

Incentive spirometry and smart phones

Performance validation and user impressions

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The work contained in this dissertation has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the dissertation contains no material previously published or written by another person except where due reference is made.

[QUT Verified Signature](#)

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Vendor acknowledgements

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Ethical Clearance

The qualitative component of this study concerns user impressions of the new QUT Inspire smart phone app. Opinions were sought from attendees at QUT Orientation Week activities at Kelvin Grove and Gardens Point campuses in early February 2018.

Approval to conduct this human research was requested from the QUT University Human Research Ethics Committee (UHREC) in late 2017. The committee assessed this application as low-risk, confirming that the project met the requirements of the National Statement on Ethical Conduct in Human Research (2007).

QUT UHREC granted ethics approval for this project on December 7 2017. (QUT UHREC Reference Number 1700001117).

About the QUT Inspire smart phone application

The QUT Inspire virtual incentive spirometer smart phone app described in this study is available for perusal at:

<https://qutinspire.netlify.com>

Developed by the author of this dissertation, the QUT Inspire app is deployed as a HTML5 web app, suitable for use on smart phones and tablet computers running Chrome™ , Firefox™ and Safari™ web browsers, in addition to recent versions of Internet Explorer™ .

A built-in or external microphone is required to detect breath sounds. A brief user guide for the app is presented in Appendix 10.1.

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1 Abstract

Incentive spirometry (ISy) is a longstanding respiratory therapy technique which encourages gradual maximal inhalation. Purposeful inflation of the lungs over and above normal inhalation is postulated to promote mucus clearance, reducing respiratory complications during post-surgical recovery, and in some chronic conditions. Contemporary ISy devices have clear plastic cases encasing spheres or a piston. As one inhales via a connected tube, the spheres or piston levitate, motivating effort and persistence with multiple iterations of inhalation for clinical efficacy. This study concerns a novel ‘virtual’ incentive spirometer app for smart phones called ‘QUT Inspire’. This new app employs the built-in smart phone microphone to detect breath sounds, displaying inhalation effort graphically on screen in several alternative layouts.

Calibrated mechanical air flows were applied to reference devices and a selection of physical ISy devices to benchmark performance. Sampled audio recordings of these flows were applied to the built-in microphones in a range of modern smart phones at varying distances, flow rates and flow aperture sizes to evaluate the app. The latter aperture size modelled different mouth shapes and diameters while using the app. Performance of the new app was also compared between common contemporary smart phones. Further, user impressions were sought from a cohort of disease-free subjects ($n=19$) as to optimal screen graphics to incentivise effort, in a participatory action research component to this study.

The QUT Inspire app performed comparably with flow-based physical incentive spirometers, demonstrating precision and reliability in detecting simulated air flows, particularly at distances of 5 cm or less from the phone microphone. The equivalent of pursed lips generated higher airflows, optimising the detection of inhalation by the phone microphone. Differences in app performance on different phone types were observed. Users preferred multiple sphere and bar-style animated displays in deference to sparser display animation alternatives. This study offers insight into techniques for evaluating mobile health (mHealth) app performance and display preferences for a virtualised respiratory therapy technique.

2 Introduction

A mark of widespread popularity and adoption of a new technology is assimilation into common parlance, and incorporation into usually cautious, evidenced-based and peer-reviewed pursuits such as medicine. mHealth is a term concerning mobile (phone) health-related technologies, an emergent field which encompasses a growing range of ‘health’ related applications for mobile devices such as smart phones, tablet computers and other wireless devices (Ben-Zeev et. al., 2015). There is a paucity of rigorous evaluation and regulation of the majority of such smart phone health-related applications (Byambasuren et. al., 2018; Herron, 2016; Yetisen et. al., 2014).

This dissertation examines a new bespoke software application “QUT Inspire” which abstracts the functionality of a commonly used respiratory therapy device (an incentive spirometer) for use on smart phones, using the built-in smart phone microphone to detect breath sounds. Despite contention as to the clinical efficacy of incentive spirometry (ISy) in respiratory therapy, physical ISy devices are in wide use for this purpose (Do Nascimento et. al., 2014). Virtualised spirometry apps have been available for over a decade (Reyes et. al., 2016), but most rely on costly add-on components to quantitate flow, rather than using the phone microphone. This is a key differentiator for the new app in question.

A narrative review of the literature is presented here, pertaining to incentive spirometry, mHealth applications for respiratory therapy and aspects of gamification theory regarding incentives for use and compliance. Methodologies used in the quantitative and qualitative investigation of the new app in this study are described, using simulated airflows to exercise smart phone microphone functionality with the new app, and user impressions of display types gained using participatory action research respectively. The focus of these investigations was development of techniques for objective and reproducible evaluation of a novel mHealth respiratory therapy smart phone app.

3. Literature review

3.1 Introduction to narrative review

For most of us, breathing is easy and requires no conscious incentive. Much like our pulse, we are aware of our breaths but have little need to over-think things. It just happens (thanks to the autonomic nervous system and endocrine feedback) (Burgess et. al., 2011). In certain clinical contexts and disease states, purposeful breathing manoeuvres such as incentive spirometry have been employed as therapeutic adjuncts to improve airway function, and to treat pathological conditions. Such “breaths with a purpose” have found favour in post-operative convalescence and management of some chronic respiratory conditions, seeking to reduce the incidence of complications such as respiratory infections and pneumonia with use of mechanical and electronic devices.

The objectives of the study at hand are two-fold, namely performance validation of a novel incentive spirometer software application for use with smart phones, and determining optimal screen display layout to motivate users to inhale while working with the app. This narrative review introduces incentive spirometry (ISy) as an established respiratory therapy technique. The emergent field of mHealth (or mobile health) technology is then defined, offering low-cost and high availability “virtualised” medical devices as apps for use with smart phones and tablet computers.

Key aspects of smart phone sensor design are described to illustrate potential differences in performance between phones. Respiratory therapy mHealth apps are then surveyed, contrasting component-based systems and self-contained smart phone suites. Measurement-style applications and therapeutic games (exergames) are considered as modalities for delivering incentive spirometer respiratory therapy. Calibration and performance evaluation strategies used in validating respiratory therapy mHealth apps are explored. Finally, theories regarding motivating users of apps to persist with, and derive

benefit from smart phone mHealth apps (such as virtualised incentive spirometers) are reviewed.

3.2 Incentive spirometry and respiratory therapy

3.2.1 Tar pipes and flashing lights: origins of incentive spirometry

It seems anathema to contemporary views on respiratory health, but incentive spirometry has origins in the combustion of tar in a pipe, inhaled with the intent of reducing symptoms of asthma and tuberculosis (Jackson, 2010; Murnane et. al., 2017). Prescribed by physicians in the early nineteenth century, resistance provided by breathing in and out through a pipe with a narrow diameter tube was believed to relieve symptoms of tuberculosis, a highly prevalent disease of the day (Atun, 2012). Like an eroded sponge, the damaged lung tissue of tuberculosis sufferers became inefficient at oxygen exchange, exacerbating mucus buildup, chronic lung inflammation and infection (Çavuşoğlu, 2014).

Figure 1 Original Inhalation tube (mid 19th century)



(Murnane et. al., 2017)

Early documented versions of such “inhalation tubes” were described as being up to four feet long, with an internal diameter one sixth of the diameter of a human airway (Murnane et. al., 2017). Acknowledgement of the benefit of breathing exercises in reducing morbidity and mortality from respiratory conditions outlived early incarnations of such “pneumotherapy” devices designed to harness purposeful breaths for therapeutic purposes (Frea, 2012).

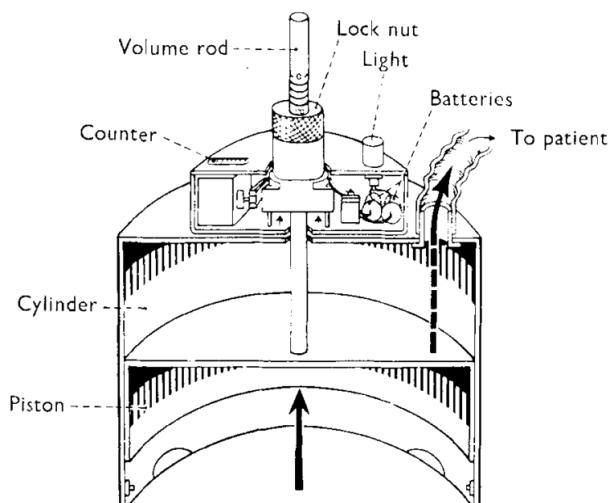
A World War One British surgeon, John MacMahon noted improvements in outcomes for soldiers convalescing from surgery where breathing exercises were prescribed as part of rehabilitation (MacMahon, 1915). Surgical techniques were improved and refined over ensuing decades, but morbidity and mortality from post-operative respiratory complications remained as significant risks for patients, with postural drainage and chest percussion as the mainstays of respiratory therapy in the 1950's and 1960's (Craven et. al., 1974).

In 1970 Bartlett developed an electronic flow meter device called an "Incentive Spirometer", designed to provide encouragement for patients to inhale (Narayan et. al., 2016). The original design was focused on re-inflating collapsed alveoli (air sacs in lungs), a condition known as alveolar atelectasis (Randtke et. al., 2015). Bartlett's original design consisted of a piston enclosed in a metal canister, with an attached hose for inhalation. A light connected to an internal flow meter signalled when a sufficiently vigorous inhalation was detected, as visual feedback for the patient (Craven et. al., 1974).

The device was intended to mimic a sigh or yawn breathing manoeuvre to promote expulsion of mucus, thereby preventing respiratory complications (Narayanan et. al., 2016). "Therapeutically sufficient" and adequate inhalations were signalled by means of the light. Further, the device itself was intended as a reminder to the patient to attempt repeated maximal inhalations (Craven et. al., 1974).

Figure 2 Early incentive spirometer designs

2a. Original design by Bartlett 1970



(Craven et. al., 1974)

2b. Spirocare™ incentive spirometer 1975



(Frea, 2012)

Bartlett is reported to have quipped that simply having the device by the bedside was a reminder and incentive to the patient to breathe deeply (Frea, 2012).

3.2.2 Levitation as motivation: incentive spirometry devices

Bartlett's design for the incentive spirometer was adapted for commercial development as a device called the Spirocare™ in 1975 (Frea, 2012; Narayan et. al., 2016). The single indicator light in the original design was replaced by an array of colourful lights providing additional feedback to the patient as to the vigour of inhalation attempts, and as incentive to maintain maximal inspiratory effort.

Today's incentive spirometers offer two approaches to encouraging such maximal effort following on from the work of Bartlett, namely flow dependant or volume displacement instrument types (Kumar, 2016).

Figure 3 Flow and volumetric physical incentive spirometers

3a. Flow-based physical device



3b. Volumetric physical device



(Teleflex, 2018)

Flow-based ISy devices today, such as the Triflo II™ and Mayo Laboratories™ incentive spirometers use balls encased in a clear plastic case to display inspiratory airflow rate. Vertical ball deflection equates to a calibrated flow rate, for example 600, 900 or 1200 cc/sec (Loh et. al., 2005).

In contrast, volumetric ISy devices such as the Voldyne 2500™ and Voldyne 5000™ report the volume of air displaced in an inhalation by movement of a piston against a calibrated scale encased in a clear plastic housing (Kumar, 2016). The volumetric device also has a small flow gauge to confirm that inspiratory flow rate was adequate. The robust construction of these plastic items allow for sterilisation and long term re-use by a patient.

Contemporary ‘prescriptions’ for post-surgical and chronic care incentive spirometry commonly involve ten repetitions of slow gradual maximal inhalations, with a 3 to 5 second breath hold at maximal inspiration. This regimen is repeated hourly (Armstrong, 2017; Heydaril et. al, 2015; Narayanan et. al., 2016; Queensland Health, 2017).

Age, height and body mass index have been identified as predictors for inspiratory capacity and flow; inspiratory capacity for normal adults and children is of the order of 2 - 3 litres in adults and 0.6 - 2 litres in children (depending on the child’s age) (Tantucci et. al., 2006; Robert et. al., 2008). Recumbent positions have been found to reduce pulmonary volumes, including inspiratory capacity (Naitoh et., al., 2014).

3.2.3 Inhalation as medication: postulated modes of action

Dislodgement of mucus in the lungs and expulsion with coughing is the primary objective of incentive spirometry (Graybill et. al., 2012; Holland & Button, 2006). Surgical anaesthesia may suppress natural mechanisms for mucus clearance such as sighing or yawning (Basoglu et. al., 2005; Narayanan et. al., 2016). Lying supine for protracted periods of post-surgical convalescence, chronic conditions such as chronic obstructive pulmonary disease (COPD), paraplegia and tetraplegia may also facilitate mucus buildup, leading to complications such as respiratory infections or pneumonia (Armstrong, 2017; Cao et. al, 2017; Tamplin & Berlowiz, 2014).

Creation of negative intrathroacic pressure by breathing in has been postulated to “re-inflate” alveoli that may have collapsed with mucus buildup (Rodriguez-Larrad, 2014; White et. al. 2016). Further, it has been postulated that the consistency of certain types of mucus components may promote fluid dynamic transport away from congested lung tissue when incentive spirometry is repeated (Zanin et. al., 2016).

Respiratory muscle exercise afforded by use of ISy devices has been identified as of additional respiratory therapeutic benefit with stroke patients, children with neuromuscular

diseases and individuals with tetraplegia (Menezes et. al., 2016; Human et. al., 2017; Tamplin & Berlowitz, 2014). Incentive spirometry has been found to improve arterial blood gases in patients with COPD, while not altering pulmonary function parameters (Basoglu et. al., 2005). In each of these cohorts, it is unclear as to whether mucus removal or respiratory muscle exercise is the underlying benefit afforded by ISy.

Volumetric displacement incentive spirometers have been found to encourage breathing patterns that access abdominal muscles involved in respiration; this is in contrast to flow-based ISy devices which predominantly leverage accessory muscles in the chest, such as the intercostal muscles (Alaparthi et. al., 2016; Marques & Faria, 2009). Flow-based ISy devices involve lower respiratory frequencies and shorter inspiration times than volumetric devices (Marques & Faria, 2009).

3.2.4 Air of doubt: debate regarding efficacy and compliance

Post-operative pulmonary complications in a range of cardiac, thoracic and abdominal surgeries have been reviewed, to assess the efficacy of ISy in preventing complications. One such review found that physiotherapy and respiratory therapy techniques such as intermittent positive pressure breathing devices were as effective as ISy in minimising complications (Overend et. al., 2001). Methodological flaws in available studies were found to significantly reduce the range of studies considered as eligible for the review. Another review cited lack of standardisation in ISy practice as problematic in assessing efficacy in patients post surgery (Carvalho et. al., 2011).

A systematic review of ISy for the prevention of post operative pulmonary complications in abdominal surgery found low quality evidence of the lack of effectiveness of ISy in preventing complications post surgery, compared with physiotherapy (Do Nascimento et. al., 2015). Poor methodological quality was also cited in this review, with inadequate data on compliance with therapy grossly reducing the sample pool of studies available for review (Do Nascimento et. al., 2015).

Notwithstanding conflicting results in reviews of studies conducted (Cattano et. al, 2010; Katsura et. al., 2015; Marques & Faria, 2009; Neto et. al., 2017), ISy remains widely used in clinical settings (Carvalho et. al., 2011, Rodman, 2014).

3.3 Mobile health (mHealth) software applications for smart phones

3.3.1 Smart phones and the “app revolution”

IBM designed the first mobile smart phone named “Simon” in 1992 (Handel, 2011). “Simon” (and competing offerings from manufacturers such as Nokia) had several pre-installed software applications (apps) including a clock, calendar, address book, calculator and games (Handel, 2011). Smart phones include advanced functionality beyond phone voice calls (Baig et. al, 2015). The added functionality now offered by additional installed applications is the catalyst for tremendous growth and diversity in the utility of these ‘smart’ phone devices (ACMA, 2013).

It has been estimated that over two billion people use smart phones worldwide, with nearly 50 % of adults globally predicted to own such devices soon (Chow et. al, 2016). Three-quarters of all mobile phones (phones or smart phones) are used in low and middle income countries (Ben-Zeev et. al, 2015). Comparing mobile cellular networks and internet availability, global mobile cellular network access has been estimated at 96 % (89 % in developing countries) while internet access was available to 77 % of the population of the developed world (39 % of developing countries) (Al Dahdah et. al., 2015). While mobile phone use is increasing in low income countries, cost and availability are barriers to wider adoption of smart phones in more impoverished areas (Bastawrous et. al., 2013).

According to a survey commissioned by the Australian Communications and Media Authority (ACMA) in 2013, 89 % of Australians aged 18-24 had a smart phone, compared with only 22 % of those aged 65 years or older (ACMA, 2013). The younger cohort were found to be more likely to have downloaded apps to enhance phone functionality (83 %) than the more senior

group (9%) in a later survey (ACMA, 2016 a). An additional ACMA survey found that over 60 % of urban phone users reported using their phone for internet use, while only 37 % of rural/ regional phone users reported doing so (ACMA, 2016 b). ACMA found that 44 % of smart phones in Australia use the Android™ operating system, while 43 % use Apple's IOS™ operating system (ACMA, 2016 a).

3.3.2 Revolution and evolution: Telehealth, eHealth and mHealth

Volta's invention of the battery in 1800 has been proposed as the genesis of modern wireless health monitoring (Clifford et. al., 2015). This early battery was implemented in wireless communication as devised by Dolbear in 1882, and leveraged by Einthoven (inventor of the electrocardiogram or ECG) (Clifford et. al., 2015). Einthoven transmitted ECG measurement signals from an early battery-powered galvanometer in his laboratory to a nearby hospital, via telephone lines in 1906 (Clifford et. al., 2015).

Telehealth is a term that encapsulates distance health applications and services that use information and communications technologies (Monteagudo et. al., 2014). eHealth has been more broadly defined as "health care practices supported by telecommunication systems and electronic processes" in inpatient, outpatient and community (i.e distance) settings (Berkery et. al, 2015).

Einthoven's achievements may thus be viewed in today's terms as an example of an eHealth initiative, delivered as an early telehealth prototype. It has been noted that telehealth was at the origins of the paradigm of removing spatial and temporal constraints from health care, giving rise to the concept of eHealth; smart phones now constitute the next phase of evolution "in transporting information to transform health care" (Cameron et. al., 2017).

The term mHealth (or mobile health) pertains to a more contemporary subset of eHealth practices based on mobile and wireless devices (WHO, 2011). mHealth encompasses "medical and public health practices supported by mobile devices such as mobile phones,

patient monitoring devices, personal digital assistants and other devices such as wearables" (Currie, 2016).

Most mHealth interventions involve changing health behaviours, management of chronic diseases and critical events (Klasnja et. al., 2012). The WHO began monitoring mHealth initiatives in 2009, acknowledging the importance of this emergent field (Doumbouya et. al., 2014).

It is estimated that over 500 million smart phone users worldwide have one or more mHealth apps installed (Khachatrian et. al., 2015). A recent 2016 review yielded an estimate of over 160,000 different mHealth apps available in popular commercial app stores such as the Google™ Play Store and Apple™ App Store (Grundy et. al., 2016); estimates vary up to over 300,000 mHealth apps (Byambasuren et. al., 2018). The number of web-hosted apps (not hosted on app stores) is indeterminate (Herron, 2016).

mHealth has been widely acknowledged as able to reach more people than through other health promotion or self-management initiatives, albeit with caveats regarding older, low income or geographically isolated individuals to whom the technology may not be accessible (Bull & Ezeanochie, 2016).

The functionality of Einthoven's ECG galvanometer is now available for under AUD \$ 200, implemented as a clip-on sensor phone case and a companion mHealth software app for smart phones. This (Alivecor™ Kardia) app detects and displays ECG waveforms in real time, performs automatic analysis for anomalies such as atrial fibrillation, and can email ECG results directly to a physician for monitoring and action (Alivecor, 2018).

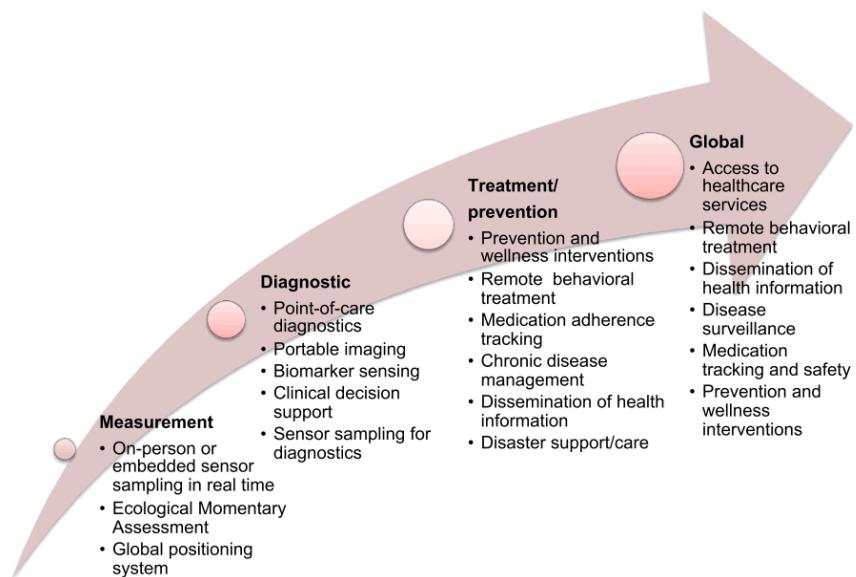
3.3.3 There's an app for that: taxonomies for mHealth apps

The aforementioned ECG app is an example of an ‘active’ mHealth app, where the mobile device uses inbuilt or external sensors to generate some kind of health data. This is as distinct from ‘passive’ mHealth apps which display or allow manual input of health information (Herron, 2016).

The US Food and Drug Administration proposed three broad categories of mHealth apps based on functionality, namely administrative, health management and medical device applications (Cortez et. al., 2014). This taxonomy was created to facilitate attempts at regulation of mHealth apps.

A continuum of mHealth tools has been described, encompassing uses of mHealth interventions and reflecting apps intended for use by health care providers and individuals (Kumar et. al., 2013). This includes measurement, diagnostic, treatment/prevention and global app types.

Figure 4 Continuum of mHealth tools



(Kumar et. al., 2013)

3.3.4 Evidence-based mHealth and prescribable mHealth

The dramatic growth in the availability of mHealth apps creates issues regarding validation of methodology and results (Grundy et. al., 2016). There are dangers for individuals in reliance on apps that may mis-report measurements, mis-diagnose medical conditions or fail to prevent or treat ailments (Agu et. al., 2013). Abstraction of real world medical devices to the virtualised app environment demands rigour in testing and validation of app performance to assert safety and clinical efficacy (Baig et. al., 2015).

Opportunities for self-care afforded by mHealth apps need to be tempered by appropriate clinical supervision to ensure effectiveness (Yetisen et. al, 2014). More broadly, health care systems need to adapt to this emergent distributed and participatory health care model (Anderson et.al., 2016; Bauer et. al., 2014).

Ratings scales have been developed for assessing the quality of mHealth apps but not widely adopted; examples include MARS - the Mobile Applications Rating Scale and CRAAP (Currency, Relevance, Authority, Accuracy and Purpose) (Chow et. al., 2016; Herron, 2016). These scales attempt to assert the validity and safety of mHealth apps.

A recent overview of systematic reviews of mHealth apps found that only 23 peer reviewed randomised controlled trials of 22 stand-alone mHealth apps could be found, out of an estimated 318,000 mHeath apps available in app stores in 2017 (Byambasuren et. al.,2018). The focus of this investigation was identification of “prescribable mHealth apps”, defined as those which are proven effective and amenable for prescription by physicians. The reviewers concluded that only a small number of available stand-alone mHealth apps have been subjected to the the rigour of randomised controlled clinical trials to assert efficacy and safety, mainly concerning diabetes, obesity and mental health (Byambasuren et. al.,2018).

3.3.5 For entertainment only: legislative and regulatory issues

In the USA, Food and Drug administration regulators identified passive and active health applications, the former offering read only information or basic data capture and the latter involving actual physiological measurement and clinical elements (Herron, 2016). App developers wishing to bypass the rigours of clinical trials and peer review have an “easy option” in declaring their apps “for entertainment purposes only” and not subject to regulation under US law (Herron, 2016).

There is a need to ensure that patient privacy and health care data is safeguarded (Allaert et. al., 2017). Health apps pose particular challenges, as many that claim to offer health benefits lack clinical evaluation and peer review (Khachatrian, 2015). Efforts by governments in the United States, United Kingdom, and Australia have yielded little benefit in curating thousands of applications claiming to be health or fitness related (Bhuyan et. al., 2017).

A paucity exists in documentation regarding the provenance of apps, where they store data, how it is stored and who has access to it; this should be of great concern to app users (Hussain et. al., 2015). Gaps in knowledge concerning phone specifications and performance further confound matters, as do vendor commercial-in-confidence agreements in preventing disclosure (Yetisen et. al., 2014).

3.4 Smart phone sensors for mHealth applications for respiratory therapy

Modern smart phones have sensors that may be categorised into several groups, namely audio frequency sensors, optical sensors, electromechanical sensors (accelerometer), electromagnetic (magnetometer) and other sensors (Daponte et. al., 2013; Li et. al., 2016).

Figure 5 Sensors in modern smart phones

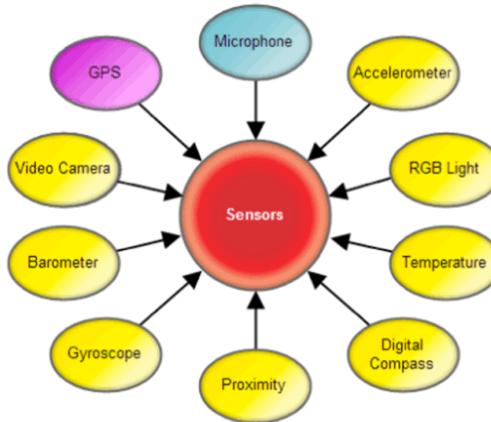


Fig. 4. Sensors integrate on a modern smartphone.

(Daponte et. al., 2013)

Measurements of respiration using smart phones have been conducted using a variety of means. Smart phone cameras have been used to detect and quantitate chest movement (Reyes, et. al., 2016). Respiratory rate has been monitored using video imaging (Nam & Nam, 2017). Recent studies have employed gait monitoring using the smart phone accelerometer to estimate respiratory function parameters (Cheng et. al., 2017). Measurement of breath rate with both external and built-in smart phone microphones has been performed in neonates (Black et, al., 2015).

The smart phone microphone has been used to detect breath sounds and quantitate lung function parameters (Misra et. al., 2008; Thap et. al., 2016). Implemented in a commercial respiratory function application called Spirosmart™, cloud-based fast Fourier analysis was used to translate monitored sounds into respiratory volume and flow estimates (Larson et. al., 2012).

Smart phones use micro electromechanical microphones to detect sound (Robinson & Tingay, 2014). Variability has been observed in sound monitored on different smart phone brands and models (Kardous & Shaw, 2014; Le Prell et. al., 2014; Maryn et. al., 2017). Apple™ phones have been found to use a low frequency filter to optimise voice detection

(Brown & Evans, 2011). The age of a smart phone microphone has also been demonstrated to affect performance, with reduced frequency response in older microphones reflecting degradation in sound detection with protracted use (Murphy & King, 2016; Ventura et. al., 2017).

The number and placement of microphones on different smart phones varies. In addition to a microphone for voice at the base of the phone, some models incorporate additional microphones for front and rear facing cameras (Nast et. al., 2014). External microphones and headsets, using condenser microphones have been found to improve detection and sensitivity, while not as readily accessible and available as intrinsic phone built-in microphones (Kardous & Shaw, 2014).

Comparison of metered sound apps on Apple™, Android™ and Windows™ phone platforms suggested that Apple™ device measurements were accurate and suited to occupational sound measurements. The latter Android™ and Windows™ vendor phones were found to be less accurate (Kardous & Shaw, 2016).

3.4.1 Examples of respiratory therapy mHealth apps

Two types of sound-based breath detection apps are found in the literature. Meter-type apps detect breath and display a reading or graphic display. Game-based apps use detected breath sounds to control game play in the context of goal-oriented sequences. The latter have been termed “Exergames”, in that motivation to persist with, and repeat (breath) behaviours is consolidated by the game play itself (Higgins, 2016).

Audioflow is an example of a meter type app which detects the sound of expiration and displays a metered value based on sound levels recorded (Titus et. al., 2016). A calibrated pressure transducer is used to detect breath sound, coupled to an Android™ phone via the phone headphone jack. The app is designed to virtualise measurement of peak expiratory flow rate, a pulmonary parameter used in the management of asthma (Titus et. al., 2016).

Flappy breath is an exergame that uses a chest belt as a transducer, using the player's breathing manoeuvres to trigger game events such as move left or right (Stafford et. al., 2016). The chest belt is coupled to a smart phone by means of wireless bluetooth connection. In contrast to Audioflow and more akin to incentive spirometry per se, the objective of this exergame is not quantification of flows, but providing incentive to persist with repetition of breathing manoeuvres.

Most smart phone implementations of such meter or game apps employ add-on components such as flow transducers or custom mouthpieces to quantitate flows (Table1). The aforementioned Spirosmart™ and Spirocall™ apps use the built-in phone microphone to detect breath sounds, and cloud-based processing to quantitate respiratory parameters, offering features comparable to formal respiratory function testing laboratory results (Larson et. al., 2013).

No published randomised controlled trials could be found evaluating the performance of these apps in clinical settings.

Table 1 Examples of apps for health-related breath detection

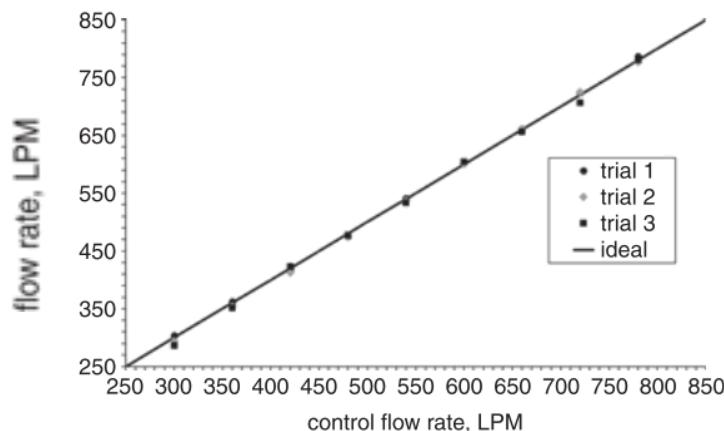
App Name	Type	Description	Platform	Add ons required	Citation
Audioflow	Meter	Quantitation of peak expiratory flow rate	Android	Custom pressure transducer coupled via headphone jack	Titus et. al., 2016
ExpGame	Game	Gamified ISy application for rehabilitation of patients with pulmonary expansion deficit	Windows PC	Custom Infrared sensor coupled to PC by Bluetooth	Chacon et. al., 2016
Flappy Breath	Game	Breathing game for respiratory therapy	Android	Custom displacement sensor/chest belt coupled by Bluetooth	Stafford et. al., 2016
Frog Jump, Bird's Journey, Tank Targets, Fish Feeding	Game	Gamification of ISy in suite of games using inspiration to trigger game actions	Windows PC	Commercial flow transducer coupled to PC via USB	Lange et. al., 2011
Spirosmart	Meter	Quantitation of respiratory function using fast fourier sound analysis	IOS	Nil - uses built-in microphone	Larson et. al., 2012
Spirocalls	Meter	Re-use of Spirosmart algorithm using telephony (no app)	Telephone	Nil - uses built-in microphone	Larson et. al., 2013
Unnamed	Meter	Quantitation of expiratory flow parameters (FEV1, FVC and ratio)	IOS	Custom mouthpiece	Thap et. al., 2016
Unnamed	Meter	Tracheal sound used to estimate expiratory and inspiratory parameters	IOS / Android	Custom microphone coupled via headphone jack	Reyes et. al., 2014
Whoosh	Meter	Non-voice acoustic input for smart watches using sip and puff breath gestures - no lsy display	Android (watch)	Nil - uses built-in microphone	Reyes et. al., 2016

3.4.2 Calibration techniques for respiratory therapy mHealth apps

Modern physical incentive spirometers are factory-calibrated, and usually have only one or two moving parts, namely spheres or a piston (Armstrong, 2017, Reyes, 2016). Methods for calibrating such devices in the laboratory include vacuum vessels which simulate 'inspiration' of a known volume of air at a set flow rate (See Figure 6).

Computer-controlled or manually actuated syringes of known volume (3-5 litres) are also commonly used to verify that displayed flow rates and air volumes are accurately and precisely measured. (Miller et. al., 2005). These methods are commonly used for calibration purposes for equipment in respiratory function testing laboratories (Miller et. al., 2005; Rodman, 2014).

Figure 6 Calibration of a flow device using a reference airflow



(Titus et. al., 2016)

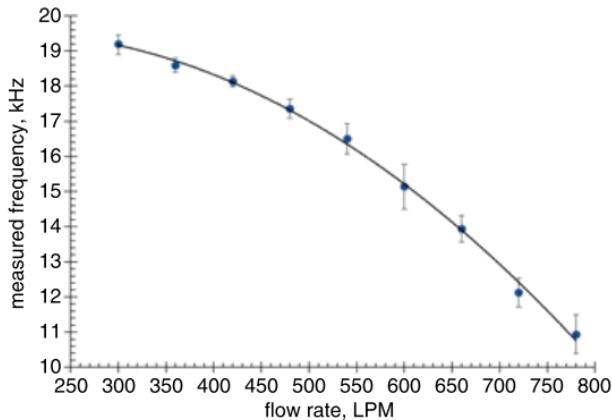
Acoustic calibration of flow rate readings for devices with microphones has also been performed, using recordings of breath sounds (Holmes et. al., 2013; Larson et. al, 2012; Seheult et. al., 2014).

Applications for such acoustic calibration methods include peak expiratory flow sound measurement adapted for acquisition by smart phones (Titus et. al., 2016). Known flow rates applied to an app are detected and plotted as a calibration curve reflecting frequency response (Figure 6) (Titus et. al., 2016). Once flow rates are calibrated, the sound frequency detected by a phone may be extrapolated to a flow rate, referring to the baseline calibration (Figure 7a).

Assessment of the efficacy of medication delivery via an dosed inhaler device has also been assessed using breath sounds detected by a phone-coupled microphone (Seheult et. al., 2014). Timings of breath components may be extrapolated from such analysis and used to access adequacy of inhalation in the context of medication delivery.

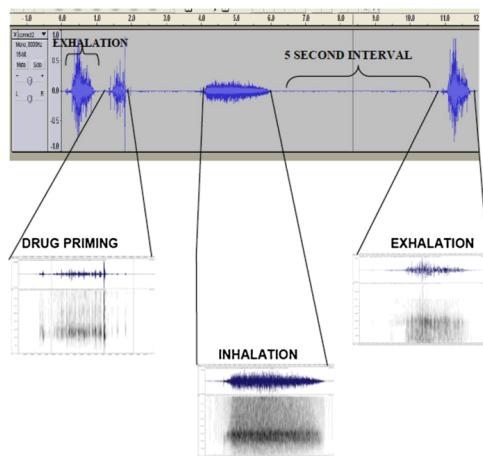
Figure 7 Acoustic calibration of devices

7a Smart phonePeak Expiratory Flow Meter



(Titus et. al., 2016)

7b Inhaler (INCA™) device



(Seheult et. al., 2014)

3.5 “Motivational affordances” and gamification

Rehabilitation following surgery, or therapy for management of a chronic respiratory condition should be repeated intensively for optimal effect (Rego et. al., 2014). By design, incentive spirometry is a motivational tool to assist an individual to persist with respiratory therapy. Whether it is activation of a light array in the original design, or by raising spheres in a cylinder, visual feedback is provided on the adequacy of an inhalation attempt.

Such visual stimuli have been termed “motivational affordances” (Deterding et. al., 2011; El-Hilly et. al., 2016). Gamification in serious games has been defined as the use of game elements in a non-game context (Deterding et. al., 2011). The term “Exergame” has been coined to describe an exercise that has a game built into its structure (Pirovano et. al., 2016). Exergames are a subset of “games with a purpose”, referred to as “serious games” to distinguish their focused intent from that of pure recreational gaming (Deterding et. al., 2011).

Therapeutic exergames have been defined as those which support all primary (therapeutic) and secondary goals (e.g compliance, technique) defined for an exercise (Lohse et. al., 2013; Pirovano et. al., 2016).

Debate exists as to the relevance and applicability of psychological constructs and theories regarding engagement and motivation using gamification of software applications in health contexts (Cho, 2016). The Technology Acceptance Model (TAM), Health Information Technology Acceptance Model (HITAM) and Unified Theory of Acceptance and Use of Technology Model (UTAUT) describe technological acceptance factors such as perceived usefulness, ease of use and intent to use as driving considerations for uptake and continued use of mHealth apps (Anderson et. al., 2016; Jiang et. al., 2016).

Attention, active learning, feedback and consolidation have been described as pillars of learning in serious gaming (Drummond et. al. 2017). Behavioural control and intrinsic motivation have been identified as key to engagement with such games (El-Hilly et. al., 2016). A clear explicit purpose, alignment with the objectives of the user and functional alignment to meet the users needs have been highlighted as further contributing to user engagement (El-Hilly et. al., 2016).

Perceived behavioural control was identified as a key driver in a study on patient compliance with incentive spirometry with cardiac surgical patients (Tung et. al., 2011). This work framed compliance in the context of the theory of planned behavioural control, and found that intent (or intrinsic motivation) played a lesser role than behavioural control in engaging patients in this cohort to comply with ISy therapy (Tung et. al., 2011)

Visual animation of inspiration in ISy manoeuvres provide users with feedback for improving technique, and may afford motivation to persist. Pictographs have been identified as optimal for displaying information to patients on smart phone screens, especially where numeracy may be an issue (Hawley et. al., 2008). Additional game-related elements such as point scoring, attainment of levels and leaderboards are regarded as extrinsic motivations, which may further motivate a user to comply (Mekler et. al., 2017).

Studies on user perceptions of mHealth apps identify lack of time, effort and discipline as barriers to compliance with mHealth apps (Peng et. al., 2016). Users report a preference to

minimise the “burden” of an app, namely excessive menu navigation or difficulty in use (Hilliard et. al., 2014). Consideration also needs to be given to the life stages of app users, as older individuals may be less familiar with app controls, game play and operations (Cunha et. al., 2016; Frey et. al., 2017).

3.6 Conclusion

Incentive spirometry has been reviewed here, describing the technique and applications in clinical practice. Despite widespread use, definitive information on clinical efficacy is lacking, compounded by the complex disease states and treatment modalities involved. mHealth and the virtualisation of medical devices has been explored. Respiratory therapy mHealth apps (and calibration strategies) have been surveyed, highlighting the paucity of dedicated virtual incentive spirometry apps available, and a deficit in clinical trials evaluating such technology. Elements of gamification pertinent to a virtualised incentive spirometer app have been discussed, indicating design elements encouraging compliance with ISy techniques.

4. Research questions

This study considers a new bespoke smart phone software application developed by the author called QUT Inspire. The smart phone microphone is used as a built-in uncalibrated pressure sensor, detecting the sound of inspiration and graphically displaying inspiratory effort as a “motivational affordance” (Deterding et. al., 2011) to encourage repeated slow gradual maximal inspiration akin to a virtualised incentive spirometer. Two research questions are considered in this study, namely:

4.1 Quantitative - Performance validation of the new QUT Inspire app

Can a novel stand-alone virtualised smart phone incentive spirometer detect and display respiratory effort using the built-in smart phone microphone to detect breath sounds ?

Assessment of the precision and sensitivity of the new virtual app against reference measures in this report contributes to validation of this new device, with additional comparisons to existing physical incentive spirometer devices; the QUT Inspire app is evaluated on examples of Apple™, Samsung™ and third party Pendo Pad™ smart phone and tablet devices, using acoustic sound sample loops of mechanically simulated air flows.

4.2 Qualitative - User impressions as to optimal graphics for motivation

What type of smart phone graphical display of respiratory effort is regarded as optimal by a cohort of disease-free subjects in encouraging the user to sustain gradual maximal inhalation effort?

Encouraging maximal inspiratory effort by a patient is considered pivotal to gaining benefit from incentive spirometry. There is a paucity of information regarding graphical displays that best represent inspiratory effort, and foster persistence with the technique. A cohort of disease-free subjects were asked to use the app, and questioned as to which of 4 distinct graphical display/animation types they considered optimal to provide incentive to gradually and maximally inhale while using the app.

5. Methodology

Methods used in the quantitative and qualitative elements of this study are discussed in this section. The QUT Inspire app is first described in brief. An overview of the performance validation strategy is then presented. Reference tests and benchmarking of measurement devices are then described. Smart phone device testing of the QUT Inspire app is then outlined, followed by statistical analysis strategies used in the study. Finally, details of the semi-structured interview methodology used in the qualitative component of the study are discussed in section 5.6.

5.1 Development of the QUT Inspire app

QUT Inspire was developed by the author using Construct 3™, an integrated app software development environment (IDE) produced by Scirra Ltd (scirra.com) in the United Kingdom. The IDE was developed for creation of 2D platform games, but is amenable to other development uses. The idea for the app came to the author from an IOS children's game app called 'Chicken Scream', allowing kids to scream into the phone microphone to make a chicken animation jump on screen.

An audio analyser example application sourced from the Scirra website was used as the foundation for the development of QUT Inspire (scirra.com, 2018). The example application used a custom audio component for sound detection from the smart phone microphone which triggered movement of a simple animation when a threshold sound level is detected. The smart phone microphone acts as an uncalibrated pressure sensor in this application, activating the animation when the threshold is reached via voice or breath sounds.

Apps created using Construct 3™ may be deployed as native IOS™ (Apple) and Android™ smartphone apps by means of Cordova™, an application designed for cross-environment bundling of code for different target application stores such as the Apple App Store™ and Google Play Store™. It also ports code to HTML5, creating 'platform-independent' code that

works on common internet browsers such as Safari™, Chrome™, Firefox™ and some newer versions of Internet Explorer™. Once run on a browser a single time, an internet connection is no longer required for operation of HTML5 web apps, as they can run offline.

The QUT Inspire app was ported to HTML5 and hosted on a free web server service called bitballoon.com as an SSL (secure socket layer) website. SSL is required to facilitate smart phone microphone access. The user licence for Construct 3™ costs \$ 99 per annum, with no royalties payable to scirra.com unless commercial apps yield more than \$ 5,000 revenue per annum (scirra.com).

5.2 Validation testing plan

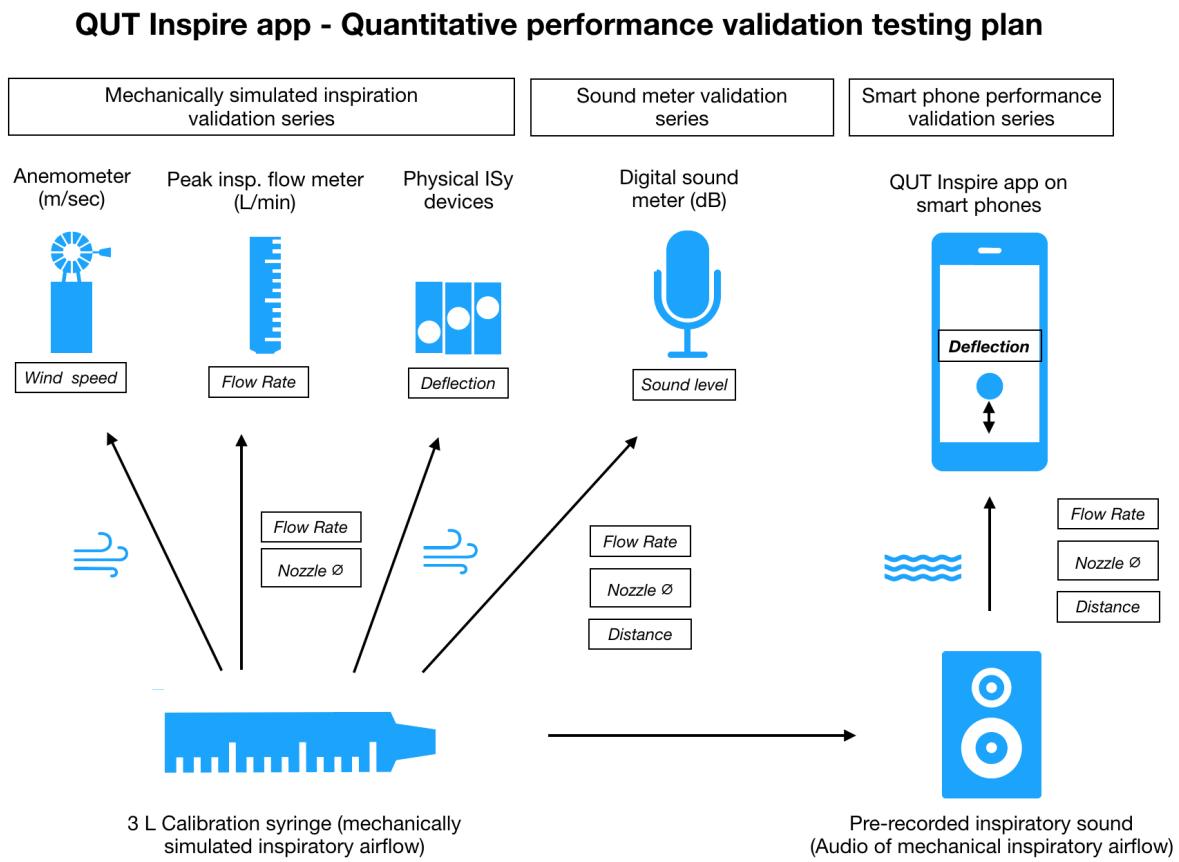
Mechanically simulated inspiratory flows were used for testing purposes in this study, generated by timed manual withdrawal of the plunger of a calibrated 3 L syringe. The need for repeatability and standardised flows (n=20 attempts for each flow rate/nozzle diameter combination), in addition to the safety of human subjects in delivering multiple inhalations precluded initial human testing in this study.

Three series of tests were developed in order to establish the reliability and precision of syringe-generated inspiratory flows, and in turn to validate the use of recorded audio samples of these flows for testing the QUT Inspire app on smart phones (Figure 8). Background noise generated in the air hose by the withdrawal of the syringe plunger necessitated use of audio samples for testing the app on smart phones, rather than direct application of mechanically simulated air flows to the phones.

Reference devices including an anemometer (wind speed meter), peak inspiratory flow meter and three physical incentive spirometer devices were tested using the 3 L syringe. The objective of this first mechanical test series was quantification of the air speed, peak inspiratory flow and inspiratory flow attained by use of the syringe at increasing flow rates and at different nozzle (mouth) diameters, as measured by these devices respectively. In

addition to the devices described, a further preliminary syringe discharge timing test was conducted to assert the precision of the counting mnemonic used for timing flow rates when actuating the syringe.

Figure 8 Overview of quantitative performance validation testing strategy



A second test series examined measurement of the sound level generated by mechanically simulated inspirations. Representative samples of sound generated in this test series was sampled for use in phone testing.

Sound artefacts such as the “thud” noise made at full syringe actuation were removed from the samples taken for each flow rate, nozzle diameter and distance combination. Loops of 20 iterations of sampled simulated inspiration sounds were created for each flow rate/nozzle diameter combination.

The third and final test series involved smart phone testing of the QUT Inspire app by playing recorded looped sound samples obtained from the second sound meter test series and monitoring deflection response of the smart phone graphic display, played via an external speaker.

5.3 Detailed description of test equipment

5.3.1 Desk retort stand and clamp

A retort stand, boss head and clamp arrangement was used to secure reference instruments, smart phones, devices and hoses for tests. Smart phones were secured to the rig for testing using a ‘sticky’ universal dash and vent mount (Jaycar Electronics Cat No: HS9050). The retort stand was located on a desktop. Tests involving measurements at distance were performed using a measuring tape to adjust boss head and clamp positions to achieve desired separation of instruments and sensors. Where distances were large, the clamp arrangement was swung away from the desk, and instruments placed below desk level to achieve desired separation.

5.3.2 Calibration syringe and air flow nozzles

A Welch Allyn™ three litre calibration syringe (Model 703480) was used to generate mechanically simulated inspirations for calibration and testing of devices. Calibrated volume of the syringe was stated as $3.003\text{ L} \pm 0.25\%$. The syringe aperture had a 25 mm diameter.

Figure 9 Calibration syringe



PVC hosing with a 25 mm internal diameter was used for all testing. Air flow nozzles fashioned from irrigation couplings (Bunnings Hardware) of increasing diameter were attached to the same length of hose for device testing to model increasing mouth opening diameters. Nozzles of 10,15, 20 and 25 mm diameter were used for testing.

Generation of simulated inhalation required manual withdrawal of the syringe plunger to create inflow. A counting mnemonic was employed in order to time syringe operation. Table 2 describes counts uttered in order to time mechanical inspirations at various flow rates.

Precision of simulated inspirations by means of the syringe was assessed in a preliminary test by conducting timed simulated inhalations using timings afforded by the mnemonics presented in table 2 (n=20 for each of four flow rates at each of four nozzle diameters).

Table 2 Counting mnemonics for flow rates with calibrated syringe

Simulated Flow Rate	Mnemonic used to time each 3 L syringe plunger withdrawal
High	One Two Three
High/Moderate	One Ten Two Ten Three Ten
Medium	One One Thousand Two One Thousand Three One Thousand
Low	One One Hundred Thousand, Two One Hundred Thousand, Three One Hundred Thousand

5.3.3 Anemometer

A Digitech wind speed meter (Jaycar Electronics Cat No: QM1644) was used to measure air speed generated by increasing mechanically generated airflows. The meter was held in place in the retort stand, with varying simulated inflow flows applied to the meter using airflow

nozzles of increasing diameter ($n=20$ attempts at each of four flow rates at each of four nozzle diameters).

Figure 10 Digitech Anemometer (wind speed meter)



No accuracy value was quoted by the manufacturer for this meter. Wind speed measuring range was quoted as 0.3 m/sec - 30 m/sec. In trials using this meter, it was found that the 10 mm diameter nozzle failed to trigger the meter reliably at any distance. The wind vane propellor housing on the device had a 20 mm diameter aperture.

It is possible that simulated inspiratory flows generated by the small narrow nozzle failed to exert sufficient air pressure to move the meter's propellor. Interpretation of results from anemometer readings may be subject to bias caused by insufficient air pressure being generated for detection.

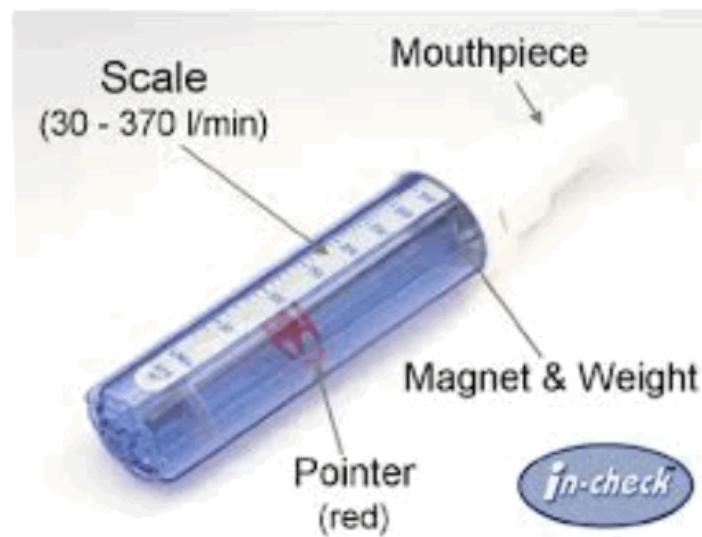
Notwithstanding this issue, air speed was measured at each flow rate using three nozzle diameters ($n=20$ attempts at each flow rate and 15, 20, 25 mm nozzle diameters at 0 cm distance). A calibration curve was sought, identifying any discernible correlation between simulated inspiratory flow rate, nozzle (mouth) diameter and measured air speed.

5.3.4 Peak inspiratory flow meter

An In-Check DIAL™ inspiratory flow training meter (Clement Clarke Model G-16) was used as a reference instrument for measuring peak inspiratory flow rate registered by the three litre calibration syringe at varying flow rates ($n=20$ attempts at each of four simulated inspiratory flow rates). The meter was attached directly to the calibration syringe using the 25 mm hose via a reduction coupling. The In-Check device has a dial mechanism to adjust resistance to flow for asthma inhaler training purposes. The dial was adjusted to the lowest resistance setting for testing purposes.

The accuracy of the In-Check DIAL™ meter was quoted by the manufacturer as ± 10 L/min, with repeatability ± 5 L/min and a measurement range of 15 - 120 L/min.

Figure 11 In-check DIAL G-16 training inspiratory flow meter



In addition to assessing the influence of syringe flow rates on measured peak inspiratory flow, the meter was used to test the effect of reducing nozzle (mouth) diameter on measured peak inspiratory flow at varying flow rates ($n=20$ attempts at each of four flow rates and each of four nozzle diameters). The reduction coupling joined the 25 mm hose to the 20 mm aperture on the meter, and accepted gasket washers of 10 mm, 15, 20 mm internal diameter respectively, in addition to use of the 25 mm diameter hose without a gasket.

This latter 25 mm scenario may result in aberrant flow due to coupling reduction from 25 mm at the syringe airflow nozzle to 20 mm at the meter aperture, warranting care in interpreting results at the largest nozzle diameter (25 mm) for this meter.

The intent of this test series is generation of calibration curves for peak inspiratory flow rate across a range of simulated inspiratory flow rates, identifying what effect varying flow and nozzle (mouth) diameters manifest in terms of peak inspiratory flow (L/min) measured

5.3.5 Physical incentive spirometers

Two flow-based and one volumetric incentive spirometers were tested using the mechanical syringe calibration method described here. The Mayo Laboratories Respiratory Exerciser (Mayo Laboratories) and Triflo II™ (Hudson) flow-based devices both have 10 mm diameter couplings which were used for direct connection (via the 10 mm nozzle) to the test hose and syringe at 0 cm. The Voldyne 2500 volumetric device (Hudson) had a 20 mm coupling, and was also directly coupled (using the 20 mm nozzle) to the syringe via the air hose. The purpose of this test series was establishment of a benchmark for comparison of measured flow rates with the app.

Figure 12 Physical incentive spirometers addressed in this study

12a. Mayo Laboratories
(flow)



12b. Triflo II
(flow)



12c. Voldyne 2500
(volumetric)



5.3.6 Sound Meter

A Digitech portable sound meter (Jaycar Electronics Cat No: QM1591) was used to ascertain sound levels generated by increasing mechanically simulated inspiratory flows, nozzle sizes and distance of nozzles from the meter ($n=20$ attempts at each flow, nozzle size and distance). The meter was clamped into the retort frame for this test series, with the airflow nozzle moved away from the device in progressive tests.

Figure 13 Digitech sound meter



The sound meter had a quoted measurement range of 30 - 130 dB A with a resolution of 0.1dB. Accuracy was quoted by the manufacturer as $\pm 3.5\text{dB}$ @ 1kHz. Distances of 0, 1, 2, 5, 10, 50 and 100 cm were selected for testing as representative of distances at which a comparable smartphone might be held from one's mouth for detection of inhalation.

The objective of this test series was construction of calibration curves assessing the effect of mechanical air flow, nozzle diameter and distance from the sound meter on measured sound level (dB A). Results for the sound meter series serve as a baseline for comparison of smart phone performance, using the same recorded mechanical air flows.

5.3.7 Audio recording, sampling and loops

5.3.7.1 Audio recording

As the QUT Inspire app uses the built-in microphone to detect inspiration sounds, audio recordings of simulated mechanical inspirations using the three litre syringe were made at each flow rate, nozzle diameter and distance for playback and testing against the app (n=20 attempts in a single recording at each flow rate, nozzle diameter at distance = 0 cm). Recordings were made with a Sony ICDPX470 digital voice recorder (JB Hi Fi SKU: 317241) and transferred to an Apple MacBook Pro™ computer .

Inspection of prototype audio files revealed a sound artefact resulting from the sound of the syringe plunger striking the end of the syringe barrel at the completion of a simulated mechanical inspiration. In order to prevent this artefact from affecting playback and phone microphone detection, each source audio file was edited using Quicktime™ Player software (version 10.4), trimming this extraneous sound from the end of audio recordings.

5.3.7.2 Audio sampling and loops

The audio recordings were reviewed and a representative single instance of mechanically simulated inhalation was isolated for each flow and nozzle diameter combination at a distance of 0 cm. Twenty instances of each sample were merged in a single looped audio file using a free online batch audio converter called AC Convert (<https://www.aconvert.com/audio/merge/#>). The intent of each loop file was to create reproducible test audio file sequences to play via an external speaker against each smart phone, facilitating assessment of QUT Inspire measurement precision, and reliability in terms of detecting audio samples of air flows.

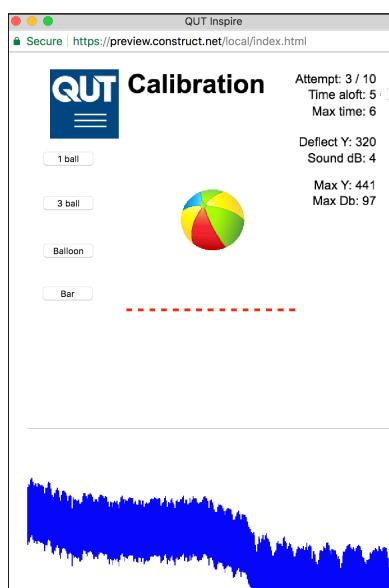
5.4 QUT Inspire app and smart phones

As described previously, a sound artefact was created with each withdrawal of the calibration syringe plunger at the end of an ‘inspiration’, especially at high simulated flows. With this in mind, audio samples were used to test the precision and reliability of breath detection using the QUT Inspire app.

Looped audio sequences were played through an external speaker, with increasing flows, nozzle sizes and distances from the built-in microphone for each phone device assessed (n=20 copies of each sound corresponding to samples recorded at different air flows, nozzle sizes, and distance of external speaker from the phone microphone).

The acceleration and degree of sphere deflection in response to a pre-recorded simulated inhalation was hard-coded in the app. A calibration mode was created for the QUT Inspire app which displayed maximum deflection and sound level detected on the phone; screen recordings of test executions were reviewed and results recorded.

Figure 14 QUT Inspire Calibration mode screen



As the app had a fixed sound threshold for triggering the animation, the maximum sound level for each test was used for analysis rather than degree of deflection.

A representative range of common smart phones and tablet/phablet devices were considered in the study. Table 3 presents a summary of the three devices considered in this research.

Table 3 Smart phones using the QUT Inspire app tested in this study

Phone/Tablet	Type	Operating System	Browser used
Apple™ iPhone 6 Plus	Smartphone	iOS™ 10.2.1	Safari™
Samsung™ J1	Smartphone	Android™ 5.1	Chrome™
Pendo™ Pad	Tablet	Android™ 6.1	Chrome™

5.5 Data analysis and statistical testing

Data was coded and analysed using SPSS Statistics™ (Version 25, 64 bit), using univariate and multiple linear regression as appropriate. Significance levels were set at 0.05 (95 % CI two-tailed) where applicable. Residual analysis was conducted on each model constructed to confirm that assumptions regarding the nature and distribution of variances satisfied requirements for modelling by linear regression.

Preliminary investigations indicated that some datasets demonstrated exponential decay rather than linear relationships. In these cases and where indicated, natural logarithmic transformations of dependant variables were performed, to facilitate linear regression analysis (Kirkwood & Sterne, 2014). Plots displaying raw sound levels (no log transformation) detected by each phone type are presented in Appendix 10.3 for reference.

5.6 User impressions of the QUT Inspire app

QUT Human Research Ethics Committee granted approval for the conduct of this human research (QUT UHREC Reference Number 1700001117). A list of starting questions was composed for semi-structured interviews with respondents attending QUT Orientation Week in February 2018 (See Appendix 10.2 for UHREC approved forms).

Participants self-nominated for involvement in the study (n=19 participants). Brief instructions were provided on use of the smart phone app before the participants were guided through selection of each of 4 types of graphic displays offered by QUT Inspire. Participants were encouraged to hold the phone less than 5 cm from their mouths.

Participants tried each display type with several normal inhalations. As there was significant background noise at the Orientation week events, respondents were coached on use of a sliding sensitivity control offered by the app to dampen the effect of background noise on the display animation. Respondents were able to review display types as they wished before they were asked which of the display types they preferred most and least as incentive to provide slow gradual inhalation (and why), using an inductive thematic approach.

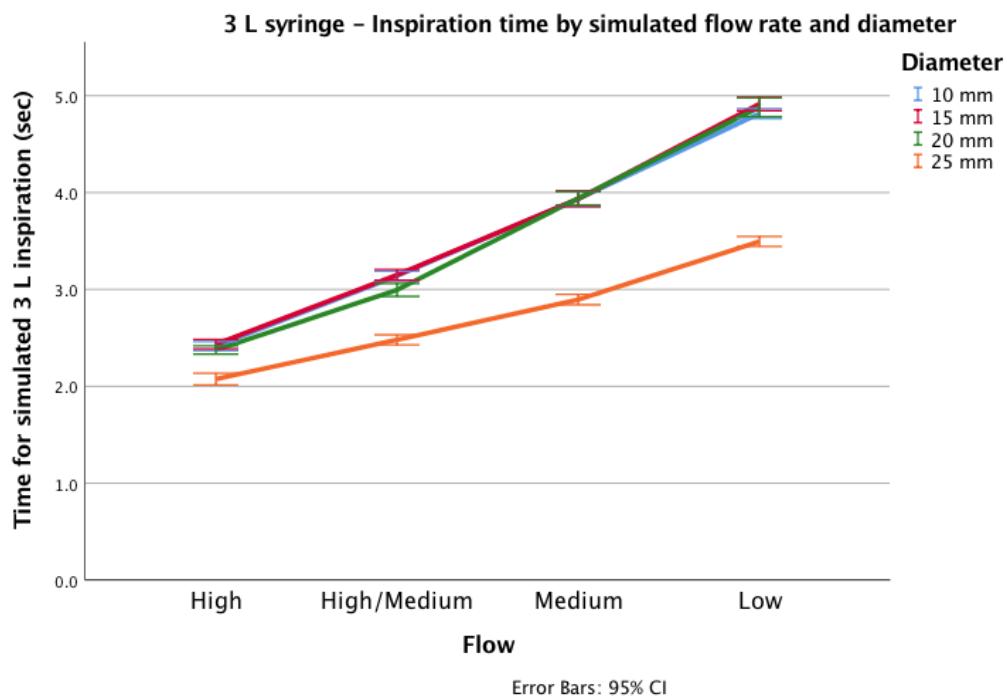
Interviews took 5 to 10 minutes each to complete, and results were transcribed from audio recordings in situ (See Appendix 10.4 for full interview transcripts).

6 Results

6.1 Mechanically simulated inspiration validation series

6.1.1 Calibration Syringe timing

Figure 15 Calibration Syringe timing calibration curve



A relationship was demonstrated between increasing simulated flow rates generated by hand actuation of the calibration syringe and reduction in the time taken to completely fill the syringe in a simulated full breath. This was noted across all flow rates and nozzle diameters. At high simulated flows, it took approximately two seconds to fill the syringe, whereas lower flow rates yielded longer syringe filling times, up to 5 seconds.

The calibration syringe had a native 25 mm flow aperture. All other nozzle diameters tested were smaller than this. At lower flow rates, the larger aperture of the 25 mm nozzle yielded consistently faster filling times than the other smaller nozzle diameters. This may reflect the 25 mm nozzle offering the least resistance to air inflow.

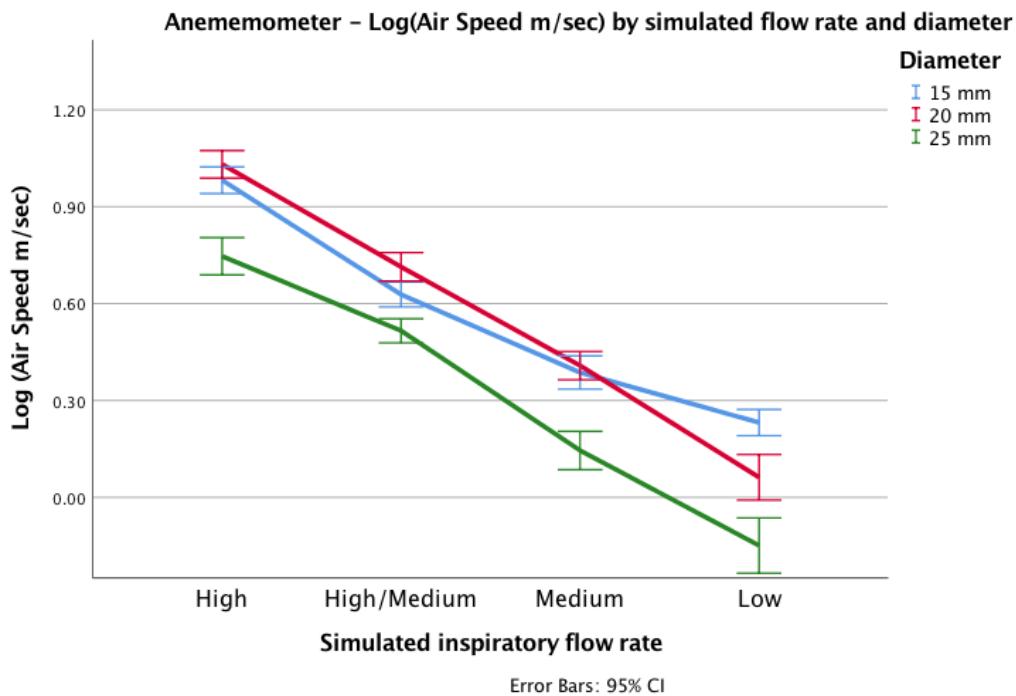
Precision in delivering simulated inspirations via the syringe using a counting mnemonic to time syringe plunger actuation was confirmed by comparable variance observed across flow rates and air flow nozzle diameters.

Multiple linear regression analysis confirmed both flow rate and nozzle diameter as contributing to the observed results of this timing analysis (Adjusted $R^2 = 0.882$). The overall model constructed for the relationship between 3 L syringe filling time, simulated flow rate and nozzle diameter was found to be significant ($F=_{2,317} 1187.73$, $p < 0.05$).

Simulated flow rate explained almost three times as much variation in inspiration time ($\beta_{\text{flow rate}} = 0.886$) as nozzle diameter ($\beta_{\text{diameter}} = -0.312$). Multicollinearity between these variables was investigated and discounted, as a low variance inflation factor was observed (VIF=1).

6.1.2 Anemometer

Figure 16 Log transformed anemometer air speed calibration curve



The meter possessed a 20 mm aperture for air flow detection. The 10 mm nozzle used for testing failed to activate the vanes on the detection device reliably at lower flows, and gave spurious results. The results of 10 mm nozzle diameter tests were excluded from this analysis as potentially unreliable.

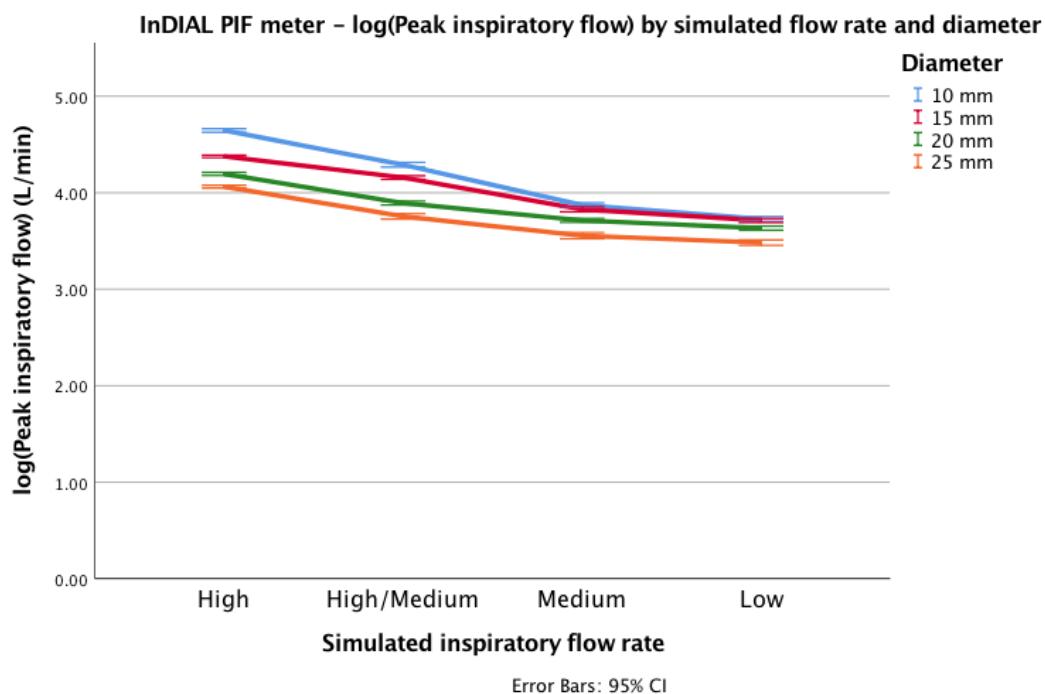
Detected airflows with decreasing simulated flow rates in the remaining dataset demonstrated exponential decay. A natural logarithmic transformation of recorded air speeds was performed to facilitate multiple linear regression analysis. A model of $\log(\text{air flow})$ consisting of flow rate and nozzle diameter was constructed (adjusted $R^2 = 0.525$) and found to be significant ($F=2,303 = 169.78$, $p < 0.05$).

Flow rate ($\beta_{\text{flow rate}} = -0.632$) and nozzle (or mouth) diameter ($\beta_{\text{diameter}} = 0.420$) both contributed to the variability observed in air speed.

Air speed ranging from approximately 2 to 3 m/sec were detected at high simulated inspiratory flows, with reduction in air speed as larger diameter nozzles were tested. Detected air speeds reduced to 1 m/sec as the flow rate was reduced and nozzle diameter increased. This air speed decay equates to taking a breath in with mouth agape as opposed to breathing in through pursed lips. The former results in lower air pressure due to the greater mouth diameter.

6.1.3 Peak inspiratory flow meter

Figure 17 Log transformed peak inspiratory flow calibration curve



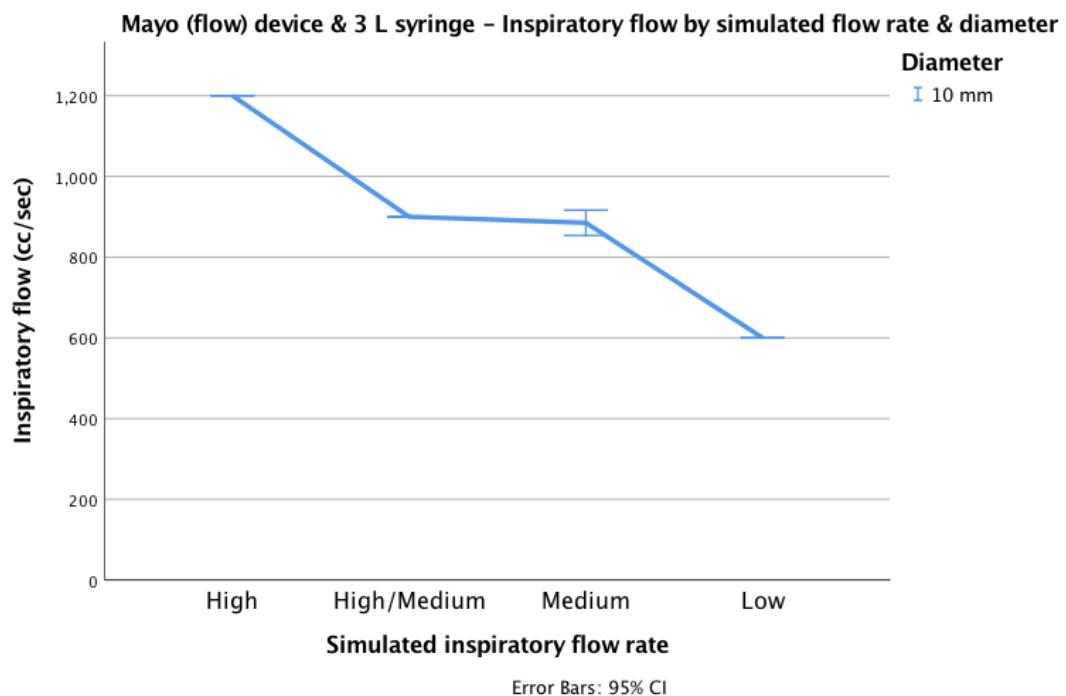
Peak inspiratory flow rate (PIF) was recorded for each flow rate and nozzle diameter combination via a commercial meter used commonly for coaching medication inhaler technique for asthma sufferers. The highest recorded PIF values (around 100 L/min) were observed when using the smallest (10 mm) nozzle diameter and the highest simulated inspiratory flow rate. PIF rates decreased with lower flow rates and nozzles of increasing diameter.

As with the anemometer, exponential decay was observed with this data. PIF values were transformed using a natural logarithmic transformation to facilitate multiple linear regression analysis. The model constructed for the relationship between $\log(\text{PIF})$, flow rate and diameter (Adjusted $R^2 = 0.913$) was significant ($F_{2,317} = 1667.07$, $p < 0.05$). Flow rate ($\beta_{\text{flow rate}} = -0.815$) contributed nearly twice as much to the observed variability in peak inspiratory flow as nozzle diameter ($\beta_{\text{diameter}} = -0.498$).

6.1.4 Physical Incentive spirometry devices

6.1.4.1 Mayo Laboratories (flow-based) incentive spirometer

Figure 18 Mayo Laboratories ISy device calibration curve

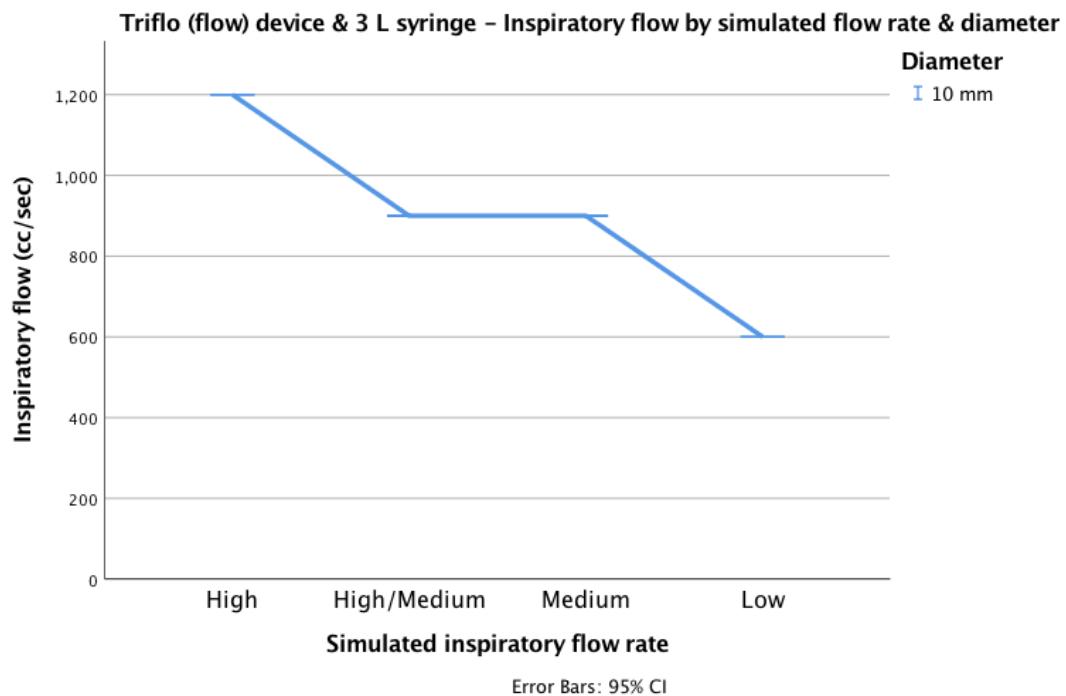


The Mayo Laboratories flow-based ISy device has a 10 mm aperture for airflow. Only the 10 mm diameter nozzle was tested with this device. High simulated air flows registered as equivalent to airflow of 1200 cc/sec using this device. High/Medium and medium airflows were recorded as 900 cc/sec, with low simulated airflows registered as equivalent to 600 cc/sec.

A univariate linear regression model constructed for the Mayo IS device using simulated flow rate for the 10 mm nozzle (Adjusted R² = 0.892) was significant (F=1,78 = 651.08, p < 0.05)

6.1.4.2 Triflo II (flow-based) incentive spirometer

Figure 19 Triflo II ISy device calibration curve

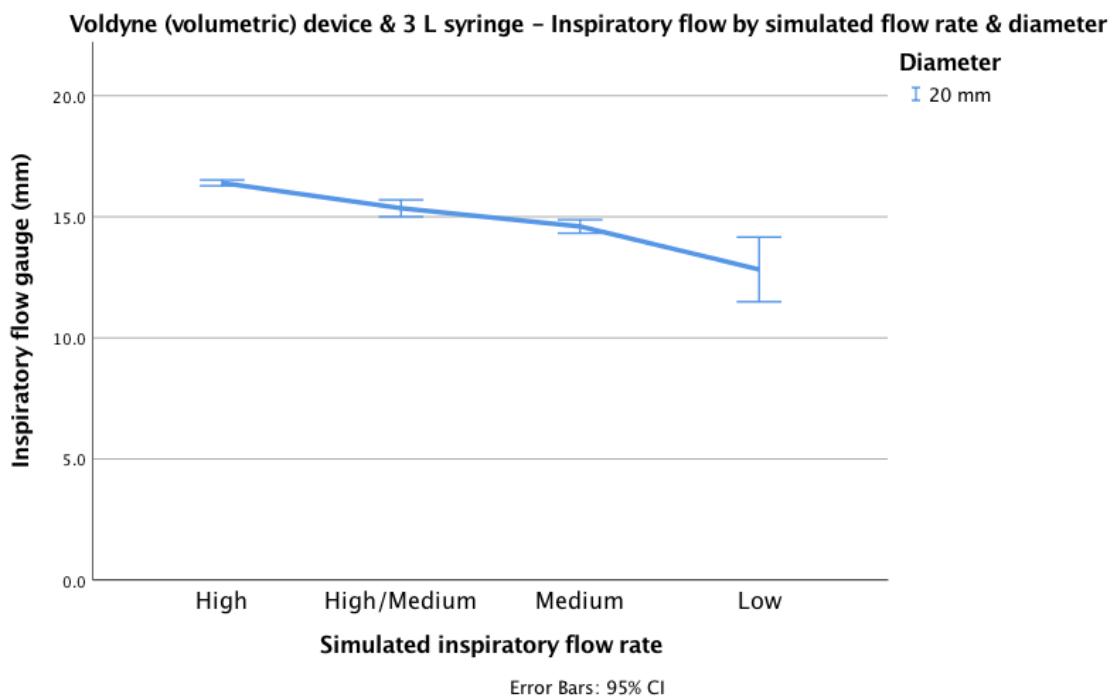


As with the Mayo ISy device, the Triflo IS flow-based ISy device possesses a fixed 10 mm aperture. Only the 10 mm nozzle was tested with this device, across the full range of simulated flows.

A univariate linear regression model constructed for flow rate (Adjusted R² = 0.899) was found to be significant ($F=1.78 = 702.00$, $p < 0.05$).

6.1.4.3 Voldyne 2500 (Volumetric-based) incentive spirometer

Figure 20 Voldyne 2500 ISy device calibration curve



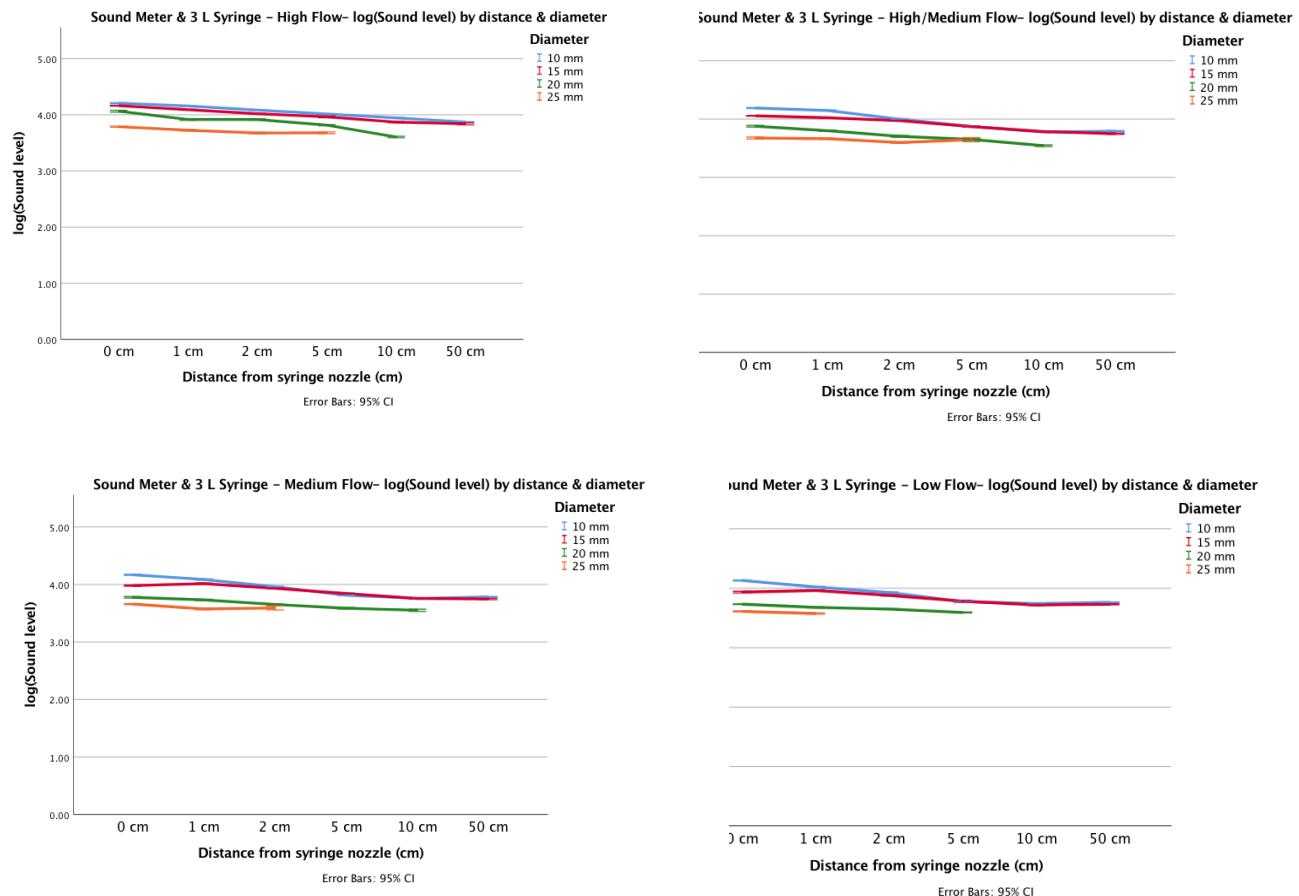
The Voldyne volumetric ISy device has a 20 mm fixed aperture. Only this nozzle diameter was tested. The device has a flow gauge which is 20 mm in height. Measurement of the degree of deflection in this gauge due to flow was conducted by review of video recordings of the testing session.

A univariate linear regression model constructed for flow rate (Adjusted R² = 0.418) was found to be significant ($F=1.78 = 57.81$, $p < 0.05$).

6.2 Sound meter validation series

The following charts present log transformed digital sound meter calibration curves obtained across a range of distances between the digital sound meter and calibration syringe.

Figure 21 Log transformations of digital sound meter calibration curves by flow



At a distance of 0 cm from the digital sound meter, high simulated air flows were recorded as attaining sound levels of approximately 65 dBA, and highest with the smallest (10 mm) nozzle diameter. Sound from air flows were detected at ranges up to 50 cm using the meter.

Sound levels dropped by a third when the largest diameter nozzle (25 mm) was used. As distance from the sound meter increased, monitored sound levels dropped. This was most marked at lower flow rates, and with larger nozzle diameters.

Reducing the flow rate and increasing the nozzle (or simulated mouth) diameter both served to reduce the noise produced with a simulated inhalation. The lower end of detection with the meter was 30 dB, and at reducing flow rates and nozzle diameters, inhalation sounds were less likely to be detected.

A model of log(sound level) was constructed (Adjusted $R^2 = 0.657$), based on flow rate, distance from the syringe nozzle and nozzle diameter respectively. The model was found to be significant ($F=_{3,1549} 992.59$, $p < 0.05$).

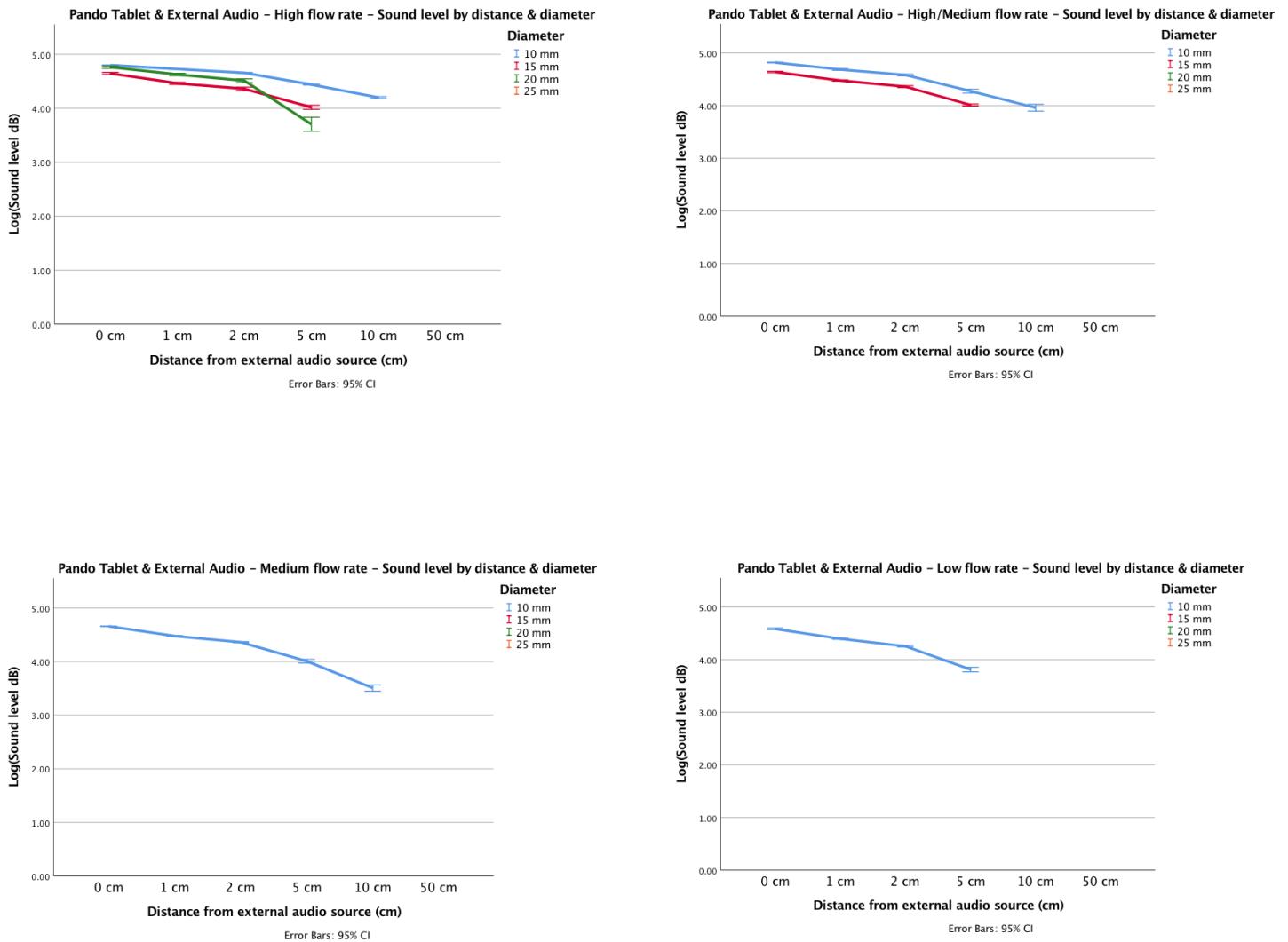
Nozzle diameter was found to explain more than twice the variance observed ($\beta_{\text{diameter}} = -0.774$) than either flow rate ($\beta_{\text{flow rate}} = -0.335$) or distance from the meter ($\beta_{\text{distance}} = -0.395$). This may be due to more audible turbulent air flow from smaller nozzle diameters at higher flow rates.

6.3 QUT Inspire - Smart phone performance validation series

6.3.1 Pendo pad (tablet computer)

The following charts present Pendo™ tablet calibration curves obtained across a range of distances between the device and external audio source.

Figure 22 Log transformations of Pendo pad calibration curves



The Pendo tablet device recorded a higher sound level compared with the digital sound meter across all samples. While the sound meter reported 65 dB for high flow and small nozzle size (10 mm), the Pendo device reported a sound level of nearly 100 dB for the same

simulated high inhalation flow and small nozzle diameter. This elevated sound level measurement compared with the sound meter was observed across all distances measured.

This device was unable to detect lower flow input at distances greater than 10 cm from the sound source, compared with detection at up to 50 cm by the sound meter. Further, the Pendo device was unable to detect flows from the largest nozzle diameter (25 mm) at any distance. Only the smallest nozzle diameters were detected at lower flow rates.

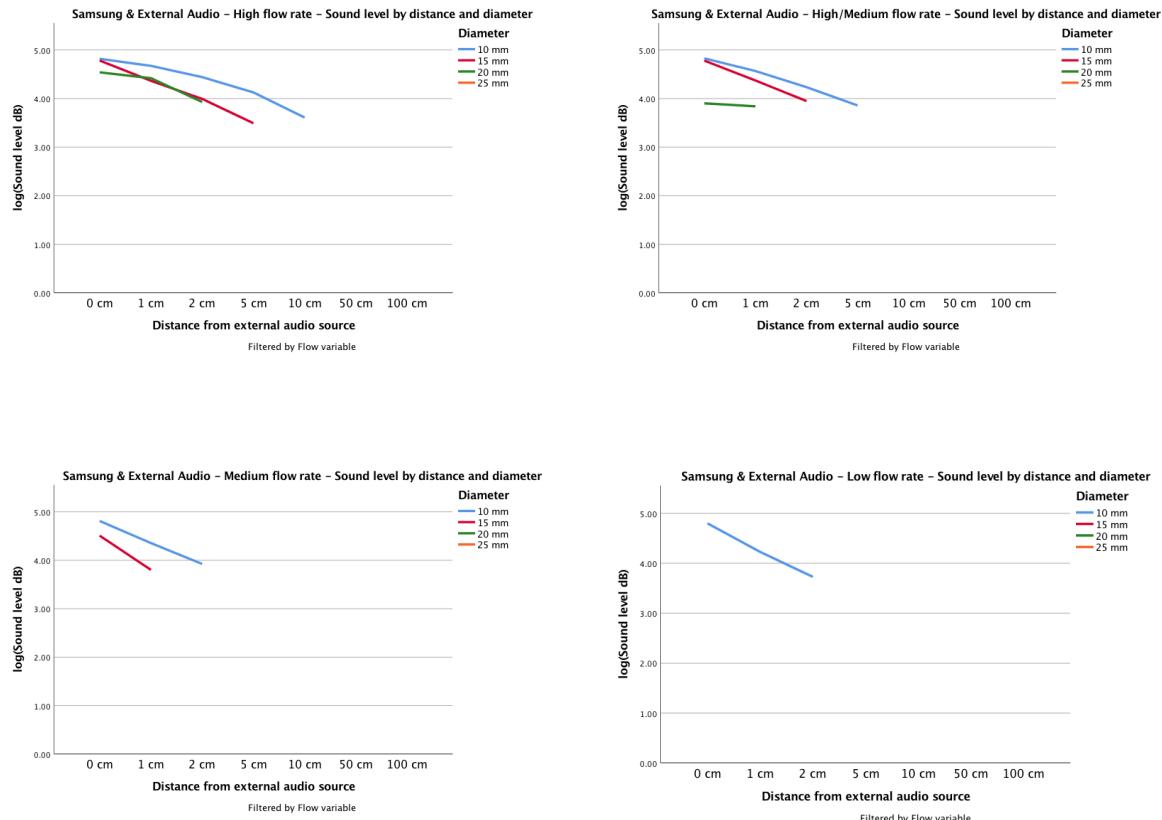
A multiple linear regression model of log(sound level) was constructed for the Pendo device using distance, flow rate and nozzle diameter (Adjusted R² =0.802). The model was found to be significant ($F_{3,584} = 795.29$, p < 0.05).

Distance ($\beta_{\text{distance}} = -0.868$) was found to have twice the influence on observed variability compared with either simulated inspiratory flow rate ($\beta_{\text{flow rate}} = -0.485$) or nozzle diameter ($\beta_{\text{diameter}} = -0.366$) when considering the Pendo device.

6.3.2 Samsung J1 (smart phone)

The following charts present log transformed Samsung™ J1 calibration curves obtained across a range of distances between the device and external audio source.

Figure 23 Log transformations of Samsung calibration curves



The Samsung device detected higher sound levels than the sound meter, akin to the Pendo device. The largest nozzle (25 mm) was also not detected at any distance. The Samsung was able to detect sound from smaller nozzle sizes than the Pendo, particularly at short distances from the audio source.

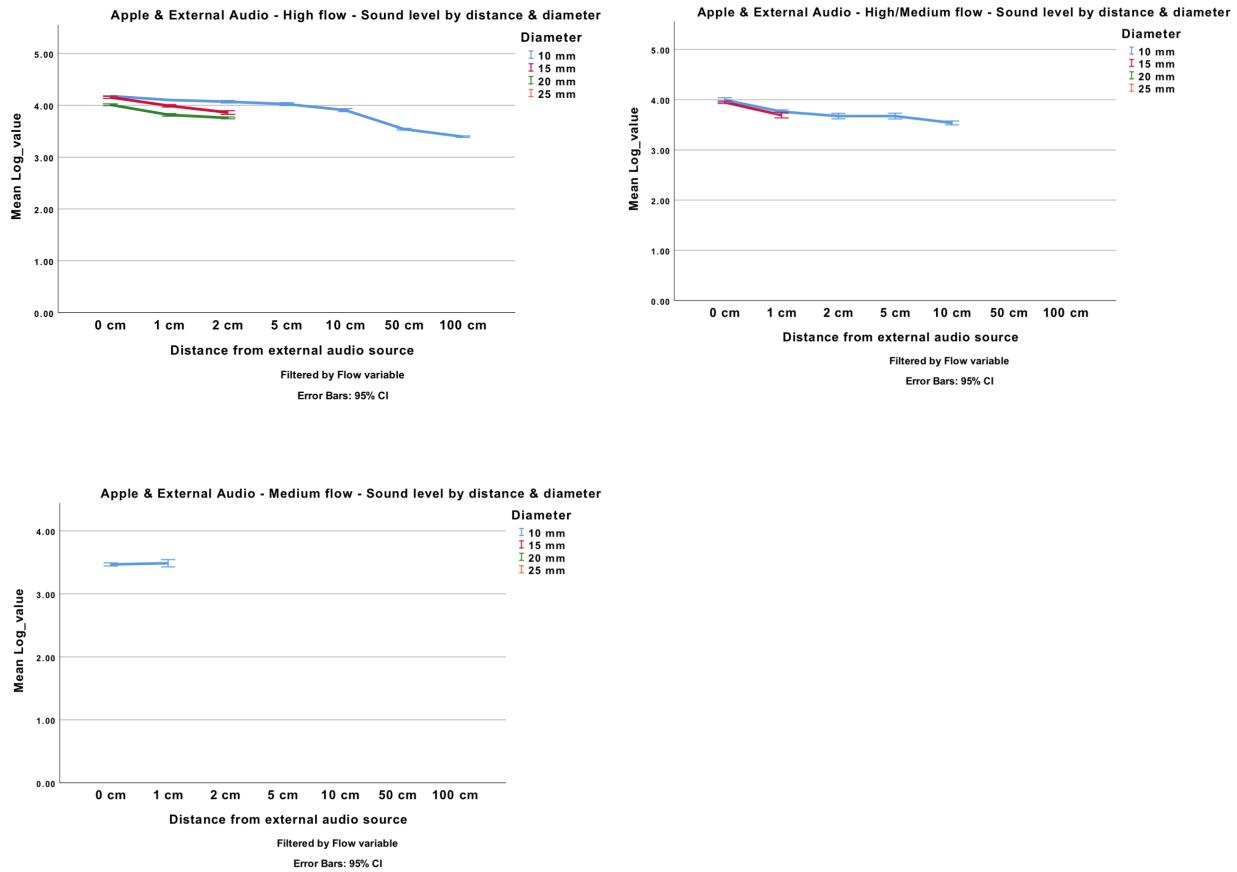
A log transformation of sound level was used for multiple linear regression modelling of sound level, considering distance, flow rate and nozzle diameter (Adjusted R² = 0.673). The resultant model was found to be significant ($F=3,581 = 401.45$, $p < 0.05$).

As with the Pendo device, distance ($\beta_{\text{distance}} = -0.900$) contributed twice as much to the observed variability in the model constructed for the Samsung than either flow rate ($\beta_{\text{flow rate}} = -0.453$) or diameter ($\beta_{\text{flow rate}} = -0.546$).

6.3.3 Apple iPhone 6 Plus (smart phone)

The following charts present log transformed Apple™ iPhone 6 Plus calibration curves obtained across a range of distances between the device and external audio source.

Figure 24 Log Apple iPhone 6 Plus calibration curves - up to 100 cm distance



The Apple device reported lower sound levels than the other devices across all flows and distances, better reflecting sound levels measured with the digital sound meter. Low flow rates were not detected by the Apple device.

As distinct from the Pendo and Samsung devices, the Apple phone was able to detect audio at up to 100 cm, albeit with higher flow rates and the small nozzle diameter (10 mm) only.

A log transformation of sound level was used to construct a multiple linear regression model, considering distance, flow rate and nozzle diameter (Adjusted R² =0.696). The resultant model was found to be significant ($F_{3,403} = 310.838$, $p < 0.05$)

Flow rate ($\beta_{\text{flow rate}} = -0.797$) and distance ($\beta_{\text{distance}} = -0.640$) were found to be comparable in explaining observed variation in the Apple iPhone 6 Plus regression model, with each explaining three times the observed variation than nozzle diameter ($\beta_{\text{diameter}} = -0.245$).

6.3.4 Summary of QUT Inspire smart phone results for looped audio source

Table 4 summarises comparative results of audio sample loop testing on the three smart phones running the QUT Inspire app considered in this study.

Where not all 20 sampled sounds were successfully detected by the app and displayed as a deflection of the graphic image on screen, the proportion of successful detections at a given distance/flow rate/nozzle diameter combination are depicted.

Solid colours indicate at all 20 sample sounds of simulated air flow were detected successfully at each distance.

The Android devices better detected simulated inspiration audio loops at lower flow rates and larger nozzle diameters than the Apple device. This may be due to the higher sound level detected by the Android phones, compared with the reference digital sound meter.

The Apple phone failed to detect sampled audio below medium flow (corresponding to 600 cc/sec on physical ISy reference devices) at anything larger than 15 mm nozzle diameters. The reported filtering of low frequency sound by Apple devices may have contributed to this observed difference compared with the Android phones. The Apple device was only able to detect high flows (approx 1200 cc/sec) at larger distances (up to 1 metre) with the smallest nozzle (simulated mouth) diameter, albeit with reduced reliability.

Reliability of detection decreased at the fringes of detection ranges of all phones tested. Optimal detection ranges for all phones studied was in the range up to 2 cm, with high medium and high flow rates and smaller nozzle diameters.

Table 4 Comparative smart phone performance by distance & nozzle (mouth) diameter

Distance - 10 mm nozzle (mouth) diameter

	0 cm	1 cm	2 cm	5 cm	10 cm	50 cm	100 cm	150 cm
High flow								
iPhone 6 Plus					12/20	12/20	-	-
Samsung J1				19/20	-	-	-	-
Pando Tablet				15/20	-	-	-	-
High/medium flow								
iPhone 6 Plus				18/20	-	-	-	-
Samsung J1			19/20	-	-	-	-	-
Pando Tablet			15/20	-	-	-	-	-
Medium flow								
iPhone 6 Plus	19/20	-	-	-	-	-	-	-
Samsung J1			19/20	-	-	-	-	-
Pando Tablet			19/20	13/20	-	-	-	-
Low flow								
iPhone 6 Plus	-	-	-	-	-	-	-	-
Samsung J1			19/20	-	-	-	-	-
Pando Tablet			19/20	-	-	-	-	-

15 mm nozzle (mouth) diameter

	0 cm	1 cm	2 cm	5 cm	10 cm	50 cm	100 cm	150 cm
High flow								
iPhone 6 Plus		15/20	-	-	-	-	-	-
Samsung J1			15/20	-	-	-	-	-
Pando Tablet			18/20	-	-	-	-	-
High/medium flow								
iPhone 6 Plus	13/20	-	-	-	-	-	-	-
Samsung J1		19/20	-	-	-	-	-	-
Pando Tablet			15/20	-	-	-	-	-
Medium flow								
iPhone 6 Plus	-	-	-	-	-	-	-	-
Samsung J1	19/20	18/20	-	-	-	-	-	-
Pando Tablet	-	-	-	-	-	-	-	-
Low flow								
iPhone 6 Plus	-	-	-	-	-	-	-	-
Samsung J1		-	-	-	-	-	-	-
Pando Tablet	-	-	-	-	-	-	-	-

20 mm nozzle (mouth) diameter

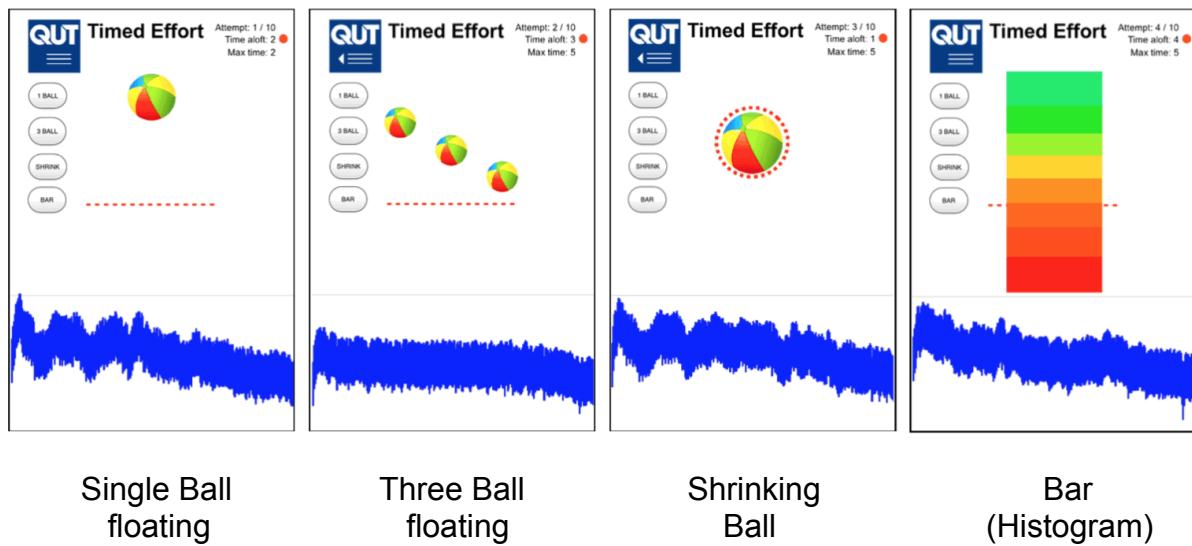
	0 cm	1 cm	2 cm	5 cm	10 cm	50 cm	100 cm	150 cm
High flow								
iPhone 6 Plus			19/20	-	-	-	-	-
Samsung J1			19/20	-	-	-	-	-
Pando Tablet			19/20	-	-	-	-	-
High/medium flow								
iPhone 6 Plus	-	-	-	-	-	-	-	-
Samsung J1		16/20	-	-	-	-	-	-
Pando Tablet	-	-	-	-	-	-	-	-
Medium flow								
iPhone 6 Plus	-	-	-	-	-	-	-	-
Samsung J1		-	-	-	-	-	-	-
Pando Tablet	-	-	-	-	-	-	-	-
Low flow								
iPhone 6 Plus	-	-	-	-	-	-	-	-
Samsung J1		-	-	-	-	-	-	-
Pando Tablet	-	-	-	-	-	-	-	-

Solid color = 20/20 successful detections; partial success indicated by proportions

6.4 User Impressions

The following section presents findings from interviews conducted with disease-free subjects ($n=19$) regarding optimal display types to provide incentive for providing maximal inspiration effort. QUT Inspire offers 4 display types for selection.

Figure 25 QUT Inspire display types



6.4.1 Best display types for providing incentive for inhalation

Nearly half of the study respondents (45 %) indicated preference for the bar display. Subjects commented that the bar display “*was clearer*” and “*more responsive*” than the other display types. Some commented further on the responsiveness of the bar display, noting that they “*saw a difference when taking a breath*”, and that “*you can see a spectrum*” when using the bar display.

Preference for the three ball display type was reported by 40 % of respondents. Responsiveness was also highlighted as a key display attribute for those preferring this three ball display. Subjects commented that “*it feels more responsive*”, “*you can see how the balls arise, like a wave*”, and that “*you get a gradual lift up*” with the three ball display.

Figure 26 Best and worst display types (n= 19 respondents)

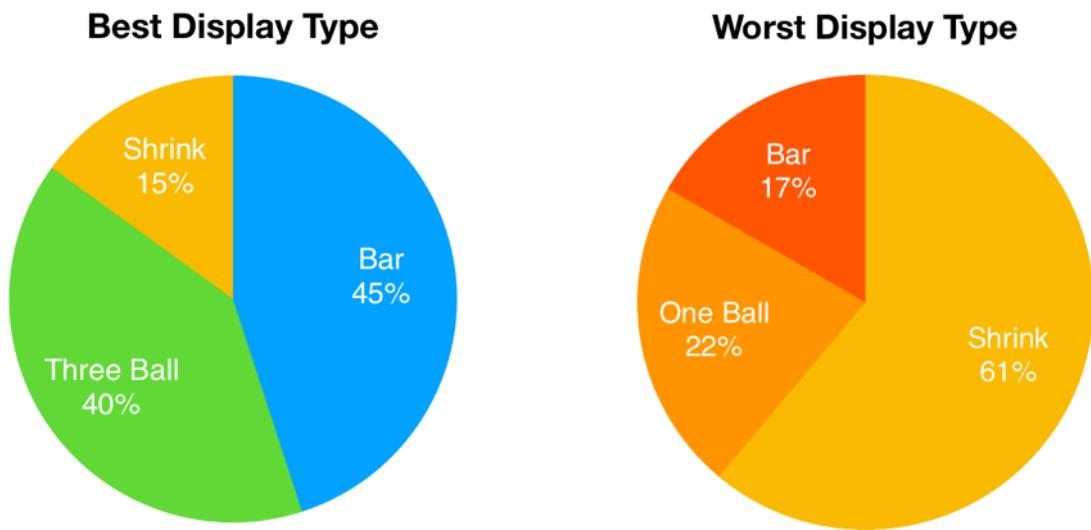


Table 5 Summary of study participant responses

Subject	Best Display	Why Best Display ?	Worst Display	Why Worst Display ?	Other ways to display ?
1	Bar	Because you can see spectrum	Shrink		
2	Bar/Shrink	Easiest to understand	One Ball	just bounces up and down really doesn't do anything	Monochrome display for color impaired. Make a game of it
3	Bar	I like the bar	Shrink	Can't be sure where it finishes	Simpler is better
4	Bar	I prefer the bar	Shrink		Color gradient display
5	Three Ball	It's classic, old-fashioned	Bar	Bounces all over the place	A meter displaying tidal volume
6	Bar	You can see the extremes	Shrink		Musical instrument-style display
7	Three Ball	It feels more responsive	Shrink		A radial gauge display
8	Three Ball				
9	Three Ball	Made me feel like I was actually doing	Shrink	Didnt feel like it was doing anything	
10	Bar	I think it's clearer	Shrink	It was hard to notice that one	Chart that goes up and down
11	Shrink	It gives a better measure of the sight	One Ball		Chart style, animation of lung shrinking
12	Three Ball	More feedback	Shrink		
13	Three Ball	You can see how the balls arise, like a wave	Bar	Its too sensitive. Jumps up straight away	Water (wave) display lifts with inhale
14	Bar	I saw the difference when I took a breath	One Ball	I couldn't see any changes too much	
15	Shrink	A bit more gradual progression	One Ball	It didn't have enough	Multiple ball 3 + and variable display
16	Bar	It's just immediate, immediate response	Shrink	Not a lot of visual stimulus or reaction. Can't see your effort	
17 *	Three Ball	You get a graduated lift up	Shrink	It's just too small	Stagger lift of balls in animated display
18 *	Three Ball		Bar	It's just a bar, less engaging or entertaining	Acceleration of the lift of balls in 3 ball display would be good
19	Bar	Most people know about bars and charts	Shrink	Can't tell how much it's going to shrink all the way	

Empty cells above indicate no response

* 17 and 18 were consecutive interviews with 2 friends. There may have been some groupthink in 18's responses re 'other ways' following from responses from

Table 6 Summary of user Impressions by display type

	Best (n)			Worst (n)
Bar*	9		Shrink	11
Three Ball	8		One ball	4
Shrink*	3		Bar	3
One Ball	0		Three Ball	0

One subject reported Bar & Shrink as best

	Best (%)			Worst (%)
Bar	45%		Shrink	61%
Three Ball	40%		One ball	22%
Shrink	15%		Bar	17%
One Ball	0%		Three Ball	0%

Only three subjects (15 %) preferred the shrinking ball style display. This subgroup of respondents noted that “*it is the easiest to understand*”, “*gives a better measurement*” and “*shows a more gradual progression*”. One subject reported equal preference for the bar and shrink display types as best.

None of the respondents nominated the one ball display as the best display type to provide incentive for slow gradual maximal inhalation.

6.4.2 Worst display types for providing incentive

Nearly two thirds of respondents (61 %) indicated that the shrinking ball display was least preferred, compared with the other display types. Subjects reported that “*you can’t be sure where it finishes*” and that “*it didn’t feel like it was doing anything*”. Other subjects also reported that the one ball (22 %) and bar displays (17 %) were the worst displays respectively. Regarding the bar display, one subject stated that the bar is “*too sensitive and*

jumps up straight away". Another commented that the one ball display "really doesn't do anything".

None of the respondents rated the three ball display as the worst display type to provide incentive for gradual maximal inhalation.

6.4.3 Preferences within respondent subgroups

Of the nine subjects who nominated the bar as the best display type, seven of these respondents indicated that the shrinking ball display was the worst of all the alternatives. Comments reflected that the shrinking ball display was "*hard to notice*" and had "*not a lot of visual stimulus or reaction*".

That the majority of subjects with a preference for the bar display also expressed dislike for the shrink display is in contrast to preferences expressed by the eight subjects who nominated the three ball display as best. Four of those latter subjects who favoured the three ball display considered the shrinking ball display as worst, reporting that "*its just too small*" and "*you can't see your effort*". A further three subjects in this subgroup (favouring the three ball display as best) nominated the bar display as worst, stating that "*its just a bar*", "*it bounces all over the place*" and that "*its too sensitive*".

7 Discussion

Through the ages, we have sought to leverage a gamut of devices to improve treatment of often debilitating respiratory conditions, whether it be by breathing through a smoky tar-filled pipe, levitating spheres in a plastic casing or vigorously inhaling adjacent to a mobile phone. Acknowledgement of the role of breathing exercises in respiratory therapy is underpinned by an evolving understanding and evidence base as to the efficacy and safety of emergent treatment modalities (Pryor, 1999; Randtke et. al., 2015; Rodriguez-Larrad et. al., 2014).

This study concerns a novel virtualised incentive spirometry application for smart phones. The internet and popular app stores are awash with “health apps”, offering diagnostic, therapeutic and information-based interventions, often without the rigour of systematic evaluation or controlled trials of efficacy (Allaert et. al., 2017; Davis, 2014; Himes & Weitzman, 2016). The present study sought to evaluate the performance of the new app compared with reference measures, and to glean user impressions as to optimal display graphics and animation to provide incentive for gradual maximal inspiration.

7.1 Validation methodology

Considerable effort in this study was directed at establishing the validity of reference measures, prior to evaluating performance of the new app. Use of human subjects in quantitative evaluation of the app was unfeasible, due to reproducibility of breaths and the safety of subjects delivering many iterations of inhalations for testing. Mechanical calibration syringe simulation of inhalations was instead employed towards this end.

An initial timing study demonstrated precision and reproducibility in generating simulated inhalations using a counting mnemonic to time manual actuation of the calibration syringe. Four simulated flow rates were established for testing, intended to represent flow rates varying from low flow that may be encountered in diseased individuals, to high flows that might be observed at the upper end of normal human inspiratory flow rates.

The observed relationship between syringe filling time, flow rate and nozzle diameter was complex. Larger diameter nozzles offered less back pressure and resulted in faster filling times. Notwithstanding this, higher simulated inspiratory flows were correlated with faster filling times. Variance was comparable across flow rates, indicating precision in using the syringe to simulate reproducible inspirations using the timed counting technique.

The anemometer and peak inspiratory flow meter quantitated the inspiratory air flows generated with the calibration syringe, confirming previous implementations of this technique (Titus et. al., 2016). Higher air speeds and peak inspiratory flows were observed with higher flow rates and smaller nozzle (mouth) diameters. The peak inspiratory flow meter recorded results across the simulated air flows tested which were comparable with in vivo values as indicated on the meter's calibrated scale, confirming that the simulated air flows reflected valid physiological flow ranges (Janssens et. al. 2008).

Physical incentive spirometer devices are calibrated to display graduated marks indicating flow rates, and highlighting those flow rates regarded as optimal for ISy effectiveness. The four simulated inspiratory flow rates registered in the 600 - 1200 cc/sec range indicated by the flow-based Mayo™ and Triflo II™ physical ISy devices. Calibrated physical Isy flow rates of 1200, 900 and 600 cc/sec were achieved with the simulated flow rates generated (1200 = high; 900 = high/medium and medium; 600 for low simulated flow rates). This confirmed that the simulated air flows represented physiologically valid therapeutic inspiratory flow rate ranges.

The flow gauge on the Voldyne™ volumetric ISy device is intended to alert the user when flow is insufficient. All tested flow rates except for low flow were observed as adequate for the volumetric device. This latter type of ISy device quantitates volume from an inspiration, whereas the former flow-devices monitor inspiratory air flow rates.

Sound metering of the mechanically simulated air flows demonstrated that higher flows through smaller nozzle diameters generated louder sounds. This equates to inspiration

through pursed (small diameter) lips resulting in higher sound levels than if the mouth was open wider. Sound levels decayed as the air flow nozzle was moved further away from the digital sound meter.

Extrapolating from the digital sound meter calibration curve, noise from high flow at short distance with a small nozzle (corresponding to 1200 cc/sec as measured by the physical ISy devices) was detected at a sound level of approximately 65 dB. This sound level decayed as distance from the meter and nozzle diameters increased, and as flow rates were reduced.

7.2 Smart phone app performance

The two Android devices (Samsung™ and Pendo™) performed comparably; both devices reported a higher sound level than the digital sound meter for a given flow rate and nozzle diameter across the range of distances tested. Detection was observed at ranges up to 10 cm between the Android phones and the external sound source. Highest sound levels were detected at minimal distance, using the highest flow rate and smallest nozzle diameter.

A pronounced audible ‘hissing’ noise was noted at higher flow rates, with nozzles of a smaller diameter. This may have reflected higher air pressure, more turbulent air flow and thus louder sound. As distance increased, only the highest flow/smallest nozzle diameter was detected. Slower flows from the largest diameter nozzle (25 mm) were not detected at all.

The Apple™ device reported sound levels comparable to the reference digital sound meter, and lower than the Android devices. As with the Android devices, detection was optimised with higher flow rates and smaller nozzle diameters. In contrast to the Android phones, the Apple™ device was able to detect the high flow/small nozzle diameter combination at distances up to 100 cm from the external sound source, akin to holding the phone at arms length from the mouth.

The optimal distance for sound detection of simulated inspiratory flows (except for low flow) was 2 cm or less for all the smart phones tested. Higher flows were better detected by all devices, with results optimised by small nozzle diameters, akin to pursed lips while inhaling adjacent to the devices. As distance increased, the reliability of detection of sound by all the phones diminished (Table 4), with failure to detect a proportion of test inhalation audio loops observed at the fringes of detection.

Concerning the multiple linear regression models of detected sound level constructed for the three phones studied, distance was found to have the greatest influence on detection with both of the Android phones, with flow rate and nozzle diameter contributing to a lesser extent. In contrast, both flow rate and distance contributed greatly to sound detection with the Apple™ phone, with nozzle diameter contributing to a lesser extent.

Modern smart phone microphones are engineered with voice control in mind, and this may impact on sound processing algorithms. Apple™ phones are reported to use selective filtering of low frequency sound to optimise voice detection (Brown & Evans, 2011; Danaher et. al., 2015); this may have contributed to the additional observed influence of flow rate as well as distance on the Apple™ device, compared with the Android phones.

Detection of a higher than actual sound level (as with the Android phones) implies a potential risk that a sub-optimal inhalation might spuriously trigger an animation. This may provide false incentive for a user and discourage more vigorous and therapeutic inhalation. Several studies report on improvement in sound detection by use of an external microphone or headset. Availability of such add on devices may vary, as may their performance characteristics in breath sound detection (Kardous & Shaw, 2016).

Sound detection on smart phones depends on phone hardware and firmware, operating system processing and code execution via app software. Each of these processing “tiers” may subject detected sound to post-processing and result in different results on divergent platforms such as Android™ and IOS™ (Silva et. al., 2015).

Differences in performance of apps with a common code base such as QUT Inspire on different smart phones is an important observation, with implications for other cross platform “health apps”. The Apple device is reported to have 3 microphones (telephony, front and rear camera microphones), whereas the Android devices may have fewer microphones (Daponte et. al., 2013).

Divergent app performance on different phone types may result in variations in the efficacy of the app by mis-reading sounds and misleading users as to successful efforts, warranting consideration in cross platform app development and testing (Agu et. al, 2013; Gordon et. al., 2017). Deployment of platform specific versions of apps may reduce this potential error source, as would specific coding to handle microphone or sound dynamics on respective phone platforms (Baig et. al., 2015).

In the case of the QUT Inspire app, actual sound levels attained were recorded to benchmark performance in the study. The audio sampling component used by the app software is set using a hard-coded sound threshold (modulated by a sliding sensitivity control to raise or lower the threshold). When this threshold is reached, the display animation is triggered. If the detected sound remains above the threshold, the animation is sustained. The threshold for triggering display animation may be set by default to be sufficient for effort to be required across different smart phone platforms, while not low enough to be subject to spurious triggering from background noise or inadequate inspiratory effort.

Limitations implicit in simulating inspiration in this study included the effect of artificial nozzles to mimic mouth diameter and the duration of simulated inspirations generated by the calibration syringe. In the case of the former, the circular apertures of the nozzles may not truly reflect oblong mouth shapes. Observation and coaching of the interview participants demonstrated that smaller mouth diameters resulted in higher flow and better detection by the app. The latter inspiration time was limited by the 3 litre capacity of the syringe. Animation activity was sustained for the duration of audio sample playback, suggesting that the app remained responsive while there was sound to monitor.

Further, there may have been alteration in the characteristics of the audio sampled inspirations by virtue of the microphone of the digital recorder device used to capture audio samples. Comparable performance between digital sound meter response to mechanical flows, and that observed on phones in response to audio samples of same suggest that the audio samples were representative of the source flows generated by the calibration syringe.

The validation methodology described here provides objective measures as to the performance of a breath-detection app such as QUT Inspire. Observed differences in performance on different types and brands of phone suggest caution should be exercised in developing and implementing such an mHealth app. Notwithstanding this, the QUT app performance was comparable with that of physical flow-based incentive spirometers.

The low cost and wide accessibility of smart phone apps offers opportunities for self-care, self-monitoring and therapy under the guidance of medical professionals, particularly in developing countries and remote areas with limited medical resources (Anderson & Emmerton, 2016; Dicianno et. al., 2015).

Compliance with therapy has been highlighted as an issue with reviews on the efficacy of incentive spirometry; storing results from virtual ISy therapy sessions may provide feedback on compliance with instructions for use, in addition to tracking improvements in performance with therapy (Do Nascimento et. al., 2015; Free et. al., 2013). The QUT Inspire app currently stores maximum time aloft for inhalation attempts and offers a timed effort mode to track performance, but the app could be enhanced further to record full details of inhalation attempts for review, therapy management, coaching inhalation technique or compliance monitoring purposes.

7.3 User impressions regarding optimal display type

Participants in the qualitative component of the study were given brief instructions on operating the app. Once initial guidance was given, all participants were able to use the app to display and change graphics styles with minimal further instruction; this reflects ease of use implicit in the design of the app and minimal “burden” from app controls and menu navigation (Hilliard et. al., 2014; Erhel & Jamet, 2013). Moving the phone closer to the mouth (within 1-2 cm) was intuitive to most of the participants, but the importance of small mouth diameter for successful sound detection required coaching.

Background noise at the Orientation week events where the interviews were conducted was considerable, and not unlike the ambient noise encountered in hospital wards. Participants self-adjusted microphone sensitivity to eliminate the effect of background noise on sound monitoring, using a sliding volume control offered by the app. Battery consumption during testing was moderate, with a participant testing session consuming approximately 10 % of the phone battery capacity.

The cohort of disease-free persons considered in this survey expressed preference for two of the four display animations offered for consideration. The least preferred styles were simple, single figure animations of a floating ball and shrinking balloon respectively. Users expressed a preference for two display styles that offered more colourful, pronounced and responsive animations in the form of a histogram (bar) or three ball animated display.

The nature of incentive spirometry is graphic display of inspiratory effort, and has been termed a “motivational affordance” (Deterding et. al., 2011). Users in the study commented that the least preferred display styles ‘did nothing’, or were unresponsive in relative terms. Ease of use may be enhanced by animations that present larger and more drastic changes in animation size or location, and reflected in the comments of those who saw little change in the less popular animations with less animated displays.

QUT Inspire has additional extrinsic motivations for compliance which were not evaluated in this study. As discussed, maximum time aloft is recorded to motivate users to persist with the technique. A flashing LED graphic indicates that flow was detected and attempt time is being recorded. An attempt counter is available on the “Timed Effort” display of the app to count the number of attempts performed in a session, as a further compliance initiative. These additions were not assessed in the current study as the focus at hand was on identifying optimal graphic animations to incentivise effort.

The participants in this study were self-selected, as they presented to a stand displaying details of the app and volunteered to take part. There may have been selection bias in the participant sample, whereby those less comfortable or familiar with technology may have been discouraged from engaging with the researcher. Orientation week attendees were mostly younger adults who may have been more technologically literate than the general population, and more familiar with apps and game play (Cota et. al., 2015, Cunha et. al, 2016; Peng et. al., 2016).

7.4 Conclusion

Based on the observations in this study, the performance of the QUT Inspire smart phone virtual spirometry mHealth app was comparable to that of commercially available flow-based incentive spirometers.

Differences in sound detection were observed in Android™ compared with Apple™ phones, but the app was able to detect breath sounds and trigger animations representing inspiratory effort. Mouth shape was a contributing factor to generating inspiratory flows sufficiently audible for detection. Minimal distance between the built-in phone microphone and the mouth also contributed to the detection on inhalation sounds.

The cohort of disease-free subjects examined in this study preferred animated, colourful displays that displayed pronounced changes and screen translations when inhalation was attempted. Animations with smaller degrees of movement or sparser layouts were poorly regarded.

Further investigation as to the potential of a respiratory therapy mHealth app such as QUT Inspire are warranted, given the widespread use of incentive spirometry in clinical practice, and the low cost and wide availability of apps and smart phones.

8 Recommendations for further action

This study has demonstrated the feasibility and potential for a simple low-cost virtualised incentive spirometry application for smart phones. The present study considered mechanically generated flows to validate performance of the app.

The app is currently bundled as a HTML web app for deployment and operation across phone platforms using web browsers. Observed differences in sound detection in different phone types warrants porting of the common app code to native Android™ and IOS™ apps, using Cordova™, a cross platform app packaging suite which is compatible with the Construct 3™ development environment used to code the app. Performance could be optimised for each phone type.

A logical next step in development of this app may be limited clinical human trials, comparing app performance with that of physical ISy devices in disease-free subjects. Such a prospective study would provide valuable comparative data on the accuracy of the app in real-world settings, including performance in subjects with a range of ages, lung capacities, and experience with app use. Further, such a preliminary study may investigate the effects of environmental factors such as ambient background noise on app performance and technology related factors such as battery consumption from using the app.

Limited human trials in normal subjects should be a mandatory precursor to controlled trials of use of the app with diseased subjects, or those about to undergo surgery. A potential subgroup worthy of such a trial would be those patients undergoing surgery who receive Fentanyl as an opiate anaesthetic. Recent reports have noted incidence of a Fentanyl-induced cough in some surgical patients, and that pre-operative incentive spirometry showed promise as prophylaxis prior to surgery (Editor - Obesity, Fitness & Wellness Week, 2017).

Mouth shape as represented by nozzle diameter in this study was an important determinant of generating inspiratory flows sufficient for monitoring with the app. Recent developments in

facial recognition technology (e.g Apple™ Face ID) promise future applications that are aware of facial expressions, such as mouth shape (Blom et. al., 2014). Incorporation of facial recognition technology into applications such as QUT Inspire may allow feedback for users to change their mouth shape to optimise detection of inhalation. Future iterations of this facial recognition technology may also make skin oximetry a possibility with smart phones, allowing an app to determine if a user was hypoxic and warning them or automatically discontinuing operation of the app for safety reasons.

Engagement with the app may be monitored with eye movement and gaze monitoring, already available in rudimentary form on some smart phone and tablet platforms (Rego et. al, 2014). Subjects in this study reported preferences for colourful and highly animated displays such as the bar and three ball displays. Eye gaze monitoring offers insight into what users are focusing on, allowing the design to be refined to provide optimal engagement, motivation and feedback for maximal inhalation.

The fields of pervasive computing and context awareness of applications are also of contemporary interest. As with mouth diameter, distance of the phone microphone from the mouth is another key determinant in monitoring inhalations with the QUT Inspire app. The further away the phone is from the mouth, the lower the sound level may be. Context awareness is an emergent field in information technology (Shen & Srivastava, 2017). It holds promise in determining posture and pose, potentially determining if the hand and phone are too far away from the mouth for successful monitoring, if a patient is lying supine or if the person is stooped over. The user could be alerted via the app to correct their posture.

Gait analysis has been implemented in recent app developments. Developers of one such app assert that by carrying around a smart phone app, their algorithms can estimate a person's total lung capacity based on attributes related to their gait (Cheng et. al., 2017). Refinement of such models holds promise for incorporation into apps such as QUT Inspire. Persons with greater or lesser lung capacity may have the threshold for triggering animation of a breath altered to suit the individual.

Opportunities for enhancement to the QUT Inspire app are many and varied, reflecting the current information technology revolution, convergence of developing technologies and resultant synergies. The large number of smart phone sensors found in today's devices (and emergent ones) have barely been exploited to their fullest potential.

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10 Appendices

QUT Inspire User Guide

A virtual Incentive spirometer app for smart phones and tablet computers

January 2018

What is QUT Inspire ?

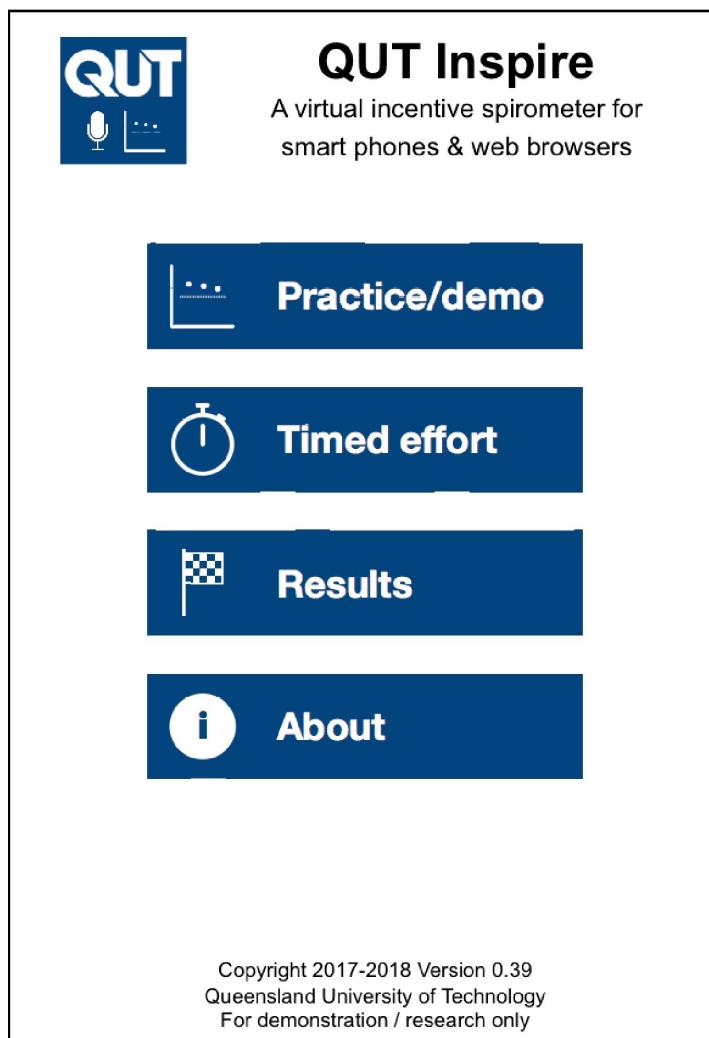
QUT Inspire is virtual incentive spirometer for use with Apple IOS and Android smart phones. Incentive spirometers are used to encourage slow gradual maximal inhalation, clearing mucus from the airways. The sound of inhalation is detected by the built-in microphone in the smart phone, and displayed using graphic animations on screen as an incentive to inhale deeply.

Starting QUT Inspire

Using your smart phone web browser (e.g Safari, Chrome, Firefox), navigate to:

<https://inspire.bitballoon.com>

Main menu and menu navigation

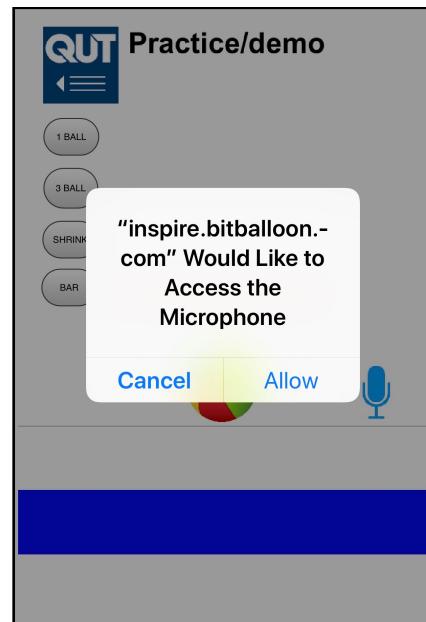
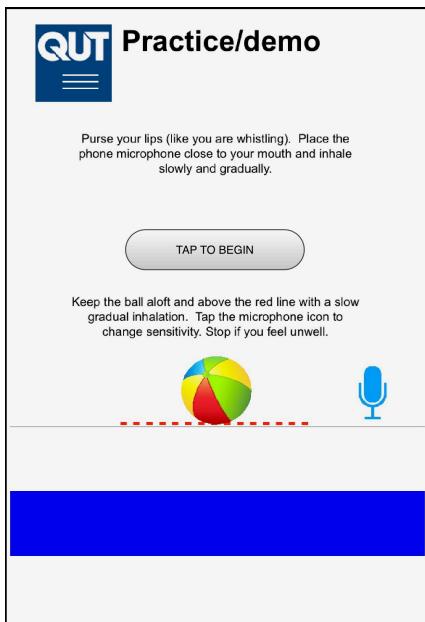


The remainder of this guide describes each of the main menu functions offered by QUT Inspire.

The top left QUT icon is used to navigate back to this home menu page.

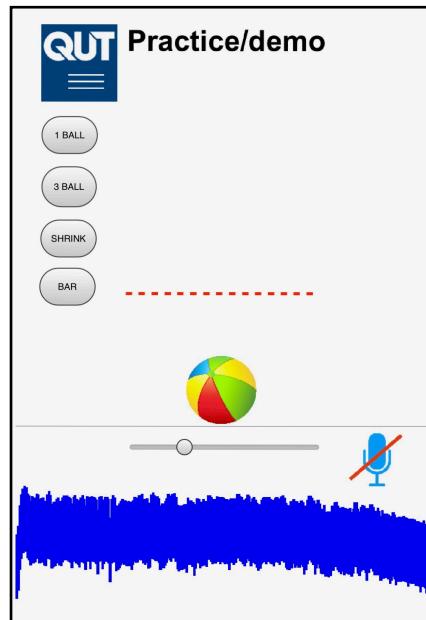
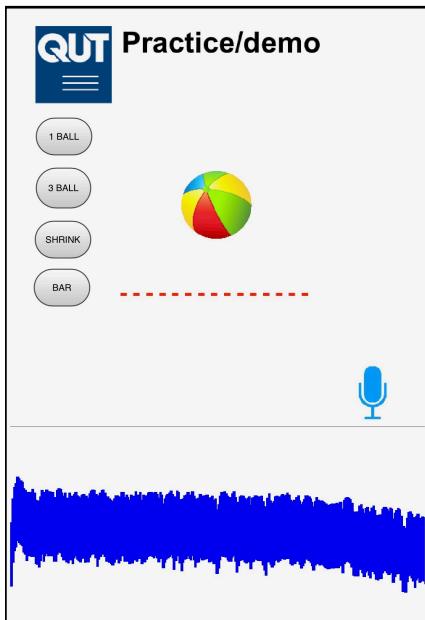
Practice/Demo

QUT Inspire offers a practice/Demo mode. Permission is required to use the microphone to detect breath sounds.



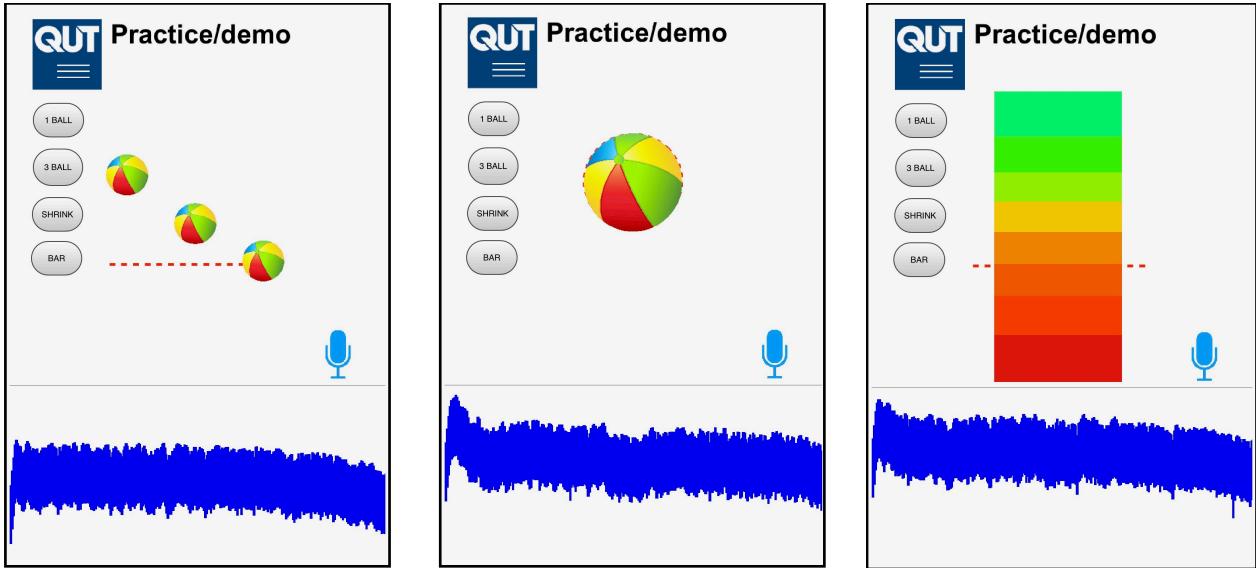
Hold the phone microphone 5 cm away from the mouth or less for optimal detection. As inhalation is detected, a single ball lifts to reflect inhalation effort.

A microphone icon at the lower right of screen toggles display of a volume control, making the microphone more or less sensitive to noise. This may also reduce the effect of background noise.



Additional display types

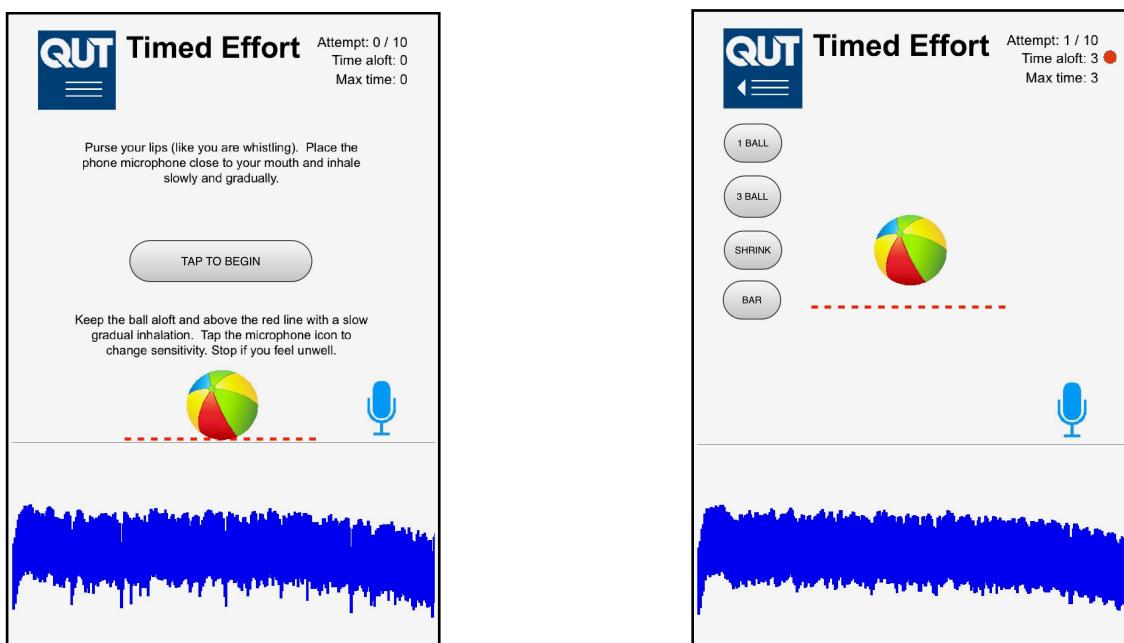
QUT Inspire offers a total of four display types. In addition to the single ball, a three-ball and shrinking ball display may be selected using the buttons to the left of the screen. A bar or histogram style of display is also available for selection.



Timed effort

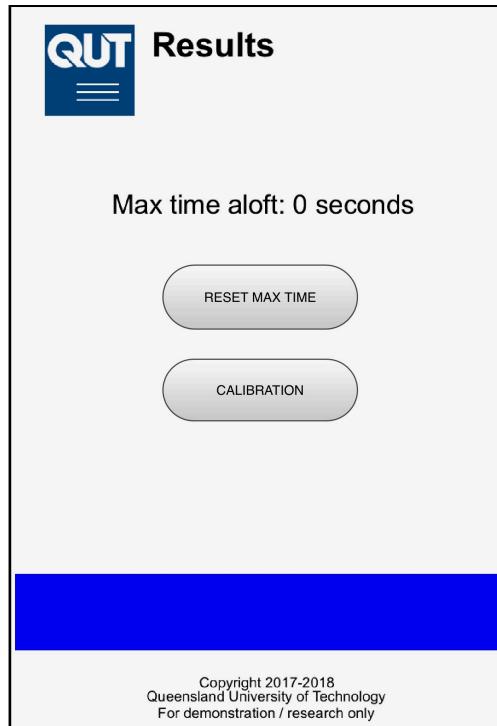
Incentive spirometry is used to encourage repeated slow gradual maximal inhalations, for optimal therapeutic effect.

The Timed Effort option displays an attempt counter at the top right of the screen, in addition to a maximum time aloft counter. While detection of an inhalation occurs, a flashing red icon indicates that timing is occurring.



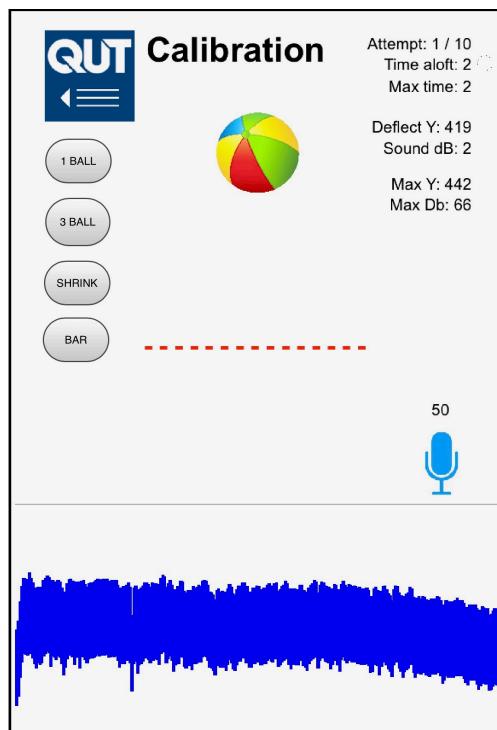
Results

The maximum time aloft across recorded attempts is displayed in the Results page. This maximum may also be reset to 0 if desired, using the displayed button option.



Calibration

A calibration mode is accessible from the Results page, displaying Y axis deflection and sound level recorded during attempts. Maximum Y axis deflection and sound level are also recorded and displayed for the current attempt.



About

The About page describes incentive spirometry, presenting a GIF animation of the physical variant of the incentive spirometer device.



About

About this app

This app has been developed as part of a Master of Public Health dissertation at QUT. It is for research/demonstration use only.

What is Incentive Spirometry ?



Incentive spirometry clears airways of mucus, using lung air pressure created by slow gradual inspiration.

Several types of device exist, with varying designs and costs.

What is a virtual smart phone incentive spirometer ?

This simple app uses the built-in microphone in modern smart phones to 'virtualise' the function of an incentive spirometer. The sound of breathing in is detected by the phone microphone and displayed on screen using several display styles to reflect breathing effort:

Display types include a floating ball display (1 or 3 ball), shrinking balloon and histogram (bar chart) displays.

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Appendix 10.2 QUT UHREC approved forms for user impression interviews



PARTICIPANT INFORMATION FOR QUT RESEARCH PROJECT

HLN750 Incentive spirometry & smart phones

QUT Ethics Approval Number 1700001117

RESEARCH TEAM

Principal Researcher: Mr Clarence Baxter Masters student

Associate Researcher: Dr Julie-Anne Carroll Supervisor

School of Public Health and Social Work, Faculty of Health

Queensland University of Technology (QUT)

DESCRIPTION

This project is being undertaken as part of the QUT subject HLN750 Dissertation, and as a component of the QUT Master of Public Health post-graduate program.

The purpose of this project is to explore a new smart phone application for detecting and displaying breathing.

We are seeking opinions from people regarding the best way to display breathing effort using this new prototype smart phone application. Several smart phone display types are presented for comparison in the study.

PARTICIPATION

Your participation will involve an audio recorded interview on site at Orientation Week 2018 or other agreed location that will take approximately 15 minutes of your time or less. This interview will be conducted in a screened-off area for privacy by an experienced clinical measurement scientist.

You will be asked to use a smartphone to detect normal inhalations (breaths in). We have developed a smartphone application which displays inhalations graphically using several different types of display to represent breaths in.

We ask that you use the application to display several breaths in (with a rest between each breath) and watch the display. Button controls displayed on the smartphone screen let you switch between several display types on-screen as you wish. We are interested in your impressions as to the best display to use to represent breaths in.

You will see animated representations of breaths displayed on-screen in several different layouts.

Examples of questions following use of the new smartphone application include:
Which of the display types do you think is best for displaying breathing effort?
What do you like and dislike about each display type?
Do you have any suggestions about other ways to display breathing effort?

If you have any medical condition that may affect your breathing, you will be excluded from this study. You will not be asked to inhale or exhale excessively for the purposes of this study.

Examples of medical conditions include any heart or blood pressure problems, breathing conditions (including asthma), any history of dizziness or fainting or other medical conditions that may affect your ability to breathe normally.

Your participation in this research project is entirely voluntary. If you do agree to participate you can withdraw from the research project without comment or penalty. You can withdraw anytime during the interview. If you withdraw with 2 weeks after your interview, on request any identifiable information already obtained from you will be destroyed. Your decision to participate or not participate will in no way impact upon your current or future relationship with QUT (for example your grades).

EXPECTED BENEFITS

It is expected that this project will not benefit you directly. However, it may benefit others by gaining insight into the opinions of people, leading to better and more effective mobile health applications.

Please note that no health information or advice will be provided as part of this project. Please consult with your GP or health practitioner for health information and advice.

RISKS AND ADVERSE EVENTS

There are no risks beyond normal day-to-day living associated with your participation in this project.

While your participation in this project is low-risk, if you experience any adverse health effects following participation in this study, please seek immediate medical assistance from your GP or health practitioner if you have any concerns about your health.

Such adverse events may include, but are not limited to dizziness, nausea, breathlessness, chest pain, jaw or arm pain. For your reference, QUT Medical Clinics are available at the following locations:

Gardens Point Campus Level 4 X Block **07 3138 2321**
Kelvin Grove Campus Level 2 44 Musk Avenue **07 3138 3161**

PRIVACY AND CONFIDENTIALITY

All comments and responses will be treated confidentially. The names of individual persons are not required in any of the responses. The study will be conducted in a screened-off area for privacy purposes.

As the research project involves an audio recording:

- You will have the opportunity to verify your comments and responses prior to final inclusion.
- The recording will be destroyed after the contents have been transcribed.
- The recording will not be used for any other purpose.
- Only the interviewer will have access to the recording.
- It is not possible to participate in the project without being recorded.

Any data collected as part of this research project will be stored securely as per QUT's Management of research data policy.

Please note that non-identifiable data from this research project may be used as comparative data in future research projects or stored on an open access database for secondary analysis.

CONSENT TO PARTICIPATE

We would like to ask you to sign a written consent form (enclosed) to confirm your agreement to participate.

QUESTIONS / FURTHER INFORMATION ABOUT THE PROJECT

If have any questions or require any further information please contact one of the listed researchers:

Clarence Baxter c.baxter@connect.qut.edu.au

Julie-Anne Carroll jm.carroll@qut.edu.au 07 3138 5803

CONCERNS / COMPLAINTS REGARDING THE CONDUCT OF THE RESEARCH PROJECT

QUT is committed to research integrity and the ethical conduct of research projects. However, if you do have any concerns or complaints about the ethical conduct of the research project you may contact the QUT Research Ethics Advisory Team on 07 3138 5123 or email humanethics@qut.edu.au. The QUT Research Ethics Advisory Team is not connected with the research project and can facilitate a resolution to your concern in an impartial manner.

**THANK YOU FOR HELPING WITH THIS PROJECT.
PLEASE KEEP THIS SHEET FOR YOUR INFORMATION.**



CONSENT FORM FOR QUT RESEARCH PROJECT

HLN750 Incentive spirometry & smart phones

QUT Ethics Approval Number 1700001117

RESEARCH TEAM CONTACT DETAILS

Clarence Baxter c.baxter@connect.qut.edu.au
Julie-Anne Carroll jm.carroll@qut.edu.au 07 3138 5803

STATEMENT OF CONSENT

By signing below, you are indicating that you:

- Have read and understood the information document regarding this project.
- Have had any questions answered to your satisfaction.
- Understand that if you have any additional questions you can contact the research team.
- Understand that you are free to withdraw at any time, without comment or penalty.
- Understand the project will include an audio recording.
- Understand that non-identifiable data from this project may be used as comparative data in future research projects.
- Understand that no individual health information or advice will be provided as part of this project.
- Understand that if you have concerns about the ethical conduct of the research project you can contact the Research Ethics Advisory Team on 07 3138 5123 or email humanethics@qut.edu.au.
- **Do not have any health condition** that may prevent you from providing normal slow breaths for the purposes of the study. A minimum of 1 minute rest and normal breathing is required between each inspiration monitored in this study. Examples of health conditions include (but are not limited to) any heart or blood pressure problems, breathing conditions (e.g asthma), any history of dizziness or fainting or other medical conditions that may affect your ability to breathe normally.
- Agree to participate in the project.

Name

Signature

Date

PLEASE RETURN THE SIGNED CONSENT FORM TO THE RESEARCHER.



ADVERSE EVENT FORM

HLN750 Incentive spirometry & smart phones

QUT Ethics Approval Number 1700001117

RESEARCH TEAM CONTACT DETAILS

Clarence Baxter c.baxter@connect.qut.edu.au
Julie-Anne Carroll jm.carroll@qut.edu.au 07 3138 5803

Participant ID Number: _____

Date/Time: _____

ADVERSE EVENT DESCRIPTION

ACTIONS TAKEN (INC REPORTING TO QUT SPHSW WH&S OFFICER)

CARE FOR PARTICIPANT HANDED TO (E.G SELF; FRIEND; GP) WHERE APPLICABLE

FOLLOW-UP WITH PARTICIPANT WHERE APPLICABLE

Team Member: _____

Date/Time: _____



SEMI-STRUCTURED INTERVIEW GUIDE

HLN750 Incentive spirometry & smart phones

QUT Ethics Approval Number 1700001117

RESEARCH TEAM CONTACT DETAILS

Clarence Baxter c.baxter@connect.qut.edu.au

Julie-Anne Carroll jm.carroll@qut.edu.au 07 3138 5803

Participant ID Number: _____

Date/Time: _____

List of starting questions:

1. Have you ever seen or used an incentive spirometer before?

Basic instructions given prior to using the smart phone device.

- Breathe in slowly and gradually with the phone placed a comfortable distance from your mouth. Watch the screen display as you breathe in. **STOP AT ANY TIME IF YOU FEEL UNWELL**
- Use the screen buttons to the left to change the display type, waiting a minute between attempts to allow for recovery.

2. Which display type do you like the best and why?
3. Which display type do you like the least and why?
4. Which display type do you think provides the most encouragement to maintain effort?
5. Which display type do you think provides the least encouragement to maintain effort?
6. Can you suggest improvements to the displays, or other ways to display breaths?

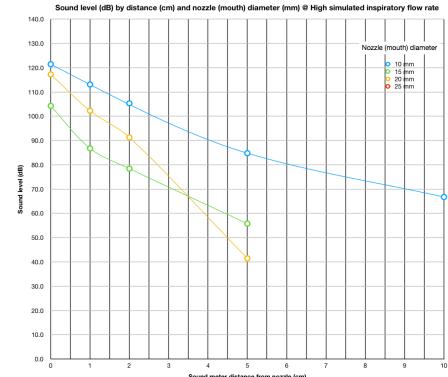
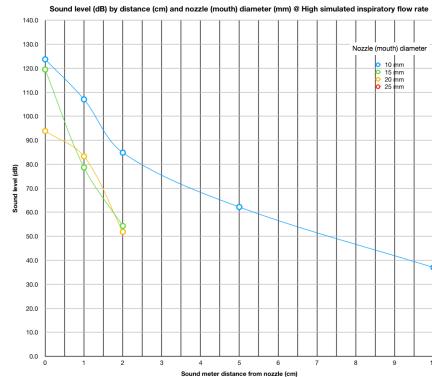
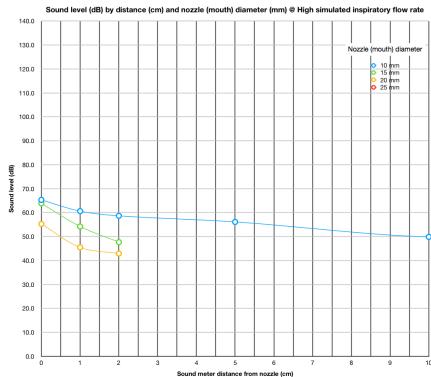
Appendix 10.3 Smart phone acoustic calibration curves (no log transformation)

High flow

iPhone 6 Plus

Samsung J1

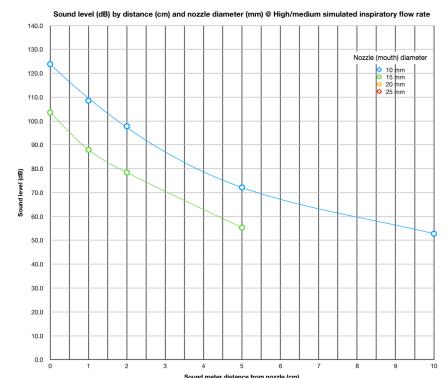
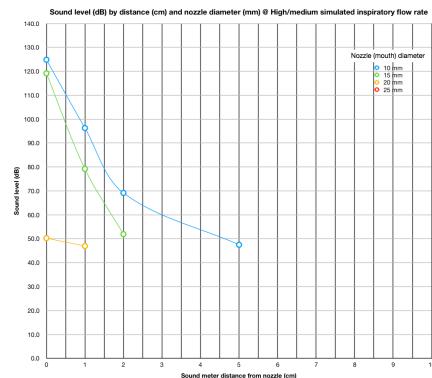
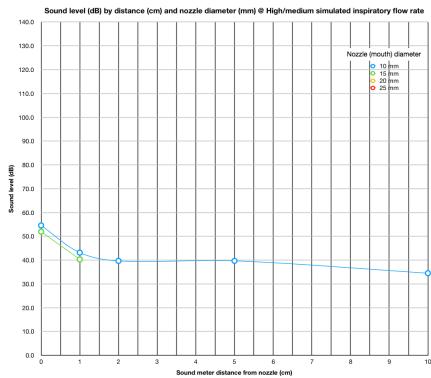
Pendo



High/Med flow iPhone 6 Plus

Samsung J1

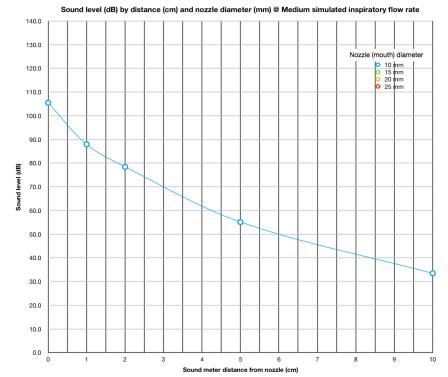
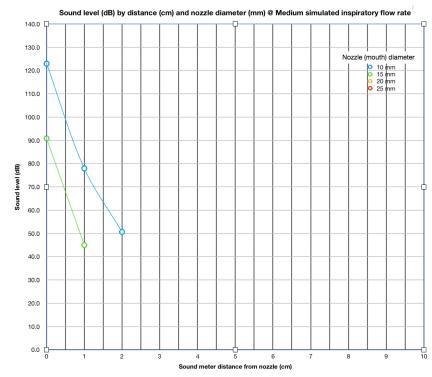
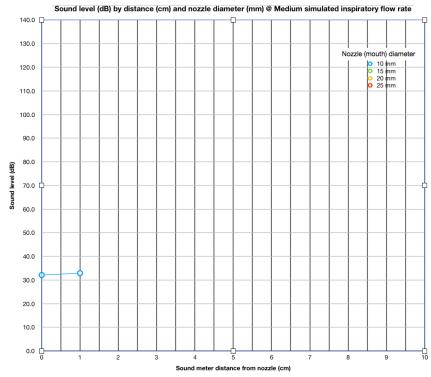
Pendo



Medium flow iPhone 6 Plus

Samsung J1

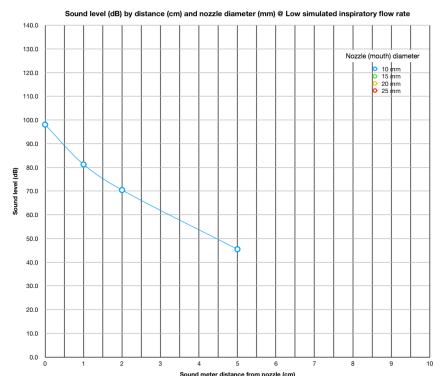
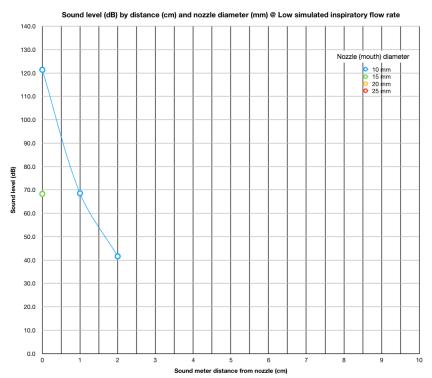
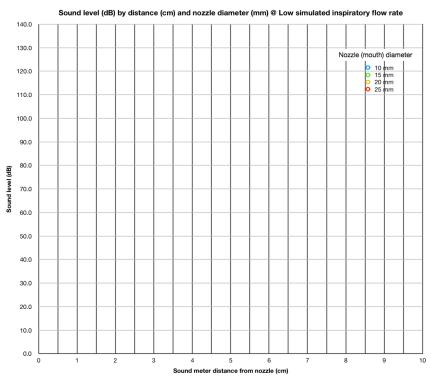
Pendo



Low flow iPhone 6 Plus

Samsung J1

Pendo



Appendix 10.4: Interview Transcripts

Legend

Symbol	Meaning
...	Short pause
[]	Non-verbal communication
=	Fast reply
[sic]	Not grammatically correct but correctly transcribed
-(Humble)	Changes thought part way through a sentence

Thematic Analysis

Code

Theme

Display types



Alternative display suggestions



Interview 1

Interview date: February 14th, 2018

Interview location: QUT Kelvin Grove Campus - Orientation Week Stall

Interviewer: Clarence Baxter

Participant: Subject 1

Start time: 9:40 am

Interviewer: This is interview number one at 9:40 on Wednesday morning the 14/2.

OK, the URL to go to is that one there [Interviewer shows subject the URL for QUT Inspire printed on page for typing]

Subject 1: Yep [sic]

Interviewer: Let it have a think [sic] for a second. ... it's got to be HTTPS otherwise the microphone won't work ... cool [sic]. Just tap on the last button there - "About" and you will get a piccie [sic] there of what it looks like when someone uses one of these devices. Now notice that when using [it] therapeutically they are doing slow gradual maximum inhalations, but there is no need for you to do that because it will still activate the screen display.

Subject 1: Yep [sic]

Interviewer: Just normal breaths in will do fine because it will still activate the screen display.

Subject 1: Yep [sic]

Interviewer: Okie dokey [sic] so if you are happy to proceed, hit that top left hand button there which navigates around things, and use the 'Practice/Demo option first off.

Subject 1: Yep [sic]

Interviewer: Tap to begin.

Subject 1: Yep [sic]

Interviewer: Once you use the microphone, just inhale with the phone close to your mouth.

Subject 1: OK [Subject attempts inhalation]

Interviewer: Try again like you are slurping [sic] spaghetti. [Interviewer demonstrates inhalation] and notice the ball travels with your movements. Now there is background noise here so there is a little microphone control which will allow us to reduce the effect of background noise ... just try that then [sic]. Cool [sic]

Subject 1: Yeah [sic] [subject attempts another breath - requires further adjustment to reduce sensitivity]

Interviewer: Bring it back down a little bit. There we go. To about there.

Subject 1: OK

Interviewer: There we go. Try that now

Subject 1: OK ... [attempts an inhalation]

Interviewer: And just put the microphone closer to your mouth

Subject 1: [attempts an inhalation]

Interviewer: There you go. Thats still a little bit too insensitive.

Subject 1: Which way ? [subject adjusts sliding sensitivity control]

Interviewer: So we will move it this way to make it a little more jumpy [sic]

Subject 1: OK [sic]

Interviewer: There we go, try that

Subject 1: [Attempts inhalations] it's fine

Interviewer: Try that again ...

Subject 1: Yeah

Interviewer: There you go, so that's one display, a single ball. Tap the second button down there.

Subject 1: Yeah [sic]

Interviewer: Try a three ball ...

Subject 1: [attempts inhalation] Ah yeah [sic] ... It like is one's sensitive [sic] than the other

Interviewer: Yeah [sic]. Try the third one down. That's a shrinking balloon. Try inhaling and watch the [inaudible] shrinking.

Subject 1: [Attempts inhalations] ... Like a whistle

Interviewer: Take a breather between breaths. We don't want to flag [sic] you out ... the last one there is a histogram, a bar chart. So give that a go

Subject 1: [Attempts inhalations] ... Ah yeah

Interviewer: Now just tap on any of those that you like ... Have a look around, just work out which display you like the best, which one you like the least.

Subject 1: I like the bar one the best cause [sic] you got the different sections

[gestures a stretched out box]

Interviewer: So you can see the spectrum ?

Subject 1: Yeah [sic], spectrum that's the word

Interviewer: OK

Subject 1: umm, I don't prefer the Shrink one, yeah [sic] over the bar one

Interviewer: OK so bar one the best because you can see the spectrum. That's cool. Can you think of any other ways that we can display breathing effort rather than the four different ways we are displaying now ?

Subject 1: I mean that by looking at the physical one I reckon you've got the three balls and the one ball, I think you've done alright.

Interviewer: Cool [sic]

Subject 1: Not much more really

Interviewer: Thats as painful as it gets [joking]. Thank you very much for your help

Subject 1: Thats alright

Interview 2

Interview date: February 14th, 2018

Interview location: QUT Kelvin Grove Campus - Orientation Week Stall

Interviewer: Clarence Baxter

Participant: Subject 2

Start time: 10:10 am

Interviewer: OK, its 10:10 on Wednesday morning - interview 02. This is called QUT Inspire

Subject 2: Yep [sic]

Interviewer: What it is does is tries to do in electronic form what that guy's doing in that picture [shows GIF animation of lsy in 'About' section of app]

Subject 2: Yeah [sic]

Interviewer: Taking deep breaths in, and in this case he is lifting balls in the air with his inhalation. Now what we are after is slow gradual inhalation [demonstrates breath] like you are slurping on spaghetti - that increases the air flow and the objective of this is just to have a look at four different ways of displaying breathing effort, and I would like you tell me which is the best way and the worst way to [inaudible]. I'm just going to turn the sensitivity down a bit because of the background noise . There we go. It may jump around a bit. Hold it up close to your mouth and have a look at it while you inhale. Fairly quickly like you are slurping on spaghetti. There you go.

Subject 2: [Attempts inhalations]

Interviewer: Great. Now have a look at the second button now. Just tap on the second button now.

Subject 2: Yeah [sic]

Interviewer: That gives you a different display - a three ball display

Subject 2: [Attempts inhalations]

Interviewer: Have a look at a third one - thats a shrinking ball. The more you inhale ...

Subject 2: [Attempts inhalations]

Interviewer: Thats alright, do you see how how it almost becomes uncomfortable, its a real incentive to breathe in.

Subject 2: [Attempts inhalations]

Interviewer: Try the last one.

Subject 2: [Attempts inhalations]

Interviewer: Thats a histogram or bar chart display

Subject 2: [Attempts inhalations]

Interviewer: Have a flick through these four again. And have a think about which one you think is the best graphical representation of a breath in.

Subject 2: [Attempts multiple inhalations] ...

Interviewer: Now question time, which one do you think is the best way to display ...

Subject 2: I think the easiest one to understand would be the bar graph

Interviewer: Bar graph, yep [sic]

Subject 2: but for little kids maybe the um maybe the three ball one and for say like if you are dealing with an athlete or something the shrinking ball one cause [sic] it that was the one that really made me suck in the air

Interviewer: Which one do you think is the worst one ?

Subject 2: Honestly the big ball that just bounces up and down really doesn't do anything. The three ball one kind of, you know you can say oh its a virtual spirometer oh yeah [sic] the three ball thing.

You know the bar one is probably the simplest to understand. The three ball for the little kids.

Interviewer: OK, now can you think of any other ways of display breathing effort ?

Subject 2: Um [sic], maybe something for color blind people. Um [sic]

Interviewer: OK

Subject 2: maybe a different shades of grey one for them ?

Interviewer: OK, a better [sic] it gives you better contrast without the color

Subject 2: Maybe have some kind of lines, measuring lines things [sic]. I haven't got the wording well today Im sorry

Interviewer: This is exactly the sort of idea we're after

Subject 2: So like you know something like you know if its a challenge to inhale and breathe out maybe make a game of it like especially for younger kids you know like maybe I don't know having the balls hitting a bell ding ding ding I don't know like [sic]

Interviewer: Like a carnival thing ?

Subject 2: Yeah no [sic] just like if its for engaging children in particular you know I mean adults should be looking at the bar graph but it's [sic] you got to take into account neurodiversity, sensory perception, age, background. That kind of thing

Interviewer: So having a few different displays

Subject 2: Yeah, I think I think the bar one would be the easiest to understand but if it's challenge for people as you said it's meant to be a challenge you need more interactivity like as I said for the kids class hitting the bell. Shrinking one should be good for

Interviewer: Goals to reach ?

Subject 2: Yeah you know, for all the, ... sorry I shouldn't say meatheads, but all the athletes who are. That was the one where I really tried like I think you'd probably noticed me

Interviewer: Yes

Subject 2: You know that one would be good to challenge esp the gym junkies and all of them, so

Interviewer: Thank you so much for all your help with this

Subject 2: You're welcome

Interview 3

Interview date: February 14th, 2018

Interview location: QUT Kelvin Grove Campus - Orientation Week Stall

Interviewer: Clarence Baxter

Participant: Subject 3

Start time: 10:25 am

Interviewer: This is interview 3 at 10:25am. So, what we'll do first off is just allow it to use the smart phone microphone. Notice straight away that background noise is setting it off

Subject 3: Yeah [sic]

Interviewer: I can make it less sensitive to that background noise [adjusts slider]. There we go. Now, pick up the phone. Hold it about there about 5 cm from your lips and breathe in like you are slurping spaghetti.

Subject 3: [Attempts inhalations]

Interviewer: Have a look at the ball while you do that, is it moving or not ?

Subject 3: Ah, no

Interviewer: Move it a bit closer ... now breathe in

Subject 3: [Attempts inhalations]

Interviewer: What I need to do is adjust the sensitivity on that ... make it more jumpy [sic]. Try that now.

Subject 3: [Attempts inhalations]

Interviewer: Bingo [sic]. Have a couple of goes like that

Subject 3: [Attempts inhalations]

Interviewer: And when you are ready to, just change to the second option down which is a different type of display.

Subject 3: [inaudible]

Interviewer: Whenever you like

Subject 3: [Attempts inhalations]

Interviewer: Now try the third one which is a shrinking ball

Subject 3: [Attempts inhalations]

Interviewer: Give it a go with the fourth one

Subject 3: [Attempts inhalations]

Interviewer: The closer you hold it say one or two centimetres away you'll register a higher number of decibels

Subject 3: Yep [sic], [Attempts inhalations]

Interviewer: Now if you go through a couple of those if you want to review a couple. Just have a think which is the best and which is the worst of those displays for displaying breathing effort.

Subject 3: [Attempts inhalations]. How come it um [sic] I notice when I started it starts here and it will jump up

Interviewer: Because its root mean square of sound. If it was instantaneous sound

Subject 3: OK

Interviewer: it would be like a richter scale. This takes the root mean square and smooths out the sound.

Subject 3: Yeah [sic]

So it's the average if you like of the sound

Subject 3: Yeah [sic], alright [Attempts inhalations]

Interviewer: Just makes you blow harder

Subject 3: [laughs] [Attempts inhalations] ... I think I like the bar

Interviewer: So you reckon the bar is the best one ?

Subject 3: Yeah [sic]

Interviewer: Why do you reckon that's so ?

Subject 3: Um [sic] that's ... I'm not sure but I like the bar better than the balls, and the three
balls I'm not sure but it seems like a little bit too much

Interviewer: Too busy ?

Subject 3: Yeah [sic], and shrink it's sort of like um [sic] can't be sure where it sort of
finishes, like it could be ...

**Interviewer: That's OK. Now can you think of any other ways we can displaying
breathing effort ?**

Subject 3: ... You intent on using these balls ?

**Interviewer: Not sold on any which way at all. So it's just which way people find the
most desirable way, the most optimal way.**

Subject 3: Yeah [sic]

Interviewer: Not wedded to the balls at all.

Subject 3: I think probably that simpler is better

**Interviewer: OK, I know with some children's radiology applications use cartoons, a
sheep, the idea in that environment to make a child hold a breath in so their lungs
hyper-inflate and the X-ray works better**

Subject 3: Yeah

**Interviewer: So, ... are different theories [sic] but we don't know of too many others
that do this incentive spirometry. I would like to thank you for your time. We are all
done**

Interview 4

Interview date: February 14th, 2018

Interview location: QUT Kelvin Grove Campus - Orientation Week Stall

Interviewer: Clarence Baxter

Participant: Subject 4

Start time: 10:42 am

Interviewer: This is interview 4 at 10:42 on Wednesday. This transcription will have a good back beat sitting behind it [music playing in background]

Subject 4: Thats it

Interviewer: It will take a second to have a think and come up. When it does, that is what we are talking about [referring to About screen and GIF animation of ISy]. These devices ... incentive spirometers are used to encourage slow gradual maximal inhalation. For what we are doing here, you don't need to huff [sic] your heart out, just active breaths so that the images move

Subject 4: Yes

Interviewer: The breath in phone microphone [sic] picks up your breaths. Lets just get back here [menu] again. Before we get under way the one thing I'll do is I will make it less sensitive to background noise ... so lets see whether that works. OK, give it a burp [sic]

Subject 4:[attempts inhalation]

Interviewer: Hold it close to your mouth. Its like slurping spaghetti

Subject 4:[Attempts inhalations]

Interviewer: Did the ball move for you ?

Subject 4: Yeah, it did

Interviewer: OK, good. So thats what we're talking about. An incentive to breathe in. I will let you go to the second one down which is a three ball display.

Subject 4:[Attempts inhalations]

Interviewer: Now try the third one down which is a shrinking balloon display

Subject 4: Oh yeah, [Attempts inhalations]

Interviewer: Try the last one which is a bar display

Subject 4: [Attempts inhalations]

Interviewer: Have a look around those four displays and just work out for you which you think is the best display to give someone incentive to breathe in deeply

Subject 4: I prefer the bar

Interviewer: Reckon the bar is the best one, OK. Which one do you reckon is the worst one?

Subject 4: The shrinking one

Interviewer: The shrinking balloon. Can you think of any other ways we can display breathing effort ?

Subject 4: Um [sic] ... it could be ... you know how they do um [sic] things so they change color, like mood rings, things like that. They could be a different color

Interviewer: What a good idea.

Subject 4: So even when you blow out, I don't know

Interviewer: What sort of color would you class fast and harsh [rapid]?

Subject 4: I'd probably use the, like red and thru green like traffic lights

Interviewer: Like traffic lights ?

Subject 4: So when it was red when you're not breathing

Interviewer: I love doing this, you think of things we don't normally think of, that is so cool

Subject 4: [laughs], ... [inaudible] so some kind of gradient. Like green a really nice green and the pace is good, and when the pace drops away, the gradient is red and then what it actually focuses on what is breathing . [laughs] ...

Interview 5

Interview date: February 14th, 2018

Interview location: QUT Kelvin Grove Campus - Orientation Week Stall

Interviewer: Clarence Baxter

Participant: Subject 5

Start time: 11:15 am

[Subject 5 shown “About” screen prior to consent form being signed, interface ready at start of interview]

Interviewer: This is interview number 5 at 11:15 on Wednesday.

Subject 5: [attempts inhalation]

Interviewer: So go harder

Subject 5: Yep [attempts inhalation]

Interviewer: Now can you see the ball move there at all or is it just moving with the music, if its just moving with the music we can make that less sensitive just by, for a sec [sic] we can make i less sensitive to the music like that [adjusts sensitivity slider].

Now thats more your voice [sic]

Subject 5: so I just, like [gestures inhalation]

Interviewer: Anywhere about 2 to 5 cm away. See it respond to your [sic] breath now

Subject 5: Yeah

Interviewer: Alright, cool. Do a couple of breaths with that first display

Subject 5: [Attempts inhalation]

Interviewer: Now on the left hand side choose the second button down which is, ooh it's upside down. There we go. Second button down

Subject 5: [Attempts inhalations]

Interviewer: Now the third one

Subject 5: [Attempts inhalations]

Interviewer: So rather than the up and down ball display, the ball shrinks as you breathe in

Subject 5: [Attempts inhalations]

Interviewer: Try the last one

Subject 5: [Attempts inhalations]

Interviewer: Now if you want to reconfirm anything go back thru the other buttons if you need to, but out of those four which do you think gives the best representation of breathing effort, breathing in ?

Subject 5: Um ... I think the three ball. I think because it's a classic. Um ... its like its transferring it to a smart phone, yeah I like it's keeping it the old fashioned way, but like you know

Interviewer: No whats the worst display ? Which one did you like the least ?

Subject 5: Probably the bar one.

Interviewer: OK, any reason why ?

Subject 5: Um, I don't, just because it kind of bounces all over the place [laughs]

Interviewer: Cool

Subject 5: Yeah, the others responded really well

Interviewer: Could you think of any other way we could display breathing effort ?

Subject 5: I should know that. You've got your spirometry. Um [sic] you've also got, even like you can do like a meter [sic]

Interviewer: Like a gauge or a scale ?

Subject 5: Yeah, it tells you like your tidal volume in your lung and things like that

Interviewer: OK so an actual quantitative thing

Subject 5: Yeah

Interviewer: Cool, thank you so much

Interview 6

Interview date: February 14th, 2018

Interview location: QUT Kelvin Grove Campus - Orientation Week Stall

Interviewer: Clarence Baxter

Participant: Subject 6

Start time: 11:21 am

Interviewer: This is interview number 6 11:21 am. So that's the application there - QUT Inspire. That's how someone using one of those real world devices [shows GIF animation]. Its all about slow gradual purposeful inhalation. With that, we are using the phone microphone as a pressure sensor. The sound you make with an inhalation is picked up by the microphone and displayed on screen. With that, almost slurping spaghetti or blowing a candle out in reverse. A small mouth diameter means a larger sound. So in your own time I will give you the application itself. I'll change the sensitivity of it because of the background music, just cause it goes off at the drop of a hat. This makes it less sensitive to external noise. I want it a little bit sensitive to pick your breath up. There you go, can you grab that ? And in your own time just hold the microphone about a cm or two away from your mouth, and take a slow deep breath in.

Subject 6: [Attempts inhalations]

Interviewer: Do you see any movement in the ball ?

Subject 6: Yeah

Interviewer: Good, take a breather and try it one more time

Subject 6: [Attempts inhalation]

Interviewer: The idea of it is as you breathe in the negative pressure in your chest pops alveoli, lung sacs and tries to move mucus out of there. Press the second button down labelled Three Ball. Now you try that one, its just a different way of displaying the same thing

Subject 6: [Attempts inhalations]

Interviewer: Tried that as well, now try the third button don, thats a shrinking ball, give that a go

Subject 6: [Attempts inhalations]

Interviewer: And you are on the home stretch now. Take a breather, no rush. And the fourth button will give you a bar display. Just give that one a burl [sic]

Subject 6: [Attempts inhalations]

Interviewer: If you want to review any of those just click the buttons to go back to other ones. Try and have a think about which do you think is the best graphic display to represent respiratory or breathing in effort

Subject 6: I think the bar

Interviewer: You think the bar. Why do you reckon the bar ?

Subject 6: That one you can see the extremes

Interviewer: It's more substantial

Subject 6: Yeah

Interviewer: Out of those four displays which is the worst ?

Subject 6: The shrink

Interviewer: The shrinking ball (of torture) [laughs]. Fair enough

Subject 6: [laughs]

Interviewer: And just finally, can you think of any other ways that we can display respiratory effort. Anything and everything will do fine

Subject 6: Um, Im not quite sure

Interviewer: If theres no answer, theres no answer thats OK

Subject 6: Maybe a musical instrument. Like breathing in a mouthpiece

Interviewer: I like it

Subject 6: I play like 5 different instruments. So ...

Interviewer: OK so

Subject 6: Use like a mouthpiece or something [gestures like a flute].

**Interviewer: Yeah, yeah, yeah. That would work. A color change on display on a flute
or a clarinet or something like that. Thank you so much for your help**

Interview 7

Interview date: February 14th, 2018

Interview location: QUT Kelvin Grove Campus - Orientation Week Stall

Interviewer: Clarence Baxter

Participant: Subject 7

Start time: 11:35 am

Interviewer: Interview number 7 11:35 am on Wednesday. So what you've got there is a representation of a ball. The microphone detects your sound, the sound of inhalation and responds with lifting the ball. What I want you to do is have a look at four different displays will be available [sic]. Tell us which you think is the best and which you think is the worst.

Subject 7: Yep

Interviewer: Now before we get under way, I'm going to whack that button to change the sensitivity of the microphone. Just start it up. Just that background noise will set it off. If we slide it up, titrate it a bit. Alright, I'll get you to hold it about 2 cm away from your mouth.

Subject 7: Yeah [sic]

Interviewer: Breathe in like you are slurping spaghetti

Subject 7: [Attempts inhalation] a bit closer ?

Interviewer: A bit closer, and can you see the ball move up in response to your breath in ?

Subject 7: No

Interviewer: OK, so that's still too much background noise [adjusts slider]. Try that now

Subject 7: [Attempts inhalations], yep [sic] better response

Interviewer: I had that in mind because of background noise in hospitals is terrible and in a ward you need to be able to change damp it down [sic]. So that's the first display.

On the left hand side, try the three ball display instead.

Subject 7: [Attempts inhalations], yeah, yeah [sic] I like that

Interviewer: Now there is a third button there. Give that a burl [sic]

Subject 7: [Attempts inhalations] What's the idea of all three ?

Interviewer: In the real world device that corresponds to 600, 900 and 1200 cc/min

Subject 7: Oh right, OK

Interviewer: but here it's just three balls

Subject 7: The bar

Interviewer: Try the bar

Subject 7: [Attempts inhalations]

Interviewer: Its just a different way of displaying respiratory effort

Subject 7: I like the Three Ball. It's a bit more ... it feels more responsive

Interviewer: More things happening ?

Subject 7: Yeah [sic]

Interviewer: Out of those four displays, which do you think is the worst display, the worst incentivising you to breathe in deeply ?

Subject 7: Ah [sic], the shrink

Interviewer: Can you think of any other way we can describe breathing effort ?

Subject 7: Maybe like a circular graph, like a tachometer

Interviewer: Like a pressure gauge ?

Subject 7: Yeah [sic], just so you can see it, like a speed-test on your internet

Interviewer: Like a radial thing, OK

Subject 7: Yeah [sic]

Interview 8

Interview date: February 14th, 2018

Interview location: QUT Kelvin Grove Campus - Orientation Week Stall

Interviewer: Clarence Baxter

Participant: Subject 8

Start time: 12:30 pm

Interviewer: Interview number 8 12:30 on Wednesday the 14th. Now what we are going to do

Subject 8: Yeah

Interviewer: So just to recap. Incentive spirometry is breathing in deeply and those balls are used as an incentive to make you maintain a gradual inhalation. So what I'd like you to do is just have a look at this display. Thats a virtual version of the same thing. Now thats going to jump like crazy because of the band. Im just going to change the sensitivity of that [adjusts slider]

Subject 8: Into that

Interviewer: So it won't listen to the band too much. There we go, thats about as best as we're going to do under the conditions. Now if you take hold of the phone, and like this just hold it about there so you can see the display, and just with a breath in [inhales]. Can you see the ball move in response ?

Subject 8: Yes [Attempts inhalations]

Interviewer: So thats the incentive to breath in deep. tap the second button there, there's a button labelled 3 Ball ... the second one down. Try that one and see what you think

Subject 8: [Attempts inhalations]

Interviewer: OK, lets try the third one now. There's only four in total. Try that one

Subject 8: [Attempts inhalations]

Interviewer: So that ball shrinks as you inhale more

Subject 8: [Attempts inhalations]. I breathe more in my mouth this time

Interviewer: Thats OK, still makes noise. Try that one now, that's the last of them

Subject 8: [Attempts inhalations]

Interviewer: So like spaghetti [inhales]

Subject 8: Like spaghetti, the mouth

Interviewer: You can go back and review any of those you like, but what I'd like you to have a think about is which display of of those four displays do you think is the best in terms of incentive to breathe in, and which was the worst.

Subject 8: Oh, I think the second one

Interviewer: The second one, the three ball one

Subject 8: Yeah [sic]

Interviewer: And why would you say that ?

Subject 8: Oh, I was using my mouth. [inaudible]

Interviewer: Do you want to see the other one again ? Lets go to the other one again. If you want to review any of the other ones we can do the other ones again

Subject 8: The Bar one

Interviewer: So the bar one, single ball. So the three ball was the best. The shrinking ball. Which one is the worst ?

Subject 8: No idea

Interviewer: OK, so the three ball was the best

Subject 8: Yeah [sic]

Interviewer: Now, off the top of your head, can you think of any other ways that we can display breathing effort ?

Subject 8: ... um, no. Im happy

Interviewer: Thank you very much

Interview 9

Interview date: February 14th, 2018

Interview location: QUT Kelvin Grove Campus - Orientation Week Stall

Interviewer: Clarence Baxter

Participant: Subject 9

Start time: 12:54 pm

Interviewer: Interview number 9 at 12:54 on Wednesday the 14th. So that's the application - QUT Inspire. As you just saw its got a representation of what the real world incentive spirometry is all about. Just press option number 1 the Practice or demo option.

Subject 9: Yep [sic]

Interviewer: What you will find is that's a virtual representation of the ball you see inside the devices themselves

Subject 9: Yeah [sic]

Interviewer: What I was going to suggest is just tap that button there to begin.

Subject 9: Yeah [sic]

Interviewer: And straight away you will find that will dance [sic] because of the music in the background. So what we will do is, that little microphone thing there [sic]. I will change the sensitivity to about there. So it's going to be your breath that sets it off. Thats about as sensitive as we are going to get. Hold it about that far away from your mouth. About 5 cm. Tilt it a bit so you can see the display. And like slurping spaghetti [inhales] its the noise you make from the inhalation that the microphone picks up.

Subject 9: [Attempts inhalation]

Interviewer: Did it move at all ?

Subject 9: Not really

Interviewer: Try and hold it a bit closer

Subject 9: [Attempts inhalations]

Interviewer: Did it move ?

Subject 9: Yep [sic]

Interviewer: There you go. You are an expert now [laughs]. Thats the first display. On the left hand side there, tap the second button down - labelled 3 ball. And there you go, try that one

Subject 9: [Attempts inhalations]

Interviewer: Try the third button, you're the expert now, Im no longer required [laughs]

Subject 9: [Attempts inhalations]

Interviewer: So that one represents a shrinking ball. The more you inhale the more the ball shrinks.

Subject 9: [Attempts inhalations]

Interviewer: Try the last one

Subject 9: [Attempts inhalations], Yep [sic]

Interviewer: So you've been through all four. If you want to go back and review any of them by all means. Out of those four, which do you think would be the best graphic display to represent, to encourage inhalation

Subject 9: The second one with the three balls

Interviewer: The three balls. Why is that ?

Subject 9: Because it make me feel like it was actually doing like [sic], I felt with the circle it didn't feel like it was doing anything. The three balls kind of [sic] you can see the progression

Interviewer: Now which one did you like the least ?

Subject 9: Um, the circle one

Interviewer: The shrinking ball ?

Subject 9: The ball one yeah [sic]

Interviewer: The shrinking ball of torture [laughs]

Subject 9: [laughs], yes. So I didn't like that one cause it felt like it wasn't doing anything

Interviewer: So you can see what we are trying to do here, representing what those real world devices do on screen. can you think of any other way that we can represent someones breathing to give them incentive to give deep maximal inspiration ?

Subject 9: ... No

Interviewer: Thank you so much for your help

Interview 10

Interview date: February 14th, 2018

Interview location: QUT Kelvin Grove Campus - Orientation Week Stall

Interviewer: Clarence Baxter

Participant: Subject 10

Start time: 13:15 pm

Interviewer: This is interview 10 at 1:15 pm. So what we'll do first off is go to the demo mode

Subject 10: Fine

Interviewer: And before I begin, its going to dance because of the background band music

Subject 10: Oh yeah

Interviewer: Im going to reduce the sensitivity of the microphone [adjusts slider]. That should be enough to stop the background noise.

Subject 10: Right, OK

Interviewer: So with that, do you want to hold it about there, and breathe in like you are slurping spaghetti cause [sic] that creates the highest flow.

Subject 10: [Attempts inhalations]

Interviewer: Just watch that ball move up in the air. So thats the incentive that incentive spirometry gives

Subject 10: [Attempts inhalations]

Interviewer: Thats the first of four displays. Hit that second button - three ball, and try that one

Subject 10: [Attempts inhalations]

Interviewer: So thats another way of displaying breathing effort ... [gestures switch to third button] ... Thats a third way with a ball that shrinks as the noise gets louder

Subject 10: [Attempts inhalations]

Interviewer: One lucky last one ... a bar display

Subject 10: [Attempts inhalations] Oh yes

Interviewer: So we tried making that sliding control, that damping thing [sic] for background noise because sometimes

Subject 10: right

Interviewer: if the background noise is huge you need to jump it up a fair bit. You were able to get it to travel on each of those four buttons.

Subject 10: I think so, yeah [sic]

Interviewer: If you want to review any of those by all means, but have a think about which of those four displays you think is the best one

Subject 10: I reckon it's the bar

Interviewer: You reckon that's the best one ? OK, what is it about the bar that makes it the best ?

Subject 10: I think it's clearer because balls are, it was hard to notice I suppose

Interviewer: Just clearer with them, OK. Out of those four, which was the worst one for incentive providing incentive [sic] for a deep breath ?

Subject 10: I think the shrinking one, eh [sic]

Interviewer: Shrinking ball

Subject 10: Yeah, It was hard to notice that one

Interviewer: Now finally, we're on the home stretch now, um can you think of any other way we could display breathing on screen ?

Subject 10: Well, if you mean ... um [sic], what you call them [gestures x and y axis] I can't really

Interviewer: Like a chart ?

Subject 10: Yeah [sic], that goes up and down basically

Interviewer: OK, like a real time display

Subject 10: Yeah [sic]

Interviewer: Thats a cool idea, I like that

Subject 10: Yeah [sic]

Interviewer: See, this is what it's all about, getting people's opinions and input that helps us design things

Subject 10: Yeah

Interviewer: I thanks you so much. Thats it

Subject 10: Great

Interview 11

Interview date: February 15th, 2018

Interview location: QUT Gardens Point Campus - Orientation Week Stall

Interviewer: Clarence Baxter

Participant: Subject 11

Start time: 9:20 am

Interviewer: This is interview number 11 Thursday the 15th of the second at 9:20. So I'll get you just to grab hold of the device. That's the application there. It's called QUT Inspire. Whack [sic] the About button at the bottom there ... and that's what the real world device looks like when it's being used, so that guy's inhaling and as he does those balls raise to demonstrate inspiratory effort and to encourage effort. So just whack [sic] that top left hand button there, yep [sic] to take you back to the menu there. Choose Practice or demo. Now you're going to get four different display styles to look at and choose from. Tap to begin. Now hold the phone up to your mouth and then like slurping spaghetti [inhales], breathe in while watching the display.

Subject 11: [Attempts inhalations]

Interviewer: Did you see the ball lift in response to your breath ?

Subject 11: Yeah [sic]

Interviewer: Right, try it once or twice more to see the effect

Subject 11: [Attempts inhalations]

Interviewer: OK, you've got three other buttons below there, try the second button which gives you a different display style

Subject 11: [Attempts inhalations]

Interviewer: And take a breather. That's a pun but you know what I mean

Subject 11: Yeah [sic]

Interviewer: Try the third one

Subject 11: [Attempts inhalations]

Interviewer: OK, so a different style of display there, and now try the fourth one

Subject 11: [Attempts inhalations]

Interviewer: Now if there is too much jumpiness [sic] going one, that button there will allow us to damp the sensitivity down. Try that now

Subject 11: [Attempts inhalations]

Interviewer: Not even trucks going past will stop us [laughs]

Subject 11: [Attempts inhalations]

Interviewer: So if you want to go back and review any of those by all means do. We'd like you to have a think about which of those display types is the best of the four for displaying inspiratory effort

Subject 11: [Attempts inhalations] I think I like the shrink one

Interviewer: The shrinking ball one ?

Subject 11: Just cause it gives you a just better measure of like the sight, you see it decreasing. Like the one ball compared to the three ball, the three ball is better just I don't know ... it gives you like a bar. Ah [sic] ... the bar ... [attempts inhalation] ... its a bit glitchy [sic] but, that's why I just prefer the shrink one just cause [sic] [gestures resize of shrinking ball with hand]

Interviewer: You think there's a big contrast when it's inflated and when it shrinks

Subject 11: Yeah [sic]

Interviewer: Now out of the four, which one is the worst ?

Subject 11: Um [sic], the worst would have to be ... [attempts inhalation] ... probably the ball, just the single

Interviewer: And why's that ?

Subject 11: Ah, just cause [sic] ... I think the best is shrink. the three ball is better than the one ball just cause it [sic] I dunno [sic] just in my eyes you see a kind of graph kind of thing

Interviewer: You see more happening, or more in response to what you're ...

Subject 11: The bar gives you more like a bar graph you know, and the ball kind of just, I dunno [sic] just ...

Interviewer: So its your least favourite. Last question, we are on the home stretch. Can you think of any other ways that we can display breathing effort ?

Subject 11: ... Like you an either make the three balls it kind of makes[sic] like a bar, you can make a kind of graph thing rise or fall

Interviewer: OK, so like a real-time graph

Subject 11: Yeah [sic]

Interviewer: Thats a wonderful idea

Subject 11: The shrink one's pretty good you can even just for aesthetics you can make a picture of a lung just decreasing

Interviewer: Like that [gestures to a lung model displayed on table] ?

Subject 11: Yeah [sic] [laughs]

Interviewer: So thats a right lobe [points at model] so something like that or just the outside

Subject 11: Yeah [sic]

Interviewer: Excellent imagination, I love that

Subject 11: And just something we can understand like a little animation of the lung

Interviewer: So you're saying its most important that people can see responsiveness in what they are seeing in that graphic with their breathing effort. OK, I thank you so much for your time with the interview, cool

Interview 12

Interview date: February 15th, 2018

Interview location: QUT Gardens Point Campus - Orientation Week Stall

Interviewer: Clarence Baxter

Participant: Subject 12

Start time: 10:41 am

Interviewer: This is interview 12 at 10:41 on Thursday the 15/2. Just whack the Practice Demo button. Have a quick read of that text there. So hit Tap to begin, and then like slurping on spaghetti [inhales] with that microphone held close ... are you finding that that noise is keeping it up in the air ? There is a dampener there which will minimise the effect of background noise. So hold it up close ... like slurping spaghetti [inhales] ... may have to go harder or closer. There you go

Subject 12: [Attempts inhalations]

Interviewer: So it's an incentive to breathe deeply and a lot. Have a go on the left hand side, there are four buttons. Try the second button down

Subject 12: So breathe in and out ?

Interviewer: What really matters is the inhalation

Subject 12: I cant inhale [sic] continuously

Interviewer: No don't, just as you feel comfortable with

Subject 12: OK, Im sorry ... [Attempts inhalations]

Interviewer: So there we go, hit the second button to try a three ball display

Subject 12:[Attempts inhalations]

Interviewer: Try a little bit closer

Subject 12:[Attempts inhalations] ... I just blow out more than I blow in ... [Attempts inhalations]

Interviewer: And with that, I'll just drop the sensitivity down so that your breaths in can be registered. Better ?

Subject 12:[Attempts inhalations]

Interviewer: With that background noise there, try that now

Subject 12:[Attempts inhalations] ... Like that ... [re-oriens the phone to landscape]

Interviewer: No, that will just turn it on it's side. You need to be able to see it as an incentive while it all happens [reorientes the phone to portrait] ... it reorientes as you move around ... there you go, there we go

Subject 12:[Attempts inhalations]

Interviewer: Great, try the third one which is a shrinking ball ... as the noise goes up the ball shrinks

Subject 12:[Attempts inhalations] ... I can't

Interviewer: That's the background noise again. Here we go [adjusts sensitivity slider] ... try that. The objective in this instance is to make that ball shrink

Subject 12: As small as possible

Interviewer: As small as you can

Subject 12: Yeah [sic] ... [Attempts inhalations]

Interviewer: So clinically the incentive to do that deep breathing is supposed to raise of lift mucus normally that would be cleared by coughing, if you had a chest full of mucus that would just encourage you to cough it up . One last one to try, we're on the home stretch. That last display

Subject 12: [Attempts inhalations] ... You said not to force it but I feel ...

Interviewer: As that background noise changes what we'll do is just bring that down a bit [adjusts sensitivity slider]. Try that now

Subject 12: [Attempts inhalations]

Interviewer: You're seeing it with the effect of the background noise, yeah [sic] ?

Subject 12: Yep [sic]

Interviewer: Now from what you've seen from those four displays, which would you say is the best of the four at displaying breathing effort ?

Subject 12: Um [sic] ... probably the third one ... more feedback

Interviewer: More feedback, that's the shrinking ball one. Which one is the worst ?

Subject 12: So I said that the three ball one was the best

Interviewer: The three ball one was the best ?

Subject 12: Probably the shrink one I guess

Interviewer: The shrink one is the worst. And can you think of any other way that we can display breathing effort to incentivise [sic] someone to breathe deep ?

Subject 12: Um [sic] ... not at the moment

Interviewer: That is OK. Thanks for your help

Interview 13

Interview date: February 15th, 2018

Interview location: QUT Gardens Point Campus - Orientation Week Stall

Interviewer: Clarence Baxter

Participant: Subject 13

Start time: 11:02 am

Interviewer: Interview 13 at 11:02 on Thursday the 15/2. I'll just get that unlocked for you. There we go. That's the application called QUT Inspire and it's just running within a browser there. Sorry, I'll just put that under there. Hit the bottom button, the one labelled About. And that shows you someone using one of those real world incentive spirometers. Notice that as he inhales, those balls levitate. The idea is that that is supposed to be an incentive to make you inhale deeply. What we've found is that by keeping your lips a small diameter like you're inhaling spaghetti [inhales], that gives you the noisiest highest flow. You can inhale and exhale, exhaling actually reduces your lung function. When you inhale, that's when your chest acts like a bellows and opens up - that's the therapeutic part of the technique. Just use that QUT button to go back to the main menu. Now let's hit the Practice or demo button and it is almost set to go. In a moment, when you do tap to begin with that tap button there, hold the phone up close to your mouth - about a centimetre or two, five centimetres away [inhales], inhale deeply and watch to see what happens to the graphic display after that. So just tap Tap to begin

Subject 13: [Attempts inhalation]

Interviewer: Excellent, and you can hear the background noise from other folks here is keeping that ball in the air. What we are going to do is we are going to dampen the sensitivity of the microphone a bit [adjusts sensitivity slider].

Subject 13: [Attempts inhalation]

Interviewer: And that's all you, good. Take a break and take a breather. Can you see how that's work ... work to actually do that. For our purposes you won't need to strain that hard to do that, just a normal breath in it will detect [sic]

Subject 13: Yeah, it easy to ...

Interviewer: Yesterday we had a band playing across from us and I had that damped all the way and it still worked. We designed it around hospital wards that are quite noisy. You need to be able to dim that background noise otherwise it wont work. Try that second button there labelled 3 ball. Give that a go

Subject 13: [Attempts inhalation]

Interviewer: Take a breather for a sec [sec] and then try the third one, shrink

Subject 13: [Attempts inhalation]

Interviewer: So you can see what's going on there, eh [sic]

Subject 13: Yeah, it's shrinking inside the dotted line, yeah [sic]

Interviewer: One last one to have a look at. Give that a go

Subject 13: Whats that .. radio frequencies [referring to Bar display]

Interviewer: What that ... LED sound meter

Subject 13: Yeah [sic] that

Interviewer: Reminds me of Star Trek - the medical bay

Subject 13: Yeah, those ones yeah [sic] ...[Attempts inhalation]

Interviewer: Now if you want to go back and review any of those other ones. Have a look around, but in a moment I'll ask you what the best and worst displays are

Subject 13: [Attempts inhalation]

Interviewer: Now crunch time. Which do you think is the best display for as [sic] an incentive for breathing in deeply?

Subject 13: I'll just try the third and first ball again cause [sic] it's between those two ... :

[Attempts inhalation] ... Um [sic] ... I would say maybe the three ball

Interviewer: And why's that ?

Subject 13: Because you can see how the balls arise, going up, and then it's like a wave so you can ...

Interviewer: So its the wave, its like a real time thing

Subject 13: Yeah [sic]

Interviewer: Now, next question. Second last question. Which is the worst of the displays ?

Subject 13: Bar, the bar

Interviewer: Bar's the worst, and why ?

Subject 13: I don't know ... it's too sensitive but its very like as you said cause I like the wave so it sort of shows the breathing realistically. The bar is sort of like just up [sic] straight away

Interviewer: It's too harsh ?

Subject 13: Yes, it's too harsh, too sensitive

Interviewer: OK, now finally, you are on the home stretch now. Can you think of any other way we can display breathing effort ?

Subject 13: Well ... um ... [laughs] ... you can maybe do a ah [sic] maybe water [gestures like a breaking wave]

Interviewer: Like a flow, like a waterfall ?

Subject 13: Maybe, or like an actual wave

Interviewer: So that's like a wave display and the more intense or harder you are breathing in the higher the wave

Subject 13: Yeah [sic]

Interviewer: It gives you an indication, you are after that flow

Subject 13: Yeah [sic]

Interviewer: OK, that great imagination, that's a good idea. I thank you so much for your help with our study

Interview 14

Interview date: February 15th, 2018

Interview location: QUT Gardens Point Campus - Orientation Week Stall

Interviewer: Clarence Baxter

Participant: Subject 14

Start time: 12:13 pm

Interviewer: Interview number 14 at Thursday the 15/2 at 12:13 pm. OK, if you just hit the bottom button, the About button there

Subject 14: Yes

Interviewer: What that gives you is a quick look at what an incentive spirometer looks like in real use, notice the guy is taking breaths in. With one big breath in he's lifting one and then multiple of those spheres in the air [inhales] with his breath. So seeing that is supposed to be an incentive to breathing in deep. OK, tap that top left blue button there, the QUT button and, read thru that first. Go to Practice or demo mode. So what's going to happen is that the microphone is going to pick up your breath in and it's going to display that as deflection of that graphic. Just tap the button there to begin. Pick up the phone. Notice how the background noise is setting it off, that noise out there

Subject 14: Yeah [sic]

Interviewer: What this will do is dampen that background noise [adjusts sensitivity slider]

Subject 14: Now what I have to do is take a breath ?

Interviewer: I'm just going to make it less sensitive so background noise won't affect it. There we go. So just hold it up to your mouth like that, about a centimetre or two away, and when you breathe in, like you are eating spaghetti [inhales]

Subject 14: OK

Interviewer: Pick up the phone, hold it up close to your mouth like that

Subject 14: How far away ?

Interviewer: About one to two centimetres

Subject 14: [Attempts inhalation]

Interviewer: Now can you see the ball move ?, Try again

Subject 14: [Attempts inhalation]

Interviewer: Try again [adjusts slider]. Thats being cruel. Try that now

Subject 14: [Attempts inhalation] Try again ?

Interviewer: You can feel it with the real devices, you go [inhales]

Subject 14: Yeah the ball is ... I can go again ... [Attempts inhalation]

Interviewer: The prescription usually is 10 goes every hour, and do it every hour. Now with that there are controls on the left hand side, try different displays

Subject 14: Will you so me how to do it

Interviewer: try the 3 ball display, second button

Subject 14: [Attempts inhalations]

Interviewer: Now, take a rest. I don't want you to pass out on me. Now hit the third button down and thats a different display

Subject 14: Can start ?

Interviewer: Yeah

Subject 14: [Attempts inhalations]

Interviewer: So as you can see your breath in shrinks that balloon down, shrinks that ball down. Give that another go

Subject 14: [Attempts inhalations] ... and what about bar ?

Interviewer: Try the last one, try bar. Hit that one again

Subject 14: [Attempts inhalations]

Interviewer: Now if you want to go back and review any of the others, by all means do.

Just with any of those buttons there

Subject 14: [Attempts inhalations]

Interviewer: Which of those four provides the best incentive to breathe in ?

Subject 14: Um [sic] ... from my observation I think that the bar was the best

Interviewer: OK, and why was the bar best ?

Subject 14: I saw the difference between when I took a breath and when I didn't took [sic]
so bar chart is the best.

Interviewer: OK. Whats the worst ?

Subject 14: I think the one ball, only because I couldn't see any changes too much

Interviewer: Gotcha [sic]

Subject 14: The bar was the best

**Interviewer: So you say one of the biggest factors is being able to see a very
pronounced change**

Subject 14: Yes, it was much significant with the bar chart

**Interviewer: Last question. Could you think of any other way that we can display
respiratory effort ?**

Subject 14: Um [sic], you ask me about the other way ? How to measure it ?

Interviewer: Or show it

Subject 14: Uh huh [sic] ... um ... I think ... um ... the way for potential person who are
taking for the research [sic] is going to be better when you show the opposite side, how
looking [sic] is the process and you see how it's change [sic] during this process.

Interviewer: So more of a quantitative display ? A meter display or values

Subject 14: From the left side, for example you have this one ball, maybe a good example is
bar chart. Now we see when I take the [inhale] ... my breath, and the other side, the right
side - this is the normal bar chart

Interviewer: and you can do comparisons ?

Subject 14: Yeah [sic] and and I can compare my persuasion

Interviewer: I love hearing people's imaginations, thats a great idea

Subject 14: But my english is not that good

Interviewer: It was great for our purposes. I thank you so much

Interview 15

Interview date: February 15th, 2018

Interview location: QUT Gardens Point Campus - Orientation Week Stall

Interviewer: Clarence Baxter

Participant: Subject 15

Start time: 12:39 pm

Interviewer: Interview number 15 Thursday the 15/2 at 12:39. I'll just get you to whack [sic] the About button. What you'll see is an example of someone using a real world incentive spirometer, the same device that we have here. So note that he's taking deep gradual maximal inhalations and that's the analogy, it's lifting those three balls, providing an incentive to breathe deeply. We don't you to bust your chops [sic], just try a normal breath in against each of our display types. Just tap that QUT icon thing there

Subject 15: Yep [sic]

Interviewer: and choose the Practice Demo mode. The graphics took like a half an hour to do, that's was incredible. Now in a moment what we'll find is when we turn the thing on by tapping here, all the background noise here will make it jump like crazy, so [inaudible] ... just tap that little microphone button there, and about three-quarters of the way slide that [sic] [adjust sensitivity slider]. Now you try breathing around that, there you go. It will be your breath that sets it off rather than the noise. We may need to adjust that again, so. We might just bring that a little way [adjust slider]. Now just hold that to your mouth about this far away, around about three to five centimetres. Down the bottom there, yeah [sic]. Breathe in like you are slurping spaghetti.

Subject 15: [Attempts inhalations]

Interviewer: There we go. Give it a couple of goes but have a breath between each

Subject 15: [Attempts inhalations]

Interviewer: Yesterday we had this with two bands playing around it [laughs]

Subject 15: Well done ... [Attempts inhalations]

Interviewer: Now, when you've had a bit of a breather, have a look at the second button down there labelled three ball. Give that a go

Subject 15: [Attempts inhalations]

Interviewer: We had hospital wards in mind with it with trolleys that go past {background trolley noise}. So you've had a look at the one ball and three ball display. Choose the third button which is the shrink button. Give that a burl [sic]

Subject 15: [Attempts inhalations]

Interviewer: You're on the home stretch now. One last one to go - the bar button

Subject 15: [Attempts inhalations]

Interviewer: Take a breather when you are done. And if you want to you can review any of those four that you like, but have a think about first off which of those four displays do you think best incentivises breathing effort, the best incentive to breathing in

Subject 15: Um ... I'm not sure about incentive ... I thought the shrink is a fairly good display, um [sic] ... but I also feel like the balls are a little bit touchy, maybe it's partially the background noise but ...

Interviewer: With the shrink in particular, what is it about that that makes it stand out as better than the other three ?

Subject 15: I don't know but it seemed to be a bit more gradual progression

Interviewer: Gradual, so you could see progressive movement in it

Subject 15: Yeah [sic]. I think progressive is important to be able to see what's going on

Interviewer: OK

Subject 15: I suppose

Interviewer: Excellent. Now at the other end of the poles, which is the worst of those four displays ?

Subject 15: I'd probably go with the single ball um ... simply because it just doesn't really have enough um [sic] ... I feel that the bar was also pretty good ... ah [sic] ... although it was

pretty sharp ... um [sic] ... but having like a multiple bar would be good. I think it would be
good for a different power intensity level

Interviewer: You started to answer my last question. So with that um [sic] ... out of those four given the problem of background noise , the shrinking ball was the best, the single ball was the worst. Can you think of any other ways, and you started to mention a couple, any other ways we could display respiratory effort ?

Subject 15: Yeah [sic], probably um [sic] ... as with the three balls to try and just basically a variable display so you can see what's done really quickly and easily at one level when it's really really hard to move um ... and I think that also would help , possibly even an extra one more than three. as that way

Interviewer: Its more of a baseline that you see extended beyond that

Subject 15: Yeah [sic]

Interviewer: OK. That's imagination that I am devoid of. Well done. Thank you so much for your help with this

Interview 16

Interview date: February 15th, 2018

Interview location: QUT Gardens Point Campus - Orientation Week Stall

Interviewer: Clarence Baxter

Participant: Subject 16

Start time: 1:00 pm

Interviewer: Interview number 16 at Thursday the 15/2 at 1:00 pm. So, we'll just put that back up there. So just whack that blue button to take us back to main menu [sic]. Have a look at the last option labelled 'About'.

Subject 16: OK

Interviewer: What that shows you is someone actually using a physical incentive spirometer

Subject 16: Oh yeah [sic]

Interviewer: So inhalations cause these spheres to raise. That leads to gradual maximal inhalations [inhales]. We don't require anything that vigorous from you

Subject 16: OK

Interviewer: Just normal inhalations, normal breaths in will do fine

Subject 16: Alright, OK

Interviewer: There's four displays to look at

Subject 16: Alright

Interviewer: So just use that QUT button once again. Click Practice or demo. So what you'll see is the first of four displays, yep [sic]. Now what you'll find is that will dance around without you doing a thing because of all the background noise. You think of this in wards of hospitals as well

Subject 16: OK, yeah [sic]

Interviewer: Now what I've got there is a damping control

Subject 16: Yes

Interviewer: Move to there [adjusting sensitivity slider]. Try that now. Hold that up to your mouth about a centimetre or two away, the bottom of the phone so that's where the microphone is, and like slurping spaghetti [inhales] take a breath in

Subject 16: Is that mic going to be on ? [mic icon on screen]

Interviewer: What we'll do is just slide that to ... it doesn't want to slide for me. If you could just slide that back two thirds of the way. Try that now.

Subject 16: [Attempts inhalations]

Interviewer: There we go, so if you hold that about a centimetre away from the edge of the phone there, and like slurping spaghetti [inhales]. No, it's still a bit

Subject 16: oh [sic] OK

Interviewer: Bring it back more that way so it's still a little bit touchy [adjusts slider]. Yep. There we go, try that

Subject 16: [Attempts inhalations]

Interviewer: OK, you did most of that until it started coming back down. Try hitting the second one, which is a three ball display. Give that a burl [sic]

Subject 16: [Attempts inhalations] ... OK

Interviewer: Try the next one down which is a shrinking ball display

Subject 16: [Attempts inhalations]

Interviewer: And the last one, give that a burl [sic]

Subject 16: [Attempts inhalations]

Interviewer: If you want to have a fish around those four options. Just refresh your memory

Subject 16: [Attempts inhalations]

Interviewer: Have a think about the best and the worst of those, from your point of view

Subject 16: [Attempts inhalations]

Interviewer: What we are after is, first off, which of those displays provides the best incentive to breathe in deeply based on what you see ?

Subject 16: [Attempts inhalations]

Interviewer: Which do you think is best ?

Subject 16: I think the bar

Interviewer: OK, and why ?

Subject 16: It's just immediate, as in immediate response

Interviewer: Excellent, so it's the immediate response. Now to the contrary, what's the worst of those displays ?

Subject 16: Probably the shrinking one

Interviewer: And why is that the worst ?

Subject 16: Cause [sic] there's not a lot of visual stimulus or reaction. You can't see your effort as clearly as you can with the bar

Interviewer: OK. Just lastly, can you think of any other way we can represent or display breathing effort

Subject 16: Um [sic] ... just a curve on a graph

Interviewer: A curve, excellent idea, a curve on a graph, alright. That would be doable, that's great. Thank you so much for your help

Subject 16: You're welcome

Interview 17

Interview date: February 15th, 2018

Interview location: QUT Gardens Point Campus - Orientation Week Stall

Interviewer: Clarence Baxter

Participant: Subject 17

Start time: 1:26 pm

Interviewer: Interview 17 Thursday 15/2 at 1:26. So what you see there is a GIF file which represents someone using a real world incentive spirometer. He's breathing in gradually and maximally [inhales] and that's raining those balls in sequence to 600, 900 and 1200 um [sic] cc/sec. What I'll be asking you to do is just to use normal breaths in. Don't [sic] need to bust your chops [sic] cause you just want to trigger a reaction for the displays . Whack that top left hand button there to return to the menu, the QUT button. Yeah [sic]

Subject 17: That's alright

Interviewer: That's alright. There you go. Whack that Practice or Demo button at the top. Now, in a moment when you tap that to begin what will happen is that any background noise is going to set that off. We needed to think about hospital environments which can be 'clanky' [sic] so once it starts what we'll do first off is use that button there to trigger a slider which allows you to dampen the background noise. So just whack that "Tap to begin" button. See that sampling frequency across the bottom and how it's going nuts. That Microphone there. Now bring that slider across about two thirds to the right. That should be cool. There you go. There's enough now so it's just your noise that does it. Now holding it close about a centimetre or two away from your mouth, the microphone's in there. Breathe in like you are slurping spaghetti.

Subject 17: [Attempts inhalations]

Interviewer: And look to see that you get movement in the ball there. So that's an incentive to breathe in. Yesterday at Kelvin Grove we had two bands playing and that still worked.

Subject 17: Fantastic

Interviewer: Try that second button down. It's a different display, give that a burl [sic]

Subject 17: [Attempts inhalations] ... Do they go up separately or all at the same time ?

Interviewer: At this stage they go up simultaneously but I've got more gravity on the last one so it drops first

Subject 17: Yep [sic]

Interviewer: All the analogies are gaming analogies for a programmer

Subject 17: Yeah [sic] [laughs]

Interviewer: So go the third button

Subject 17: [Attempts inhalations]

Interviewer: Is that a bit different ?

Subject 17: Yep [sic]

Interviewer: Try the last one. You are on the home stretch

Subject 17: [Attempts inhalations]

Interviewer: You can go back and review any of the other three, by all means do. Have a think about which of those is the best and worst way to display an incentive for breathing in deeply

Subject 17: I think the three ball, if you could apply gravity in a way that's calibrated and similar to that

Interviewer: OK, so on the lift up you get a graduated lift up

Subject 17: Yeah [sic], a graduated lift so that the harder you breathe in you get

Interviewer: OK

Subject 17: That would also represent that with more accuracy for medical professions

Interviewer: Gotcha [sic]. OK so if that's the best of the ways, which is the worst of the four ?

Subject 17: I'd say the shrinking. Maybe it's just too small [gestures degree of movement/travel with thumb and index finger]... [Attempts inhalations]

Interviewer: Someone just referred to that as “cat's bottom” view [laughs]

Subject 17: I think three ball, then bar and then shrinking ball the worst

Interviewer: OK, so just hold off or a second. Just to finish off our chat, can you think of any better way to display breathing effort ? And you mentioned having the three ball having a staggered lift almost

Subject 17: Yeah [sic], that would be my preference

Interviewer: Excellent idea. So many things I didn't think of. That's fantastic. I thank you so much for that

Interview 18

Interview date: February 15th, 2018

Interview location: QUT Gardens Point Campus - Orientation Week Stall

Interviewer: Clarence Baxter

Participant: Subject 18

Start time: 1:33 pm

Interviewer: Interview 18 on [sic] Thursday the 15/2. It is 1:33. So same deal again.

You saw the little demonstration view of the guy using it in the GIF file. That's the first of four displays there, that single ball display.

Subject 18: Yep [sic]

Interviewer: We might adjust the slider there to make it more or less sensitive to suit the background noise, but if you're happy to give it a go.

Subject 18: Sounds good

Interviewer: Breathe in like you are slurping on spaghetti, and that actually creates more pressure as you do the inhalation. There's almost a Valsalva manoeuvre in what's going on as you do the inhalation.

Subject 18: Cool ... [Attempts inhalations]

Interviewer: You look at pulsus paradoxus when you actually get a pulse paradox as you do it

Subject 18: I must be dead [laughs]. Now it's moving

Interviewer: Slide that back to the left [adjusts sensitivity slider]. It's a standard HTML slider and sometimes it's really hard to activate.

Subject 18:[Attempts inhalations]

Interviewer: Cool. So try the three ball one

Subject 18:[Attempts inhalations]

Interviewer: Tap the next one Just don't think about cats [laughs] [overheard from last interview]

Subject 18: [Attempts inhalations]

Interviewer: Take a breather. Now with that, have a think about which of those is the best that you've seen in terms of incentivising a deep breath in

Subject 18: Yep [sic], definitely the three, and I'd agree with Dylan that making it come up joined would be good.

Interviewer: And that wouldn't be hard. At the moment I just set gravity on the third ball and it settles faster on the way down. The objects they refer to as sprites and sprites are like classes, you can apply things to one or multiple in a box, so it's doable. Cool. Which is the worst of those displays ?

Subject 18: Um [sic] ... I reckon the bar

Interviewer: The bar, and why's that ?

Subject 18: Um [sic] ... cause it's less sort of engaging or entertaining

Interviewer: It's just a bar ? [laughs]

Subject 18: Yeah [sic]. It's just a bar whereas these have got balls, you'd just be a lot more familiar with the balls

Interviewer: OK, finally can you think of any other way or different ways [sic] to display breathing effort. You mentioned that staggered acceleration for the three ball one, that's a good idea

Subject 18: Yeah [sic], I think that's about it. Yeah [sic]

Interviewer: Cool. Gentlemen thank you so much

Subject 18: Not a problem

Interview 19

Interview date: February 15th, 2018

Interview location: QUT Gardens Point Campus - Orientation Week Stall

Interviewer: Clarence Baxter

Participant: Subject 19

Start time: 1:52 pm

Interviewer: Interview number 19 [sic] Thursday the 15/2 at 1:52 pm. So that is what the QUT Inspire app looks like. Hit the “About” button at the very bottom, the very last of those buttons and that gives you an example of what the real world device looks like. So that guy’s doing a gradual maximal inhale [inhales] all the way in. We won’t be asking you to do that, just normal breaths will do fine. OK, so I’ll just take us back to the main menu again. We’re going to be using the practice or demo mode. So that’s the first of four display types that we’ll be using. When I tap that to begin the process, all the background noise is going to set that off like crazy. So before we get under way, what I am going to do is I am going to [sic] move that slider to there [adjusts sensitivity slider]. Now, hold that up to your mouth and breathe in like you are slurping spaghetti.

Subject 19: [Attempts inhalations]

Interviewer: Didn’t move because I made the sensitivity too much. [adjusts sensitivity slider]. Give that a go now

Subject 19: [Attempts inhalations]

Interviewer: And that moved for you ?

Subject 19: Yes ... [Attempts inhalations]

Interviewer: Hit the second button down, that’s a three ball display. Give that a go.

Subject 19: [Attempts inhalations]

Interviewer: OK, the third one, give that a burl [sic]

Subject 19: [Attempts inhalations]

Interviewer: So as you breathed in, the ball contracted

Subject 19: Yes

Interviewer: Try the last one

Subject 19: [Attempts inhalations]

Interviewer: So that's four displays. You can go back through and review them if you want ... which of those was the best display do you think to encourage deep inhalations ?

Subject 19: I think the bar

Interviewer: OK, and why's that ?

Subject 19: Um [sic] ... Most people know about graphs and charts from early childhood

Interviewer: OK, good observation. Which of those is the worst display ?

Subject 19: Um [sic] ... the shrinking one

Interviewer: And why's that ?

Subject 19: Um [sic] ... because you can't tell how much it's going to shrink all the way

Interviewer: OK, now have a think. Can you think about any other ways to display respiratory effort.

Subject 19: ... No

Interviewer: That's OK. Thank you so much for taking part

Subject 19: Thank you

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