Northern Periphery and Arctic Programme 2014-2020

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A Transnational Home-Based Rehabilitation Service Delivery Model

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WEARABLE SENSOR TECHNOLOGIES
SENDoc

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Introduction

The European Commission aims to assist the EU Member states to enhance their health systems and the health of their citizens. In a report by the European Union (2018), it was observed that, in order to be more effective, health care systems need to be more people-centred to efficiently handle the care of people living with chronic conditions. The report also highlights the need for more prevention and improving access to healthcare. Finally, it was stated that healthcare systems should be resilient, i.e. able to adapt to changing environments and needs. Thus, it is vitally important that health care system services are appropriately designed, evolved, and modelled to reflect and implement these desired characteristics.

Service design is the activity of planning and organising people, infrastructure, communication, and resources of a service in order to improve its quality and the interaction between the service provider and its users. If service design is conducted successfully, it can help predict failures, extract critical points, and consider the intangible and contextual part of the product (Marin et al., 2017). Research work conducted by Strasser et al. noted that to achieve sustainability, remote and rural communities require health service models that are designed within and for these settings and are responsive to local population health needs (Strasser et al. 2018). While service models cover many aspects of health services, this work will focus on developing a health service model for home-based rehabilitation.

There are a number of challenges in designing a service delivery model. For example, delivery models usually involve multiple stakeholders having a diverse set of needs that must be considered (European Union, 2018). In addition, there are many technologies available that appear suitable to solve the same problem. However, distinguishing which technology is the most appropriate for a specific condition can be overwhelming for health professionals. There are a number of factors which must be considered by health professionals when considering a particular technology. For example, factors such as; validity, reliability, effectiveness, efficiency, accuracy, connectivity issues, usability in a real-life scenario, comfortability to wear, intuitiveness, or whether training or technical support will be necessary all must be considered. For example, in the UK, it is not recommended that patients purchase assistive living technology without seeking advice from their occupational therapist or General Practitioner (GP) (Which?, 2020).

Given the significant challenges involved, the design of a service delivery model which incorporates wearable technology will ultimately have to focus on solving a problem that goes further than the development of the technology itself. According to Marin et al. (2019), it is necessary to consider the specific context and how the technology will be utilised. During the development, we aim to identify the key steps of the process, predict and prevent failures, and take into account intangible and

contextual aspects of the product. Therefore, the design of our service delivery model follows a Person-Centred Care (PCC) approach. The Health Foundation states that PCC is a new and evolving area with no single definition (The Health Foundation, 2015). It can be used to relate to several activities and principles. The underpinning rationale is that it depends on a specific patient´s needs, preferences, and circumstances, which are subject to change over time. The Health Foundation identified a Framework that includes four principles of PCC (See Figure 1). These principles are: (1) Affording people dignity, compassion and respect, (2) Offering coordinated care, support or treatment, (3) Offering personalised care, support or treatment, and (4) Supporting people to recognise and develop their own strengths and abilities to enable them to live an independent and fulfilling life.

Figure 1. The Four Principles of Person-Centred Care (The Health Foundation, 2015, p. 7)

One of the objectives of the Interreg Smart sENsor Devices fOr rehabilitation and Connected health (SENDoc) project funded by the EU Northern Periphery and Artic (NPA) programme was to propose a transnational, predominately home-based, rehabilitation service delivery model, which was to be generalisable, sustainable, and of use beyond the project (SENDoc, 2017). The final outcome is to enhance or support independent living, which is one of the goals that the SENDoc project shares with the PCC principles.

The design of this model draws on the findings of the demonstrator projects at the four SENDoc partner sites. It also draws on advice from a number of clinicians, existing literature, and from current best practices identified within SENDoc. The model considers the potential benefits, risks, and

requirements, of introducing wearable technology at scale in rural areas for ageing populations. The model adapts traditional rehabilitation provision to encompass connected healthcare concepts, which aim to enhance and improve care provision.

Background

Technology can facilitate effective and accessible models of service delivery, enabling healthcare outside the hospitals and institutions. Indeed, The World Health Organization (WHO) have stated that telehealth, defined as the delivery of healthcare through remote technologies, is an effective service delivery model for rehabilitation professionals (World Health Organization, 2011). There is an abundance of research which supports the use of Information and Communication Technology in the field of rehabilitation. Technology solutions have already been adapted by some rehabilitation practices over the last decade, the most emergent of which has been the use of synchronous videoconferencing to deliver rehabilitation therapy to clients who are in a different location to their provider (Cason, 2014). Evidence on the efficacy and effectiveness of telerehabilitation shows that it can lead to similar or better clinical outcomes when compared to conventional interventions (Kiary, 2009). More so, it is cited that telehealth solutions can improve access to care for people who live in rural areas, as well as for clients who have mobility impairments (Brennan, 2009). In addition, telehealth solutions provide scope for greatly reducing a practitioners travel time, thus allowing them to have more time to spend with clients, or are able to facilitate additional daily check-ups. While the evidence for telehealth provision is striking, many countries, health institutions, and policy makers are yet to incorporate such technology services into their service delivery model. The need for change was highlighted in 2020 when the global pandemic struck.

Telehealth in a global pandemic

In December 2019 there was an outbreak of a new highly contagious respiratory illness in the Hubei province of China, known as the SARS-CoV-2 virus, or, more commonly, coronavirus (Esakandari et al., 2020). Major indicators of infection are the presence of several symptoms, notably cough, fever, and fatigue which often present themselves within 7 days of exposure to the viral pathogen (Esakandari et al., 2020). In the months following the outbreak, the virus spread globally and by March 2020 it had been classified by WHO as a global pandemic. Healthcare systems globally were placed under enormous strain, not only because ICU units were at maximum capacity in many regions, but also because many health care workers had contracted the virus themselves, leaving hospitals short staffed. A large number of people experienced the wrath of COVID-19, especially the elderly populations who were particularly susceptible to the virus, with 219 million cases and 4.55 million

deaths in total (as per August 2021). With their healthcare systems at failure point, many governments responded with a stay at home order for all their citizens to try to limit the spread of the infection and contain the virus. This stay at home order was originally proposed by some countries (like the UK) for 3 weeks, but in reality, lasted much longer. For example, in the UK the first lockdown initially lasted for 3 months followed by a second which lasted for approximately a further 6 months. All non-mandatory hospital appointments were cancelled, leaving many patients and rehabilitees at home with no check-ups. To counteract this, health systems made attempts at implementing telehealth solutions, although of course this cannot be simply achieved overnight. Doctors resorted to phone calls with their patients, and therapists a similar approach with their rehabilitees. Some health systems were able to deploy video-conferencing applications so that patient appointments could be virtual face-to-face.

One proposed solution to help rehabilitate patients recovering from COVID-19 was the use of remote services (Salawu, 2020). In their paper, Salawu et al. discuss the strain that the pandemic placed global healthcare systems under, not only because of the huge influx of patients but also due to healthcare staff having to self-isolate. The paper identifies that COVID-19 patients have rehabilitation needs after being discharged from hospital in the form of post-discharge follow up, led by a respiratory nurse, and that this could be delivered using tele-conferencing facilities. By utilising the remote delivery of rehabilitation to COVID-19 patients, social distancing protocols introduced to reduce the spread of the virus can be adhered to (Monaghesh, 2020) identify 8 different research works which discuss the use of telehealth solutions in light of the COVID-19 pandemic. This paper again largely focuses on the use of tele-conferencing applications for the delivery of remote rehabilitation for a host of medical ailments, from the triaging of COVID-19 patients to providing allergy services, and for follow up in multiple cancer settings. They also highlight the use of technology for the delivery of training in the provision of content for new nurses.

While the pandemic has most certainly highlighted the need for telehealth provision, and expediated the delivery of some of these services, there is still much room for improvement. As highlighted, almost all telehealth services at present use some form of teleconferencing technology to facilitate remote triaging, diagnosing, and follow-up. However, this neglects the quantifiable measurements that clinicians often perform during check-ups, or therapists take during rehabilitation activities. In order to fully achieve a complete remote delivery of services, sensors need to be incorporated which gives health practitioners access to meaningful measurements of their patient from their home.

Identifying suitable sensors: SENDoc

SENDoc took the first steps in assessing the feasibility of deploying wearable sensor-based telehealth solutions, those that would provide remotely accessible quantifiable information to clinicians, in rural communities. The goal of SENDoc was to prevent, diagnose and rehabilitate (e.g. monitor and improve) an individual's functional capacity through various forms of assistance, in order to delay the need for longer-term provision of hospital services or loss of independent living. To achieve this goal, thirteen demonstrator projects (Nordström et al. 2021) within the four partner regions in Northern Europe tested various wearable technologies for prevention, diagnosis, and rehabilitation. These pilot studies, performed over the duration of the SENDoc project, were used to test a range of technologies for connected health, from the development of sensory-based frailty tests to functional tests for frailty measurements, as well as sensor-based gait analysis for an exercise plan. For each pilot, user needs were identified and translated to technical specifications, available devices in the market were screened and rated against the specifications, then the selected devices were verified and validated for use in real-life context. While some of the pilot studies showcased wearable sensors with a technology readiness level of ready to market, others highlighted connectivity problems which clinicians could not solve, thus making the technology unusable in real world healthcare settings.

The demonstrator projects also sought to investigate the acceptability and sustainability of wearable sensors from the user perspective. A transnational wearable sensor trial was designed to perform usability testing on rural ageing groups in the 4 partner regions, as this is a key component when it comes to the feasibility of deploying telehealth solutions. At present, most device manufacturers are focused on device accuracy, which often comes at the expense of device comfort, however analysis from our user acceptability testing in this study shows that while device accuracy is important to the end user, it comes second to device comfort and usability (Alamäki et al. 2021b). The findings from each of these studies helped identify requirements for both clinical and home settings. The identified requirements have in turn informed the proposed service delivery model.

A reference point when defining the new delivery model was provided by the User Guide to Technologies (Alamäki et al. 2019a) which was developed during the SENDoc project, as well as providing a knowledge source for developing future pilot studies utilising wearable sensors in the longer term. This user guide highlights the transnational nature of the need for remote service delivery; that each of the partner locations in the SENDoc project are similarly focused on decentralising care, avoiding admissions of long-term elderly patients to acute hospitals, and making the rehabilitation process more cost effective in time and money for both the patient and the local authorities. The new delivery models therefore seek to define a clear path which would help achieve each of these goals. The handbook suggests that by using wearable technologies and sensors, these

goals and objectives could be achieved, although only limited research, especially in the remote context, has been carried out thus far.

A new model for remote healthcare

The design of the proposed healthcare delivery model will aim to anticipate the rapid evolution of technology in future years; hence sustainability is critical. The model will consist of a collection of visually appealing graphics to quickly and clearly convey core concepts of the model. Graphics will be disseminated widely to stakeholders (clinicians, physio or occupational therapists, service planners, patients and their care givers), with availability online. The produced delivery model must be focused on the needs of the end-users. Existing research on remote health service delivery has also been considered and used as a basis.

The transnational nature of the research has increased the generalisation and transferability of the model. The model can act as a guideline for supporting independent living in rural areas. Regional best practices and knowledge have been collated and published in both the Wearable Technology Supported Home Rehabilitation Services in Rural Areas handbook (Alamäki et al. 2019a) and in the Guidelines on the use of wearable sensor systems in-home rehabilitation combined with remote connections handbook (Alamäki et al. 2021a). Clinicians in service delivery, regional academic institutions and hospitals have provided valuable guidance and support by commenting on draft versions of the model. Their feedback on the proposals will help ensure model validity, full user acceptance for sustainability, further applicability, and replication.

The service delivery model will help guarantee that the SENDoc results will have lasting contributions beyond the project lifetime. Knowledge gained during SENDoc demonstrator projects have provided input into the new model development ensuring the model is current and feasible. It provides a signpost for further development potential for sustainability in the 4 demonstrator project regions and beyond. Successes, failures, and lessons learnt have been documented to strengthen service delivery. The aim is that the model will encourage remote monitoring in everyday practice and this practice grows to become scalable. Certain requirements and resources need to be fulfilled to allow healthcare professionals and applied researchers to build on SENDoc success after completion.

As previously mentioned, the service delivery model will be designed as a series of Infographics. The plan to complete these series of Infographics is shown in Figure 2.

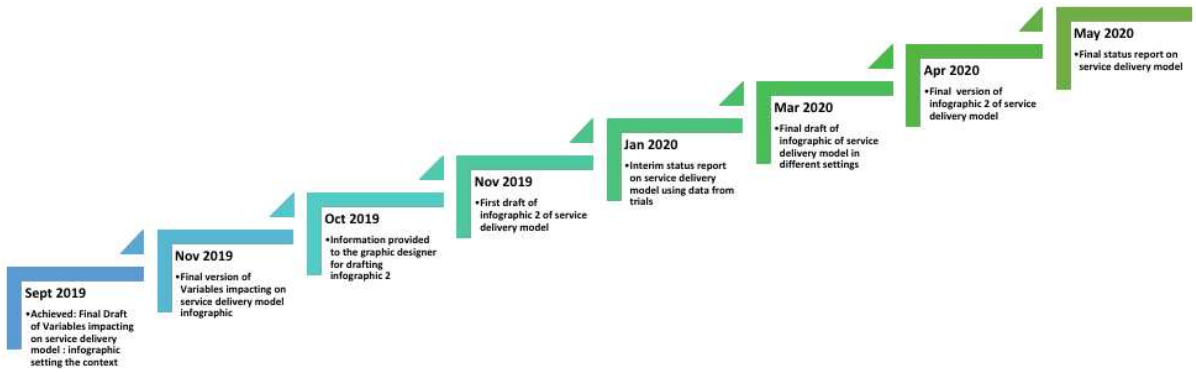

Figure 2. Plan to complete the series of Infographics depicting the Revised Service Delivery Model

Model Contextualisation

The SENDOC project is comprised of a multidisciplinary team of experts from a range of clinical and technical backgrounds. Some of the settings for SENDOC trials were clinic-based services while some were focused on in-home delivery of services or a hybrid model (including both remote and in-clinic delivery). Some partners were detached from service delivery, and thus needed to seek out clinical support. Some sites were focused on the prevention of the deterioration of health (stopping or delaying the event), others on diagnosis (obtaining information and evidence to achieve an accurate representation of the problem/illness), and others on rehabilitation (recovering health and capability after the event). The diverse set of trials meant a broad definition of rehabilitation was used to include what would usually be seen as prevention. Based on input from clinicians and physiotherapists, it was decided that the model should incorporate both clinic and home-based rehabilitation service delivery. Currently, health care services follow a reactive model that is financially unsustainable as demands on health services increase. In order to cope with the increasing demand for health services, a revised delivery model is essential. This could include an increased focus on community care and improved tools for clinic-based care. The focus of the proposed delivery model is on protocols defined by clinicians working with technicians. These protocols focus on the use of wearable system technology that supports clinicians to attain more objective measurements corresponding to the actual state of patients, moving to a more personalised and patient-centric approach. The aim is therefore to be able to show what this model looks like using the demonstrations and experience obtained in SENDoc.

In the first instance, the SENDoc team drew up an infographic of the context of rehabilitation focusing on the health of the person. The infographic was informed both by the clinicians and specialists which made up the SENDoc team, but also from the findings of demonstrator projects, in particular the results from the transnational demonstration (Alamaki et al. 2021b). In this demonstration, 65 older persons between the 4 partner countries participated in a week long study to examine the usability of a wearable device. While the sensor chosen was an activity tracker, it was assumed that the results

were scalable to other wearable sensors. Our results showed that 80% of participants were either neutral or agreed that wearing a wearable device for remote monitoring helped them be more active. In an interview performed after the trial, one participant mentioned that he felt having a remote monitoring device was comparable to having a personal trainer. We also learnt from interviewing the trial manager at one of the supporting community centres that the older people who attend her centre enjoy learning new skills which helps lead to a healthy mind and gives elders a purpose. The infographic is presented in Figure 3.

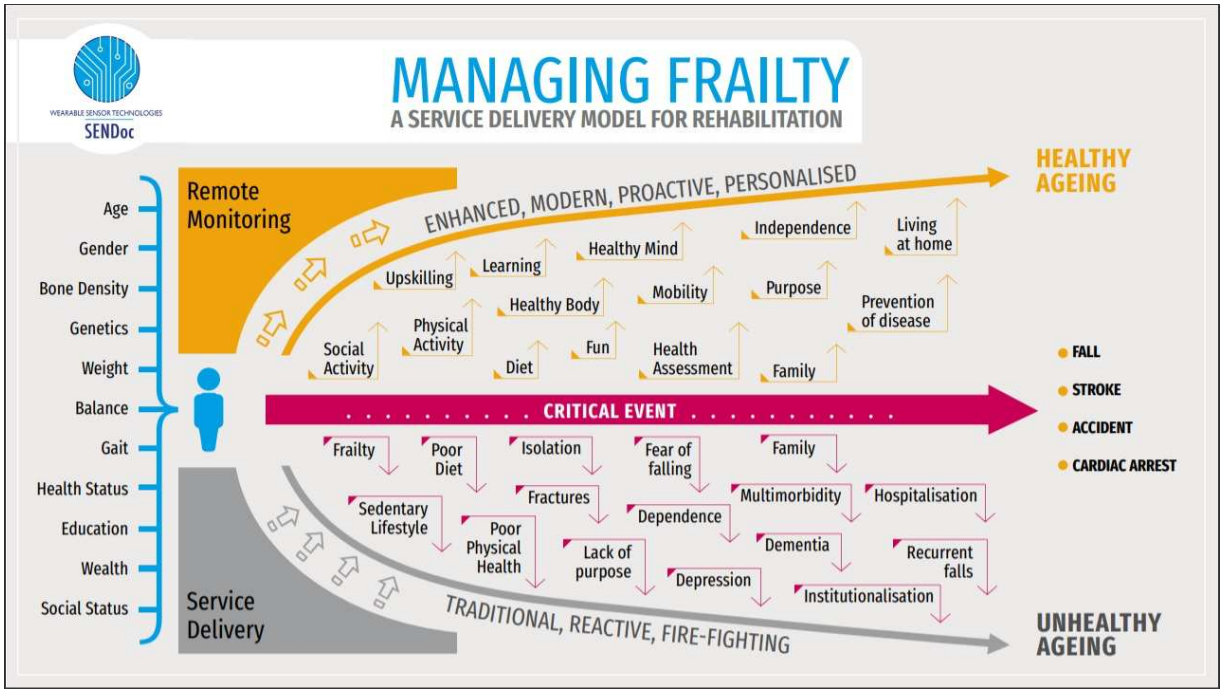

Figure 3. Infographic depicting the Context corresponding to the Rehabilitation Service Delivery Model

The infographic identifies factors associated with health outcomes in the context of service delivery.

- At the top, the revised remote service delivery is seen as enhanced modern, proactive and personalised helping lead to healthy ageing
- At the bottom, the service delivery is seen as traditional reactive and firefighting, fixing things after they have gone wrong which may lead to unhealthy ageing
- Remote rehabilitation can be broader and can encourage behaviour change before the event can be pervasive and persuasive.
- Events are important in the trajectory of ageing. An event could be a fall, a stroke, a cardiac event, or an accident which causes loss of capability and maybe independence. Falls are seen as critical. However, functional capacity also is lost gradually over time because of the natural process of aging. Additionally, sometimes personal or family concerns arise, which prompts the person to seek some kind of health service.

In Table 1 below, we have examined the characteristics of remote service delivery and considered the benefits and drawbacks of the approach.

CHARACTERISTIC	BENEFIT	DRAWBACK
Pervasive	Technology allows us to collect information about health and activity all the time. This continual monitoring may provide a more accurate and complete picture.	It becomes impossible to escape. It is difficult to identify the relevant activities or periods without human input, e.g. diaries
Personalised	Data collection and treatment can be tailored to the individual for improved health outcomes	Is it appropriate particularly if personalisation is related to Genetics
Preventative	Saves resources and ensures better outcomes for individuals and populations	More of life becomes medicalised
Dependency/control	Technology might free people and allow them to remain self-reliant longer	We may become over-reliant on technology. And it might be used to control the lives of elderly people
Logistics	Processes, information, diagnosis and prognosis can be automated making logistics around maintenance scalable and sustainable	Too much unnecessary data
Reliability	Technology can operate reliably and accurately; very little unscheduled downtime	Technology often fails at some point in its lifecycle
Current State of technology. Still not there but steps	There is a general hesitancy on the uptake of new technology, this may have a positive effect allowing more time to get things right	Clunky, not user friendly not accurately collecting the right information
Current state of health service Delivery	The current state of the healthcare system and particularly recent events in relation to the global pandemic have shown that even in	Clinicians do not have time to explore and others are not making changes a priority therefore whole

	a crisis existing and new technology can be adapted and deployed efficiently and effectively to solve problems	system changes are slow moving
Future population	Elderly populations continue to grow and age for longer, creating an increased demand on health services. Remote technology monitoring saves time thus allows clinicians to monitor larger cohorts of patients	Remote technology could leave future elderly populations feeling isolated due to the lack of physical presence of health professionals
Carbon footprint	Travel saved	
Data Privacy / Security		Sensitive patient data could be exposed in a data leak / hack, which could be used maliciously. Commercial terms and conditions on technology may permit the sale of patient data

Table 1. Benefits and Drawbacks

Model Aims

The service delivery model will map how prevention and monitoring with sensors (micro-service) can be incorporated into the rehabilitation model (macro-service), and the impact of increased personal information at each stage. Technology enhances the possibility that pre-emptive actions can be entwined into peoples' lifestyles, that self-care can be encouraged. With increased ability to capture data, an ethical question arises on whether data should be captured by health service systems? The answer to this question may depend on the situation and application. For example, it may be appropriate in situations where performing a specific activity is critical to recovery.

For example, capturing the number of steps, or duration of sleep, per day are important yet easy indicators for healthy activity. A wrist mounted activity tracker was selected (MiBand 3) for trialling among older adults. Wearable technology needs to be easy to use and provide easy mechanisms for

monitoring. The measurements derived from the sensor also need to be accurate. For example, a common issue is incorrectly detecting walking activity when a user is only swinging their arm while travelling. Wearable sensors also need to be cost-effective, truly usable, i.e. with long-lasting battery life, easy to connect, able to incentivise activity, and integrate with health care information. Incorporating technology that can be utilized for 'preventative' care, such as the MiBand, will be central to the model we produce. Additionally, the model will capture how technology can be used at both the diagnosis stage and the rehabilitation stage, to enhance the rehabilitation process and potentially lead to improved independent living for patients. Technologies such as the Dorsa-Vi and Movesole insoles have been trialled at the partner locations with promising results showing that these could be used in the rehabilitation process in the future.

The service delivery model will therefore demonstrate how each of these new technologies can fit into and improve the current rehabilitation process.

Technology can be a 'pull' towards healthy ageing utilising a preventative approach or it can help to 'push' back from unhealthy ageing. It can be an addition or help to support traditional service delivery. Therefore, we propose to develop two different versions of the model

1. A home-based rehabilitation model (Push model)
2. A 'preventive' rehabilitation model (Pull model)

Some of the work undertaken has been focused on specific diseases and measuring and recording more detailed information.

Much of the technology deployed and tested has taken place in laboratory conditions, with little consideration of service delivery, clinical perspectives of what is useful, or usability. Much of this research has remained in the lab. However it is important to move this research into communities and clinics in order for the research to be fully developed, market-ready, and of direct value to patients and clinicians.

Results

A Home-Based Rehabilitation Service Delivery Model

Presented in Figure 4, below, is the proposed SENDoc Transnational Home-Based Rehabilitation Service Delivery Model. The generalisable model was created by firstly mapping the process of a rehabilitee from the point of entry into the rehabilitation service to the exit point, through consultation with clinicians and rehabilitation specialists over the four partner institutions. Through a change or concern about their functional capacity, a patient goes under an initial assessment by a rehabilitation specialist. A rehabilitation plan is then created, and a timeline is agreed upon based on

the results of the assessment. After the plan is made, the intervention is deployed. It is at this stage that our proposed delivery model demonstrates how technology can be used, highlighting the benefits that wearable sensor systems can bring to the rehabilitation process versus the traditional approach. After the planned rehabilitation is finished, an end assessment is performed by the rehabilitation professional. At this point, it is decided whether the patient is ready for independent living or if some level of services are still required. If some level of services are required, a new plan is made by the rehabilitation professional and the process starts over again.

By examining the infographic, it is clear to the range of stakeholders that the model is targeted towards technology that can not only be used as a tool to assist in the rehabilitation of patients, but it can also be used to create a personalised program, allow for more check-ups, and ultimately has the potential to lead to a quicker and easier path to behaviour change and independent living. This is symbolised by the solid fill arrow coming from the 'rehabilitation with wearable technology' box compared to the narrower dashed arrow coming from the 'rehabilitation without wearable technology' box.

For remote rehabilitation to be feasible, the proposed model depends on the rehabilitees willingness to wear wearable sensor hardware. The technology therefore needs to be usable and acceptable by the end user. During the SENDoc project, user acceptability testing was performed on the wearable sensor system that was deployed for the transnational trial. We postulate that the results from this pilot study using an activity tracker are scalable to other wearable sensor systems. Traditionally, wearable device manufacturers have been focused on the accuracy of their device, which can often come at the expense of comfort and other factors. However, the results from our user study show that when considering extended use of a wearable sensor device, the device accuracy / fit for purpose comes second ($r_\tau = 0.340$, $p = 0.003$) to how comfortable it is to wear ($r_\tau = 0.348$, $p = 0.003$). For the remote rehabilitation model to be successfully deployed into health care systems, we need to ensure that the technology we are requesting rehabilitees to wear are both comfortable and offer accuracy for the rehabilitation specialist. Neglecting just one of these factors will likely result in the unsuccessful utilisation of wearable sensor technology in the rehabilitation process.

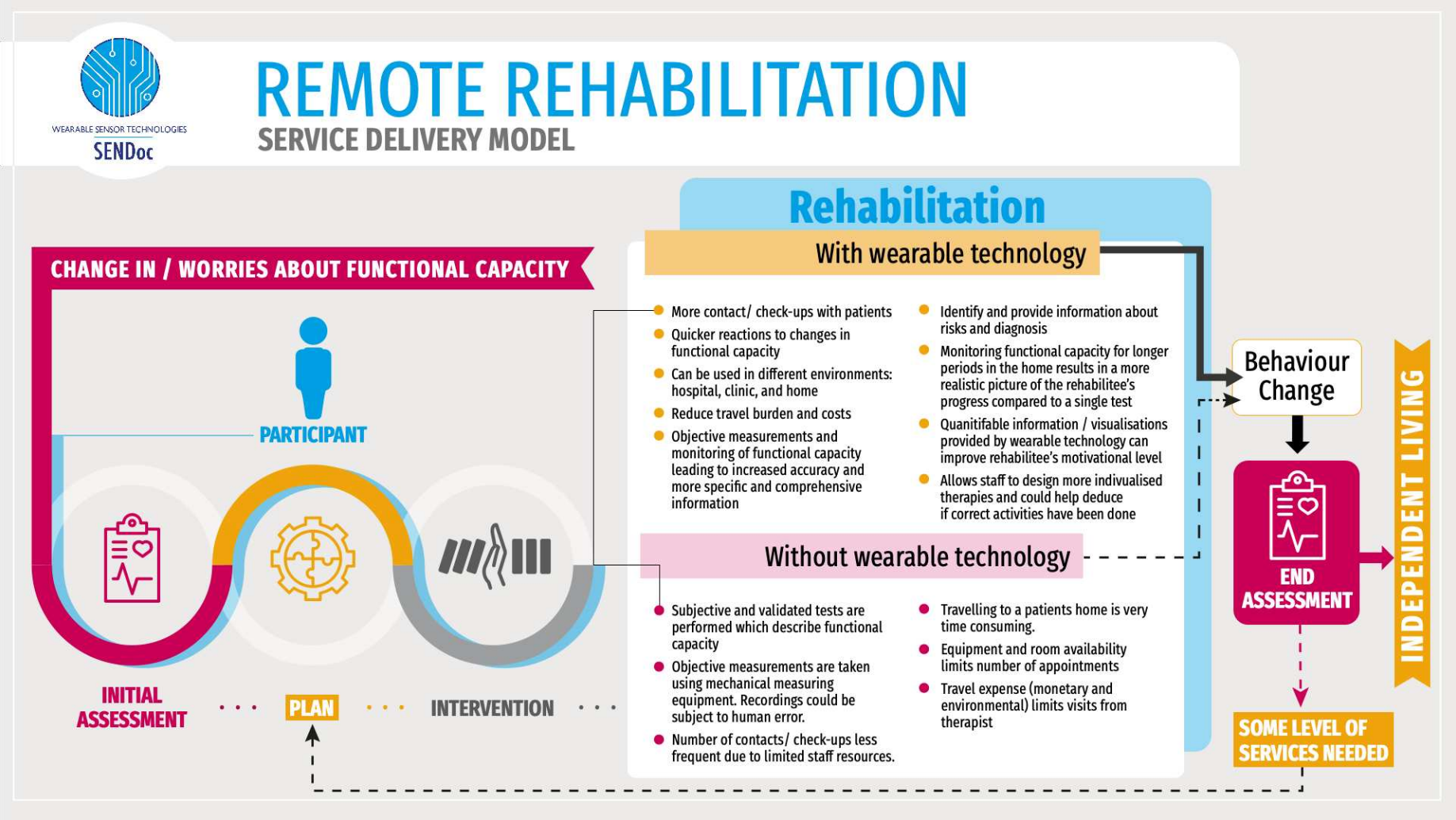

Figure 4. The finalised Remote Rehabilitation Service Delivery Model

A 'Preventive' Rehabilitation Service Delivery Model

Falls can have a number of negative effects resulting in decreased quality of life due to reduced activities of daily living, physical deterioration and social isolation. They also have a significant economic burden on national health care services, with falls costing between 0.85% and 1.5% of the total health care expenditures. In fact, falls are estimated to cost the NHS more than £2.3 billion per year. Therefore, as part of SENDoc's research, various technologies were explored which could potentially delay or alleviate the need for rehabilitation through pre-emptive actions and self-care. This 'preventive' approach shows how health care systems could move away from the traditional fire-fighting approach currently employed for rehabilitation by utilising wearable technology in a preventative manner. This technology is to be used prior to a change in functional capacity to promote lifestyle change and thus healthy ageing in the hope that the risk of a critical event such as a fall is mitigated. We propose that this can be achieved through simple exercise tracking and digital feedback and notification, which in turn lowers the likelihood of reduced mobility. In tandem, sleep tracking can be a useful tool for older people as sleep disturbances are linked to increased frailty. Wearable technology, however, can create awareness of sleep cycles and allow the elderly person to make changes in an attempt to improve their sleeping patterns.

Figure 5, presented below, documents the proposed SENDoc Transnational Home-Based 'Preventive' Rehabilitation Service Delivery Model. The proposed future healthcare model was based on our original mapping of the home-based rehabilitation process but shows how an older person can pre-emptively be in control of their health prior to any change in functional capacity. By employing preventive technology to help keep fit and healthy, an older person reduces the chances of decreased mobility and thus creates sustained path to independent living. Naturally, changes in functional capacity can still occur despite employing preventive technology. However, we postulate in our service model that this route is less likely to happen, indicated by the dashed arrow, compared to the sustainable route to independent living through maintaining a healthier lifestyle using wearable technology, indicated by the thicker, solid arrow.

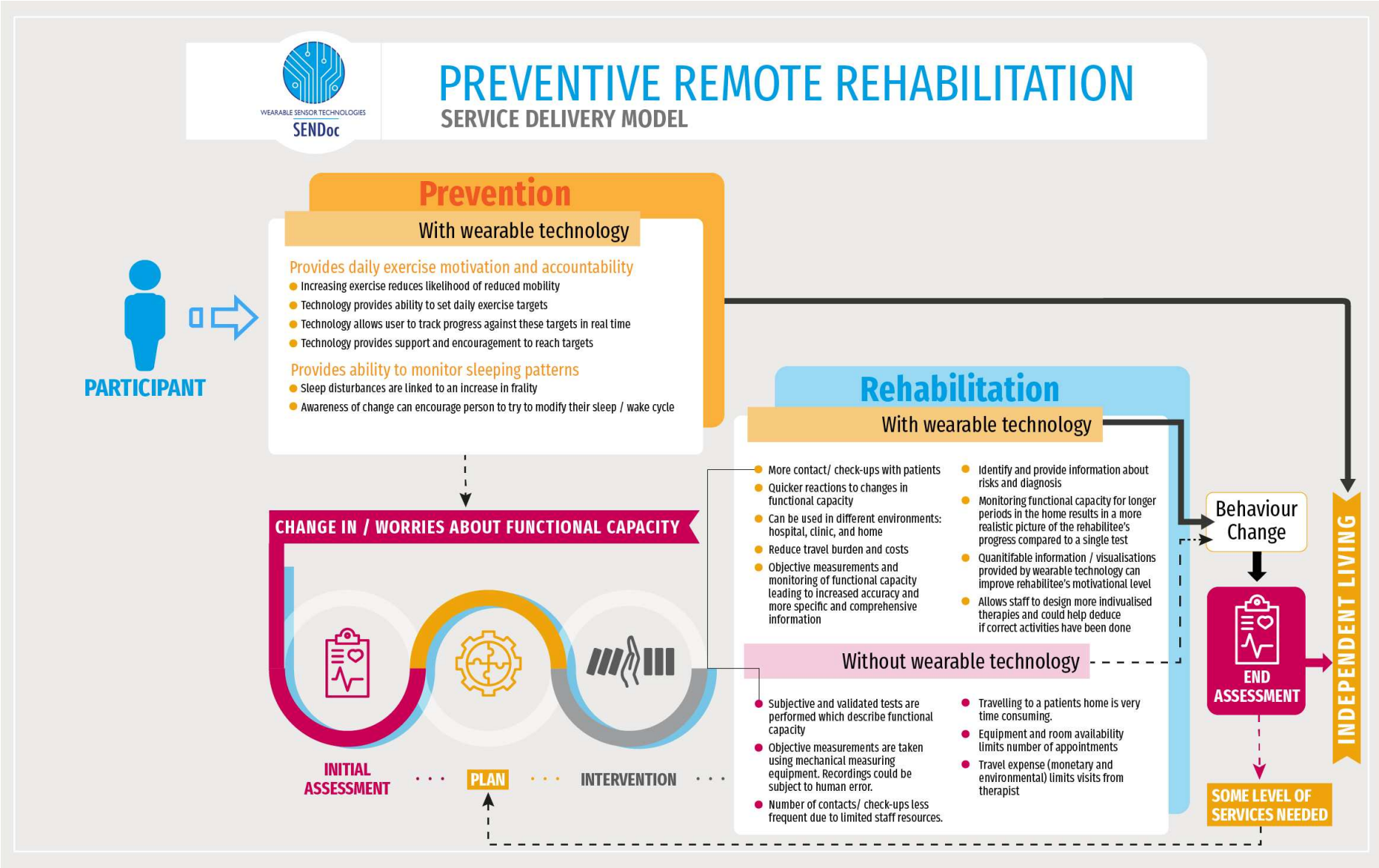

Figure 5: The proposed Preventive Rehabilitation Service Delivery Model

Discussion

The traditional approach taken to rehabilitation relies on rehabilitation professionals performing face-to-face in person measurements, diagnosis and check-ups on patients throughout the rehabilitation programme. This can be a major burden on older patients, especially if they live rurally as long commutes to clinics can become cumbersome, uncomfortable, and costly, especially depending on the specialist they may need access to. Alternatively, specialists can travel to patients homes to perform check-ups, however the expense of doing so (time, monetary, and environmental) limits the number of visits from these staff. Remote healthcare presents a potential solution to some of these problems if deploying and used in the correct manner.

During the course of the SENDoc programme, the need for remote services in healthcare was further highlighted when the global COVID-19 pandemic struck the world. Social distancing measures were introduced to reduce the spread of the virus, resulting in many hospital appointments being cancelled and patients left unable to access the services they needed. There is an obvious opportunity for service reform in this field with the number of wearable technology devices available for the remote monitoring of rehabilitees rapidly expanding.

SENDoc proposes a transnational home-based remote rehabilitation service delivery model, created through consultations with clinicians, health professionals, and academics over the 4 partner regions of SENDoc and further afield, showcasing how wearable technology could be introduced into the service delivery of rehabilitation practice. The remote rehabilitation model, documented in Figure 4, demonstrates the clear advantages of wearable technology being chosen for the required rehabilitation intervention, and how ultimately, it leads to an easier, clearer, and conceivably faster path to behaviour change and independent living.

The overarching benefits of home-based rehabilitation using wearable sensors are several. More patient data being recorded means that personalised plans can be created and updated as required, allowing for a more effective rehabilitation, while authentic connected health wearable sensor system solutions mean patients living in rural areas can gain access to the services they require remotely. The benefits from the bigger picture are also worth noting. With climate change commitments a priority from nations worldwide, technology which can help reduce carbon footprint is going to be vitally important going forward. Wearable sensor technologies allow for this by reducing journeys to/from the clinic by patients and practitioners alike, while the reduction in travel time for practitioners means they can spend more quality time with patients as well as performing more virtual visitations.

Nevertheless, there are risks in moving to a remote healthcare delivery model which need to be considered. Telehealth devices, such as wearable sensors for remote rehabilitation, rely on an internet connection to allow data to be transferred by the patient and clinician remotely. Fast internet is required not only for data transfer from such devices, but also for high quality videoconferencing, a key element of the remote rehabilitation model, allowing medical practitioners to meet with their patients remotely and perform check-ups. Poor internet connectivity will therefore act as a blocker to technology adoption. Furthermore, poor connectivity is especially associated with rural areas where adoption of our model would be most beneficial. However, the world bank considers broadband a basic necessity for economic and human development in both developed and developing countries and is strongly committed to strategies and models to realise broadband rollout throughout the world. The development of 5G infrastructure is one strategy currently being deployed to bring fast internet to rural communities, for example by 2023 Sweden aims to have 99% of its population covered by 5G. Further, Scandinavia as a whole are world leaders in connecting remote areas to broadband and at present 91% of their population are using broadband. Remote service delivery is therefore well within the scope of these countries futures.

There will also be significant training needs for both the practitioner and the patient if wearable sensor solutions are to be deployed at scale. Learning how to appropriately don and doff equipment, configure, and initialise the remote connection will require upskilling from therapists and patients alike. A significant initial investment in training will therefore be required. As the end users of these systems are likely to be elderly, it is crucial that the technology is easy to use and to troubleshoot.

The ethical aspect of remote health monitoring is also worth examining. For example, there are concerns arising from the over-reliance on data. Firstly, clinicians overly relying on a technology and data which doesn't indicate a problem can create a false sense of security, and lead to missed diagnosis and intervention. On the other hand, data can lead to overdiagnosis resulting in unnecessary health anxiety for the patient. Over-reliance on data can also result in reductionism whereby patients are simply reduced to their data, and the human aspect of healthcare is lost. Data from wearable devices do not capture the mental or emotional state of a patient, meaning the benefit of time savings on face-to-face appointments could be at the cost of gaining contextual data and more subtle cues provided from a patient during a face-to-face interaction. Further ethical concerns arise from a privacy perspective, whereby the use of wearable technology infringes on a patients privacy and leaves them feeling watched. While this can be reassuring to patients who have reduced functional capacity, it could lead to distrust and lack of cooperation from those who feel like all their movements are being monitored.

One final risk to consider is the initial cost of investment in telehealth solutions. As remote monitoring technologies are still in their infancy, their cost tends to be expensive. For these solutions to be taken under serious consideration for widescale deployment by policy makers in the relevant health departments, the cost of the technology will to have to reduce. However, as the popularity of wearable sensor technology for rehabilitation continues to surge, the increased competition should help realise a more competitive pricing structure for investment in the future of health care.

For the SENDoc team, the benefits of remote healthcare technologies for remote rehabilitation outweigh the risks, certainly as we look forward to a society where broadband accessibility is increasing daily and new devices are appearing on the market at a ferocious rate helping drive quality and comfort while lowering the price. Yet, there are positives to the current rehabilitation programme which are beneficial, effective, and simply cannot be replaced with technology at this stage. The SENDoc team proposes a hybrid model going forward, combining suitable elements from both wearable technology sensors for rehabilitation and traditional rehabilitation practices to deliver effective rehabilitation programmes.

SENDoc proposed in a second model, documented in Figure 5, that the health and well-being of citizens could be improved through the use of preventive wearable technology. This technology could encourage self-care and lifestyle changes to enhance mobility and thus reduce the likelihood of requiring rehabilitation altogether.

The preventive wearable technology which we piloted during the SENDoc project were simple wrist-worn activity trackers. These sensors are cheap, comfortable, and easy to use. From our results, only 20% of the participants had previous experience of wearing an activity tracker, yet by the end of the seven-day trial 65% of the participants indicated they wanted to continue to wear the device. These results demonstrate that there is a clear interest from previously inexperienced elders in using wearable sensors which help motivate a healthier lifestyle, verifying that the proposed model of preventive wearable sensors would appeal to / have successful uptake from the intended end users. Indeed, 80% of the participants were either neutral or agreed that the wearable sensor increased their daily activity. This simple example of technology for prevention of declining health can also help monitor sleeping habits, which can affect frailty.

‘Preventive’ technology of course cannot guarantee that you will not experience a critical event, however it can promote and support the pursuit of a healthier lifestyle and thus healthier ageing.

Conclusion

The European Commission aims to assist the EU Member states to enhance their health systems and the health of their citizens, by creating health care systems which are more people-centred, focusing on prevention provision, and improving access to healthcare. SENDoc identified that to realise these goals, the model for healthcare service delivery would need revised. Healthcare access to rural community dwellers is a long-standing issue, especially within the ageing community.

In this report, we present two models for home-based service delivery. In the first, we focus on rehabilitation, showing how wearable sensor technology can be deployed at the intervention stage allowing remote monitoring from clinicians from the comfort of the patient's home. Pilot studies held over the duration of the SENDoc project have shown that the technology and infrastructure is now in place, providing scope for these sensor solutions to be offered as a viable alternative to the traditional rehabilitation practices.

In the second, we showcase a 'preventive' model. This model demonstrates that by utilising off-the-shelf wearable sensors available to consumers at present, healthy ageing can be promoted through an increase in exercise and awareness of sleeping habits. This promotion of self-care can in turn help delay a decline in functional capacity and perhaps mitigate future critical events. For example, the transnational trial held over the duration of the SENDoc project showed that 80% of participants were either neutral or agreed that wearing a wearable device for remote monitoring helped them be more active.

We believe that achieving more people-centred care is within reach of healthcare systems in 2021. The global COVID-19 pandemic has further highlighted the need for change, and beyond that demonstrated that telehealth solutions are indeed effective. Now, the challenge is to introduce wearable sensor technology for home use, so that personalised, people centred care can be delivered to the people who need it.

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