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Original Paper

Clinician perceptions of a prototype wearable exercise biofeedback system for orthopaedic rehabilitation: a qualitative exploration.

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Abstract

Objectives: To explore the opinions of orthopaedic healthcare professionals regarding the opportunity and challenges of using wearable technology in rehabilitation, and understand the perceived impact of an exemplar exercise biofeedback system that incorporates wearable sensing, involving the clinician in the user-centred design process.

Design: A qualitative study consisting of one-to-one semi-structured interviews, including a demonstration of a prototype wearable exercise biofeedback system. Interviews were audio recorded and transcribed, with thematic analysis conducted of all transcripts.

Setting: The study was conducted in the orthopaedic department of an acute private hospital.

Participants: Ten clinicians from a multidisciplinary team of healthcare professionals involved in the orthopaedic rehabilitation pathway participated in the study.

Results: Findings suggest that there is currently a challenge in gathering timely and objective data for monitoring of patients in orthopaedic rehabilitation. Whilst there are challenges in the design and implementation of biofeedback systems, clinicians perceive significant value in the use of wearable biofeedback systems such as the exemplar demonstrated for use following total knee replacement.

Conclusions: Clinicians see an opportunity for wearable technology to continuously track data in real-time, and feel that feedback provided to users regarding exercise technique and adherence can further support the patient at home. There was perceived value in the prototype system demonstrated to participants which supports the ongoing development of such exercise biofeedback platforms.

Keywords

biofeedback; biomedical technology; exercise therapy; orthopedics; mobile health; qualitative

Strengths and limitations of this study

- There is a need for innovative solutions to counteract poor adherence and increasing pressure on patient self-management, and a user-centred design approach with key stakeholders is recommended.
- Few studies have investigated clinicians' perceptions of exercise biofeedback systems and offered the opportunity for healthcare professionals to contribute to the user-centred design process.
- This study uses qualitative methods to allow for an in-depth exploration of participant opinions, yet results are of a subjective nature and are not necessarily generalisable.
- Study participants were recruited from a number of different disciplines across nursing and therapies, although from a single healthcare institution.

Introduction

It has been estimated over 10% of the population will need a total knee replacement (TKR) by eighty years of age [1]. Home-based exercises following TKR form the mainstay of rehabilitation, with typical physiotherapy programmes consisting of exercises targeted to increase strength, range of movement and function, as well as reduce post-operative complications [2]. However, adherence rates to home-based exercises are alarmingly low, with patients reporting various reasons for non-compliance with the prescribed programme [3, 4]. Patients often report a lack of confidence following discharge from hospital, insecurity surrounding their post-operative expectations, and poor recall of exercise technique [5]. Poor performance of exercise technique such as insufficient range of motion, alignment, or compensatory movements may impact on the efficacy of the rehabilitation programme, and hence the outcome of the procedure [6]. Poor adherence may even lead to further complications, readmission to hospital, additional healthcare costs and prolonged pain and disability for the patient [7].

The lack of support reported by patients may also result from the changing nature of joint replacement surgery globally, moving towards value-based care and a drive for reduction in the length of hospital stay, placing a greater emphasis than ever on the self-management skills of the patient. Healthcare providers need to make the most of the opportunity that new and emerging technologies present [1, 8], and connected health solutions may provide the opportunity to bridge this gap between the home and clinician [3]. With the advancement of sensor technologies and mobile computing platforms, it is now possible to empower patients to self-manage more effectively, acquire data with far greater efficiency, and use this to support the clinician in making more objective, data-driven decisions about clinical care [8]. Inertial measurement units (IMUs) can be used to measure the three-dimensional position of a limb segment and have been shown to be a cost-effective, accurate method of assessing exercise technique in rehabilitation exercises [9–12], presenting the opportunity to build such a classification system into a connected health intervention.

When designing a connected health intervention, in order to promote user-engagement and maximise impact, an iterative design process involving consultation with key stakeholders is recommended throughout the design and development phase to optimise the effectiveness of the system [13, 14]. As well as the end-user, clinicians should be encouraged to participate in the design and evaluation of connected health solutions to ensure clinical acceptability [15]. However, few studies have assessed the opinions of clinicians regarding wearable technology [16], or have provided the opportunity for rehabilitation professionals to offer feedback in the design process of such systems.

The aim of this study was two-fold. In the first instance we sought to perform an exploration of clinicians' perceptions of wearable technology, the opportunities that this technology may provide in their area of expertise, and to identify what methods are currently employed in clinical practice to provide monitoring and feedback of patients following knee replacement surgery. Following this, clinicians were provided with a demonstration of a prototype system for exercise biofeedback after TKR, and their perceptions of its potential use in the clinical setting were evaluated.

Methods

Patient and Public Involvement

No patients or members of the general public were involved in this study.

Participants

A total of 10 participants (6 females, 4 males, age: 36.5 [SD 9.06]) from a variety of clinical disciplines (4 Physiotherapists, 2 Clinical Nurse Specialists, 2 Orthopaedic Assistants, 1 Occupational Therapist and 1 Staff Nurse) were recruited from a private hospital in Dublin, Ireland, and were involved in the care of patients in the orthopaedic joint replacement pathway within the hospital. Each participant signed a consent form prior to commencing the study, and the study protocol was approved by the Beacon Hospital Research Ethics Committee.

Experimental Procedure

Participants were required to attend a single hour-long session as part of the study. All interview data were recorded using a Dictaphone and an interview topic guide (Supplemental File 1) was constructed based on the main research questions and aims of the study, in order to ensure consistency between interviews [17]. Prior to introducing the concept and exemplar biofeedback system, and to prevent bias, a semi-structured interview was conducted with each participant to gain an understanding of what methods clinicians are currently using to monitor and provide feedback to patients, the perceived opportunities and challenges of connected health interventions, and their current knowledge of wearable technology. A demonstration of the exemplar wearable exercise biofeedback system was then provided, followed by a further semi-structured interview to identify the perceived impact and clinical implications of such a system.

Prototype Exercise Biofeedback System

A prototype has been developed consisting of a single IMU (Shimmer, Dublin, Ireland) and an Android application developed for a tablet computer to be used by the patient in their own home. The IMU is placed on the shin in a neoprene sleeve and is connected via Bluetooth to the Android application on the tablet. As the user exercises, the IMU streams sensor data to the tablet, and an on-screen avatar mirrors the movements and the repetitions are counted for each exercise. At the end of the set, the user is provided with feedback on their technique [11, 18], and if erroneous, advice on how to improve technique is displayed. Patient reported outcomes are captured on a regular basis and the user's progress is also presented graphically to track adherence. An illustration of the user setup is included in figure 1 with screenshot in figure 2.

Figure 1: User setup of biofeedback system with single IMU placed on the shin and associated tablet application.

Figure 2: Screenshot of Android application during exercise mode.

Data Analysis

Audio from interview recordings was transcribed and anonymised. Thematic analysis of the interview transcript took place with a grounded-theory approach [17]. The interview guide

was used to create an early coding template, which then developed and refined sub-themes following further data analysis, conducted by RA (Research Physiotherapist) and PS (Experienced Qualitative Researcher) [19]. A constant comparison approach was taken with regular cross-checking to ensure reliability of emerging sub-themes with a strong correlation between researchers [20]. Any outliers were discussed, and agreement reached, with data saturation agreed when no further themes were occurring in the interview data [17].

Results

A summary of results are reported below, additional quotations to support these results can be found in Supplemental File 2.

Current Methods of Monitoring & Feedback

Clinical practice at present tends to rely on a combination of objective and subjective markers. Participants spoke about the wide-use of range of motion measurement as a key objective marker following TKR. Additionally, markers such as swelling, pain and functional scores are used to monitor changes in the patient's condition.

> *Generally, I would manually take objective measures, traditional measures such as muscle strength, range of motion, and then some subjective ones as well, opinion based on movement quality.* [Physiotherapist]

However, participants commented on the lack of objectivity of assessing muscle strength, gait and exercise technique, with visual assessment and patient self-report forming the basis for ongoing monitoring.

> *Objective markers are few and far between and we're still reliant on the old clinical measures like range of motion, muscle strength - which if you're testing on an Oxford scale it's a very subjective thing.* [Physiotherapist]

Those participants working in the post-acute phase of care stated that feedback was primarily offered verbally, and it is not possible to offer other feedback between clinic appointments.

> *I guess just verbal feedback is our only option… but when they go home we're not giving them any feedback 'til they come back to the clinic.* [Physiotherapist]

Perceptions & Knowledge of Wearables

Participants were aware of wearable technology, with many stating they have used some sort of wearable device in their personal lives, yet discussion was almost exclusively on the application in the fitness space.

> *The apps on the smartphone that you have to have a phone in your pocket for the app to work and it tracks how many steps you've done... I know about Fitbit.* [Clinical Nurse Specialist]

Participants also discussed the motivational aspect associated with using a wearable device. They felt that as well as motivating the user to meet their goals, the opportunity to track their own data and analyse their results was of benefit.

> *You kind of got little rewards or prompts from it you know, 'congratulations you've done 5 days in a row' and I liked that.* [Occupational Therapist]

Drawbacks of such technology were also highlighted. One participant felt that it would not be beneficial for them to use wearables themselves, with others reporting the amount of choice being overwhelming, and questioning the validity of such measures.

> *How can it differentiate between height and weight, and I don't know that is always taken into account with some of these technologies.* [Clinical Nurse Specialist]

Opportunities & Challenges for Connected Health in Orthopaedic Rehabilitation

Participants were unanimous in agreement that there is an opportunity and wide scope for connected health interventions, including wearable and mobile technology, to play a role in orthopaedic rehabilitation.

> *I think there's definitely a place for it, because it's so much more in people's lives than ever. Lots of people like apps now and they like to tag into something, and if it can give more specific individual feedback then there's definitely a role for it to be a part of their progression, especially resulting in something that will rehab for months.* [Physiotherapist]

A number of potential features were highlighted that clinicians would consider useful, such as progress tracking, feedback, remote monitoring, regular range of motion measurement, and counting repetitions.

> *Even something like a Fitbit that showed a graph that you can go and check if they've actually done their exercise and if they've achieved their targets.* [Staff Nurse]

> *I love the idea of real-time feedback, the idea something can tell you you're doing something wrong immediately and help you correct it.* [Occupational Therapist]

Participants were also quick to point out the challenges of delivering healthcare solutions in this way. All participants interviewed stated that the usability of any technology would be a significant barrier to engagement that will need to be overcome.

> *I mean if the interface is difficult or if something, if errors keep occurring. I think the more simple a thing is and the more intuitive it is, the easier it will be from an uptake and ongoing compliance issue.* [Occupational Therapist]

Compliance with use of any connected health intervention was widely reported to be a challenge.

> *I think there are an awful lot of opportunities there but a lot of it comes down to patient compliance.* [Clinical Nurse Specialist]

There were additional challenges relating to the reliability and validity of any such technology, with discussion of aspects such as internet capability, bugs and glitches.

> *The technology actually working, how many times you know, the lack of Wi-Fi, computer crashing… I suppose they would be the huge elements.* [Clinical Nurse Specialist]

Data security challenges were also noted, with the potential for confidential healthcare data being accessed without permission.

> *One would have said data protection, that's always going to be your main challenge.* [Clinical Nurse Specialist]

Participants also spoke of the important balance in the patient-clinician relationship, and the need for technology to enhance the role of the professional, rather than attempt to replace the clinician. It was noted that such technologies need to work without shifting the focus away from the patient's own self-management.

> *So I would think with technology the person who has to be driving the connection is the patient.* [Clinical Nurse Specialist]

The final notable sub-theme to arise when discussing challenges of connected health systems, is the user's own ability and confidence with technology.

> *If you look at the elderly population that are primarily receiving joint replacements, are a lot of them au fait with? Some of them would be but presumably there are a large percentage who aren't au fait with iPads, iPhone and similar technologies.* [Physiotherapist]

However other participants offered counter arguments that this may not be the case compared to years gone by.

> *I suppose, a lot of people have the technology, that's not as much a barrier. It's so accessible now on smartphones and so many people have smartphones... I'm seeing 90-year olds using Skype and Facebook and I think that barrier is reducing.* [Occupational Therapist]

Perceived Impact of Exemplar System

Having completed a demonstration of the prototype exercise biofeedback system as described above, all participants perceived this system as potentially having a positive impact in orthopaedic rehabilitation. Every participant noted the ability to capture and track data in a manner that has not previously been possible as a major benefit. Participants were excited by the prospect of tracking and leveraging metrics such as adherence, difficulty, pain and mood to guide their decisions.

> *Then at least you can track as well, to see if they're actually using it at all. Because if they're not using it then they're likely not doing anything.* [Physiotherapist]

> *One of my favourite things about it is that you can score the difficulty, if somebody is scoring 5,5,5 then they're finding it too difficult but if they're soring 1,1,1 you can progress them on very quickly.* [Physiotherapist]

They also felt using this system would improve the outcome of rehabilitation. They suggested that if the patient was demonstrating greater adherence, this would be of benefit.

> *It'll improve the quality of the patient's rehab. So I think they will be more likely to follow more structured programmes when they have the visual feedback to do it.* [Physiotherapist]

> *I think they would rehab quicker and be more confident in their rehab, which is the best thing.* [Staff Nurse]

Through instilling added reassurance and motivation, clinicians felt that this system could improve the patient experience.

> *I think it will enhance patient confidence in their recovery… it's reassuring to know you're on track.* [Clinical Nurse Specialist]

Participants suggested this system could contribute to a more efficient healthcare system, both for the patient and the service provider.

> *… you're hopefully not going to need MUA's* (Manipulation under anaesthetic) *and that kind of thing because you're doing it right from the beginning.* [Staff Nurse]

> *As a patient, I would imagine that if I was doing my exercises correctly, I would need less appointment time with a physiotherapist… If I wasn't doing the exercises correctly, the physiotherapist might call me to go through how to do it, but if I'm doing my exercises correctly, if I'm reaching the goals I need to and the activity levels that I need to, why do I need to come in and see a physio?* [Clinical Nurse Specialist]

Challenges

Participants also felt that this increased efficiency could emerge as a challenge however, as there is a risk of the patient placing a reliance on the technology over the human. Although there was an acknowledgement from some that this would not be the case.

> *As long as I follow it… I wouldn't go and see the physio again.* [Orthopaedic Assistant]

> *It's not going to take the place of the therapist you know, but it just serves to really hammer home the message you're trying to get across to the patient.* [Physiotherapist]

A major challenge for such a system which was discussed by five clinicians, related to the accuracy of the data provided by the technology.

> *The worry that it won't be giving you the right information and then it's going to skew your thought process and that of others because you can only report on what you're being given.* [Physiotherapist]

Interviews highlighted the difficulty of tailoring an automated programme to the individual, with only a small number of standard exercises included in this system compared to the breadth of options prescribed in clinical practice.

> *My issue would be if we use this app after two weeks should we not be progressing their exercises so you're no longer going to be performing those exercises.* [Physiotherapist]

An interesting discussion evolved with a number of participants relating to what a system such as this would do for the responsibility of care, with some clinicians stating that they feel no amount of technology will promote self-management.

> *Some people would see that as a tool for assisting self-management, other people no matter how much education or technology you provide, will still see their recovery as incumbent on the healthcare professional looking after them.* [Clinical Nurse Specialist]

One feature of the remote monitoring aspect of the prototype system is to send an alert to the clinician if there is a concerning change in the data, but some participants stated that the responsibility of the clinician would have to be clearly defined in this instance, in order not to detract from the patient's own self-management.

> *I guess it depends who is responsible for their care… I wouldn't want alerts about patients who went home a week ago but are in 10/10 pain. I want to educate that patient and put that responsibility on them, the more we give patients the responsibility the better. By doing that alert it makes the patient more passive and we want to encourage the patient to take responsibility, educate them on taking steps like icing and taking pain medication, and then if it still doesn't settle down, then the patient needs to call. I think if we put the responsibility onto us we're leading down a dangerous path.* [Physiotherapist]

Discussion

Principal Findings

This study has found that clinicians see technology as having the potential to improve and assist the rehabilitation process, but there are numerous challenges involved in designing such solutions. Clinicians highlighted a need for a solution which deals with the issue of

exercise adherence and lack of support for patients at home [4, 5]. When presented with a demonstration of the prototype system, all participants felt that this type of technology has the potential to positively impact on the outcomes of orthopaedic rehabilitation. There was strong interest in the opportunity to track data and maximise the effectiveness of rehabilitation, yet it was felt that such systems can undergo further iterations to extend this impact.

Current clinical practice provides little opportunity for monitoring or feedback outside of the clinic. Patients with negative experiences of TKR have unmet needs regarding support and managing expectations [21], yet there is a heavy reliance on the patient's self-motivation at home. It was perceived by the participants that wearable devices offer the opportunity to improve self-motivation and achievement of goals through increased engagement. Participants also reported using a combination of objective and subjective outcome measures for monitoring, yet these measures are only captured at limited time-points and self-reported measures such as adherence can be unreliable [3, 22]. The results from this study would suggest there is benefit in capturing further objective outcome measures, such as movement quality, or accurate monitoring of range of movement and adherence remotely.

The findings suggest potential implementation challenges such as usability, data protection and reliability which are known to be problematic, with further investigation required [23–25]. Many researchers are investigating the technical feasibility of using wearable sensing systems to support rehabilitation [26–29], yet few have explored the opinions of the end-user to evaluate and guide the design of such systems [30]. This study builds on Papi et al's work [16] by going on to offer an exemplar biofeedback system for evaluation, and including the clinician in the user-centred design process.

Prototype System Evaluation

Most clinicians believed the demonstrated prototype would improve the quality of patient rehabilitation, and therefore the outcome of surgery, whilst many were excited by the opportunity to capture data in a more objective and timely manner than current practice. It is perceived that this system could increase adherence to exercise programmes by using evidence based interventions discussed in the literature to improve adherence in an automated manner [3, 31–33]. Interestingly, several participants felt this system had the potential to improve the efficiency of the healthcare system, by harnessing the data collected to make better use of appointment scheduling, which has been highlighted as a design requirement by healthcare professionals previously [15, 16]. Published research has shown the ability of IMU based systems to record and classify exercise technique [11, 18], and this study has highlighted the clinical applications of such work.

Challenges

There are however concerns that such a system could lead to a reliance on technology, rather than the clinician, but with design refinements and appropriate training, this tool has the ability to augment the clinician's decision-making process rather than seek to replace the human expert. There was also concern that this system might increase the responsibility clinicians have for their patients by sending alerts. Yet arguably, such a system may illustrate shortcomings in current practice, with a user who has not received sufficient education

regarding pain or management being highlighted. A clinician may consider a user educated in self-management and not wish for alerts, yet if this user continues to report severe symptoms, either the success of education is questionable or further assessment is required. When developing such systems, there is also a need to allow for customisation of exercise programmes from the clinician, with participants highlighting the variance between individuals, the need for a larger exercise library, and the desire to choose when progressions should be offered. The major challenge in the development of such a support system which harnesses machine learning technology including repetition counting and technique feedback is in ensuring the accuracy and reliability of the information provided to users. Clinicians were concerned that inaccuracy can lead to a lack of trust in the system, and has the potential to negatively impact user engagement. This study has shown the need for clear and transparent real-world validation and end-user evaluation of any such system prior to implementation, an aspect that is lacking in the current literature [25, 30].

Limitations

Due to the qualitative nature of this study, there are number of factors to consider when reviewing this research. All participants were provided with a demonstration of the prototype system on one occasion only. It is quite possible that with ongoing use, or given further time to reflect on the system, the participant's opinions may change. It is important to highlight that these results relate to perceived impact solely from the participants' own opinions, and in order to determine the objective clinical impact of such a system, further research needs to take place in the form of a longitudinal study assessing a variety of clinical outcomes. This sample was selected from a single institution in the private healthcare sector, and whilst this sample comes from a cross-section of the multidisciplinary team, it does not guarantee that the opinions provided reflect the wider population of rehabilitation professionals. Despite these limitations, this paper provides evidence to support the need, ongoing design and development, and use of such systems in clinical practice.

Future Work

Having now understood that there is a positive perceived impact for this system, future work will seek to deploy the platform as part of a pilot study with patients following TKR surgery. This work will seek to answer some of the questions posed by participants in this study relating to usability and engagement, while including the patient as well as the clinician in the design process to develop further iterations, prior to objective assessment of clinical impact and real-world validation.

Conclusions

Rehabilitation following joint replacement is complex and varied, yet there is a reliance on the patient's own self-management and motivation to maximise the effect of the home exercise programme, with little opportunity for expert monitoring, assessment or feedback outside of the clinic setting. A prototype system for interactive exercise biofeedback consisting of a single wearable sensor and an Android application was perceived to potentially have a positive impact on the rehabilitation of patients following knee replacement surgery. Clinicians were excited by the opportunity to continuously track data in real-time, and felt the exercise technique and adherence feedback would further support the patient in the home environment. Such systems need to be evaluated by clinicians as

well as patients as the end-users, alongside real-world validation of the technical aspects of any such platforms.

Contributorship

RA, PS, AD and BC conceived and designed the study. RA conducted the recruitment and data collection with the assistance of PS, AD and MN. AB contributed to the development of the prototype biofeedback system. RA and PS conducted the data analyses and drafted and revised the manuscript. All authors read and approved the final manuscript.

Competing Interests

The authors declare that there is no conflict of interest.

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Ethical Approval

The research ethics committee of Beacon Hospital approved this study (REF: BEA0065).

Data Sharing

No additional data available.

References

[1] Kremers HM, Larson DR, Crowson CS, et al. Prevalence of total hip and knee replacement in the United States. *J Bone Jt Surg Am* 2015; 97: 1386–9355.

[2] American Academy of Orthopaedic Surgeons. Total Knee Replacement Exercise Guide, http://orthoinfo.aaos.org/topic.cfm?topic=a00301 (2017, accessed 24 May 2018).

[3] Argent R, Daly A, Caulfield B. Patient Involvement With Home-Based Exercise Programs: Can Connected Health Interventions Influence Adherence? *JMIR mHealth uHealth* 2018; 6: e47.

[4] Bassett SF. The assessment of patient adherence to physiotherapy rehabilitation. *New Zeal J Physiother* 2003; 31: 60–66.

[5] Perry MA, Hudson HS, Meys S, et al. Older adults' experiences regarding discharge from hospital following orthopaedic intervention: A metasynthesis. *Disabil Rehabil* 2012; 34: 267–278.

[6] Friedrich M, Cermak T, Maderbacher P. The Effect of Brochure Use Versus Therapist Teaching on Patients Performing Therapeutic Exercise and on Changes in Impairment Status. *Phys Ther* 1996; 76: 1082–1088.

[7] Holden MA, Haywood KL, Potia TA, et al. Recommendations for exercise adherence measures in musculoskeletal settings: a systematic review and consensus meeting (protocol). *Syst Rev* 2014; 3: 10.

[8] Caulfield BM, Donnelly SC. What is connected health and why will it change your practice? *Qjm* 2013; 106: 703–707.

[9] Burns A, Greene BR, McGrath MJ, et al. SHIMMER^{TM} – A Wireless Sensor Platform for Noninvasive Biomedical Research. *IEEE Sens J* 2010; 10: 1527–1534.

[10] Giggins OM, Persson UM, Caulfield B. Biofeedback in rehabilitation. *J Neuroeng Rehabil* 2013; 10: 1.

[11] Giggins OM, Sweeney KT, Caulfield B. Rehabilitation exercise assessment using inertial sensors: a cross-sectional analytical study. *J Neuroeng Rehabil* 2014; 11: 158.

[12] O'Reilly MA, Whelan D, Ward T, et al. Technology in Strength and Conditioning: Assessing Bodyweight Squat Technique With Wearable Sensors. *J Strength Cond Res* 2017; 31: 2303–2312.

[13] Michie S, Yardley L, West R, et al. Developing and evaluating digital interventions to promote behavior change in health and health care: Recommendations resulting from an international workshop. *J Med Internet Res*; 19(6).

[14] Shah SGSS, Robinson I. Benefits of and barriers to involving users in medical device technology development and evaluation. *Int J Technol Assess Health Care* 2007; 23: 131–7.

[15] Bergmann JHM, McGregor AH. Body-Worn Sensor Design : What Do Patients and Clinicians Want ? *Ann Biomed Eng* 2011; 39: 2299–2312.

[16] Papi E, Murtagh GM, McGregor AH. Wearable technologies in osteoarthritis: a qualitative study of clinicians' preferences. *BMJ Open* 2016; 6: e009544.

[17] Ritchie J. *Qualitative research practice: a guide for social science students and researchers*. 2nd ed. Sage Publications Sage CA: Los Angeles, CA, 2014.

[18] Bevilacqua A, Huang B, Argent R, et al. Automatic Classification of Knee Rehabilitation Exercises Using a Single Inertial Sensor : a Case Study. In: *2018 IEEE 15th International Conference on Wearable and Implantable Body Sensor Networks (BSN)*. IEEE, 2018, pp. 21–24.

[19] Fereday J, Muir-Cochrane E. Demonstrating Rigor Using Thematic Analysis: A Hybrid Approach of Inductive and Deductive Coding and Theme Development. *Int J Qual Methods* 2006; 5: 80–92.

[20] Boeije H. A purposeful approach to the constant comparative method in the analysis of qualitative interviews. *Qual Quant* 2002; 36: 391–409.

[21] Goldsmith LJ, Suryaprakash N, Randall E, et al. The importance of informational, clinical and personal support in patient experience with total knee replacement: A qualitative investigation. *BMC Musculoskelet Disord* 2017; 18: 1–13.

[22] Hall AM, Kamper SJ, Hernon M, et al. Measurement Tools for Adherence to Non-Pharmacologic Self-Management Treatment for Chronic Musculoskeletal Conditions : A Systematic Review. *Arch Phys Med Rehabil* 2015; 96: 552–562.

[23] Piwek L, Ellis DA, Andrews S, et al. The Rise of Consumer Health Wearables: Promises and Barriers. *PLoS Med* 2016; 13: e1001953.

[24] Zapata BC, Fernández-Alemán JL, Idri A, et al. Empirical Studies on Usability of mHealth Apps: A Systematic Literature Review. *J Med Syst* 2015; 39: 1–19.

[25] Peake JM, Kerr G, Sullivan JP. A Critical Review of Consumer Wearables, Mobile Applications, and Equipment for Providing Biofeedback, Monitoring Stress, and Sleep

in Physically Active Populations. *Front Physiol* 2018; 9: 743.

[26] Ayoade M, Baillie L. A novel knee rehabilitation system for the home. In: *Proceedings of the SIGCHI Conference on human factors in computing systems*. ACM, 2014, pp. 2521–2530.

[27] Chen KH, Chen PC, Liu KC, et al. Wearable sensor-based rehabilitation exercise assessment for knee osteoarthritis. *Sensors (Switzerland)* 2015; 15: 4193–4211.

[28] Brutovský J, Novák D. Low-cost motivated rehabilitation system for post-operation exercises. *Annu Int Conf IEEE Eng Med Biol - Proc* 2006; 6663–6666.

[29] Kos A, Tomažič S, Umek A. Suitability of smartphone inertial sensors for real-time biofeedback applications. *Sensors* 2016; 16: 301.

[30] O'Reilly M, Caulfield B, Ward T, et al. Wearable Inertial Sensor Systems for Lower Limb Exercise Detection and Evaluation: A Systematic Review. *Sport Med* 2018; 48: 1221–1246.

[31] Jack K, McLean SM, Moffett JK, et al. Barriers to treatment adherence in physiotherapy outpatient clinics: A systematic review. *Man Ther* 2010; 15: 220–228.

[32] Jordan JL, Holden MA, Mason EE, et al. Interventions to improve adherence to exercise for chronic musculoskeletal pain in adults. *Cochrane Database Syst Rev* 2010; 1: CD005956.

[33] Peek K, Sanson-Fisher R, Mackenzie L, et al. Interventions to aid patient adherence to physiotherapist prescribed self-management strategies: a systematic review. *Physiotherapy* 2016; 102: 127–135.

Figure 1: User setup of biofeedback system with single IMU placed on the shin and associated tablet application (written consent provided for use of image).

1066x1422mm (72 x 72 DPI)

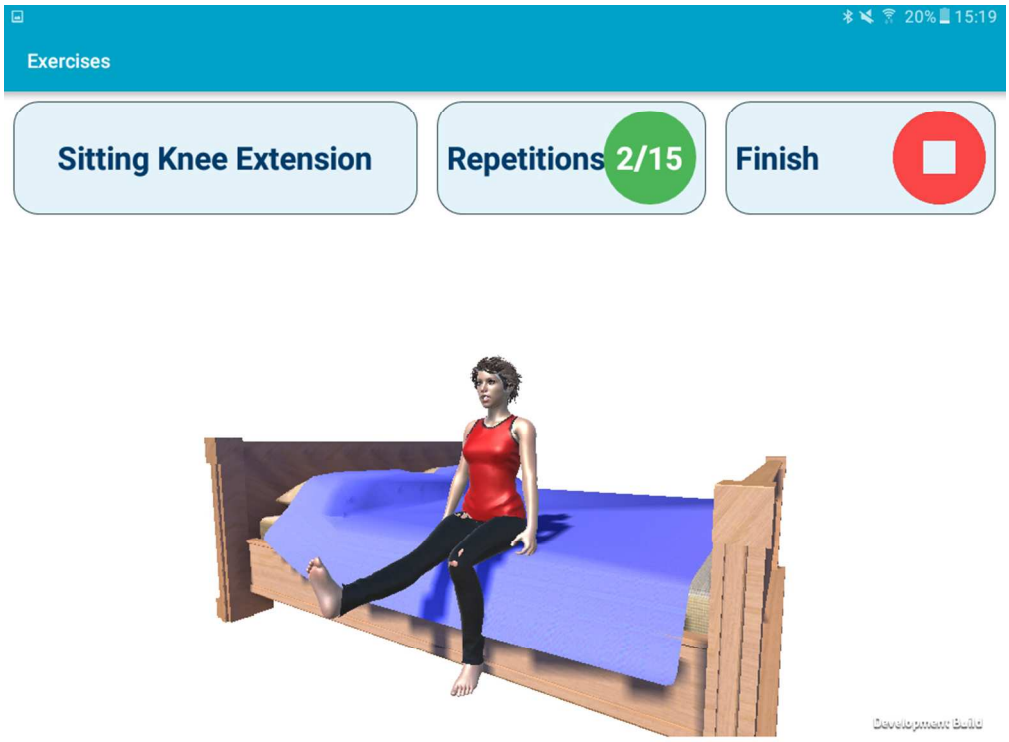

Figure 2: Screenshot of Android application during exercise mode.

361x270mm (72 x 72 DPI)

INTERVIEW TOPIC GUIDE:

Current Practice

- What methods would you currently use for monitoring and feedback during patient rehabilitation?

Wearables

- Do you know anything about wearable technology?
    - If so tell me what you know, how they're used and your view of them.

Opportunities & Challenges for Connected Health in Orthopaedic Rehabilitation

- What do you think are the opportunities of using technology in orthopaedic rehabilitation?
    - Equally what do you think are the challenges?
- What do you think of the role of mobile phones and tablets in monitoring of patients.

Perceived Impact

- Having used this technology, what do you think about using software like this for this purpose?
- How did you find using this particular application?
- What impact do you think this could have for patient rehabilitation?
    - Both for the patient, and for clinicians.
    - How would you perceive a system like this changing clinical practice?
- Is there any way we can improve on this application from your experience?
- What did you think about the way the information was presented in the app?
- Did you encounter any difficulties whilst using the software, any tasks that you found difficult or technical issues?

Theme	Sub Theme(s)	Quote	Participant
Current Practice	Measures Used	*Generally, I would manually take objective measures, traditional measures like muscle strength, range of motion, and then some subjective ones as well, opinion based on movement quality.*	Physiotherapist
		We use the goniometer to measure how much flexibility has come into their hip or knee. That's the only indication we can give them by using something as a tool. Otherwise we eyeball and give a rough estimate.	Orthopaedic Assistant
		To give an example, the lady that I saw yesterday she was 3 weeks and 6 days after her knee replacement and had 130 degree knee bend. Whereas I know from doing this job and from seeing a lady earlier on in the week and only has 70 degree knee bend. You can see with the lady who has 130 knee bend she doesn't realise how well she is doing, but she thinks she should be further along.	Clinical Nurse Specialist
		Measuring the range with a goniometer but there's a lot of intra reliability issues with it you know, as to whether you're specifically getting the right measure from one to the next so I wouldn't say how valid it is.	Physiotherapist
		Say for a knee replacement they have their CPMs so once they start to reach towards their 90 degrees.	Staff Nurse
		I would start out with the swelling, if there's any swelling present around the knee or the hip.	Orthopaedic Assistant
		Any lag with some of their movements they were doing, I would tell them you were lagging yesterday but today you're much better than what you were yesterday.	Orthopaedic Assistant
		We would look for breaking down different parts of their gait, the distance they've walked, the time they would take to do the distance which would give the speed as well, the stepping pattern, the step length.	Physiotherapist
		Some patients would use the tick box in the booklet, like a diary, a list of the exercises and dates and times that they can tick it off.	Physiotherapist
		Using scales like pain scales and functionality scales.	Physiotherapist
		Decreasing pain reports, or decreasing reports about their pain experience, and decreasing levels of analgesia would be the two outcome measures.	Clinical Nurse Specialist

		Their pain is another thing we would use as a measure as well to I guess progress, you know often the reason people have had an ortho procedure is because of pain so that's an important thing for the patient to show that they're improving and that's something we would definitely take as an objective measure.	Physiotherapist
		We're probably not as, like with physio they're looking at ROM and they're commenting specifically on joint range, we're more looking at it from a functional perspective, are they able to you know perform a task in a safe manner whilst adhering to the guidelines that are set out past their surgery.	Occupational Therapist
		Returning to function is another important measure, we would check pre-during and post-op, especially pre and post from a function point of view. Are they back doing ADLs, Sport, working. So those type of things we would check. Sometimes it's just asking through subjective questions or others would be questionnaires such as the WOMAC to find out functionally how that is improving.	Physiotherapist
		How many can you achieve before you fatigue / movement quality is poor. That's gold.	Physiotherapist
		…but it would be nice to have an objective measure of movement quality to feedback to the patients.	Physiotherapist
	Lacking Objectivity	*Objective markers are few and far between and we're still reliant on the old clinical measures like range of motion, muscle strength - which if you're testing on an Oxford scale it's a very subjective thing.*	Physiotherapist
		I suppose it's a lot of observation and it is quite subjective in a lot of other ways like stair mobility.	Occupational Therapist
		Objectively again you'd ask their pain scales, I'll ask them to keep an exercise diary, what duration they would walk, how many times they exercises a day, and again keep a record of it, as if they don't it's just a subjective response.	Physiotherapist
		Monitoring them you're really just looking at visually just using your visual aids yourself so gauging yourself their progression.	Physiotherapist
		But it is more, kind of, you don't have anything to, how do I say it, you don't have machines. So it is really a more kind of ongoing assessment.	Staff Nurse
	Feedback & Monitoring	*I guess just verbal feedback is our only option… but when they go home we're not giving them any feedback 'til they come back to the clinic.*	Physiotherapist

		Verbal feedback or sometimes written feedback so you're adapting things to their ability… most of the patients in the early post-op phase need it to be clearly documented in front of them to make a change otherwise they forget.	Physiotherapist
		Purely conversation.	Clinical Nurse Specialist
		Some patients themselves have said when they contacted me that they don't know what stage they should be at, even though we provide them with the info at pre assessment beforehand, even though we go through the information when they're here in the hospital.	Clinical Nurse Specialist
		They can call in if they have a problem but between the visits of the teams that are going out once a day over the course of the first week, no they have to get on with it themselves, they don't have anything to work off except what they've been educated to do.	Physiotherapist
		You're not watching them and they're like oh yeah I did my exercises and you just have to go by that they did it.	Staff Nurse
Wearables	Current Use & Awareness	*A mobile phone that measures your distance, and measures calories and distance walked and you can go back and check and see exactly what you've done for a day.*	Orthopaedic Assistant
		I've used a pedometer here at work when they were trying to get people to take more steps, I have used a HR monitor when training.	Physiotherapist
		Yes, erm map my run… . I have another mobility app and its more for tracking distance.	Occupational Therapist
		I've used the sensors, the HR monitor sensors and things like that for GAA training in the past and that was more to do specific testing.	Physiotherapist
		I've used the watch technology for some swim training and some gym training when I was training for specific things.	Physiotherapist
		I actually haven't used any wearable technology so there's not much I can tell you to be honest.	Orthopaedic Assistant
		I haven't used any… I know you can get all sorts of apps that'll measure all sorts of objective measurements of sports performance.	Physiotherapist
		A lot of my patients at the moment all have fitbits for measurements of how many steps do they take per day, a lot of the smartphones obviously have apps as well that record how many calories and steps they're taking, what distance they walked, run, cycle.	Physiotherapist

	Motivational	*It gives you a sense of achievement. At the end of each session say I've gone for a nice long walk and I've made sure it is uphill/downhill all that stuff you know. If I look at it and say well I've walked 10km I think I'm quite happy with that for a day, you're delighted with yourself so you do get a sense of accomplishment from it.*	Orthopaedic Assistant
		The 10k steps definitely does encourage people to be more active, they're more conscious, they're more objective.	Physiotherapist
		I just think for the whole kinda like tracking your steps, my friend was showing me hers and it tells you what you've done and what you have to do and you can compete with other people. I think they're quite motivating.	Staff Nurse
		I like it from a motivational point of view and you have an excel spreadsheet and you can compare averages like this time to a year ago.	Physiotherapist
		And you kind of got little rewards or prompts from it you know, congratulations you've done 5 days in a row and I liked that.	Occupational Therapist
	Track Data	*Well I suppose I would predominantly have used it for measuring distance, so if I was tracking myself or setting myself a goal for exercise in terms of time and distance, erm, it would have been, it's a useful thing for a tracker.*	Occupational Therapist
		You give a patient an exercise and the subjective they may report one thing but at least with the objective measurements you have something in front of you that they walked 5k in a certain time or they did do a certain amount of steps.	Physiotherapist
		I think they can be used to encourage people to give feedback, they can see their improvements and if people are into tech they can actually track their different training programmes and log, you can see how you're improving and just from peoples feedback to me some people really like that.	Orthopaedic Assistant
		I did look at the data but I probably haven't uploaded the data anywhere or done anything more with it than literally monitor anything.	Clinical Nurse Specialist
	Negatives	*How can it differentiate between height and weight and I don't know if that is always taken into account with some of these technologies.*	Clinical Nurse Specialist
		I know there are newer and updated versions of fitbits and other wearables coming out that have HR and calories burnt but again how specific is that to the patient compared to a generalised population.	Physiotherapist

		My opinion is I personally would find it irritating. Why? I hate email reminders, and uninvited contact from companies. For me a fitbit is impractical as we have a bare wrist policy so most of my life it has no relevance to me. But the main block would be uninvited contact.	Clinical Nurse Specialist
		It's the remote setting of goals, or the setting of goals that you then fail. So your sense of failure overrides your sense of success. I think there's a possibility of the two things happening and I think for me would detract from the benefit of wearing it. If I felt I wasn't meeting goals.	Clinical Nurse Specialist
		There is nearly an obsession that they have to achieve 10k steps when I have seen security guards just marching on the spot rather than just walking.	Physiotherapist
		I think you can get sick of having that many options available to you. And I think that there's so much choice out there and you never know what one is going to work for you until you have downloaded a few and seen what works best for you and your lifestyle and what you want to use it for.	Staff Nurse
		I don't particularly like being on technology overly so I don't necessarily want to have to go after my run onto my laptop to track my run. I've been involved in sport at a high level for a long time so I have a good understanding myself of how to push myself so I don't need that feedback but I can see how it is really good for people who wouldn't have that background.	Physiotherapist
Connected Health in Orthopaedics	Opportunity	*I think there's definitely a place for it because it's much more in peoples life than ever. Lots of people like apps now and they like to tag into something and if it can give more specific individual feedback then there's definitely a role for it to be a part of their progression, especially resulting in something that will rehab for months.*	Physiotherapist
		I suppose if they had an app and stuff on them, do you know they could like, everyone kinda YouTube's stuff and they're not accurate. Everyone's saying oh well that looks like that's what I'm doing but you don't really know. But if you did have the fitbit you could say right well I actually have done it and you just feel a bit more secure I suppose.	Staff Nurse
		A lot of GP surgeries are using remote technology with their patients, even medical records are being shared with patients that they then take into their hospital. I mean there's huge growth in that.	Clinical Nurse Specialist

		Erm I think I've seen a lot of people and proposals in relation to an introduction of kind of these wearables into the health and not just the fitness sector and to do with health and health monitoring so I think there is definitely a huge role to play.	Occupational Therapist
		Well I suppose orthopaedic rehab because it's so prescriptive and it's so specific, and I know it had to be personalised and individualised but the exercises are pretty much the exercises you're going to do after a knee surgery or hip surgery so I mean in a way I think its I suppose there aren't as many variables with it.	Physiotherapist
		I'm a bit of a control freak and I would love if I was a patient if I could have something that easily helped me track my health in terms of my BP, glucose levels, HR, O2 levels. So it took a more holistic view, something that I could track.	Occupational Therapist
		The last job I had in spinal wards where if there was something there, if there's people there and they could see progress on a screen rather than just being told, you're doing great, you're doing fantastic. I'm sure that grinds on people a bit you know. Definitely in the orthopaedic ward, if there's a way of saying this is where you were at the start, now you're here, now you're here I'm sure that would be brilliant.	Orthopaedic Assistant
		I think it's the future of physiotherapy probably, what we tried to introduce was emailing, there's always going to be some issues with emailing. Not just pictures and descriptions but videos of how an exercise should be performed.	Physiotherapist
	Features	*You can always video call them and see how are you getting on, that way you don't have to physically go to the house to see how they're getting on. They can just show you the exercise.*	Orthopaedic Assistant
		Unless you had the smartphone or something you can communicate with the patient through that, obviously for example you have facetime	Staff Nurse
		Even something like a fitbit that showed a graph that you can go and check if they've actually done their exercise/if they've achieved their targets. It's very easy to say oh yeah you look like you're doing it right until you kinda see.	Staff Nurse
		I think it would give the patient an opportunity to give a much more personal record of their experience. And, you know, also a central monitoring or central axis, I mean if you had a patient tablet in a room and a nurse had a smartphone or something in her pocket.	Clinical Nurse Specialist

		That she could check into, and say ok patient in 302 is reporting pain in the last hour, I haven't been in there ill check. Very simple things whereas patients don't always tell you?	
		Even from an older persons discharging to home perspective from family to be able to see how their health is doing its not this subjective, oh mum started feeling unwell, I think it was 3 or 4 days ago but if something even, just temperatures, something very basic and something very objective that you could measure over time that'd be really helpful.	Occupational Therapist
		How much bend they have on their knee without being strapped to the machine (CPM). Maybe that'd be something in the future that could be even better again, something along those lines.	Orthopaedic Assistant
		I love the idea of real-time feedback, the idea something can tell you you're doing something wrong immediately and help you correct it. I think some patients having that insight and that awareness and that something to prompt you on the spot because that's what we would sometimes find is that people would get into behaviours or habits of doing things. I'm trying to think about the transition from hospital to home, a lot of the time they go home and it's as if we're starting from scratch with them.	Occupational Therapist
		When they come to pre-ops rather than handing them loads of sheets that they're given that information via email or an app so once they come in they download the app and get all that information and say refer them to that during it.	Clinical Nurse Specialist
	Challenges	*Getting the patient to buy in to it is the number one challenge, from everything. A piece of tech that I've used with athletes would be monitoring of their load fitting in their activity duration during their training session to build up their profile of how much training they've done – getting them to use it is a problem but when they do use it its invaluable.*	Physiotherapist
		I think there are an awful lot of opportunities there but a lot of it comes down to patient compliance.	Clinical Nurse Specialist
		The more work they have to do the less reliable it is.	Physiotherapist
		If you expect the patient to go back and log onto a computer to record data you're not going to get it.	Physiotherapist
		Time… in an outpatient session you've got 30 mins to get them in, assessed, treated, progressed, and then how relative is it going to be taking up your time to look up their adherence levels etc. because if they come in and you see that they've improved and their	Physiotherapist

		quality of movement has improved you can be fairly confident they've been adherent to their exercises.	
		If you don't have a good understanding of the app or the technology itself, it can be quite difficult for someone to use it. For example, if it is someone quite elderly, they wouldn't be as tech savvy as someone in their teens or early twenties. So it's the whole aspect of getting to know about the app or technology before they start using it. That would be the only difficulty there.	Orthopaedic Assistant
		I suppose how user friendly the app and I suppose that can be a weakness and a strength for patients, depending on the patient age population.	Clinical Nurse Specialist
		And the big problem is if they cannot use it then it is pointless	Physiotherapist
		I mean if the interface is difficult or if something, errors keep occurring, I think the more simple a thing is and the more intuitive it is the easier it will be from an uptake and an ongoing compliance issue.	Occupational Therapist
		The technology actually working, how many times you know, the lack of WIFI, computer crashing. I suppose they would be the huge elements.	Clinical Nurse Specialist
		The ability to pick up on the false in particular because obviously there's going to be a limit to what the technology can do so it needs to be factored towards a specific goal so whatever that is.	Physiotherapist
		If you look at the elderly population that are primarily getting joint replacements are a lot of them au fait with, some of them would be but there would be presumably a large percentage who aren't au fait with iPad, iPhone and similar technologies.	Physiotherapist
		I suppose, a lot of people have the technology, that's not as much a barrier. It's so accessible now on smartphones and so many people have smartphones I don't really see that as a barrier. Nor do I see the whole age profile of the patients as a barrier because I'm seeing 90 year olds using skype and Facebook and I think that barrier is reducing.	Occupational Therapist
		Yes of course, without being rude and I would put myself in the same bracket, not being ageist. But certain people of an age are fantastic with technology, you know I know we have the silver surfers and that's what they're being christened, but I see a lot in the hospital where they're skyping families – telling them they're feeling well.	Orthopaedic Assistant

		I think the barriers to technology in health are coming down every day. I see such changes for the older population on the ward now.	Occupational Therapist
		One would have said data protection, that's always going to be your main challenge.	Clinical Nurse Specialist
		So I suppose how can the app be, you know, I know this seems like a strange one, but how many times have we heard of people being hacked, and the technology being there and being stolen and stuff like that and I think unfortunately that's getting more and more common. I don't know if that's something anybody will think of when it comes to this kind of app for healthcare for better patients. But I do think that's something the potential is there for.	Clinical Nurse Specialist
		So I would think that with technology the person that has to be driving the connection is the patient.	Clinical Nurse Specialist
		So you need to overcome that barrier with the patient that they might perceive it as something that you are handing over responsibility when in fact what you're trying to do is get a better understanding to deepen a relationship. You want to use it in a way that enhances the trusting element of the patient-HCP relationship. That has to be the fundamental process. You have to utilise it in a way that actually increases that relationship as opposed to detracts from it.	Clinical Nurse Specialist
		Just that it can't replace actually somebody being there looking at them. Even though you can have two people looking at someone doing an exercise a highly trained physio is going to see what needs to be tweaked in your technique with something. It's very easy to do an exercise that actually is going to ramp up your pain and you can just change it slightly and often you're not, and I don't think tech can replace that part of it but if it's going to be used to iron out the simpler things, but the higher things you need an experienced eye to see I don't necessarily know how you can replace that.	Physiotherapist
Perceived Impact of Exemplar	Track Data	*Then at least you can track as well to see if they're actually using it at all. Because if they're not using it then they're likely not doing anything.*	Physiotherapist
		One of my favourite things about it is that you can score the difficulty, if somebody is scoring 555 then they're finding it too difficult but if they're scoring 111 you can progress them on very quickly.	Physiotherapist

		I like the mood as well in terms of from a depression point of view, they're so much depression out there, these people may act knowledge it and this could pick up a few mental health issues as well.	Physiotherapist
		It gathers up data and tells you whether the patients are doing the exercises or not. That way if they say they have done it you can say no, you didn't do the exercise I've got the information here so yes its quite good to go back to.	Staff Nurse
		The data is automatically taken and you're not physically putting the data into a computer, all you're doing is log into the app and just go onto the page you want to see and put it all together. Instead of spending hours on a computer putting the data in so yeah it'll be a big hit for sure.	Orthopaedic Assistant
		It would change maybe the clinical practice, because if you were noticing a certain surgeons patients experienced more pain, or people discharged over the weekend have higher pain levels, you know then what you're doing is establishing patterns that allow you to intervene.	Clinical Nurse Specialist
		You're always going to see what you see, but this is something where you can record data and it doesn't lie.	Orthopaedic Assistant
		I'm very impressed by the spreadsheet at the end that tells you if you've done it correctly or incorrectly, I'm impressed by the graphs and saying the amount of reps performed and if you've done your dosage for the day or over a period.	Physiotherapist
	Improve Outcome	*Very useful, I think it'll improve the quality of the patients exercise.*	Physiotherapist
		It'll improve the quality of the patients rehab. So I think they will be more likely to follow more structured programmes when they have visual feedback to do it.	Physiotherapist
		There are times when you could be doing the exercise but you wouldn't know if you were doing it right or wrong so to be told that you are doing the exercises incorrectly it makes you go back and do them properly again that way you know you're getting the best out of it.	Orthopaedic Assistant
		I think they'd rehab quicker and be more confident in their rehab, which is the best thing.	Staff Nurse
		I think you're going to do the same thing, but at a better standard and a better quality.	Physiotherapist
	Motivation & Support	*I think it will enhance the patient confidence in their recovery… it's reassuring to know you're on track.*	Clinical Nurse Specialist

		There are times when you could be doing the exercise but you wouldn't know if you were doing it right or wrong so to be told that you are doing the exercises incorrectly it makes you go back and do them properly again that way you know you're getting the best out of it.	Orthopaedic Assistant
		The feedback from the screen, makes you think how am I going to complete these exercises correctly you know.	Clinical Nurse Specialist
		From their perspective they're getting feedback immediately that they're doing something wrong and there's a prompt to give them the idea of maybe what they're doing and how they could perform the exercise better which is great.	Occupational Therapist
		Yeah well its correcting you and telling you that you're not doing it properly or that you're doing it perfectly and its nice for people to feel like they have sort of backup when they go home.	Staff Nurse
		I think it will be a fantastic impact on the patient it really would. I can't overemphasise the amount of times that people, when they see themselves progressing they go much further again and it shoots along. They really get a sense of wellbeing, accomplishment all that sort of stuff and they know I'm getting there, I can see I'm getting there. I can visibly see and I can see the data as well you know.	Orthopaedic Assistant
	Healthcare Efficiency	*… you're hopefully not going to need MUA's* (Manipulation under anaesthetic) *and that kind of thing because you're doing it right from the beginning.*	Staff Nurse
		As a patient, I would imagine that if I was doing my exercises correctly, I would need less appointment time with a physiotherapist… If I wasn't doing the exercises correctly, the physiotherapist might call me to go through how to do it, but if I'm doing my exercises correctly, if I'm reaching the goals I need to and the activity levels that I need to, why do I need to come in and see a physio?	Clinical Nurse Specialist
		It would even reduce the phone calls in saying I don't know if I'm doing this right or I think I'm doing something wrong because it's there in front of you.	Staff Nurse
		As a patient I would imagine that if I was doing my exercises correctly, I would need less appointment time with a physiotherapist. Particularly if I'm paying for it.	Clinical Nurse Specialist
		It would save them from travelling out of the house, a lot of patients would struggle to get a lift to the hospital and trying to manage around people's workloads to get lifts.	Orthopaedic Assistant

	Challenges	*As long as I follow it… I wouldn't go and see the physio again.*	Orthopaedic Assistant
		It's not going to take the place of the therapist you know, but it just serves to really hammer home the message you're trying to get across to the patient.	Physiotherapist
		The worry that it won't be giving you the right information and then it's going to skew your thought process and that of others because you can only report on what you're being given.	Physiotherapist
		Well overall I suppose if you thought you were doing great and then this pops up you'd kind of get a bit of an oh I've been doing it wrong and you might be put off and you might be like I'm not using that again, but I think that'd be very dramatic.	Staff Nurse
		The worry that it won't be giving you the right information and then it's going to skew your thought process and that of others because you can only report on what you're being given.	Physiotherapist
		There was some issues when I was using it that it wasn't picking up all my reps correctly. So that is an issue. If I was using that at home it would frustrate me if I had done 15 and it said I had done 10.	Physiotherapist
		It's quite sensitive in that regard but it's better to have it too sensitive than not. The only thing is if it constantly tells the patient the exercise is wrong are they going to say I can't do that exercise right anyway so I'm not doing it and skipping it.	Physiotherapist
		How it is at the moment it's not picking up the exercises correctly.	Clinical Nurse Specialist
		My issue would be if we use this app after two weeks should we not be progressing their exercises so you're no longer going to be performing those exercises.	Physiotherapist
		The only thing is some of the nuances in rehab, it's obviously not going to pick up on. Such as Such as still 3-4/52 post TKR. Still absent in last 10 of knee extension, so they're going to look like they're doing the exercise well, this is going to tell you they're doing the reps of a knee bend well – what's the quality of the knee bend like?	Physiotherapist
		You'll always modify the generic programme to a certain person who lacks flexion v extension, strength v ROM.	Physiotherapist

		Some people would see that as a tool for assisting self-management, other people no matter how much education or technology you provide, will still see their recovery as incumbent on the healthcare professional looking after them.	Clinical Nurse Specialist
		I think the patients that come in with a non-compliant element already, I don't know if you're ever going to change their attitudes and beliefs no matter how much information you provide or give them, or how much resource you provide and give them. I just think there may some way of change in them but I don't know if this app or anything else will be it. I don't know if there is technology out there that is designed that may help them, but again that's unknown.	Staff Nurse
		I guess it depends who is responsible for their care… I wouldn't want alerts about patients who went home a week ago but are in 10/10 pain. I want to educate that patient and put that responsibility on them, the more we give patients the responsibility the better. By doing that alert it makes the patient more passive and we want to encourage the patient to take responsibility, educate them on taking steps like icing and taking pain medication, and then if it still doesn't settle down, then the patient needs to call. I think if we put the responsibility onto us we're leading down a dangerous path.	Physiotherapist

SRQR Checklist

No.	Topic	
	Title and abstract	
S1	**Title** - Concise description of the nature and topic of the study Identifying the study as qualitative or indicating the approach (e.g., ethnography, grounded theory) or data collection methods (e.g., interview, focus group) is recommended.	Page 1
S2	**Abstract** - Summary of key elements of the study using the abstract format of the intended publication; typically includes background, purpose, methods, results, and conclusions	Page 2 Lines 44 – 65
	Introduction	
S3	**Problem formulation** - Description and significance of the problem/phenomenon studied; review of relevant theory and empirical work; problem statement	Page 3
S4	**Purpose or research question** - Purpose of the study and specific objectives or questions	Page 3 Lines 123 – 129
	Methods	
S5	**Qualitative approach or research paradigm** - Qualitative approach (e.g., ethnography, grounded theory, case study, phenomenology, narrative research) and guiding theory if appropriate; identifying the research paradigm (e.g., postpositivist, constructivist/ interpretivist) is also recommended; rationale	Page 4 Lines 176 – 177
S6	**Researcher characteristics and reflexivity** - Researchers' characteristics that may influence the research, including personal attributes, qualifications/experience, relationship with participants, assumptions, and/or presuppositions; potential or actual interaction between researchers' characteristics and the research questions, approach, methods, results, and/or transferability	Page 4 Lines 177 – 183
S7	**Context** - Setting/site and salient contextual factors; rationale	Page 4 Lines 138 – 140
S8	**Sampling Strategy** - How and why research participants, documents, or events were selected; criteria for deciding when no further sampling was necessary (e.g., sampling saturation); rationale	Pages 4-5 Lines 138 – 140. Lines 181 – 183
S9	**Ethical issues pertaining to human subjects** - Documentation of approval by an appropriate ethics review board and participant consent, or explanation for lack thereof; other confidentiality and data security issues	Page 4 Lines 140 – 142
S10	**Data collection methods** - Types of data collected; details of data collection procedures including (as appropriate) start and stop dates of data collection and analysis, iterative process, triangulation of sources/methods, and modification of procedures in response to evolving study findings; rationale	Pages 4-5 Lines 144 – 155. Lines 175 – 183
S11	**Data collection instruments and technologies** - Description of instruments (e.g., interview guides, questionnaires) and devices (e.g., audio recorders) used for data collection; if/how the instrument(s) changed over the course of the study	Page 4 Lines 145 – 148. Supplementary file 1.
S12	**Units of study** - Number and relevant characteristics of participants, documents, or events included in the study; level of participation (could be reported in results)	Page 4 Lines 136 – 138

S13	**Data processing** - Methods for processing data prior to and during analysis, including transcription, data entry, data management and security, verification of data integrity, data coding, and anonymization/de-identification of excerpts	Page 5 Lines 175 – 183
S14	**Data analysis** - Process by which inferences, themes, etc., were identified and developed, including the researchers involved in data analysis; usually references a specific paradigm or approach; rationale	Page 5 Lines 175 – 183
S15	**Techniques to enhance trustworthiness** - Techniques to enhance trustworthiness and credibility of data analysis (e.g., member checking, audit trail, triangulation); rationale	Page 5 Lines 175 – 183
	Results/findings	
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S17	**Links to empirical data** - Evidence (e.g., quotes, field notes, text excerpts, photographs) to substantiate analytic findings	Pages 5 – 9 and Supplementary file 2.
	Discussion	
S18	**Integration with prior work, implications, transferability and contribution(s) to the field** - Short summary of main findings; explanation of how findings and conclusions connect to, support, elaborate on, or challenge conclusions of earlier scholarship; discussion of scope of application/generalizability; identification of unique contribution(s) to scholarship in a discipline or field	Pages 9 – 11
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Original Paper

Clinician perceptions of a prototype wearable exercise biofeedback system for orthopaedic rehabilitation: a qualitative exploration.

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Original Paper

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Abstract

Objectives: This study explores the opinions of orthopaedic healthcare professionals regarding the opportunities and challenges of using wearable technology in rehabilitation. It continues to assess the perceived impact of an exemplar exercise biofeedback system that incorporates wearable sensing, involving the clinician in the user-centred design process, a valuable step in ensuring ease of implementation, sustained engagement and clinical relevance.

Design: This is a qualitative study consisting of one-to-one semi-structured interviews, including a demonstration of a prototype wearable exercise biofeedback system. Interviews were audio recorded and transcribed, with thematic analysis conducted of all transcripts.

Setting: The study was conducted in the orthopaedic department of an acute private hospital.

Participants: Ten clinicians from a multidisciplinary team of healthcare professionals involved in the orthopaedic rehabilitation pathway participated in the study.

Results: Participants reported that there is currently a challenge in gathering timely and objective data for the monitoring of patients in orthopaedic rehabilitation. Whilst there are challenges in ensuring reliability and engagement of biofeedback systems, clinicians perceive significant value in the use of wearable biofeedback systems such as the exemplar demonstrated for use following total knee replacement.

Conclusions: Clinicians see an opportunity for wearable technology to continuously track data in real-time, and feel that feedback provided to users regarding exercise technique and adherence can further support the patient at home, although there are clear design and implementation challenges relating to ensuring technical accuracy and tailoring rehabilitation to the individual. There was perceived value in the prototype system demonstrated to participants which supports the ongoing development of such exercise biofeedback platforms.

Keywords

biofeedback; biomedical technology; exercise therapy; orthopedics; mobile health; qualitative

Strengths and limitations of this study

- There is a need for innovative solutions to counteract poor adherence and increasing pressure on patient self-management, and a user-centred design approach with key stakeholders is recommended.
- Few studies have investigated clinicians' perceptions of exercise biofeedback systems and offered the opportunity for healthcare professionals to contribute to the user-centred design process.

- This study uses qualitative methods in the form of semi-structured interviews to allow for an in-depth exploration of participant opinions, yet results are of a subjective nature and are not necessarily generalisable.
- Study participants were recruited from a number of different disciplines across nursing and therapies, although from a single healthcare institution.

Introduction

It has been estimated over 10% of the population will need a total knee replacement (TKR) by eighty years of age [1]. Home-based exercises following TKR form the mainstay of rehabilitation, with typical physiotherapy programmes consisting of exercises targeted to increase strength, range of movement and function, as well as reduce post-operative complications [2]. However, adherence rates to home-based exercises are alarmingly low, with patients reporting various reasons for non-compliance with the prescribed programme [3, 4]. Patients often report a lack of confidence following discharge from hospital, insecurity surrounding their post-operative expectations, and poor recall of exercise technique [5]. Poor performance of exercise technique such as insufficient range of motion, alignment, or compensatory movements may impact on the efficacy of the rehabilitation programme, and hence the outcome of the procedure [6]. Poor adherence may even lead to further complications, readmission to hospital, additional healthcare costs and prolonged pain and disability for the patient [7].

The lack of support reported by patients may also result from the changing nature of joint replacement surgery globally, moving towards value-based care and a drive for reduction in the length of hospital stay, placing a greater emphasis than ever on the self-management skills of the patient. Healthcare providers need to make the most of the opportunity that new and emerging technologies present [1, 8], and connected health solutions may provide the opportunity to bridge this gap between the home and clinician [3]. With the advancement of sensor technologies and mobile computing platforms, it is now possible to empower patients to self-manage more effectively, acquire data with far greater efficiency, and use this to support the clinician in making more objective, data-driven decisions about clinical care [8]. Inertial measurement units (IMUs) can be used to measure the three-dimensional position of a limb segment and have been shown to be a cost-effective, accurate method of assessing exercise technique in rehabilitation exercises [9–12], presenting the opportunity to build such a classification system into a connected health intervention.

When designing a connected health intervention, in order to promote user-engagement and maximise impact, an iterative design process involving consultation with key stakeholders is recommended throughout the design and development phase to optimise the effectiveness of the system [13, 14]. As well as the patient end-user, clinicians should be encouraged to participate in the design and evaluation of connected health solutions to ensure clinical acceptability [15]. However, there is currently a lack of collaboration between technology developers and healthcare professionals, which in turn is affecting acceptance and adoption of new technologies [15, 16].

The aim of this study was two-fold. In the first instance we sought to perform an exploration of the opportunities and challenges of using wearable technology in rehabilitation after joint

replacement surgery. Following this, clinicians were provided with a demonstration of an exemplar wearable exercise biofeedback system, and their perceptions of its potential use in the clinical setting were evaluated whilst incorporating the healthcare professional in the user-centred design process.

Methods

Patient and Public Involvement

No patients or members of the general public were involved in this study.

Participants

A total of 10 participants (6 females, 4 males, age: 36.5 [SD 9.06]) from a variety of clinical disciplines (4 Physiotherapists, 2 Clinical Nurse Specialists, 2 Orthopaedic Assistants, 1 Occupational Therapist and 1 Staff Nurse) were recruited as a sample of convenience from a private hospital in Dublin, Ireland, and were involved in the care of patients in the orthopaedic joint replacement pathway within the hospital. Potential participants were identified and introduced to the study by an Orthopaedic Consultant (MN) and the Allied Therapies Manager (AD). Each participant signed a consent form prior to commencing the study, and the study protocol was approved by the Beacon Hospital Research Ethics Committee.

Experimental Procedure

Participants were required to attend a single hour-long session as part of the study. All interview data were recorded using a Dictaphone and an interview topic guide (Supplemental File 1) was constructed based on the main research questions and aims of the study, in order to ensure consistency between interviews [17]. Prior to introducing the concept and exemplar biofeedback system, and to prevent bias, a semi-structured interview was conducted with each participant to gain an understanding of what methods clinicians are currently using to monitor and provide feedback to patients, the perceived opportunities and challenges of connected health interventions, and their current knowledge of wearable technology. A demonstration of the exemplar wearable exercise biofeedback system was then provided, followed by a further semi-structured interview to identify the perceived impact and clinical implications of such a system.

Prototype Exercise Biofeedback System

A prototype has been developed consisting of a single IMU (Shimmer, Dublin, Ireland) and an Android application developed for a tablet computer to be used by the patient in their own home. The IMU is placed on the shank in a neoprene sleeve and is connected via Bluetooth to the Android application on the tablet. As the user exercises, the IMU streams sensor data to the tablet, and an on-screen avatar mirrors the movements and the repetitions are counted for each exercise. At the end of the set, the user is provided with feedback on their technique [11, 18], and if erroneous, advice on how to improve technique is displayed. Patient reported outcomes are captured on a regular basis and the user's progress is also presented graphically to track adherence. An illustration of the user setup is included in figure 1 with screenshot in figure 2.

Insert Figure 1: User setup of biofeedback system with single IMU placed on the shin and associated tablet application (written consent provided for use of image).

Insert figure 2: Screenshot of Android application during exercise mode.

Data Analysis

Audio from interview recordings was transcribed and anonymised. Thematic analysis of the interview transcript took place with a grounded-theory approach [17]. The interview guide was used to create an early coding template, which was then refined and finalised as further themes emerged during data analysis [19], conducted by RA (Research Physiotherapist) and PS (Experienced Qualitative Researcher). A constant comparison approach was taken with regular cross-checking to ensure reliability of emerging sub-themes with a strong correlation between researchers [20]. Any outliers were discussed, and agreement reached, with data saturation agreed when no further themes were occurring in the interview data [17].

Results

A summary of results are reported below, additional quotations to support these results can be found in Supplemental File 2.

Current Methods of Monitoring & Feedback

Clinical practice at present tends to rely on a combination of objective and subjective markers. Participants spoke about the wide-use of range of motion measurement as a key objective marker following TKR. Additionally, markers such as swelling, pain and functional scores are used to monitor changes in the patient's condition.

> *Generally, I would manually take objective measures, traditional measures such as muscle strength, range of motion, and then some subjective ones as well, opinion based on movement quality.* [Physiotherapist]

However, participants commented on the lack of objectivity of assessing muscle strength, gait and exercise technique, with visual assessment and patient self-report forming the basis for ongoing monitoring.

> *Objective markers are few and far between and we're still reliant on the old clinical measures like range of motion, muscle strength - which if you're testing on an Oxford scale it's a very subjective thing.* [Physiotherapist]

Those participants working in the post-acute phase of care stated that feedback was primarily offered verbally, and it is not possible to offer other feedback between clinic appointments.

> *I guess just verbal feedback is our only option… but when they go home we're not giving them any feedback 'til they come back to the clinic.* [Physiotherapist]

Perceptions & Knowledge of Wearables

Participants were aware of wearable technology, with many stating they have used some sort of wearable device in their personal lives, yet discussion was almost exclusively on the application in the fitness space.

> *The apps on the smartphone that you have to have a phone in your pocket for the app to work and it tracks how many steps you've done... I know about Fitbit.* [Clinical Nurse Specialist]

Participants also discussed the motivational aspect associated with using a wearable device. They felt that as well as motivating the user to meet their goals, the opportunity to track their own data and analyse their results was of benefit.

> *You kind of got little rewards or prompts from it you know, 'congratulations you've done 5 days in a row' and I liked that.* [Occupational Therapist]

Drawbacks of such technology were also highlighted. One participant felt that it would not be beneficial for them to use wearables themselves, with others reporting the amount of choice being overwhelming, and questioning the validity of such measures.

> *How can it differentiate between height and weight, and I don't know that is always taken into account with some of these technologies.* [Clinical Nurse Specialist]

Opportunities & Challenges for Connected Health in Orthopaedic Rehabilitation

Participants were unanimous in agreement that there is an opportunity and wide scope for connected health interventions, including wearable and mobile technology, to play a role in orthopaedic rehabilitation.

> *I think there's definitely a place for it, because it's so much more in people's lives than ever. Lots of people like apps now and they like to tag into something, and if it can give more specific individual feedback then there's definitely a role for it to be a part of their progression, especially resulting in something that will rehab for months.* [Physiotherapist]

A number of potential features were highlighted that clinicians would consider useful, such as progress tracking, feedback, remote monitoring, regular range of motion measurement, and counting repetitions.

> *Even something like a Fitbit that showed a graph that you can go and check if they've actually done their exercise and if they've achieved their targets.* [Staff Nurse]

> *I love the idea of real-time feedback, the idea something can tell you you're doing something wrong immediately and help you correct it.* [Occupational Therapist]

Participants were also quick to point out the challenges of delivering healthcare solutions in this way. All participants interviewed stated that the usability of any technology would be a significant barrier to engagement that will need to be overcome.

> *I mean if the interface is difficult or if something, if errors keep occurring. I think the more simple a thing is and the more intuitive it is, the easier it will be from an uptake and ongoing compliance issue.* [Occupational Therapist]

Compliance with use of any connected health intervention was widely reported to be a challenge.

> *I think there are an awful lot of opportunities there but a lot of it comes down to patient compliance.* [Clinical Nurse Specialist]

There were additional challenges relating to the reliability and validity of any such technology, with discussion of aspects such as internet capability, bugs and glitches.

> *The technology actually working, how many times you know, the lack of Wi-Fi, computer crashing… I suppose they would be the huge elements.* [Clinical Nurse Specialist]

Data security challenges were also noted, with the potential for confidential healthcare data being accessed without permission.

> *One would have said data protection, that's always going to be your main challenge.* [Clinical Nurse Specialist]

Participants also spoke of the important balance in the patient-clinician relationship, and the need for technology to enhance the role of the professional, rather than attempt to replace the clinician. It was noted that such technologies need to work without shifting the focus away from the patient's own self-management.

> *So I would think with technology the person who has to be driving the connection is the patient.* [Clinical Nurse Specialist]

The final notable sub-theme to arise when discussing challenges of connected health systems, is the user's own ability and confidence with technology.

> *If you look at the elderly population that are primarily receiving joint replacements, are a lot of them au fait with? Some of them would be but presumably there are a large percentage who aren't au fait with iPads, iPhone and similar technologies.* [Physiotherapist]

However other participants offered counter arguments that this may not be the case compared to years gone by.

> *I suppose, a lot of people have the technology, that's not as much a barrier. It's so accessible now on smartphones and so many people have smartphones... I'm seeing 90-year olds using Skype and Facebook and I think that barrier is reducing.* [Occupational Therapist]

Perceived Impact of Exemplar System

Having completed a demonstration of the prototype exercise biofeedback system as described above, all participants perceived this system as potentially having a positive

impact in orthopaedic rehabilitation. Every participant noted the ability to capture and track data in a manner that has not previously been possible as a major benefit. Participants were excited by the prospect of tracking and leveraging metrics such as adherence, difficulty, pain and mood to guide their decisions.

> *Then at least you can track as well, to see if they're actually using it at all. Because if they're not using it then they're likely not doing anything.* [Physiotherapist]

> *One of my favourite things about it is that you can score the difficulty, if somebody is scoring 5,5,5 then they're finding it too difficult but if they're scoring 1,1,1 you can progress them on very quickly.* [Physiotherapist]

They also felt using this system would improve the outcome of rehabilitation. They suggested that if the patient was demonstrating greater adherence, this would be of benefit.

> *It'll improve the quality of the patient's rehab. So I think they will be more likely to follow more structured programmes when they have the visual feedback to do it.* [Physiotherapist]

> *I think they would rehab quicker and be more confident in their rehab, which is the best thing.* [Staff Nurse]

Through instilling added reassurance and motivation, clinicians felt that this system could improve the patient experience.

> *I think it will enhance patient confidence in their recovery… it's reassuring to know you're on track.* [Clinical Nurse Specialist]

Participants suggested this system could contribute to a more efficient healthcare system, both for the patient and the service provider.

> *… you're hopefully not going to need MUA's* (Manipulation under anaesthetic) *and that kind of thing because you're doing it right from the beginning.* [Staff Nurse]

> *As a patient, I would imagine that if I was doing my exercises correctly, I would need less appointment time with a physiotherapist… If I wasn't doing the exercises correctly, the physiotherapist might call me to go through how to do it, but if I'm doing my exercises correctly, if I'm reaching the goals I need to and the activity levels that I need to, why do I need to come in and see a physio?* [Clinical Nurse Specialist]

Challenges

Participants also felt that this increased efficiency could emerge as a challenge however, as there is a risk of the patient placing a reliance on the technology over the human. Although there was an acknowledgement from some that this would not be the case.

> *As long as I follow it… I wouldn't go and see the physio again.* [Orthopaedic Assistant]

> *It's not going to take the place of the therapist you know, but it just serves to really hammer home the message you're trying to get across to the patient.* [Physiotherapist]

A major challenge for such a system which was discussed by five clinicians, related to the accuracy of the data provided by the technology.

> *The worry that it won't be giving you the right information and then it's going to skew your thought process and that of others because you can only report on what you're being given.* [Physiotherapist]

Interviews highlighted the difficulty of tailoring an automated programme to the individual, with only a small number of standard exercises included in this system compared to the breadth of options prescribed in clinical practice.

> *My issue would be if we use this app after two weeks should we not be progressing their exercises so you're no longer going to be performing those exercises.* [Physiotherapist]

An interesting discussion evolved with a number of participants relating to what a system such as this would do for the responsibility of care, with some clinicians stating that they feel no amount of technology will promote self-management.

> *Some people would see that as a tool for assisting self-management, other people no matter how much education or technology you provide, will still see their recovery as incumbent on the healthcare professional looking after them.* [Clinical Nurse Specialist]

One feature of the remote monitoring aspect of the prototype system is to send an alert to the clinician if there is a concerning change in the data, but some participants stated that the responsibility of the clinician would have to be clearly defined in this instance, in order not to detract from the patient's own self-management.

> *I guess it depends who is responsible for their care… I wouldn't want alerts about patients who went home a week ago but are in 10/10 pain. I want to educate that patient and put that responsibility on them, the more we give patients the responsibility the better. By doing that alert it makes the patient more passive and we want to encourage the patient to take responsibility, educate them on taking steps like icing and taking pain medication, and then if it still doesn't settle down, then the patient needs to call. I think if we put the responsibility onto us we're leading down a dangerous path.* [Physiotherapist]

Discussion

Principal Findings

This study has found that clinicians see technology as having the potential to improve and assist the rehabilitation process, but there are numerous barriers to overcome when designing such solutions. Clinicians highlighted a need for a solution which deals with the issue of exercise adherence and lack of support for patients at home [4, 5]. When presented with a demonstration of the prototype system, all participants felt that this type of technology has the potential to positively impact on the outcomes of orthopaedic rehabilitation, however there are challenges in ensuring the accuracy of information provided, and the ability to tailor such systems to the individual. There was strong interest in the opportunity to track data and maximise the effectiveness of rehabilitation, yet it was felt that such systems can undergo further iterations to extend this impact.

Current clinical practice provides little opportunity for monitoring or feedback outside of the clinic. It has been shown that patients with negative experiences of TKR have unmet needs regarding support and managing expectations [21], yet these results suggest there is a heavy reliance on the patient's own self-motivation at home, with limited monitoring or feedback from clinicians. Participants also reported using a combination of objective and subjective outcome measures for monitoring, but these measures are only captured at limited time-points and self-reported measures such as adherence are well reported to be unreliable [4, 22]. The results from this study would suggest there is benefit in capturing further objective outcome measures such as movement quality, or accurate monitoring of range of movement and adherence remotely, both of which are feasible with the use of IMUs [3, 23].

There is growing evidence that clinicians see wearable devices supporting various aspects of assessment and intervention in rehabilitation [24, 25], and the results of this study further add to this evidence. Furthermore these findings show that clinicians share the concerns reported in the literature relating to usability, data protection and reliability, that are known to be problematic with wearable devices [26–28]. Many researchers are investigating the technical feasibility of using wearable sensing systems to support rehabilitation [29–32], but in a recent systematic review, few have conducted user evaluations to guide the design of such systems in a user-centred manner [33].

Prototype System Evaluation

Most clinicians believed the demonstrated prototype would improve the quality of patient rehabilitation by fostering greater motivation and self-efficacy, underpinned by the concept of persuasive technology [34, 35]. Clinicians were also excited by the opportunity to capture timely and objective data in a manner not currently available in practice [8]. It was felt that this data-driven aspect could enhance clinical decision making, a perceived benefit that could increase usefulness and facilitate technology acceptance [36]. It is perceived that this system could increase adherence to exercise programmes by using evidence based interventions discussed in the literature to improve adherence in an automated manner [3, 37–39]. Interestingly, several participants felt this system had the potential to improve the efficiency of the healthcare system, by harnessing the data collected to make better use of appointment scheduling, which has been highlighted as a design requirement by healthcare professionals previously [15, 24]. Existing literature has shown the ability of IMU based

systems to record and classify exercise technique [11, 18], and this study has highlighted the clinical applications of such work.

Challenges

There were conflicting reports within these results as to whether such a system could lead to a reliance on technology rather than the clinician, however previous research has suggested healthcare professionals see technology as having the ability to augment the clinician's decision-making process, rather than seek to replace the human expert [24]. There was also concern that this system might increase the responsibility clinicians have for their patients by sending alerts, although this may be used to illustrate shortcomings in current practice. A clinician may consider a user educated in self-management and not wish for alerts, yet if this user continues to report severe symptoms, either the success of education is questionable or further assessment is required. When developing such systems, there is also a need to allow for customisation of exercise programmes from the clinician, with participants highlighting the variance between individuals, the need for a larger exercise library, and the desire to choose when progressions should be offered. The major challenge in the development of such a support system which harnesses machine learning technology is in ensuring the accuracy and reliability of the information provided, as clinicians were concerned that inaccuracy could negatively impact user engagement. This study has shown the need for clear and transparent real-world validation, and end-user evaluation of any such system prior to implementation, an aspect that is lacking in the current literature [28, 33].

Limitations

Due to the qualitative nature of this study, there are number of factors to consider when reviewing this research. All participants were provided with a demonstration of the prototype system on one occasion only. It is quite possible that with ongoing use, or given further time to reflect on the system, the participant's opinions may change. It is important to highlight that these results are derived solely from the participants' own opinions via interviews, and in order to determine the objective clinical impact of such a system, further research needs to take place in the form of a longitudinal study assessing a variety of outcomes with a mixed-methods approach. This sample was selected from a single institution in the private healthcare sector, and whilst this sample comes from a cross-section of the multidisciplinary team, it does not guarantee that the opinions provided reflect the wider population of rehabilitation professionals. Finally, the purpose of this study was to assess clinician perceptions of wearable systems, nonetheless the lack of patient involvement is a limitation in this study. Despite these limitations, this paper provides evidence to support the need, ongoing design and development, and use of such systems in clinical practice.

Future Work

Having now understood that there is a positive perceived impact for this system, future work will seek to deploy the platform as part of a pilot study with patients following TKR surgery. This work will seek to answer some of the questions posed by participants in this study relating to usability and engagement, while including the patient as well as the clinician in the design process to develop further iterations, prior to objective assessment of clinical impact and real-world validation.

Conclusions

Rehabilitation following joint replacement is complex and varied, yet there is a reliance on the patient's own self-management and motivation to maximise the effect of the home exercise programme, with little opportunity for expert monitoring, assessment or feedback outside of the clinic setting. A prototype system for interactive exercise biofeedback consisting of a single wearable sensor and an Android application was perceived to potentially have a positive impact on the rehabilitation of patients following knee replacement surgery. Clinicians were excited by the opportunity to continuously track data in real-time, and felt the exercise technique and adherence feedback would further support the patient in the home environment. However, there are challenges in the design and implementation of such systems to ensure acceptability. In order to achieve successful deployment, these technologies need to be evaluated by clinicians as well as patients as the end-users, alongside real-world validation of the technical aspects of any such platforms.

Contributorship

RA, PS, AD and BC conceived and designed the study. RA conducted the recruitment and data collection with the assistance of PS, AD and MN. AB contributed to the development of the prototype biofeedback system. RA and PS conducted the data analyses and drafted and revised the manuscript. All authors read and approved the final manuscript.

Competing Interests

The authors declare that there is no conflict of interest.

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Ethical Approval

The research ethics committee of Beacon Hospital approved this study (REF: BEA0065).

Data Sharing

No additional data available.

References

[1] Kremers HM, Larson DR, Crowson CS, et al. Prevalence of total hip and knee replacement in the United States. *J Bone Jt Surg Am* 2015; 97: 1386–9355.

[2] American Academy of Orthopaedic Surgeons. Total Knee Replacement Exercise Guide, http://orthoinfo.aaos.org/topic.cfm?topic=a00301 (2017, accessed 24 May

2018).
[3] Argent R, Daly A, Caulfield B. Patient Involvement With Home-Based Exercise Programs: Can Connected Health Interventions Influence Adherence? *JMIR mHealth uHealth* 2018; 6: e47.
[4] Bassett SF. The assessment of patient adherence to physiotherapy rehabilitation. *New Zeal J Physiother* 2003; 31: 60–66.
[5] Perry MA, Hudson HS, Meys S, et al. Older adults' experiences regarding discharge from hospital following orthopaedic intervention: A metasynthesis. *Disabil Rehabil* 2012; 34: 267–278.
[6] Friedrich M, Cermak T, Maderbacher P. The Effect of Brochure Use Versus Therapist Teaching on Patients Performing Therapeutic Exercise and on Changes in Impairment Status. *Phys Ther* 1996; 76: 1082–1088.
[7] Holden MA, Haywood KL, Potia TA, et al. Recommendations for exercise adherence measures in musculoskeletal settings: a systematic review and consensus meeting (protocol). *Syst Rev* 2014; 3: 10.
[8] Caulfield BM, Donnelly SC. What is connected health and why will it change your practice? *Qjm* 2013; 106: 703–707.
[9] Burns A, Greene BR, McGrath MJ, et al. SHIMMER™ – A Wireless Sensor Platform for Noninvasive Biomedical Research. *IEEE Sens J* 2010; 10: 1527–1534.
[10] Giggins OM, Persson UM, Caulfield B. Biofeedback in rehabilitation. *J Neuroeng Rehabil* 2013; 10: 1.
[11] Giggins OM, Sweeney KT, Caulfield B. Rehabilitation exercise assessment using inertial sensors: a cross-sectional analytical study. *J Neuroeng Rehabil* 2014; 11: 158.
[12] O'Reilly MA, Whelan D, Ward T, et al. Technology in Strength and Conditioning: Assessing Bodyweight Squat Technique With Wearable Sensors. *J Strength Cond Res* 2017; 31: 2303–2312.
[13] Michie S, Yardley L, West R, et al. Developing and evaluating digital interventions to promote behavior change in health and health care: Recommendations resulting from an international workshop. *J Med Internet Res*; 19(6).
[14] Shah SGSS, Robinson I. Benefits of and barriers to involving users in medical device technology development and evaluation. *Int J Technol Assess Health Care* 2007; 23: 131–7.
[15] Bergmann JHM, McGregor AH. Body-Worn Sensor Design : What Do Patients and Clinicians Want ? *Ann Biomed Eng* 2011; 39: 2299–2312.
[16] Blumenthal J, Wilkinson A, Chignell M. Physiotherapists' and Physiotherapy Students' Perspectives on the Use of Mobile or Wearable Technology in Their Practice. *Physiother Canada* 2018; 70: 1–11.
[17] Ritchie J. *Qualitative research practice: a guide for social science students and researchers*. 2nd ed. Sage Publications Sage CA: Los Angeles, CA, 2014.
[18] Bevilacqua A, Huang B, Argent R, et al. Automatic Classification of Knee Rehabilitation Exercises Using a Single Inertial Sensor : a Case Study. In: *2018 IEEE 15th International Conference on Wearable and Implantable Body Sensor Networks (BSN)*. IEEE, 2018, pp. 21–24.
[19] Fereday J, Muir-Cochrane E. Demonstrating Rigor Using Thematic Analysis: A Hybrid Approach of Inductive and Deductive Coding and Theme Development. *Int J Qual Methods* 2006; 5: 80–92.
[20] Boeije H. A purposeful approach to the constant comparative method in the analysis

of qualitative interviews. *Qual Quant* 2002; 36: 391–409.

[21] Goldsmith LJ, Suryaprakash N, Randall E, et al. The importance of informational, clinical and personal support in patient experience with total knee replacement: A qualitative investigation. *BMC Musculoskelet Disord* 2017; 18: 1–13.

[22] Hall AM, Kamper SJ, Hernon M, et al. Measurement Tools for Adherence to Non-Pharmacologic Self-Management Treatment for Chronic Musculoskeletal Conditions : A Systematic Review. *Arch Phys Med Rehabil* 2015; 96: 552–562.

[23] Cooper G, Sheret I, McMillian L, et al. Inertial sensor-based knee flexion/extension angle estimation. *J Biomech* 2009; 42: 2678–2685.

[24] Papi E, Murtagh GM, McGregor AH. Wearable technologies in osteoarthritis: a qualitative study of clinicians' preferences. *BMJ Open* 2016; 6: e009544.

[25] Sprint G, Cook DJ, Weeks DL. Designing Wearable Sensor-Based Analytics for Quantitative Mobility Assessment. *IEEE Int Conf Smart Comput SMARTCOMP 2016*.

[26] Piwek L, Ellis DA, Andrews S, et al. The Rise of Consumer Health Wearables: Promises and Barriers. *PLoS Med* 2016; 13: e1001953.

[27] Zapata BC, Fernández-Alemán JL, Idri A, et al. Empirical Studies on Usability of mHealth Apps: A Systematic Literature Review. *J Med Syst* 2015; 39: 1–19.

[28] Peake JM, Kerr G, Sullivan JP. A Critical Review of Consumer Wearables, Mobile Applications, and Equipment for Providing Biofeedback, Monitoring Stress, and Sleep in Physically Active Populations. *Front Physiol* 2018; 9: 743.

[29] Ayoade M, Baillie L. A novel knee rehabilitation system for the home. In: *Proceedings of the SIGCHI Conference on human factors in computing systems*. ACM, 2014, pp. 2521–2530.

[30] Chen KH, Chen PC, Liu KC, et al. Wearable sensor-based rehabilitation exercise assessment for knee osteoarthritis. *Sensors (Switzerland)* 2015; 15: 4193–4211.

[31] Brutovský J, Novák D. Low-cost motivated rehabilitation system for post-operation exercises. *Annu Int Conf IEEE Eng Med Biol - Proc* 2006; 6663–6666.

[32] Kos A, Tomažič S, Umek A. Suitability of smartphone inertial sensors for real-time biofeedback applications. *Sensors* 2016; 16: 301.

[33] O'Reilly M, Caulfield B, Ward T, et al. Wearable Inertial Sensor Systems for Lower Limb Exercise Detection and Evaluation: A Systematic Review. *Sport Med* 2018; 48: 1221–1246.

[34] Fogg BJ. *Persuasive Technology: Using Computers to Change What We Think and Do*. San Francisco, CA: Morgan Kaufmann, 2003.

[35] Chow Y-W, Susilo W, Phillips JG, et al. Video Games and Virtual Reality as Persuasive Technologies for Health Care: An Overview. *J Wirel Mob Networks, Ubiquitous Comput Dependable Appl* 2017; 8(3): 18–35.

[36] Holden RJ, Karsh BT. The Technology Acceptance Model: Its past and its future in health care. *J Biomed Inform* 2010; 43: 159–172.

[37] Jack K, McLean SM, Moffett JK, et al. Barriers to treatment adherence in physiotherapy outpatient clinics: A systematic review. *Man Ther* 2010; 15: 220–228.

[38] Jordan JL, Holden MA, Mason EE, et al. Interventions to improve adherence to exercise for chronic musculoskeletal pain in adults. *Cochrane Database Syst Rev* 2010; 1: CD005956.

[39] Peek K, Sanson-Fisher R, Mackenzie L, et al. Interventions to aid patient adherence to physiotherapist prescribed self-management strategies: a systematic review. *Physiotherapy* 2016; 102: 127–135.

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Figure 1: User setup of biofeedback system with single IMU placed on the shin and associated tablet application (written consent provided for use of image).

1066x1422mm (72 x 72 DPI)

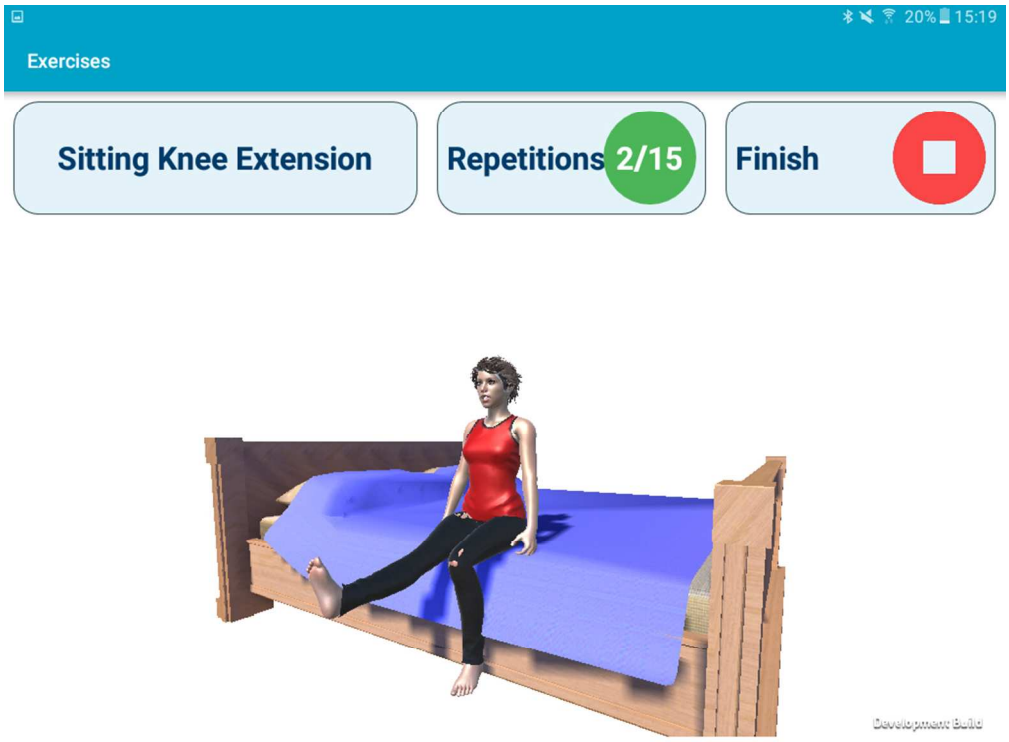

Figure 2: Screenshot of Android application during exercise mode.

361x270mm (72 x 72 DPI)

SUPPLEMENTAL FILE 1: INTERVIEW TOPIC GUIDE

Main questions formed the core structure of the interview, further follow-up questions were put forward dependent on initial response.

- What methods would you currently use for monitoring and feedback during patient rehabilitation?
  Example of follow-up questions:
  - *What about outside of the clinic?*
  - *When do you employ these methods?*
  - *Does that provide the information that you need? Why?*

- Do you know anything about wearable technology?
  Example of follow-up questions:
  - *If so tell me what you know, how they're used and your view of them.*
  - *Why do you have that view of them?*
  - *What do you think are the benefits / drawbacks of those you're aware of?*

- What do you think are the opportunities of using technology in orthopaedic rehabilitation?
  Example of follow-up questions:
  - *Have you been involved in / are you aware of any projects taking place?*
  - *Why do you think technology might help in that instance?*

- Equally what do you think are the challenges?
  Example of follow-up questions:
  - *What do you think the risk would be when encountering that challenge?*
  - *How do you think those challenges could be overcome?*

- What do you think of the role of mobile phones and tablets in monitoring of patients?
  Example of follow-up questions:
  - *You say you think it'd be useful, in what way could it help?*
  - *Why do you think smart phones can play that role?*

<u>DEMONSTRATION OF EXEMPLAR SYSTEM PROVIDED</u>

- Having used this technology, what do you think about using software like this for this purpose?
  Example of follow-up questions:
  - *Why does this system have that effect?*
  - *You think it'll improve the quality of rehabilitation – How?*

- How did you find using this particular application?

- What impact do you think this could have for patient rehabilitation?
  Example of follow-up questions:
  - *And what about any impact on your practice?*
  - *How do you see the difference using that might have on the way you work?*

- Based on your experience, what could be improved in the system?
  Example of follow-up questions:
  - *What did you think about the way the information was presented in the app?*
  - *Did you encounter any difficulties whilst using the software, any tasks that you found difficult or technical issues?*
  - *How would you comment on the user experience of the system?*
  - *What else needs to be considered in the design of the system?*

CODE-BOOK: CLINICIANS INTERVIEW DATA

PRIMARY THEME: CURRENT PRACTICE

Sub-theme	Description	Quotations	Participant
Measures Used	References relating to how data is currently collected: what metric it is and how it is measured.	*Generally, I would manually take objective measures, traditional measures like muscle strength, range of motion, and then some subjective ones as well, opinion based on movement quality.*	Physiotherapist
		We use the goniometer to measure how much flexibility has come into their hip or knee. That's the only indication we can give them by using something as a tool. Otherwise we eyeball and give a rough estimate.	Orthopaedic Assistant
		To give an example, the lady that I saw yesterday she was 3 weeks and 6 days after her knee replacement and had 130 degree knee bend. Whereas I know from doing this job and from seeing a lady earlier on in the week and only has 70 degree knee bend. You can see with the lady who has 130 knee bend she doesn't realise how well she is doing, but she thinks she should be further along.	Clinical Nurse Specialist
		Measuring the range with a goniometer but there's a lot of intra reliability issues with it you know, as to whether you're specifically getting the right measure from one to the next so I wouldn't say how valid it is.	Physiotherapist
		Say for a knee replacement they have their CPMs so once they start to reach towards their 90 degrees.	Staff Nurse
		I would start out with the swelling, if there's any swelling present around the knee or the hip.	Orthopaedic Assistant
		Any lag with some of their movements they were doing, I would tell them you were lagging yesterday but today you're much better than what you were yesterday.	Orthopaedic Assistant
		We would look for breaking down different parts of their gait, the distance they've walked, the time they would take to do the distance which would give the speed as well, the stepping pattern, the step length.	Physiotherapist

		Some patients would use the tick box in the booklet, like a diary, a list of the exercises and dates and times that they can tick it off.	Physiotherapist
		Using scales like pain scales and functionality scales.	Physiotherapist
		Decreasing pain reports, or decreasing reports about their pain experience, and decreasing levels of analgesia would be the two outcome measures.	Clinical Nurse Specialist
		Their pain is another thing we would use as a measure as well to I guess progress, you know often the reason people have had an ortho procedure is because of pain so that's an important thing for the patient to show that they're improving and that's something we would definitely take as an objective measure.	Physiotherapist
		We're probably not as, like with physio they're looking at ROM and they're commenting specifically on joint range, we're more looking at it from a functional perspective, are they able to you know perform a task in a safe manner whilst adhering to the guidelines that are set out past their surgery.	Occupational Therapist
		Returning to function is another important measure, we would check pre-during and post-op, especially pre and post from a function point of view. Are they back doing ADLs, Sport, working. So those type of things we would check. Sometimes it's just asking through subjective questions or others would be questionnaires such as the WOMAC to find out functionally how that is improving.	Physiotherapist
		How many can you achieve before you fatigue / movement quality is poor. That's gold.	Physiotherapist
		…but it would be nice to have an objective measure of movement quality to feedback to the patients.	Physiotherapist
Current Issues	References relating to the issues with the current measures that are captured, and the comparison of subjective to objective data.	*Objective markers are few and far between and we're still reliant on the old clinical measures like range of motion, muscle strength - which if you're testing on an Oxford scale it's a very subjective thing.*	Physiotherapist
		I suppose it's a lot of observation and it is quite subjective in a lot of other ways like stair mobility.	Occupational Therapist
		Objectively again you'd ask their pain scales, I'll ask them to keep an exercise diary, what duration they would walk, how many times they exercises a day, and again keep a record of it, as if they don't it's just a subjective response.	Physiotherapist

		Monitoring them you're really just looking at visually just using your visual aids yourself so gauging yourself their progression.	Physiotherapist
		But it is more, kind of, you don't have anything to, how do I say it, you don't have machines. So it is really a more kind of ongoing assessment.	Staff Nurse
Feedback & Monitoring	References relating to how feedback and monitoring is conducted/provided in current practice.	*I guess just verbal feedback is our only option… but when they go home we're not giving them any feedback 'til they come back to the clinic.*	Physiotherapist
		Verbal feedback or sometimes written feedback so you're adapting things to their ability… most of the patients in the early post-op phase need it to be clearly documented in front of them to make a change otherwise they forget.	Physiotherapist
		Purely conversation.	Clinical Nurse Specialist
		Some patients themselves have said when they contacted me that they don't know what stage they should be at, even though we provide them with the info at pre assessment beforehand, even though we go through the information when they're here in the hospital.	Clinical Nurse Specialist
		They can call in if they have a problem but between the visits of the teams that are going out once a day over the course of the first week, no they have to get on with it themselves, they don't have anything to work off except what they've been educated to do.	Physiotherapist
		You're not watching them and they're like oh yeah I did my exercises and you just have to go by that they did it.	Staff Nurse

PRIMARY THEME: WEARABLES

Sub-theme	Description	Quotations	Participant
Current Use & Awareness	References relating to participant knowledge of types of wearable devices both in private or professional context.	*A mobile phone that measures your distance, and measures calories and distance walked and you can go back and check and see exactly what you've done for a day.*	Orthopaedic Assistant
		I've used a pedometer here at work when they were trying to get people to take more steps, I have used a HR monitor when training.	Physiotherapist
		Yes, erm map my run… . I have another mobility app and its more for tracking distance.	Occupational Therapist
		I've used the sensors, the HR monitor sensors and things like that for GAA training in the past and that was more to do specific testing.	Physiotherapist
		I've used the watch technology for some swim training and some gym training when I was training for specific things.	Physiotherapist
		I actually haven't used any wearable technology so there's not much I can tell you to be honest.	Orthopaedic Assistant
		I haven't used any… I know you can get all sorts of apps that'll measure all sorts of objective measurements of sports performance.	Physiotherapist
		A lot of my patients at the moment all have fitbits for measurements of how many steps do they take per day, a lot of the smartphones obviously have apps as well that record how many calories and steps they're taking, what distance they walked, run, cycle.	Physiotherapist
Motivational	References relating to the use of wearable devices discussed in the current use and awareness sub-theme offering a motivational aspect.	*It gives you a sense of achievement. At the end of each session say I've gone for a nice long walk and I've made sure it is uphill/downhill all that stuff you know. If I look at it and say well I've walked 10km I think I'm quite happy with that for a day, you're delighted with yourself so you do get a sense of accomplishment from it.*	Orthopaedic Assistant
		The 10k steps definitely does encourage people to be more active, they're more conscious, they're more objective.	Physiotherapist
		I just think for the whole kinda like tracking your steps, my friend was showing me hers and it tells you what you've done and what you have to do and you can compete with other people. I think they're quite motivating.	Staff Nurse

		I like it from a motivational point of view and you have an excel spreadsheet and you can compare averages like this time to a year ago.	Physiotherapist
		And you kind of got little rewards or prompts from it you know, congratulations you've done 5 days in a row and I liked that.	Occupational Therapist
Track Data	References relating to the use of wearable devices discussed in the current use and awareness sub-theme providing the opportunity to track data.	*Well I suppose I would predominantly have used it for measuring distance, so if I was tracking myself or setting myself a goal for exercise in terms of time and distance, erm, it would have been, it's a useful thing for a tracker.*	Occupational Therapist
		You give a patient an exercise and the subjective they may report one thing but at least with the objective measurements you have something in front of you that they walked 5k in a certain time or they did do a certain amount of steps.	Physiotherapist
		I think they can be used to encourage people to give feedback, they can see their improvements and if people are into tech they can actually track their different training programmes and log, you can see how you're improving and just from peoples feedback to me some people really like that.	Orthopaedic Assistant
		I did look at the data but I probably haven't uploaded the data anywhere or done anything more with it than literally monitor anything.	Clinical Nurse Specialist
Negatives	References relating to perceived challenges and drawbacks of the use of wearable devices discussed in the current use and awareness sub-theme.	*How can it differentiate between height and weight and I don't know if that is always taken into account with some of these technologies.*	Clinical Nurse Specialist
		I know there are newer and updated versions of fitbits and other wearables coming out that have HR and calories burnt but again how specific is that to the patient compared to a generalised population.	Physiotherapist
		My opinion is I personally would find it irritating. Why? I hate email reminders, and uninvited contact from companies. For me a fitbit is impractical as we have a bare wrist policy so most of my life it has no relevance to me. But the main block would be uninvited contact.	Clinical Nurse Specialist
		It's the remote setting of goals, or the setting of goals that you then fail. So your sense of failure overrides your sense of success. I think there's a possibility of the two things happening and I think for me would detract from the benefit of wearing it. If I felt I wasn't meeting goals.	Clinical Nurse Specialist

		There is nearly an obsession that they have to achieve 10k steps when I have seen security guards just marching on the spot rather than just walking.	Physiotherapist
		I think you can get sick of having that many options available to you. And I think that there's so much choice out there and you never know what one is going to work for you until you have downloaded a few and seen what works best for you and your lifestyle and what you want to use it for.	Staff Nurse
		I don't particularly like being on technology overly so I don't necessarily want to have to go after my run onto my laptop to track my run. I've been involved in sport at a high level for a long time so I have a good understanding myself of how to push myself so I don't need that feedback but I can see how it is really good for people who wouldn't have that background.	Physiotherapist

PRIMARY THEME: CONNECTED HEALTH IN ORTHOPAEDICS

Sub-theme	Description	Quotations	Participant
Opportunity	References relating to participants views on where technology could improve patient care / clinical workflow.	*I think there's definitely a place for it because it's much more in peoples life than ever. Lots of people like apps now and they like to tag into something and if it can give more specific individual feedback then there's definitely a role for it to be a part of their progression, especially resulting in something that will rehab for months.*	Physiotherapist
		I suppose if they had an app and stuff on them, do you know they could like, everyone kinda YouTube's stuff and they're not accurate. Everyone's saying oh well that looks like that's what I'm doing but you don't really know. But if you did have the fitbit you could say right well I actually have done it and you just feel a bit more secure I suppose.	Staff Nurse
		A lot of GP surgeries are using remote technology with their patients, even medical records are being shared with patients that they then take into their hospital. I mean there's huge growth in that.	Clinical Nurse Specialist
		Erm I think I've seen a lot of people and proposals in relation to an introduction of kind of these wearables into the health and not just the fitness sector and to do with health and health monitoring so I think there is definitely a huge role to play.	Occupational Therapist
		Well I suppose orthopaedic rehab because it's so prescriptive and it's so specific, and I know it had to be personalised and individualised but the exercises are pretty much the exercises you're going to do after a knee surgery or hip surgery so I mean in a way I think its I suppose there aren't as many variables with it.	Physiotherapist
		I'm a bit of a control freak and I would love if I was a patient if I could have something that easily helped me track my health in terms of my BP, glucose levels, HR, O2 levels. So it took a more holistic view, something that I could track.	Occupational Therapist
		The last job I had in spinal wards where if there was something there, if there's people there and they could see progress on a screen rather than just being told, you're doing great, you're doing fantastic. I'm sure that grinds on people a bit you know. Definitely in the orthopaedic ward, if there's a way of saying this is where you were at the start, now you're here, now you're here I'm sure that would be brilliant.	Orthopaedic Assistant

		I think it's the future of physiotherapy probably, what we tried to introduce was emailing, there's always going to be some issues with emailing. Not just pictures and descriptions but videos of how an exercise should be performed.	Physiotherapist
Potential Features	References relating to desirable features of future technology enabled interventions in the orthopaedic setting.	*You can always video call them and see how are you getting on, that way you don't have to physically go to the house to see how they're getting on. They can just show you the exercise.*	Orthopaedic Assistant
		Unless you had the smartphone or something you can communicate with the patient through that, obviously for example you have facetime	Staff Nurse
		Even something like a fitbit that showed a graph that you can go and check if they've actually done their exercise/if they've achieved their targets. It's very easy to say oh yeah you look like you're doing it right until you kinda see.	Staff Nurse
		I think it would give the patient an opportunity to give a much more personal record of their experience. And, you know, also a central monitoring or central axis, I mean if you had a patient tablet in a room and a nurse had a smartphone or something in her pocket. That she could check into, and say ok patient in 302 is reporting pain in the last hour, I haven't been in there ill check. Very simple things whereas patients don't always tell you?	Clinical Nurse Specialist
		Even from an older persons discharging to home perspective from family to be able to see how their health is doing its not this subjective, oh mum started feeling unwell, I think it was 3 or 4 days ago but if something even, just temperatures, something very basic and something very objective that you could measure over time that'd be really helpful.	Occupational Therapist
		How much bend they have on their knee without being strapped to the machine (CPM). Maybe that'd be something in the future that could be even better again, something along those lines.	Orthopaedic Assistant
		I love the idea of real-time feedback, the idea something can tell you you're doing something wrong immediately and help you correct it. I think some patients having that insight and that awareness and that something to prompt you on the spot because that's what we would sometimes find is that people would get into behaviours or habits of doing things. I'm trying to think about the transition from	Occupational Therapist

		hospital to home, a lot of the time they go home and it's as if we're starting from scratch with them.	
		When they come to pre-ops rather than handing them loads of sheets that they're given that information via email or an app so once they come in they download the app and get all that information and say refer them to that during it.	Clinical Nurse Specialist
Challenges	References relating to the potential challenges in design and development of technology based systems in orthopaedics.	*Getting the patient to buy in to it is the number one challenge, from everything. A piece of tech that I've used with athletes would be monitoring of their load fitting in their activity duration during their training session to build up their profile of how much training they've done – getting them to use it is a problem but when they do use it its invaluable.*	Physiotherapist
		I think there are an awful lot of opportunities there but a lot of it comes down to patient compliance.	Clinical Nurse Specialist
		The more work they have to do the less reliable it is.	Physiotherapist
		If you expect the patient to go back and log onto a computer to record data you're not going to get it.	Physiotherapist
		Time… in an outpatient session you've got 30 mins to get them in, assessed, treated, progressed, and then how relative is it going to be taking up your time to look up their adherence levels etc. because if they come in and you see that they've improved and their quality of movement has improved you can be fairly confident they've been adherent to their exercises.	Physiotherapist
		If you don't have a good understanding of the app or the technology itself, it can be quite difficult for someone to use it. For example, if it is someone quite elderly, they wouldn't be as tech savvy as someone in their teens or early twenties. So it's the whole aspect of getting to know about the app or technology before they start using it. That would be the only difficulty there.	Orthopaedic Assistant
		I suppose how user friendly the app and I suppose that can be a weakness and a strength for patients, depending on the patient age population.	Clinical Nurse Specialist
		And the big problem is if they cannot use it then it is pointless	Physiotherapist

		I mean if the interface is difficult or if something, errors keep occurring, I think the more simple a thing is and the more intuitive it is the easier it will be from an uptake and an ongoing compliance issue.	Occupational Therapist
		The technology actually working, how many times you know, the lack of WIFI, computer crashing. I suppose they would be the huge elements.	Clinical Nurse Specialist
		The ability to pick up on the false in particular because obviously there's going to be a limit to what the technology can do so it needs to be factored towards a specific goal so whatever that is.	Physiotherapist
		If you look at the elderly population that are primarily getting joint replacements are a lot of them au fait with, some of them would be but there would be presumably a large percentage who aren't au fait with iPad, iPhone and similar technologies.	Physiotherapist
		I suppose, a lot of people have the technology, that's not as much a barrier. It's so accessible now on smartphones and so many people have smartphones I don't really see that as a barrier. Nor do I see the whole age profile of the patients as a barrier because I'm seeing 90 year olds using skype and Facebook and I think that barrier is reducing.	Occupational Therapist
		Yes of course, without being rude and I would put myself in the same bracket, not being ageist. But certain people of an age are fantastic with technology, you know I know we have the silver surfers and that's what they're being christened, but I see a lot in the hospital where they're skyping families – telling them they're feeling well.	Orthopaedic Assistant
		I think the barriers to technology in health are coming down every day. I see such changes for the older population on the ward now.	Occupational Therapist
		One would have said data protection, that's always going to be your main challenge.	Clinical Nurse Specialist
		So I suppose how can the app be, you know, I know this seems like a strange one, but how many times have we heard of people being hacked, and the technology being there and being stolen and stuff like that and I think unfortunately that's getting more and more common. I don't know if that's something anybody will think of when it comes to this kind of app for healthcare for better patients. But I do think that's something the potential is there for.	Clinical Nurse Specialist

		So I would think that with technology the person that has to be driving the connection is the patient.	Clinical Nurse Specialist
		So you need to overcome that barrier with the patient that they might perceive it as something that you are handing over responsibility when in fact what you're trying to do is get a better understanding to deepen a relationship. You want to use it in a way that enhances the trusting element of the patient-HCP relationship. That has to be the fundamental process. You have to utilise it in a way that actually increases that relationship as opposed to detracts from it.	Clinical Nurse Specialist
		Just that it can't replace actually somebody being there looking at them. Even though you can have two people looking at someone doing an exercise a highly trained physio is going to see what needs to be tweaked in your technique with something. It's very easy to do an exercise that actually is going to ramp up your pain and you can just change it slightly and often you're not, and I don't think tech can replace that part of it but if it's going to be used to iron out the simpler things, but the higher things you need an experienced eye to see I don't necessarily know how you can replace that.	Physiotherapist

PRIMARY THEME: PERCEIVED IMPACT OF EXEMPLAR SYSTEM

Sub-theme	Description	Quotations	Participant
Improve Outcome	References relating to a perceived change improvement in clinical outcome with the use of the demonstrated system.	*Very useful, I think it'll improve the quality of the patients exercise.*	Physiotherapist
		It'll improve the quality of the patients rehab. So I think they will be more likely to follow more structured programmes when they have visual feedback to do it.	Physiotherapist
		There are times when you could be doing the exercise but you wouldn't know if you were doing it right or wrong so to be told that you are doing the exercises incorrectly it makes you go back and do them properly again that way you know you're getting the best out of it.	Orthopaedic Assistant
		I think they'd rehab quicker and be more confident in their rehab, which is the best thing.	Staff Nurse
		I think you're going to do the same thing, but at a better standard and a better quality.	Physiotherapist
Track Data	References relating to the use of data to monitor patients with the use of the demonstrated system.	*Then at least you can track as well to see if they're actually using it at all. Because if they're not using it then they're likely not doing anything.*	Physiotherapist
		One of my favourite things about it is that you can score the difficulty, if somebody is scoring 555 then they're finding it too difficult but if they're scoring 111 you can progress them on very quickly.	Physiotherapist
		I like the mood as well in terms of from a depression point of view, they're so much depression out there, these people may act knowledge it and this could pick up a few mental health issues as well.	Physiotherapist
		It gathers up data and tells you whether the patients are doing the exercises or not. That way if they say they have done it you can say no, you didn't do the exercise I've got the information here so yes its quite good to go back to.	Staff Nurse
		The data is automatically taken and you're not physically putting the data into a computer, all you're doing is log into the app and just go onto the page you want to see and put it all together. Instead of spending hours on a computer putting the data in so yeah it'll be a big hit for sure.	Orthopaedic Assistant

		It would change maybe the clinical practice, because if you were noticing a certain surgeons patients experienced more pain, or people discharged over the weekend have higher pain levels, you know then what you're doing is establishing patterns that allow you to intervene.	Clinical Nurse Specialist
		You're always going to see what you see, but this is something where you can record data and it doesn't lie.	Orthopaedic Assistant
		I'm very impressed by the spreadsheet at the end that tells you if you've done it correctly or incorrectly, I'm impressed by the graphs and saying the amount of reps performed and if you've done your dosage for the day or over a period.	Physiotherapist
Motivation & Support	References relating to the use of the demonstrated system to provide motivation or support to patients.	*I think it will enhance the patient confidence in their recovery… it's reassuring to know you're on track.*	Clinical Nurse Specialist
		There are times when you could be doing the exercise but you wouldn't know if you were doing it right or wrong so to be told that you are doing the exercises incorrectly it makes you go back and do them properly again that way you know you're getting the best out of it.	Orthopaedic Assistant
		The feedback from the screen, makes you think how am I going to complete these exercises correctly you know.	Clinical Nurse Specialist
		From their perspective they're getting feedback immediately that they're doing something wrong and there's a prompt to give them the idea of maybe what they're doing and how they could perform the exercise better which is great.	Occupational Therapist
		Yeah well its correcting you and telling you that you're not doing it properly or that you're doing it perfectly and its nice for people to feel like they have sort of backup when they go home.	Staff Nurse
		I think it will be a fantastic impact on the patient it really would. I can't overemphasise the amount of times that people, when they see themselves progressing they go much further again and it shoots along. They really get a sense of wellbeing, accomplishment all that sort of stuff and they know I'm getting there, I can see I'm getting there. I can visibly see and I can see the data as well you know.	Orthopaedic Assistant
Healthcare Efficiency	References relating to the use of the	*… you're hopefully not going to need MUA's* (Manipulation under anaesthetic) *and that kind of thing because you're doing it right from the beginning.*	Staff Nurse

	demonstrated system to improve working practices and healthcare efficiency.	*As a patient, I would imagine that if I was doing my exercises correctly, I would need less appointment time with a physiotherapist… If I wasn't doing the exercises correctly, the physiotherapist might call me to go through how to do it, but if I'm doing my exercises correctly, if I'm reaching the goals I need to and the activity levels that I need to, why do I need to come in and see a physio?*	Clinical Nurse Specialist
		It would even reduce the phone calls in saying I don't know if I'm doing this right or I think I'm doing something wrong because it's there in front of you.	Staff Nurse
		As a patient I would imagine that if I was doing my exercises correctly, I would need less appointment time with a physiotherapist. Particularly if I'm paying for it.	Clinical Nurse Specialist
		It would save them from travelling out of the house, a lot of patients would struggle to get a lift to the hospital and trying to manage around people's workloads to get lifts.	Orthopaedic Assistant
Challenges	References relating to the perceived challenges and risks associated with the use of the demonstrated system.	*As long as I follow it… I wouldn't go and see the physio again.*	Orthopaedic Assistant
		It's not going to take the place of the therapist you know, but it just serves to really hammer home the message you're trying to get across to the patient.	Physiotherapist
		The worry that it won't be giving you the right information and then it's going to skew your thought process and that of others because you can only report on what you're being given.	Physiotherapist
		Well overall I suppose if you thought you were doing great and then this pops up you'd kind of get a bit of an oh I've been doing it wrong and you might be put off and you might be like I'm not using that again, but I think that'd be very dramatic.	Staff Nurse
		The worry that it won't be giving you the right information and then it's going to skew your thought process and that of others because you can only report on what you're being given.	Physiotherapist
		There was some issues when I was using it that it wasn't picking up all my reps correctly. So that is an issue. If I was using that at home it would frustrate me if I had done 15 and it said I had done 10.	Physiotherapist

		It's quite sensitive in that regard but it's better to have it too sensitive than not. The only thing is if it constantly tells the patient the exercise is wrong are they going to say I can't do that exercise right anyway so I'm not doing it and skipping it.	Physiotherapist
		How it is at the moment it's not picking up the exercises correctly.	Clinical Nurse Specialist
		My issue would be if we use this app after two weeks should we not be progressing their exercises so you're no longer going to be performing those exercises.	Physiotherapist
		The only thing is some of the nuances in rehab, it's obviously not going to pick up on. Such as Such as still 3-4/52 post TKR. Still absent in last 10 of knee extension, so they're going to look like they're doing the exercise well, this is going to tell you they're doing the reps of a knee bend well – what's the quality of the knee bend like?	Physiotherapist
		You'll always modify the generic programme to a certain person who lacks flexion v extension, strength v ROM.	Physiotherapist
		Some people would see that as a tool for assisting self-management, other people no matter how much education or technology you provide, will still see their recovery as incumbent on the healthcare professional looking after them.	Clinical Nurse Specialist
		I think the patients that come in with a non-compliant element already, I don't know if you're ever going to change their attitudes and beliefs no matter how much information you provide or give them, or how much resource you provide and give them. I just think there may some way of change in them but I don't know if this app or anything else will be it. I don't know if there is technology out there that is designed that may help them, but again that's unknown.	Staff Nurse
		I guess it depends who is responsible for their care… I wouldn't want alerts about patients who went home a week ago but are in 10/10 pain. I want to educate that patient and put that responsibility on them, the more we give patients the responsibility the better. By doing that alert it makes the patient more passive and we want to encourage the patient to take responsibility, educate them on taking steps like icing and taking pain medication, and then if it still doesn't settle down, then the patient needs to call. I think if we put the responsibility onto us we're leading down a dangerous path.	Physiotherapist

SRQR Checklist

No.	Topic	
	Title and abstract	
S1	**Title** - Concise description of the nature and topic of the study Identifying the study as qualitative or indicating the approach (e.g., ethnography, grounded theory) or data collection methods (e.g., interview, focus group) is recommended.	Page 1
S2	**Abstract** - Summary of key elements of the study using the abstract format of the intended publication; typically includes background, purpose, methods, results, and conclusions	Page 2 Lines 44 – 65
	Introduction	
S3	**Problem formulation** - Description and significance of the problem/phenomenon studied; review of relevant theory and empirical work; problem statement	Page 3
S4	**Purpose or research question** - Purpose of the study and specific objectives or questions	Page 3 Lines 123 – 129
	Methods	
S5	**Qualitative approach or research paradigm** - Qualitative approach (e.g., ethnography, grounded theory, case study, phenomenology, narrative research) and guiding theory if appropriate; identifying the research paradigm (e.g., postpositivist, constructivist/ interpretivist) is also recommended; rationale	Page 4 Lines 176 – 177
S6	**Researcher characteristics and reflexivity** - Researchers' characteristics that may influence the research, including personal attributes, qualifications/experience, relationship with participants, assumptions, and/or presuppositions; potential or actual interaction between researchers' characteristics and the research questions, approach, methods, results, and/or transferability	Page 4 Lines 177 – 183
S7	**Context** - Setting/site and salient contextual factors; rationale	Page 4 Lines 138 – 140
S8	**Sampling Strategy** - How and why research participants, documents, or events were selected; criteria for deciding when no further sampling was necessary (e.g., sampling saturation); rationale	Pages 4-5 Lines 138 – 140. Lines 181 – 183
S9	**Ethical issues pertaining to human subjects** - Documentation of approval by an appropriate ethics review board and participant consent, or explanation for lack thereof; other confidentiality and data security issues	Page 4 Lines 140 – 142
S10	**Data collection methods** - Types of data collected; details of data collection procedures including (as appropriate) start and stop dates of data collection and analysis, iterative process, triangulation of sources/methods, and modification of procedures in response to evolving study findings; rationale	Pages 4-5 Lines 144 – 155. Lines 175 – 183
S11	**Data collection instruments and technologies** - Description of instruments (e.g., interview guides, questionnaires) and devices (e.g., audio recorders) used for data collection; if/how the instrument(s) changed over the course of the study	Page 4 Lines 145 – 148. Supplementary file 1.
S12	**Units of study** - Number and relevant characteristics of participants, documents, or events included in the study; level of participation (could be reported in results)	Page 4 Lines 136 – 138

S13	**Data processing** - Methods for processing data prior to and during analysis, including transcription, data entry, data management and security, verification of data integrity, data coding, and anonymization/de-identification of excerpts	Page 5 Lines 175 – 183
S14	**Data analysis** - Process by which inferences, themes, etc., were identified and developed, including the researchers involved in data analysis; usually references a specific paradigm or approach; rationale	Page 5 Lines 175 – 183
S15	**Techniques to enhance trustworthiness** - Techniques to enhance trustworthiness and credibility of data analysis (e.g., member checking, audit trail, triangulation); rationale	Page 5 Lines 175 – 183
	Results/findings	
S16	**Synthesis and interpretation** - Main findings (e.g., interpretations, inferences, and themes); might include development of a theory or model, or integration with prior research or theory	Pages 5 – 9
S17	**Links to empirical data** - Evidence (e.g., quotes, field notes, text excerpts, photographs) to substantiate analytic findings	Pages 5 – 9 and Supplementary file 2.
	Discussion	
S18	**Integration with prior work, implications, transferability and contribution(s) to the field** - Short summary of main findings; explanation of how findings and conclusions connect to, support, elaborate on, or challenge conclusions of earlier scholarship; discussion of scope of application/generalizability; identification of unique contribution(s) to scholarship in a discipline or field	Pages 9 – 11
S19	**Limitations** - Trustworthiness and limitations of findings	Page 11 Lines 469 – 481.
	Other	
S20	**Conflicts of interest** - Potential sources of influence or perceived influence on study conduct and conclusions; how these were managed	Page 12 Lines 510 – 511
S21	**Funding** - Sources of funding and other support; role of funders in data collection, interpretation, and reporting	Page 12 Lines 513 – 517