study was reviewed and approved by the University of Arizona Institutional Review Board (IRB). The "We Sense Tai Chi" study was conducted between February and June 2022, in Tucson, Arizona, United States. Both qualitative and quantitative research methods (focus group and questionnaires) were used to evaluate the remote TCQ intervention. In this paper, we reported the overall study design, data collection methods, and preliminary results on the feasibility of using wearable sensors and VR to deliver and evaluate the intervention.

Selection of wearable sensors

To determine which sensors to utilize for the study, multiple sensors were considered and tested in the sensor lab. Due to the limited timeframe of the intervention period and complications with obtaining large numbers of sensors during the COVID pandemic, the research team decided to move forward with comparing only two wrist sensors: the Fitbit Charge 5[16] and Garmin Vivoactive 4, [17] in this feasibility study.

Intervention Development

The two-week TCQ intervention incorporated Tai Chi "Ba Fa Wu Bu" and Healthy Qigong "Ba Duan Jin". The selected Tai Chi and Qigong forms have been used in a range of research supporting their effectiveness and they are relatively easy to learn for beginners. [18–22] The TCQ intervention was developed by a large team. The team consisted of an accomplished Tai Chi master who provided instruction, doctoral students who acted as students in the TCQ classes and provided narration for the Zoom recordings, and the principal investigator who designed the intervention and directed the filming. The intervention consisted of six classes that each lasted about 15-20 minutes.

The VR videos were developed in collaboration with the University of Arizona Center for Digital Humanities. Filming was conducted on the university campus. The camera used was the Insta360 Pro 2, in 5k, 60fps, 50mbps, and in HDR. These settings were specifically chosen to function smoothly with the Pico Neo headsets. The Insta360 Pro 2 has an application called Insta360 Stitcher that automatically stitches the video. It does this by taking each video from the cameras and stitching them together based on the preview file. After the files were processed, they were put into Adobe Premiere Pro and edited. Voices and music were added to the video for each TCQ class. The completed videos were uploaded to the VR Headsets (Pico Neo 3 Pros) [23] for use.

The same TCQ classes were also recorded in a Tai Chi Martial Arts School (Zhang Kung Fu Institute, Union City, California) using Zoom to provide 2D videos for the intervention. A university online course was developed for the present study. The recorded classes were posted to the online course platform.

Study Sample

Community-dwelling adults living in Tucson, AZ, who were aged 50 years and older and without any serious disease (e.g., active cancer treatment), were recruited for the study. Recruitment methods included emails, flyers, and word of mouth. Recruitment mainly focused on faculty and staff working in the Health Sciences of the University where the study was conducted. Current and former students of several local Tai Chi groups were also recruited for the study using emails and flyers.

Individuals who were interested in learning more about the study could contact the research team using the study email address and phone number on the flier. Potential participants also could either scan the QR code or click on the study link on the study flier to directly answer screening questions about study eligibility and sign an informed consent in REDCap. The inclusion criteria included: aged 50 years or older, fluent in English reading and speaking, and without any mental or physical health issues (self-reported) that could prevent them from practicing Tai Chi or wearing wrist sensors. After completing the online informed consent form, participants completed a set of baseline questionnaires via REDCap.

Study Procedures

Participants were randomized at 1:1 ratio to receive either the TCQ intervention via VR in the first week followed by the TCQ intervention via Zoom recorded videos in the second week or via Zoom in the first week followed by VR in the second week. Permutated block randomization was used with block size of two, and randomization was stratified by prior Tai Chi experience (Yes/No). Randomization was performed using the blockrand package (Version 1.5)[24] of the statistical software environment R (Version 4.1.3).[25]

Participants attended an in-person training on campus to learn how to connect sensors to their phone, how to use VR headset, and how to access a Community D2L (Desire to Learn: an online class platform at the University) for class instruction and zoom videos. During a 2-hour time period, participants received step by step training on the wearable sensors and VR headset conducted by the research staff and graduate research assistants.

TCQ class instructions were provided using multiple methods: in-person during the training, written documents provided during the training, and on the D2L website. Due to limited availability of VR headsets, two intervention cohorts were formed with 8 participants in each. Each cohort had 50% of participants with history of practicing Tai Chi and 50% of participants with no previous experience with Tai Chi. All participants were instructed to practice Tai Chi three days per week for 30 minutes each time. A daily survey was emailed to each participant and included questions about usage of wearable sensors and participation in the TCQ intervention. Cohort 1 completed the intervention as planned. For Cohort 2, the intervention was modified due to a possible injury report from a participant in Cohort 1. The reported injury occurred when the participant was practicing movements while watching the TCQ class using the VR headset. The protocol was modified and instructed participants to only watch the TCQ class using the VR headset, but not to wear the VR headset while performing the TCQ movements.

Participants received itemized monetary incentives (up to $500) for the completion of different tasks including completing the questionnaires at baseline and follow-up, participating in the study orientation and training before the intervention, completing the intervention and measurements, returning sensors and VR headset, and participating in focus group interviews.

Data Collection

Participants completed a set of questionnaires online in REDCap prior to and immediately following the completion of the 2-week intervention. The baseline questionnaire included a demographic questionnaire, a General Health Questionnaire-12 (GHQ-12) [26], International Physical Activity Questionnaire –Short Form (IPAQ-SF) [27], Perceived Stress Scale (PSS-10) [28] and the Pittsburgh Sleep Quality Index (PSQI) [29]. After the intervention, the participants completed the GHQ-12, IPAQ-SF, PSS-10, and PSQI again. In addition, participants completed a satisfaction questionnaire post-intervention.

All participants participated in virtual focus group interviews after completing the intervention to provide additional information and feedback about their experiences using the wearable sensors and VR and practicing TCQ using VR and Zoom classes. Description of the methods and results from the focus group interviews will be reported in a separate manuscript. Data from the wearable sensors were collected from all participants, and participants' adherence with wearing the sensors and completing the intervention were assessed with a daily survey.

Each participant was given one Fitbit Charge 5 and one Garmin Vivoactive 4 to wear during the 2-week intervention. The Fitbit Charge 5 is a 28.0 g sensor with a 26.4 mm watch face which collects data on physical activity, oxygen saturation, heart rate, respirations, and sleep levels. The Garmin Vivoactive 4 is a 50.5 g sensor with a 33.0 mm watch face that collects data on heart rate, respiratory rate, pulse oxygen, energy monitor, and sleep stages. Participants were asked to wear these two watches at the same time and one on each wrist for at least 3 days a week during the day and the night. Data collection with the Fitbit Charge 5 Fitness Tracker and Garmin Vivoactive Sensors:4/4s GPS Smartwatch-Slate was done by all the participants on their mobile phones through applications associated with the devices.

Data analysis method

This feasibility study was not powered to detect any difference in the outcome measures between any subgroups, so no formal comparison was performed. Descriptive statistics were reported on participants' baseline characteristics, study adherence and completion measures, levels of satisfaction, and the heart rate variability measure. Continuous and count variables were summarized by median/interquartile range (IQR) and mean/standard deviation (SD), and categorical variables by frequency and proportion. Summary statistics were provided for all study participants, with each subgroup defined by prior Tai Chi experience, and/or with each of the two intervention cohorts.

Results

A total of 16 older adults enrolled in the study. The majority of participants were females (75%, n=12), and consisted of 8 participants who had practiced Tai Chi for at least one year and 8 participants who had never learned Tai Chi before the study. With regards to minority enrollment, there was one Native American, one African American, and 3 Hispanic white participants. All study participants had some college education and 9 of them had graduate degrees (Table 1).

All participants completed the 2-week intervention study following the protocol except one participant in Cohort 1 who reported that she injured her neck while conducting the warm-up with the VR headset. We reported the injury to IRB and took action immediately to prevent injury in the second cohort of the study. Although the exact reason for the injury could not be confirmed, the participant indicated that the weight of the VR headset was the reason for the neck injury. The participant did not seek medical care and did not want to report the recovery outcome. To prevent potential injuries, Cohort 2 participants were instructed to view the VR videos without practicing the movements at the same time, but they practiced the movements while following the Zoom videos. However, one participant in Cohort 2 still practiced the movements while wearing the VR headset even with the warning of the risk and the instruction for the modified class activities. This participant did not report any injury during the study period.

During the 14 days of the TCQ intervention, participants wore sensors on average 12.9 days (SD = 2.1) and 11.5 nights (SD = 3.5). While participants in Cohort 2 wore the sensors more frequently during day and night compared to participants in Cohort 1, the differences were within a standard deviation. On average, participants performed the TCQ intervention for a total of 8 days (SD = 3) during the 2-week intervention (Table 2).

Participants reported high study satisfaction (Table 3). Most (14 out of 16) of the participants agreed or strongly agreed that they had a very positive experience from this study. The majority of the participants had strong interest in using sensors, felt sensors were easy to use, and considered VR helpful for learning TCQ. However, still 25-37% of participants did not think VR was helpful for TCQ class or that sensors were easy to use.

Heart rate variability (HRV) data was captured from 5 participants using the Garmin watch (Table 4). It showed that Tai Chi practitioners had higher HRV on average than participants who had never learned Tai Chi before this study. We were unable to access the Fitbit research data portal, and there were connectivity issues with Cohort 1, so only 5 participants had sufficient data for the HRV analysis.

All participants completed baseline and post-intervention questionnaires. There were no significant changes in stress and sleep based on the questionnaires (data not shown).

Table 1. Characteristics of the Study Participants

	All Participants	Cohort		Tai Chi Experience	
	All (n=16) n (%)	1 (*n=8*) n (%)	2 (*n=8*) n (%)	Yes (*n=8*) n (%)	No (n=8) n (%)
Age					
50-59	7 (43.8)	5 (62.5)	2 (25)	3 (37.5)	4 (50)
60-69	4 (25)	2 (25)	2 (25)	1 (12.5)	3 (37.5)
70-79	3 (18.7)	1 (12.5)	2 (25)	2 (25)	1 (12.5)
80-89	2 (12.5)	0 (0)	2 (25)	2 (25)	0 (0)
Race					
White	14 (87.5)	7 (87.5)	7 (87.5)	7 (87.5)	7 (87.5)
Black or African American	1 (6.2)	0 (0)	1 (12.5)	1 (12.5)	0 (0)
American Indian or Alaska Native	1 (6.3)	1 (12.5)	0 (0)	0 (0)	1 (12.5)
Hispanic/Latino or Spanish Origin					
Yes	3 (18.7)	2 (25)	1 (12.5)	1 (12.5)	2 (25)
No	13 (81.3)	6 (75)	7 (87.5)	7 (87.5)	6 (75)
Sex					
Male	4 (25)	2 (25)	2 (25)	2 (25)	2 (25)
Female	12 (75)	6 (75)	6 (75)	6 (75)	6 (75)
Highest Degree of Education Completed					
1-3 years of college [1]	1 (6.2)	0 (0)	1 (12.5)	1 (12.5)	0 (0)
4 years or more of college [2]	2 (12.5)	2 (25)	0 (0)	1 (12.5)	1 (12.5)
Graduate degree [3]	13 (81.3)	6 (75)	7 (87.5)	6 (75)	7 (87.5)

[1] 1 to 3 years of some college or technical school

[2] College 4 years or more (college graduate)

[3] Graduate degree (post college)

Table 2. Survey Completion, Sensor Use, and Tai Chi Intervention Adherence

	All participants	Cohort		Tai Chi Experience	
	All *n=16 (%)*	Cohort 1 *n=8 (%)*	Cohort 2 *n=8 (%)*	Yes *n=8 (%)*	No *n=8 (%)*
Surveys					
PSS-10	16 (100)	8 (100)	8 (100)	8 (100)	8 (100)
IPAQ	16 (100)	8 (100)	8 (100)	8 (100)	8 (100)
GHQ	16 (100)	8 (100)	8 (100)	8 (100)	8 (100)
PSQI	16 (100)	8 (100)	8 (100)	8 (100)	8 (100)
Sensor adherence (Day)[1]					
Mean (SD)	12.9 (2.1)	12.6 (2.0)	13.3 (2.3)	13.9 (1.4)	12.0 (2.3)
Median (IQR)	13.0 (12.5, 14.5)	13.0 (12.5, 14.0)	14.0 (12.0, 15.0)	14.0 (13.5, 15.0)	13.0 (10.5, 13.0)
Sensor adherence (Night)[1]					
Mean (SD)	11.5 (3.5)	10.9 (4.3)	12.1 (2.6)	12.9 (1.6)	10.1 (4.4)
Median (IQR)	12.0 (11.0, 14.0)	12.0 (10.5, 13.5)	12.5 (11.0, 14.0)	13.0 (12.0, 14.0)	12.0 (8.0, 13.0)
Tai Chi adherence (total times of practice during the study)					
Mean (SD)	8.1 (3.0)	7.3 (2.5)	8.9 (3.5)	8.9 (3.8)	7.3 (2.1)
Median (IQR)	7.0 (6.0, 10.0)	6.5 (6.0, 7.5)	7.0 (6.0, 12.5)	7.0 (6.0, 13.0)	6.5 (6.0, 7.5)

Table 3. Satisfaction Questionnaire Results

Statement	Strongly Agree n (%)	Agree n (%)	Neutral n (%)	Dis agree n (%)	Strongly Disagree n (%)
1. Wrist sensors are interesting to me	7 (43.8)	6 (37.5)	2 (12.5)	0 (0)	1 (6.2)
2. Wrist sensors are easy to use	4 (25)	5 (31.3)	3 (18.7)	4 (25)	0 (0)
3. I want to know the results from the wrist sensors	10 (62.5)	3 (18.8)	0 (0)	1 (6.2)	2 (12.5)
4. VR video is helpful to me to learn Tai Chi and Qigong	7 (43.7)	2 (12.5)	1 (6.2)	3 (18.8)	3 (18.8)
5. VR video is easy to watch and follow	5 (31.3)	4 (25)	1 (6.2)	4 (25)	2 (12.5)
6. VR video can be used on its own for learning Tai Chi and Qigong	5 (31.3)	4 (25)	1 (6.2)	4 (25)	2 (12.5)
7. VR video should be used together with zoom classes to help me learn Tai Chi and Qigong	3 (18.8)	8 (50)	1 (6.3)	2 (12.5)	2 (12.5)
8. Attending Tai Chi and Qigong classes three times per week is acceptable	6 (37.5)	7 (43.8)	0 (0)	2 (12.5)	1 (6.2)
9. Tai Chi and Qigong classes that last 30 minutes is a good length	7 (43.8)	6 (37.5)	1 (6.2)	2 (12.5)	0 (0)
10. My overall experience with this study is positive	9 (56.3)	5 (31.3)	1 (6.2)	0 (0)	1 (6.2)

[1] Satisfaction questionnaire was completed by all participants (n=16)

Table 4. Heart Rate Variability from Garmin

	Heart Rate Variability	**Prio Tai Chi Experience**	
	All participants n=5[1]	Yes n=3 (60%)	No n=2 (40%)
	HRV Week 1		
Mean (SD)[2]	32.69 (9.07)	35.28 (9.55)	29.09 (7.00)
Median (IQR)	32.2 (26.3, 38.1)	33.5 (27.5, 39.8)	29.3 (24.7, 33.4)
	HRV Week 2		
Mean (SD)	33.49 (13.15)	37.33 (13.49)	27.7 (10.31)
Median (IQR)	31.6 (22.6, 41.3)	33.0 (28.2, 47.2)	26.6 (17.9, 35.5)

Abbreviations: SD standard deviation, IQR interquartile range, HRV heart rate availability

[1] Data sequence for eleven of the participants was too short to perform a full analysis of HRV, therefore, a number of participants were excluded from the analysis. The analysis was completed on cohort 2 participants due to data sufficiency.

[2] Mean and median values are in units of milliseconds (ms) for the HRV values measured by root mean square successive differences (RMSSD) for 5-minute time intervals throughout the days of sensor use in both weeks of the intervention. HRV analysis was done on Kubios Ltd.

Discussion

In this study, we found great enthusiasm for the TCQ intervention from these community-based older adults. The screening and recruitment of the 16 participants were completed within less than two weeks. This study included both men and women from diverse race and ethnicity backgrounds. The level of diversity in our study sample is comparable or better than many previous Tai Chi studies. [30]

There is limited evidence on using wearable sensors to collect outcome data in TCQ interventions. [31] Our research revealed good feasibility as well as some challenges among older adults when using wearable sensors and VR for TCQ intervention research. With our preliminary data analysis, we found excellent adherence to the study protocol. Every participant completed the questionnaires, intervention, and sensor data collection, except for the one participant who reported possible neck injury while wearing the VR headset during warm-up. The high level of adherence in our study is likely due to the nature of the small and short duration of the study, the characteristics of the study participants, the incentives we provided and the close interactions between our research team and the participants. Participants showed strong interest in TCQ lessons and had good acceptance of using wearable sensors and VR headsets. However, there are a few participants who reported having some difficulties using these devices.

Due to the issues related to data synching and the quality of the data that was synched, HRV was only available to be analyzed for some of the participants from Cohort 2 for the Garmin device. The data for all participants from the Fitbit Charge 5 server was inaccessible due to privacy issues and availability of the data. Synching of the data from the FitBit and Garmin to the mobile applications was a challenge related to data recording. If the device became disconnected via Bluetooth from the participants' mobile phone or if the mobile applications were not opened often enough (at least once a day) data synching became disrupted. Furthermore, the devices should be adequately worn to optimize the data collection process. Placement of the sensor on participants' wrists should be addressed to improve data collection quality. For example, if the wearable sensors are worn too far up the arm and not directly on the wrist, data collection becomes obstructed.

We used VR headsets to provide immersive 3D experiences for the participants, because participants can see both the instructor up front and students who seemed on the participant's side. This mimics the in-class feeling of exercising with others. Despite participants' satisfaction using VR for the remote TCQ intervention, there were some challenges using VR in the current study. VR headsets are expensive, and taking VR videos requires strong technical support. The use of VR videos for a TCQ intervention has a potential risk for injury and fall because the VR headset is heavy and when people wear a VR headset, they cannot see their surroundings. In this feasibility study, one study participant reported hurting the neck during warm-up. Although the participant did not visit a physician or other healthcare provider, and no injury was confirmed, we still took precautions and modified the VR protocol to minimize any potential risk. Participants from the second cohort were instructed only to watch classes on VR and practice the movements without wearing the VR headset. Longer training time and more detailed protocols for preventing falls and injury when using the VR headset should be provided in future studies.

The training protocol for using sensors and VR can be improved based on this feasibility study. More training time and effort on using sensors is needed in future research. For future protocol development, it is recommended to instruct participants to wear the devices for a minimum of five full days (24 hours, including nights) a week to improve data collection quality. The associated applications with the devices should be opened by the participants at least once a day when the device is worn to ensure the data is synching to the server. Since it relies on the participants to sync the data to the servers, with the data retrieved later by researchers from the servers, this is a restriction on controlling the quality of the data collection. Ongoing quality control should be implemented to monitor how well the data are uploaded to the server. The size and location of the sensor may affect participants' comfort especially during sleep, so these factors should be taken into consideration in future studies.

Finally, as a feasibility study, the intervention was conducted only for 2 weeks, while most of the intervention studies suggested that an intervention of 12 weeks is necessary to see significant changes in health outcomes associated with Tai Chi intervention. [32] Therefore, it was not expected to observe any significant intervention effect in the study.

Limitations

A major limitation was the short timeframe allotted to conduct the current study. We only had 5 months to complete the entire study including the development of VR videos, developing protocols for wearable sensors, writing instructions for using VR and Zoom lesson videos, recruitment, intervention, data collection and initial data analysis. We had to modify the protocol of using VR upon receiving the information from one of the participants on possible injury with wearing VR for the TCQ class. These factors limited our ability to develop a more detailed study protocol and to have more experience with using VR in teaching Tai Chi.

Implications for practice

Our results suggest that using wearable sensors in TCQ research among older adults is feasible. However, more detailed protocols and training on how to use wearable sensors and an ongoing quality control procedure is needed. Setting up an agreement with the sensor company for accessing participants' data is critical, especially for some sensors. We suggest using VR as an additional resource for visualizing TCQ classes; however, whether to use VR while doing the Tai Chi movements needs further research to test out how to avoid potential risk of fall or injury, especially among older adults.

Conclusion

This feasibility study produced valuable insights for a larger subsequent trial. Results showed that older adults had strong interest in and good acceptance with using wearable sensors and VR headset for a TCQ intervention. However, several challenges were identified. Over one third of the participants had some difficulties with using the sensors and VR videos, despite the in-person training prior to the intervention. Future studies should provide detailed protocols, training, and technical assistance to improve the use and satisfaction of using wearable sensors and VR for health promotion intervention research.

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Appendix

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Consent for publication

Not applicable.

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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