

Virtual respiratory therapy delivered through a smartphone app: a mixed-methods randomised usability study

Clarence Anthony Baxter ,¹ Julie-Anne Carroll ,¹ Brendan Keogh ,² Corneel Vandelanotte ³

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¹School of Public Health & Social Work and Institute of Health and Biomedical Innovation, Queensland University of Technology Faculty of Health, Kelvin Grove, Queensland, Australia
²Digital Media Research Centre, Queensland University of Technology Faculty of Creative Industries Education and Social Justice, Kelvin Grove, Queensland, Australia
³Physical Activity Research Group, Central Queensland University Appleton Institute, Rockhampton, Queensland, Australia

Correspondence to

Clarence Anthony Baxter;
c.baxter@hdr.qut.edu.au

ABSTRACT

Introduction A new smartphone app (QUT Inspire) has been developed to detect inspiratory sound and deliver virtual incentive spirometry (ISy), a respiratory therapy technique used in postoperative recuperation, management of some chronic conditions and with potential applications in SARS-CoV-2 rehabilitation. The aim of this study was to compare the usability of this new app with a clinical ISy device as measured by effectiveness, efficiency and satisfaction.

Methods In this mixed-methods randomised usability study, healthy volunteers (aged 39.2±12.2 years, n=24) compared inspirations using the QUT Inspire app and a Triflo II clinical ISy device. A post-test questionnaire and a semi-structured interview explored dimensions of usability regarding the new app.

Results The duration of inspirations performed using the QUT Inspire app (7.3±2.0 s) were comparable with use of the Triflo II ISy device (7.5±2.3 s). No artefacts arising from the order of device testing were identified. App users held their phones adjacent but not proximal to their mouths (13.6±6.4 cm), notwithstanding instructions to keep the phone less than 5 cm away for optimal breath sound detection. The use of onscreen text or video instructional materials did not result in a significant reduction in this distance. Participants reported clear preferences for the app (100%, n=24) to motivate persistence with repeated inspirations. App gamification features such as a timer (75%, n=18) and breath counter (83.3%, n=20) were well regarded. Analysis of semi-structured interviews identified four main themes arising from this study: visual reward from responsive app animations, clinical look and feel influencing credibility, perceived effort affecting engagement and selective adoption of gamification features.

Conclusion This study demonstrates that a virtual ISy app can be effective, efficient and have high satisfaction. Improvements informed by this research include use of additional phone sensors to optimise sound detection and minimising the distance that phones are held from the user's mouth. Further research in randomised controlled trials are needed to evaluate performance of this app in clinical contexts where ISy is currently employed.

INTRODUCTION

Developed in the 1970s, incentive spirometers are motivational devices designed to engage patients to persist with repeated

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Virtual incentive spirometry (ISy) is a novel emergent mHealth technology but little is known about the usability of apps compared with longstanding clinical devices for this respiratory therapy?

WHAT THIS STUDY ADDS

⇒ This study contributes knowledge regarding the usability of a new virtual ISy app compared with a clinical incentive spirometer device.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE AND/OR POLICY

⇒ A paucity of evidence regarding safety and efficacy presents barriers to more widespread adoption of mHealth apps for prescription by clinicians to patients. Evidence from this study may contribute to broader adoption of ubiquitous smartphone technology for health improvement.

gradual maximal inspirations for respiratory therapy.^{1,2} The original purpose for this therapy was encouragement to produce inspirations which mimicked a yawn or a sigh, intended to reinflate collapsed alveoli (ie, alveolar atelectasis) arising as a side effect from surgical anaesthesia or protracted periods of postoperative recuperation in bed.^{3,4} Designed as a 'bedside reminder' for patients to practice deep inhalations, applications for incentive spirometry (ISy) therapy now encompass prevention of chest infections and pneumonia due to mucus build-up in the airways, including chronic conditions such as chronic obstructive pulmonary disease and cystic fibrosis.⁵⁻⁸ Recent reports also indicate a potential emergent role for ISy in rehabilitation for SARS-CoV-2 patients.⁹⁻¹² ISy therapy may decrease ventilation/perfusion mismatch and atelectasis in patients with mild to moderate SARS-CoV-2 related acute respiratory distress syndrome.¹³

While early ISy devices coupled a breathing hose to an enclosed mechanical piston levitated by means of a vacuum created with

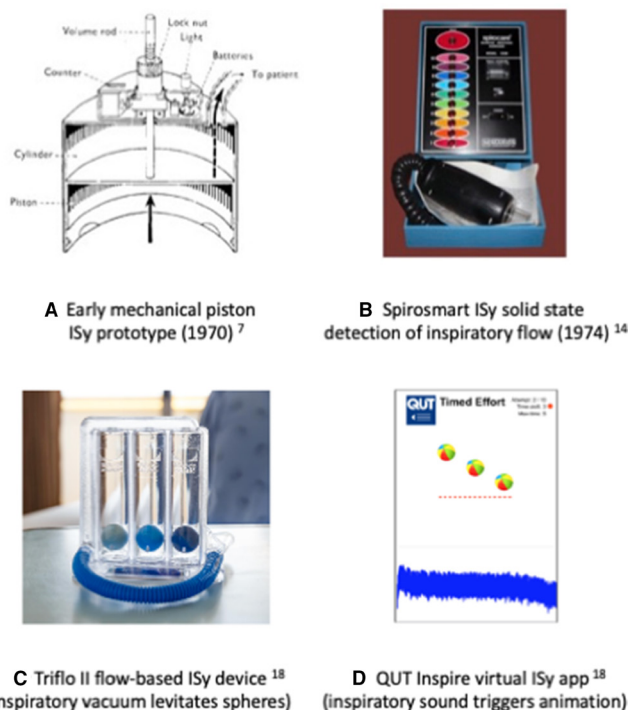


Figure 1 Mechanical, electronic, inspiratory vacuum and sound detection incentive spirometry (ISy) devices.

purposeful inspiration (figure 1A), later ISy incarnations employed flow meter with LED displays (figure 1B) and more recently encased plastic spheres (figure 1C) or pistons to display and motivate inspiratory effort.^{5–8 14 15} Contemporary flow-based ISy devices levitate spheres at calibrated inspiratory flow rates (IFR) while volume-based ISy devices deflect a piston to indicate inspired volume.¹⁶ Annual prescription costs of ISy used for postoperative patients in the USA alone are estimated to be of the order of US\$1.04 billion, reflecting widespread contemporary use of ISy.¹⁷ Implementing ISy therapy (including device purchase, initial education and nursing reminders) costs between US\$65.30 to US\$240.96 depending on the length of stay as an inpatient.¹⁷

We have previously described a virtual ISy app for smartphones (QUT Inspire) which detects inspiratory sound at the mouth using the built-in phone microphone as an uncalibrated pressure sensor (figure 1D).¹⁸ The QUT Inspire app is an HTML5 web app using the built-in smartphone microphone to detect inspiratory sounds, sustaining a responsive animated graphic display for as long as detectable breath sound is sustained. The app runs using the web browser on popular Apple and Android smartphones. A microphone volume control (Microphone icon) offers adjustment of sound sensitivity to eliminate background noise or increase the inspiratory sound volume required to trigger and sustain the onscreen animation. While reliable detection of high simulated IFR was demonstrated for the app at distances of up to 50 cm separating smartphones from a calibrated sound source, optimal sound detection for high, medium

and low flow rates was established at distances of 5 cm or less.¹⁸

The QUT Inspire ISy app offers a low-cost, widely accessible means to increase access to ISy for health improvement. A paucity of literature exists regarding the usability of respiratory mHealth apps using the built-in phone microphone sensor for detection of inspiratory sound for display as a virtual incentive spirometer, and comparison of usability with clinical ISy devices. As a new virtualised incarnation of a longstanding respiratory therapy device, it would be negligent and potentially dangerous to conduct early usability studies on the QUT Inspire app using people with diseases amenable to treatment with ISy therapy without first deriving a better understanding of the app's performance in a relatively lower risk setting, namely by using a cohort of healthy persons to compare the traditional and virtual ISy devices. Should the app be found to be usable and perform well for healthy people (ie, encourage inspirations of adequate and comparable vigour and duration compared with traditional ISy devices and without any adverse events occurring during testing), studies in more vulnerable groups with relevant disease conditions may be indicated.

In this study, we compare the usability of the new QUT Inspire virtual ISy app (figure 1D) with a flow-based Triflo II clinical ISy device (figure 1C) in healthy subjects, considering effectiveness, efficiency and satisfaction as dimensions of usability.¹⁹ While the reliability and clinical validity of this app has previously been demonstrated using calibrated acoustic simulation studies, assessment of interactions between people and the app are needed to further refine its design and functionality prior to prospective studies assessing the efficacy of virtual ISy therapy in cohorts with relevant diseases.¹⁸

METHODS

The usability of the new QUT Inspire virtual incentive spirometer mHealth app was investigated in this study using a mixed-methods randomised usability approach. Usability was measured according to effectiveness, efficiency and user satisfaction.¹⁹ Effectiveness and efficiency were measured in the initial quantitative study phase, and satisfaction in a latter qualitative component. In the first phase, a cohort of healthy participants compared gradual maximal inspirations performed using the new app and the clinical incentive spirometer (Triflo II Model: 8884717301) in a randomised cross-over approach to control for any device testing order effects. Effectiveness was compared by monitoring duration of sustained inspiratory effort with both devices. Efficiency was assessed using the distance that participants held their phones from their mouths. At the completion of device testing, participant satisfaction was canvassed in the second phase using semi-structured interviews.

Patient and public involvement

The design of this research was informed in part by insights gained from an earlier Master of Public Health dissertation by Clarence Baxter in 2018 regarding user impressions concerning an initial design prototype of the app. Users in this earlier study reported a preference for more responsive graphic animations in response to inspiratory effort. The app was updated based on feedback received.

Participant recruitment procedure

The SARS-CoV-2 global pandemic presented constraints in recruitment of participants for this study and due caution on the part of the Ethics Committee regarding participant safety; approval was granted on conditions including (1) receipt of informed consent by disease-free adult participants over 18 years of age, (2) that participants use their own phones for testing (to minimise cross infection risk) and (3) that testing must not impose excessive repetitive inspiratory exertion on the part of participants over and above that required to experience use of, and then comment on app usability compared with a traditional ISy device. Testing was conducted with a rest period interspersed between each of three slow gradual maximal inspiration attempts performed with each device tested.

Email and social media advertising targeting potential participants were employed to garner interest in this research. Healthy people were recruited from a Queensland university and members of the public affiliated with community organisations between May and June 2021, using opportunistic and snowballing recruitment strategies. Using sample size methodology published by the *BMJ* and assuming two-sided $\alpha=0.05$ and $\beta=0.10$, an approximate sample size (n) of 25 was calculated as required for this study (ie, $n=16*\sigma^2/d^2$ where a clinically valid difference in inspiratory duration of 4 s (d) and between-subject variability of 5 s (σ) were assumed).²⁰ Further, saturation and triangulation of data were achieved in the qualitative study component using this cohort, thus removing a need for further recruitment in this phase.

Testing was conducted face-to-face in office settings at several urban locations in South-East Queensland, Australia. Participants were excluded from the study if any pre-existing medical condition prevented gradual maximal inspiration. Participants were also excluded if unable to provide a sustained inspiratory flow of 600 cc/s using the clinical ISy device or unable to trigger the app's display animation due to insufficient sound from inspiratory flow. To minimise risk of SARS-CoV-2 cross-infection, participants used their own Apple or Android smartphone internet browser to run and test the app. Written informed consent to take part in this study was obtained from all participants.

Phase 1: randomised usability study

Figure 2 presents a Consolidated Standards of Reporting Trials diagram for this study. To control for potential

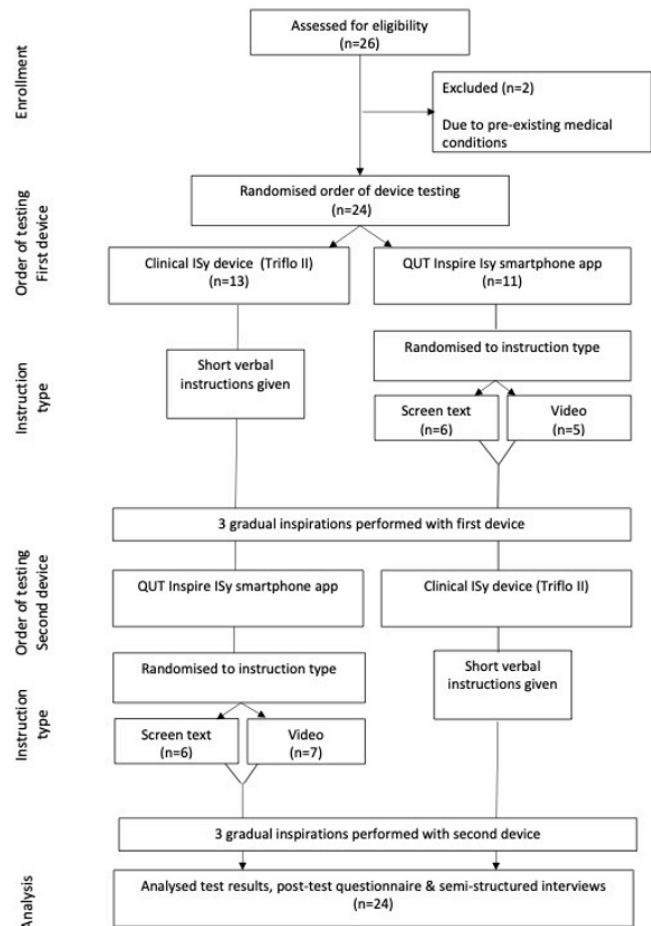


Figure 2 Consolidated Standards of Reporting Trials diagram for study.

device testing order effects, participants were randomly assigned (using a random number table) to use either the Triflo II ISy device or the new QUT Inspire app first, and then to use the other device. Prior to testing the app, participants were randomly assigned to view onscreen text or a short instructional video describing how to use the app (including the need to minimise distance between their mouths and phone for optimal sound detection). In keeping with standards for the performance of clinical spirometry, only the data from the highest of three comparable inspirations using each device were recorded.²¹ The duration of inspirations using the devices were measured using a stopwatch. When testing the app, the distance separating the phone and user's mouth was measured with a ruler. Quantitative measures were calculated using IBM SPSS Statistics (V.28.0.0.0.190). A self-administered questionnaire was completed by participants following device testing (see online supplemental appendix 1). A 5-point Likert scale captured responses to questions regarding the user-friendliness, layout and ease of use of the new app in addition to breathing effort required in completing inhalations using the devices. Participants were also asked to rate the utility of instructions for the app, and whether gamification features such as a timer and an attempt counter were helpful to keep track of

Table 1 Participant demographics

Gender	n (%)
Female	14 (58%)
Male	10 (42%)
Age and age distribution	39.2±12.2 years
Under 25	1 (4%)
25–34	8 (33%)
35–44	2 (8%)
45–54	11 (46%)
55–64	2 (8%)
65 and above	0 (0%)
Education	n (%)
High school	14 (58%)
Undergraduate degree	6 (25%)
Postgraduate degree	4 (17%)
Phone type	n (%)
Android	10 (42%)
Apple	14 (58%)
Internet browser used	n (%)
Chrome	8 (33%)
Firefox	4 (17%)
Safari	12 (50%)

inhalations. Questionnaire responses were consolidated as ‘agree’ where ‘agree’ or ‘strongly agree’ was reported by respondents, or ‘disagree’ where ‘neutral’, ‘disagree’ or ‘strongly disagree’ was reported.

Phase 2: qualitative usability study

Semi-structured interviews were conducted with participants after completion of the quantitative testing phase. All interviews were digitally recorded. Using a set of starter questions, participants were asked about their device

preferences for motivating inhalations and whether gamification features such as a timer and breath counter provided additional motivation (see online supplemental appendix 2). Interview recordings were transcribed and inductive thematic analysis was performed using axial coding.

RESULTS

Of 26 initial respondents to email or social media invitations to participate in this research, 2 were excluded due to screening for pre-existing medical conditions precluding repeated maximal inspirations (figure 2). Of the remaining participants (n=24), all completed quantitative testing and post-test qualitative studies (table 1). No adverse events were reported during or after testing, and all participants were able to supply adequate inspirations.

Statistical analysis and findings

Participant demographics are presented in table 1. Participants were aged between 21 and 64 years of age, with equivalent numbers of users having Apple or Android smartphone types. More than two-thirds of study participants (70.8%, n=17) had no prior knowledge of ISy, while under a third (29.2%, n=7) had seen or used a clinical ISy device.

No significant difference was found between the duration of inspirations (seconds) generated using the QUT Inspire app compared with the Triflo II clinical ISy device (table 2A). Inspiratory durations when using the app were comparable regardless of device testing order. A device order effect was identified regarding measurement of inspiratory flow rates (IFR_{max}) using the Triflo II device; the mean IFR_{max} was found to be higher (1176.9±83.2 cc/s) if this device was used first, with lower mean IFR_{max} observed (1036.4±156.7 cc/s) when the Triflo II was the second device tested (p=0.018). As the QUT Inspire app

Table 2 Comparison of quantitative usability measures—effectiveness and efficiency

(A) Effectiveness: duration of inspirations (s) by device testing order (QUT Inspire and Triflo II)			
	Order of device testing		Significance
Inspiration duration	QUT Inspire app	Triflo II ISy	
Tested first (s)	7.3±2.0	7.5±2.3	p=0.787
Tested second (s)	7.2±2.1	7.4±2.2	p=0.732
(B) Efficiency: distance between mouth and phone (cm) by testing order (QUT Inspire only)			
	Order of QUT Inspire app testing		
Mouth↔phone	QUT Inspire App tested first	QUT Inspire App tested second	
Distance (cm)	13.6±6.4	9.2±5.7	p=0.088
(C) Efficiency: distance between mouth and phone (cm) by order of instructions (QUT Inspire only)			
	Order of presenting app instructions		
Mouth↔phone	On screen text shown first	Video instructions shown first	
Distance (cm)	10.4±5.4	12.1±7.2	p=0.529

Table 3 Questionnaire responses

Question	Agree	Disagree
I think the app is user friendly	24 (100%)	0
I like the overall layout of the app	24 (100%)	0
I was easily able to complete 3 inhalations using the app	24 (100%)	0
Similar effort was required for me to inhale using the app and the plastic device	20 (83.3%)	4 (16.7%)
I could easily understand the screen instructions displayed by the app	21 (87.5)	3 (12.5%)
The attempt counter displayed by the app is useful for tracking inhalations	20 (83.3%)	4 (16.7%)
The timer displayed by the app gave me motivation to persist	18 (75.0%)	6 (25.0%)

does not measure or display IFR_{max} , no comparison of this measure with the Triflo II device was possible.

The distance that participants held their smartphones away from their mouths for inspiratory sound detection was comparable and independent of device testing order (QUT Inspire app tested first: 13.6 ± 6.4 cm and: 9.2 ± 5.7 cm when tested second). Few participants held their phones at distances less than 5 cm (optimal for sound detection) away from their mouths (table 2B). This distance was not minimised significantly when either onscreen text or video instructional materials were presented to the user prior to app testing (table 2C). While users held their phones at distances greater than recommended, no instances were observed where the app failed to detect inspiratory sound.

Post-test questionnaire

Table 3 presents participant responses to a post-test questionnaire; all agreed that the app was user friendly, that they liked the app layout and that they were easily able to complete three inhalations using the app.

While most participants (83.3%, n=20) agreed that similar effort was required to inhale using the app and the clinical ISy device, four participants (16.7%) reported that less effort was required to use the app. Most participants (87.5%, n=21) reported that they understood the screen and video instructions. Three-quarters of participants (75.0%, n=18) agreed that the timer provided motivation to persist with inspirations, and that the attempt counter was useful for tracking inhalations (83.3%, n=20).

Qualitative findings

The average time taken for semi-structured interviews was 15 min, ranging from 11 min to 17 min. Interview transcripts were analysed using thematic analysis and axial coding to identify emergent concepts related to participant satisfaction in the context of app usability. Four main concepts and themes were identified in this analysis:

- ▶ Visual reward from responsive app animations.
- ▶ Clinical look-and-feel influencing credibility.
- ▶ Perceived effort affecting engagement.
- ▶ Selective adoption of additional gamification elements.

Theme: visual rewards from responsive app animations

Most participants preferred the new virtual app as best for displaying inspirations. Responsiveness of the app screen display and compactness when using the app on a smartphone were reported as advantages of the virtual ISy device:

The phone ... [app] responded quicker ... worked when I breathed in it jumped up and stayed up ... [gestures upwards movement of balls using hand]. (Participant 4, male, aged 21 years)

Most users favoured the smartphone app for maintaining inspiratory effort with some noting more rapid responsiveness to inspiratory sound compared with the clinical ISy device:

The app definitely ... I could see it change as soon as I started breathing in. (Participant 16, male, aged 29 years)

Theme: clinical look-and-feel influencing credibility

Of those participants with a preference for the virtual app, several noted similarities in the appearance of the clinical device and virtual app display:

I was impressed by the smartphone [app]. It looks like the medical one and shows my breaths on the screen. (Participant 18, female, aged 58 years)

In contrast, one participant preferred the clinical device display, likening the app display to a trivial game:

The Triflo one ... The app looked like a bit of a game. (Participant 22, male, aged 35 years)

Participants were offered onscreen text instructions and an instructional video guiding use of the app. Ten participants expressed a clear preference for on-screen text instructions while six preferred video instruction:

The on-screen help spelled it all out. The video took extra time to watch. (Participant 4, male, aged 21 years)
Video. I think I understand better with pictures... so I can go back and check it again. (Participant 13, female, aged 31 years)



Use of both onscreen text and video instruction were favoured by eight participants.

Theme: perceived effort affecting engagement

Some participants reported that it was easier to trigger and maintain elevation of the spheres with the app compared with the Triflo II device, and preferred the app for this:

The app worked best. It was harder breathing in using the plastic tube I didn't like it [gestures towards Triflo device]. (Participant 14, male, aged 34 years)

In contrast, four participants described a preference for the Triflo II clinical ISy device due to greater inspiratory effort needed to elevate spheres using the clinical device:

The plastic one was more of a workout. I had to inhale harder to get the plastic balls in the phone to jump. (Participant 17, male, aged 26 years)

Theme: selective adoption of additional gamification elements

Participants were allowed to discover gamification features such as an on-screen timer to measure the duration of each inspiration, and an inspiration counter. More than half of the participants reported that gamification features afforded some degree of additional incentive, with some tempering their views due to the small number of inhalations required during the study. Some others reported that they were too pre-occupied with the app's main display to make use of gamification features:

Yes, the counter was good for to keeping track of your breathing. (Participant 7, female, aged 49)

Nine participants reported no additional incentive from the app's timer and breath counter:

I looked at the timer ... less so with the counter ... I was looking at the balls. I was too busy keeping the balls up in the air and making sound to look. (Participant 3, female, aged 61)

DISCUSSION

In its many incarnations, ISy embodies key tenets of 'serious gaming' (ie, a game for a non-recreational purpose such as healthcare) called therapeutic exergaming.^{22 23} A therapeutic exergame engages a patient in a primary exercise goal using inspiratory effort to keep real or virtual spheres aloft (or by levitating an encased piston), with a secondary therapeutic goal built into the activity, namely performing repeated gradual maximal inspirations for dislodgment of mucus from the airways for expulsion by coughing.²⁴ Traditional ISy devices are simple in design and easy to use, with inhalation via a breathing tube offered as the sole manoeuvre required for therapy. The new QUT Inspire app is a skeuomorphic

design which presents a virtualised representation of a traditional clinical flow-based ISy device.

A recent review noted that usability is not fixed, and that evaluations of 'technical usability' (ie, quantitative assessments, scale-based questionnaires) and qualitative usability insights are only relevant in the context where they are applied.^{25 26} Technical usability has been further defined as the capability for a technology to be understood, learnt, used and attractive to the user when used under specified conditions.²⁷ It has been (boldly) suggested that up to 80% of usability problems can be identified by using as few as five subjects and further, that almost all of high-severity usability problems can be uncovered with usability assessment by only three subjects.²⁸ The International Standards Organisation (ie, ISO) has proposed and revised standards for quality assessment of health and well-being apps.²⁹ The ISO defines usability as the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.²⁹ Critics claim that the most recent ISO standards lack nuance regarding the diversity of app users and contexts for use.²⁹ For the purposes of this study, effectiveness measures the outcomes of interactions between people and systems; the primary comparative measure of effectiveness in this study was the duration of inspirations sustained when using each device.¹⁹ Participants in this study produced inspirations of similar duration using both the new QUT Inspire app and a Triflo II clinical incentive spirometer. This was independent of the order of device testing.

Clinical ISy devices such as the Triflo II connect users to the device by means of a breathing tube of fixed length and a mouthpiece of fixed diameter. Given these dimensions are known for the Triflo II, IFR_{max} can be displayed on the device chassis (600, 900 or 1200 cc/s, respectively) and represented with sequential levitation of spheres. A device testing order effect was noted in this study where lower IFR_{max} was observed where the Triflo II device was the second device used. This may be attributable to fatigue arising from the first round of testing or familiarity with the app in the first round of testing influencing the amount of effort expended by participants when subsequently testing the Triflo II device.

Detection of breath sounds using smartphones has been demonstrated previously, including use of external add-on microphones for attenuation of sounds arising from tracheal airflows or by adding plastic tube-like spacer devices of known dimensions to constrain mouth shape and facilitate flow rate estimates for smartphone-based respiratory function testing.^{30 31} In contrast to vacuum-induced levitation of spheres, the new QUT Inspire app uses the smartphone microphone as an uncalibrated pressure sensor for detection of sustained inspiratory sound, triggering and maintaining a levitating ball animation while sound is sustained over and above an adjustable threshold sound level. Several users (n=4) reported that the app required less effort to use than the Triflo II

device. Inspiratory workload can be increased for the app by adjusting the microphone sound level (Microphone icon) and raising the sound level threshold for triggering the display animation (not evaluated in this study).

The second quantitative dimension of usability examined in this study concerns efficiency. Efficiency relates to completeness in achievement of goals.¹⁹ The distance that a phone user holds their phone away from their mouth when using the QUT Inspire app can be considered as an indicator of efficiency in this study. Participants held their phones between 9 and 13 cm away; neither onscreen or video instructional materials resulted in a significant reduction in this distance. While screen readability may be a barrier to holding the phone extremely close, distances measured in this study were within the range of detection for medium and high inspiratory flow sounds (up to 50 cm) identified in a previous QUT Inspire acoustic simulation study.¹⁸

Satisfaction was investigated as a third component of usability arising from qualitative studies using this cohort, reflecting positive attitudes and 'comfort' when using the app.¹⁹ Favourable comments were made concerning the app's portability, display animations and responsiveness. The clinical 'look and feel' of the app display was generally well regarded. Some participants expressed preference for the Triflo II device because they felt more inspiratory work was required, while others expressed the converse view. Satisfaction reported by a healthy cohort such as this study group does not directly equate to a likelihood to use or persist with virtual ISy therapy, as the needs of people with health conditions may compel compliance (or attempt to comply) for treatment purposes. While gamification features were generally well received, several users commented that they were too busy keeping the animated balls aloft to look at the timer and attempt counter features. Traditional ISy devices do not offer attempt counters or inspiration times. While remembering a count of three inspirations may be straightforward, the ability for the app to count up to a prescription of 10 inspirations for therapeutic benefit may help some users keep track of progress. There may be additional benefit in inspecting inspiratory performance to analyse duration of inhalations performed. Enhancements to the display animations were suggested, including a windmill-style display which spins faster with higher airflows and use of avatars which move with breathing effort.

Strengths and Limitations

Apps such as QUT Inspire offer a low-cost means of improving health by leveraging built-in microphone sensors available in all smartphones to perform ISy. Given the app runs as an HTML5 web app on any Android or Apple device with a web browser, QUT Inspire is compatible with most contemporary smartphone devices. While smartphones are widely adopted and used, older app users may require training if unfamiliar with such virtual technology, not unlike training currently required to use

a traditional ISy device. Following on from this usability study, evaluation of this new app using subjects with relevant health conditions potentially amenable to ISy therapy is a logical next step in asserting that the app is safe and effective.

Participants in this study only performed three inhalations using each device, in contrast to clinical 'prescriptions' for ISy therapy which commonly involve 10 slow gradual maximal inspirations, with this set of ten repetitions performed hourly.²⁴ Coughing induced by disease conditions or as a therapeutic byproduct resulting from ISy therapy may present additional challenges (eg, potential spurious noise generation) particular to virtual ISy use but not encountered in healthy subjects.

This study cohort was skewed towards adults and more mature persons, and represented those with (at a minimum) some experience with smartphone technology. Neither children nor adolescents were represented in the study cohort, and future clinical studies will need to factor in usability among younger persons with conditions such as cystic fibrosis where ISy therapy may be indicated.

Future research

Key observations arising from this study concern compliance required from app users regarding minimising the distance separating the user and their smartphone. Modern smartphones possess proximity or approach sensors which can measure the distance between phone and user; an enhancement to the app could warn if the phone is too far from the user's head for optimal detection of inspiratory sound. As some users commented that less work was needed to use the app, inspiratory effort or work can be increased when using the app by adjusting the microphone sound level control to raise the threshold sound level required to trigger the display animation. The default preset sound threshold may warrant being increased, but this was not examined in the current study.

Suggestions from study participants will be included in refinements to the app design. Larger font sizes, additional animation styles and making the app available for use on smartwatches will be considered among design refinements. Regression testing of the enhanced app using an additional cohort of healthy subjects would be warranted. Following implementation of enhancements arising from this research, clinical studies regarding safety and efficacy are the next step in evaluating the QUT Inspire app.

CONCLUSION

Development of an mHealth app such as QUT Inspire is an iterative process. App prototyping involving bench testing provides formative evidence of functionality. Simulations contribute additional data under controlled conditions with opportunities to apply rigorous test sequences not possible when using human subjects. In this study, usability testing with healthy subjects contributes further

insights into the operation of this app ‘in the wild’. These insights contribute to improvements in the app, with particular reference to optimising distance between the user and their phone for inspiratory sound detection and improving the user interface.

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Patient and public involvement Patients and/or the public were involved in the design, or conduct, or reporting, or dissemination plans of this research. Refer to the Methods section for further details.

Patient consent for publication Not applicable.

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ORCID iDs

Clarence Anthony Baxter <http://orcid.org/0000-0001-8258-4836>

Julie-Anne Carroll <http://orcid.org/0000-0003-0770-6527>

Brendan Keogh <http://orcid.org/0000-0003-4565-4641>

Corneel Vandelanotte <http://orcid.org/0000-0002-4445-8094>

REFERENCES

- Rodrigues A, Muñoz Castro G, Jácome C, *et al*. Current developments and future directions in respiratory physiotherapy. *Eur Respir Rev* 2020;29:200264–13.
- Zhang P. Motivational affordances: reasons for ICT design and use. *Commun ACM* 2008;51:145–7.
- Bartlett RH, Krop P, Hanson EL, *et al*. Physiology of yawning and its application to postoperative care. *Surg Forum* 1970;21:223–4.
- Van de Water JM, Watring WG, Linton LA. Prevention of postoperative pulmonary complications. *Surg Gynecol Obstet* 1972;135:229–33.
- Bartlett RH, Gazzaniga AB, Geraghty TR. Respiratory maneuvers to prevent postoperative pulmonary complications. *JAMA* 1973;224:1017–21.
- Cao X, White PF, Ma H. Perioperative care of elderly surgical outpatients. *Drugs Aging* 2017;34:673–89.
- Craven JL, Evans GA, Davenport PJ, *et al*. The evaluation of the incentive spirometer in the management of postoperative pulmonary complications. *Br J Surg* 1974;61:793–7.
- Eltorai AEM, Szabo AL, Antoci V, *et al*. Clinical effectiveness of incentive spirometry for the prevention of postoperative pulmonary complications. *Respir Care* 2018;63:347–52.
- Navas-Blanco JR, Dudaryk R. Management of respiratory distress syndrome due to COVID-19 infection. *BMC Anesthesiol* 2020;20:177.
- Sheth AR, Faraji M, Boparai S, *et al*. Judicious use of incentive spirometry in resource limited times of COVID-19 pandemic. *Am J Emerg Med* 2021;47:290–1.
- Siroya V, Fernandes L, Wadhokar OC. A pioneering Physiotherapeutic approach to the treatment of a COVID affected patient – a case report. *J Pharm Res Int* 2021;33:17–24.
- Wang TJ, Chau B, Lui M, *et al*. Physical medicine and rehabilitation and pulmonary rehabilitation for COVID-19. *Am J Phys Med Rehabil* 2020;99:769–74.
- Seyller H, Gottlieb M, Colla J. A breath of fresh air: the role of incentive spirometry in the treatment of COVID-19. *Am J Emerg Med* 2021;48:369.
- Frear R. 1970-present: history of incentive spirometer. Available: <http://hardluckasthma.blogspot.com.au/2012/09/1970-present-history-of-incentive.html> [Accessed 06 Jun 2022].
- Kumar AS, Alaparathi GK, Augustine AJ, *et al*. Comparison of flow and volume incentive spirometry on pulmonary function and exercise tolerance in open abdominal surgery: a randomized clinical trial. *J Clin Diagn Res* 2016;10:KC01–6.
- Loh L, Teh P, Raman S. Incentive spirometry as a means to score breathlessness. *Malaysian Journal of Medical Sciences* 2005;12:39–50.
- Eltorai AEM, Baird GL, Pangborn J, *et al*. Financial impact of incentive spirometry. *Inquiry* 2018;55:1–8.
- Baxter C, Carroll J-A, Keogh B, *et al*. Seeking inspiration: examining the validity and reliability of a new smartphone respiratory therapy Exergame APP. *Sensors* 2021;21:6472.
- Frokjaer E, Hertzum M, Hornbæk K. Measuring usability: are effectiveness, efficiency, and satisfaction really correlated? *Conference on Human Factors in Computing Systems - Proceedings*, 2016:345–52.
- Swinscow T. Statistics at square one. BMJ publishing group. available at. Available: <https://bmj.com/about-bmj/resources-readers/publications/statistics-square-one> [Accessed 06 June 2022].
- Graham BL, Steenbruggen I, Miller MR, *et al*. Standardization of spirometry 2019 update. An official American thoracic Society and European respiratory Society technical statement. *Am J Respir Crit Care Med* 2019;200:e70–88.
- Deterding S, Dixon D, Khaled R. Gamification: using game design elements in Non-Game contexts. *Proceedings of the 2011 Annual Conference Extended Abstracts on Human Factors in Computing Systems (CHI 2011)*, 2011:2425–8.
- Pirovano M, Surer E, Mainetti R, *et al*. Exergaming and rehabilitation: a methodology for the design of effective and safe therapeutic exergames. *Entertain Comput* 2016;14:55–65.
- Eltorai AEM, Baird GL, Eltorai AS, *et al*. Perspectives on incentive spirometry utility and patient protocols. *Respir Care* 2018;63:519–31.
- Arthurs N, Tully L, O'Malley G, *et al*. Usability and engagement testing of mHealth Apps in paediatric obesity: a narrative review of current literature. *Int J Environ Res Public Health* 2022;19:1453.
- Hamilton C, Lovarini M, van den Berg M, *et al*. Usability of affordable feedback-based technologies to improve mobility and physical activity in rehabilitation: a mixed methods study. *Disabil Rehabil* 2021;1–10.
- Parmanto B, Pramana G, Yu DX, *et al*. iMHere: a novel mHealth system for supporting self-care in management of complex and chronic conditions. *JMIR Mhealth Uhealth* 2013;1:e10.
- Maramba I, Chatterjee A, Newman C. Methods of usability testing in the development of eHealth applications: a scoping review. *Int J Med Inform* 2019;126:95–104.
- Neal D, Engelsma T, Tan J, *et al*. Limitations of the new iso standard for health and wellness apps. *Lancet Digit Health* 2022;4:e80–2.
- Reyes BA, Reljin N, Chon KH. Tracheal sounds acquisition using smartphones. *Sensors* 2014;14:13830–50.
- Larson E, Goel M, Boriello G. SpiroSmart: using a microphone to measure lung function on a mobile phone. *Proceedings of the 2012 ACM Conference on Ubiquitous Computing - UbiComp '12*, 2012:280.