Review article

Patient and clinician use characteristics and perceptions of pulse oximeter use: A scoping review

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ABSTRACT

Background and objectives: The need to monitor patients outside of a formal clinical setting, such as a hospital or ambulatory care facility, has become increasingly important since COVID-19. It introduces significant challenges to ensure accurate and timely measurements, maintain strong patient engagement, and operationalise data for clinical decision-making. Remote Patient Monitoring (RPM) devices like the pulse oximeter help mitigate these difficulties, however, practical approaches to successfully integrate this technology into existing patient-clinician interactions that ensure the delivery of safe and effective care are vital. The objective of this scoping review was to synthesise existing literature to provide an overview of the variety of user perceptions associated with pulse oximeter devices, which may impact patients' and clinicians' acceptance of the devices in a RPM context.
Methods: A search over three databases was conducted between April 2021 – June 2021 using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Scoping Review (PRISMA-ScR) guidelines. A total of 16 articles were included in this scoping review.
Results: Results indicate there has been an increase in use of pulse oximeters across hospital and community settings for continuous vital signs monitoring and remote monitoring of patients over time. Research in this area is shifting towards increasing accessibility of care through the development and implementation of telehealth systems and phone oximeters. Aspects of pulse oximeter UX most frequently investigated are usability and acceptability, however, these terms are often undefined, or definitions vary across studies. Perceived effectiveness, opportunity costs, and attitude towards use remain unexplored areas of UX. Overall, patients and clinicians view the pulse oximeter positively and find it user-friendly. A high level of learnability was found for the device and additional benefits included increasing patient self-efficacy and clinician motivation to work. However, issues getting an accurate reading due to device usability are still experienced by some patients and clinicians.
Conclusion: This scoping review is the first to summarise user perceptions of the pulse oximeter in a healthcare context. It showed that both patients and clinicians hold positive perceptions of the pulse oximeter and important factors to consider in designing user-focused services include ease-of-use and wearability of devices; context of use including user's prior health and IT knowledge; attitude towards use and perceived effectiveness; impact on user motivation and self-efficacy; and finally, potential user costs like inconvenience or increased anxiety. With the rapid increase in research studies examining pulse oximeter use for RPM since COVID-19, a systematic review is warranted as the next step to consolidate evidence and investigate the impact of these factors on pulse oximeter acceptance and effectiveness.

1. Introduction

The COVID-19 pandemic has transformed the way healthcare services are delivered. The standard face-to-face consultation has been partially or fully replaced by virtual care to ensure continuity of care whilst simultaneously minimising COVID-19 transmission. Remote Patient Monitoring (RPM) technology is one component of virtual care gaining momentum. Pulse oximeters are an example of a RPM device that provide a simple, non-invasive way of approximately measuring a patient's arterial oxygenation (SpO_2) and are frequently used in the

management of COVID-19 patients [1,2]. They can be used for vital signs monitoring at home and enable the early escalation of deteriorating patients to avoid invasive ventilation and unnecessary ICU readmission, while allowing for the optimal utilization of health care resources [3].

Although pulse oximeters have become common practice in a variety of clinical situations, there is limited work synthesising user experience (UX) of these devices [4]. Previous research is limited to measuring accuracy and assessing the technology's impact on patient outcomes; no review currently exists that focuses on user experience of pulse oximeters [5]. The usability of healthcare devices can have a significant impact on acceptance of the devices, patient compliance, and ultimately health outcomes [6]. The objective of this scoping review was to synthesise existing literature to provide an overview of the variety of user perceptions associated with pulse oximeter devices, which may impact patients' and clinicians' acceptance of the devices in a RPM context.

2. Methods

A systematic search was conducted for studies that provided data to address the following key questions:

RQ: What patient characteristics and health problems are the focus for pulse oximetry technology?
RQ2: What aspects of pulse oximeter UX have been investigated?

RQ3: What are clinical and non-clinical users' perceptions of pulse oximeters?

2.1. Search strategy

An experienced research librarian was consulted to develop search strategies for three databases: Medline (via Ovid 1946 - present), Scopus (via Elsevier), and Web of Science (Core Collections). The search strategies utilised subject terms, where appropriate, and free-text terms to capture the following concepts: (1) Intervention - pulse oximetry as a health intervention, or a pulse oximeter; (2) Measure – a method for collecting user feedback, including the following terms: questionnaire, survey, interview or focus group; and (3) Outcome – UX sentiment characterised by the following terms: usability, acceptability, satisfaction, ease of use, wearability, user experience, and user evaluation. All studies evaluating UX of a pulse oximeter were desirable, so initially no restrictions were added in terms of age or context that might limit the yield. Very few studies exist that primarily assess the pulse oximeter from a UX perspective, so this search strategy provided us with access to studies where UX of a pulse oximeter was a secondary study factor in a larger system implementation. Additional articles were obtained by manually screening the bibliographies of pertinent studies. The search strategy and initial yields from each database are shown in Fig. 1.
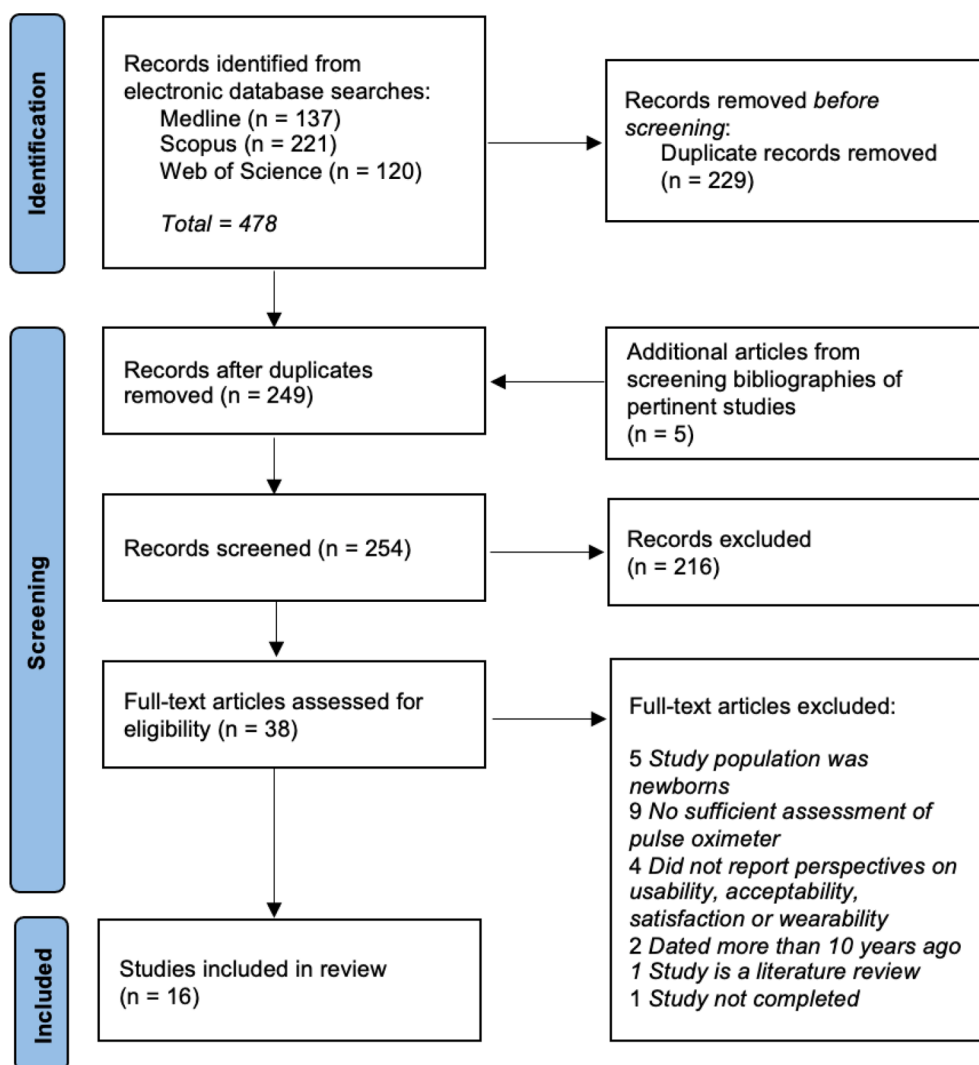

Fig. 1. Literature search and selection for user experience of pulse oximeter.

2.2. Inclusion and exclusion criteria

Articles were determined suitable for inclusion if they reported UX of a pulse oximeter in any healthcare setting (i.e., in-hospital or ambulatory), however, a focus was placed on RPM and virtual care. For articles where a pulse oximeter device was used within the implementation of a larger RPM system, the device itself had to be evaluated within that system for the article to be included. Articles were included if they evaluated user perceptions of the device (i.e., from the perspective of patients, clinicians, or healthy volunteers). Articles were excluded if they did not include a qualitative or quantitative method for gathering user feedback, such as surveys, interviews or focus groups. Articles where the patient population was newborns were excluded because acceptability from the mothers' perspective usually included factors (such as skin-to-skin contact) not relevant to our focus on RPM. Articles had to be primary studies to be included and review papers were excluded. Articles dated more than 10 years ago were excluded because pulse oximeter technology (introduction of smartphones etc.) may have evolved since then. Also articles not written in English were excluded due to difficulties translating.

2.3. Data extraction

The screening process was conducted using the PRISMA extension for scoping reviews (Fig. 1) [7]. Titles and abstracts were screened for inclusion according to the specified criteria (see section above on Inclusion and Exclusion Criteria). Extracted data included article characteristics (country, author(s) name, year of publication, journal name, article type), area of research, the pulse oximeter's application in the study, the UX dimension, the user population, and the type of study method. A qualitative synthesis of the articles was conducted to identify clinical and non-clinical perceptions of pulse oximeters, reasons for their use, and variables impacting their UX and acceptance within RPM systems.

2.4. Study selection

The initial search of the three databases resulted in 249 articles identified after duplicates were removed. During the title and abstract screening stage, 216 articles were excluded due to prespecified criteria. At this stage, five additional articles were added after screening the bibliographies of pertinent studies. A secondary reviewer screened 10% of the studies' title and abstracts to establish inter-rater reliability of 76% (19/25 agreement). A total of 38 articles were assessed as full-text, and a further 22 articles were excluded for reasons outlined in Fig. 1. As a result, 16 articles were included in this study. One reviewer extracted all the data from the 16 articles.

3. Results

3.1. Article characteristics

The search identified 16 unique articles across 15 different journals. The number of studies evaluating UX of pulse oximeters has increased significantly in recent years (see Fig. 2), ranging from one to two publications per year up to 2019, then jumping to the recent increased uptake of six publications in 2020. First authors of the included studies represent 10 different countries (see Summary Table 1).

3.2. Area of research

Seven studies (43.8%) [8–14] were intervention studies that introduced a new telehealth system that included a pulse oximeter and gathered user experience feedback. Two studies were case studies assessing the usability of a pulse oximeter in a healthcare context [15,16]. Four more were development studies that described the design and development of a new phone-oximeter and evaluated its usability [17–20]. Three more were qualitative studies evaluating: 1) the wearability of multiple monitoring devices; 2) the effect of prior health knowledge on the usability of a pulse oximeter; and 3) clinicians' perceptions, beliefs, and motivations to use pulse oximeters [4,21,22].

3.3. Pulse oximeter application

Four of the included studies (25%) examined the use of pulse oximeters as a tool to increase availability of care through pairing with a smartphone application [17–20]. Other applications included: as a diagnostic tool for children with pneumonia [15,16]; a monitoring tool in paediatric telehomecare [11]; remote risk-based monitoring tool for patients at risk of Cardiovascular disease (CVD) [8,10]; a general monitoring tool for blood oxygenation levels [21,22]; post-operative continuous vital sign monitoring for patients recovering from surgery [14]; data capture and transmission to streamline clinical trials [9]; long-term oxygen therapy (LTOT) optimization [12]; and as a digital
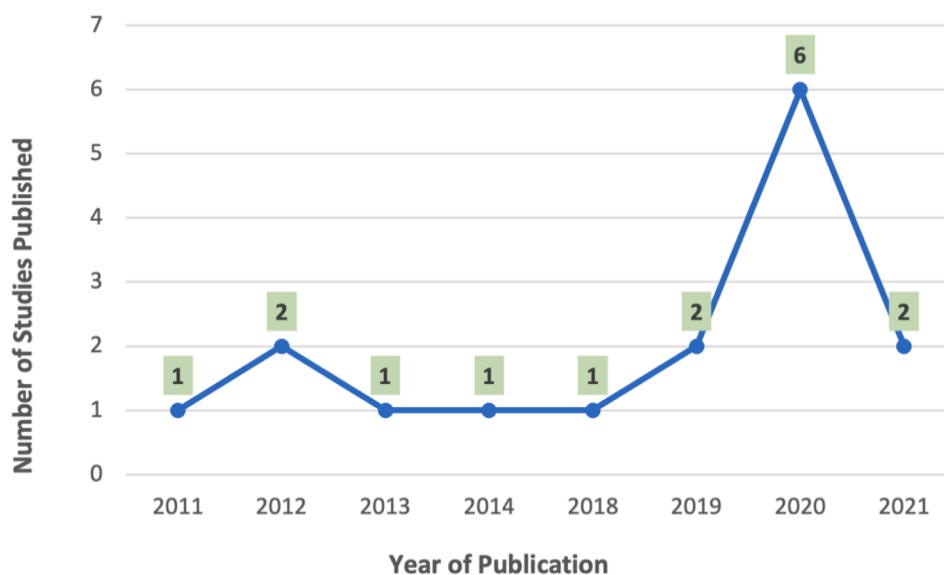

Fig. 2. Number of publications by year.

Table 1
Article characteristics for included studies.

Year	Setting	Author(s)	Journal	Study type	Research area	Hardware/ Software	Population	Usability dimension	Procedure
2021	Dublin, Ireland	Slevin P, et al. (Slevin et al., 2021)	Health Informatics Journal	Qualitative study	Digital health interventions in the management of COPD	N/A (general)	Full-time carers to COPD patients	Perceptions, beliefs, motivations of use	Semi-structured interviews
2021	St. Stephen's Hospital Marg, Tis Hazari, New Delhi, India	Sarin E, et al. (Sarin et al., 2021)	Journal of Family Medicine and Primary Care	Qualitative study	Assessment of PO in outpatient management of children with Acute Respiratory Infection (ARI) during COVID-19	Masimo Rad-G multimodal handheld pulse oximeter	Service providers to children with Acute Respiratory Infection (ARI)	Usability	In-depth interviews held over the phone
2020	Sant Joan de Déu Hospital in Barcelona	Lopez S, et al. (Lopez Segui et al., 2020)	JMIR Paediatrics and Parenting	Interventional Prospective Pilot Study	Assessment of families' degree of satisfaction with paediatric telehomecare	iHealth Air Oximeter	Paediatric patients and their families	Satisfaction	Questionnaire
2020	Lost Angeles, California	Chang E, et al. (Chang et al., 2020)	Biology of Blood and Marrow Transplantation	Feasibility and acceptability study	Assessment of RPM system for HCT survivors at high risk of CVD	mTelehealth RPM Kit (mTelehealth, Delray, Beach, FL)	HCT survivors in existing electronic database at City of Hope, Duarte, California	Feasibility and acceptability	Patient satisfaction survey and observation
2020	Ethiopia, Africa	Baker K, et al. (Baker et al., 2020)	Acta Paediatrica	Cross-sectional study	Assessment of device usability for health workers for pneumonia diagnosis of signs and symptoms in children under five	Masimo Rad-G	Health extension workers (HEWs), First-level health facility workers (FLHFWs), and caregivers	Usability and acceptability	Direct observation of HEW consultations and semi-structured interviews with FLHFWs and caregivers
2020	Oxford, UK	Areia C, et al. (Areia et al., 2020)	JMIR MHealth and UHealth	Prospective Observational Cohort Study	Assessment of wearability of a selection of commercially available ambulatory monitoring systems (AMSs)	Nonin WristOx2 3150 (Nonin), Checkme O2+ (Viatom Technology), PC-68B, and AP-20 (both from Creative Medical); Wavelet Health	Healthy volunteers and inhouse research staff	Wearability	Observation and general free-text feedback
2020	Amiens, France	Chaniaud N, et al. (N. Chaniaud et al., 2020)	JMIR MHealth and UHealth	Experimental usability study	Assessment of the impact of prior health knowledge on usability outcome of 2 medical devices	iHealth Air Oximeter	Students at the Université Picardie Jules Verne	Usability	SUS Questionnaire and self-recorded observation
2020	Ontario, Canada and Liverpool, UK.	McGillion M, et al. (McGillion et al., 2020)	Journal of Medical Internet Research	User testing study	Assessment of user performance and acceptance of a remote automated monitoring (RAM) and virtual hospital-to-home care intervention using Philip's devices.	Philip's Guardian Solution, including wireless continuous pulse oximeter monitor	Surgical ward nurses and patients recovering from cardiac or major vascular surgery	User satisfaction and acceptance	Net Promoter Scale (NPS) survey and debrief interview
2019	Hamilton, Canada	Harsha P, et al. (Harsha et al., 2019)	JMIR Medical Informatics	Reactive analysis of a randomised controlled trial	Issues and challenges associated with introducing wireless monitoring systems into complex hospital infrastructure during the	N/A (general)	Patients and staff in Juravinski Hospital in Hamilton, Canada	User experience, guided by Lau et al's. Clinical Adoption (CA) framework	Evaluating data gathered from VIGILANCE implementation: and nurse-feedback questionnaire

Table 1 (*continued*)

Year	Setting	Author(s)	Journal	Study type	Research area	Hardware/ Software	Population	Usability dimension	Procedure
2019	Columbia, Vancouver, Canada	Chan C, et al. (Chan et al., 2019)	Physiotherapy	Usability study	VIGILANCE eHealth intervention implementation Assessment of PO diagnostic tool during exercise; telerehabilitation of COPD patients	Kenek O2 Pulse Oximeter	Patients with chronic lung disease and healthy controls	Usability	Questionnaire and direct observation
2018	Sanofi-Aventis Recherche & Dévelopement, Chilly-Mazarin, France	Russell C, et al. (Russell et al., 2018)	Digital Biomarkers	Pilot study	Comparison of mobile technologies with clinical standard devices for data capture and transmission, to streamline clinical trials	Comparing GE Healthcare Dinamap Procare 400 (clinical device) to Nonin Onyx II 9560 (mobile technology)	Healthy volunteers	Usability	Subject Device Usability Questionnaire (DUQ) and Investigator After-Scenario Questionnaire (ASQ)
2014	Lisbon, Portugal	Faria, I, et al. (Faria et al., 2014)	Telemedicine and E-Health	Intervention assessment	Evaluation of the clinical relevance of a home telemonitoring system in LTOT optimisation	Avant 4000; Nonin Medical, Plymouth, MN	Patients with chronic lung disease	Acceptance	Questionnaire
2013	Nottingham, UK	Craven M. P., et al. (Craven et al., 2013)	International Conference on Human-Computer Interaction	Case study descriptions	Evaluation of user requirements for development of PO smartphone self-reporting app	Android phone running the SimpleEye Live App in association with a Nonin 9560 Onyx II Bluetooth-enabled fingertip oximeter	Males of age 18 + who reported having mild asthma	User experience	Semi-structured interviews
2012	University of Queensland, QLD, Australia	Tang J, et al. (Tang et al., 2012)	International Journal of Telemedicine and Applications	Pilot study	Assessment of remote PO system for pulmonary rehabilitation	Onyx II 9560, Nonin Medical Inc., Plymouth, MN	Healthy volunteers	Usability	Questionnaire and direct observation
2012	Canada and Uganda	Hudson J, et al. (Hudson et al., 2012)	Anaesthesia	Evaluation study	Development and evaluation of a prototype pulse oximeter and smartphone app	Apple iPod Touch hardwired to a Nonin Xpod OEM pulse oximeter module	Medical care providers in Canada and Uganda setting	Usability	Think Aloud and Mobile Phone Usability Questionnaire (MUQ)
2011	BC Children's Hospital, Vancouver, Canada	Karlen W, et al. (Karlen et al., 2011)	Healthinf 2011: Proceedings of the International Conference on Health Informatics	Development and evaluation study	Development and evaluation of a phone oximeter	iPod Touch (Apple, Cupertino, USA) hardwired via the serial port through the dock connector to a certified 8bit OEM Nonin Xpod oximeter sensor	Healthy volunteers working in a hospital environment	Usability	Think Aloud and Mobile Phone Usability Questionnaire (MUQ)

health intervention for managing Chronic Obstructive Pulmonary Disease (COPD) patients, either as a diagnostic tool or during rehabilitation [4,13].

3.4. Dimensions in user experience

In the included studies, *usability* was by far the most frequent type of UX dimension examined (8/16, 50%) [9,13,15–19,22]. However, there was no standard definition or method for assessing the concept of usability across the papers. Baker et al., [16] defined the pulse oximeter's usability as 'adherence to the World Health Organisation requirements to assess fast breathing and device manufacturer instructions for use'.

Meanwhile, Russell et al., [9] and Karlen et al., [19] defined usability as 'ease of use' and 'how willing subjects were to use the device on a regular basis'. Chaniaud, Metayer, Megalakaki and Loup-Escande [22] used the ISO 9241-11 definition for usability as 'the extent to which a product can be used by specified users to achieve specified goals', and the remaining four studies did not define the term usability [13,15,17,18]. The second most frequently explored UX dimension was user *acceptance / acceptability*, which also varied in definition by study [8,10,12,16]. Lopez Segui et al., [11] used the UX dimension *satisfaction*, however, did not define what this meant in the context of using the system. Areia et al., [21] assessed *wearability*, but also did not provide a definition and only listed the types of measurements collected. Finally, three studies

[4,14,20] gathered general *user experience* feedback to assess the pulse oximeter.

3.5. Types of study methods

Questionnaires or surveys were most frequently used method, utilized in 12 out of the 16 included studies (75%) [8–14,17–19,21,22]. (See Fig. 3).

Other methods for assessing UX included semi-structured interviews [4,16,20], in-depth interviews over the telephone [15], direct observation [10,13,16,17,21,22], think-aloud [18,19] indirect observation [12,22], video analysis [22], free-text written feedback [21], and assessing case report forms or electronic medical records (eMRs) [10,14]. Finally, this review found only one paper (TFA PAPER) used a theoretical framework when exploring users' perception of the pulse oximeter.

3.6. User population

The participants in the included studies were clinicians [4,8,14–16,18,19], patients [8,10–12,14,17] or healthy volunteers [9,13,17,20–22]. One study included the families of paediatric patients [11]. Some studies included more than one type of participant. Notably, only two studies explored both patients' *and* clinicians' experiences of pulse oximeters [8,14]. Chan et al., [17] compared the UX of patients to healthy controls (See Summary Table 1).

3.7. Clinical and caregivers perceptions of pulse oximeter

Overall, clinicians viewed the pulse oximeter to be accurate, when used correctly, and believed in its ability to provide a true indicator of health, even when accuracy was not measured in the study [15,16]. Additionally, some clinicians said that data generated remotely using a pulse oximeter 'could provide a truer representation of the patient's health' in situations where patients may be unwilling or unable to share exact details [4]. Most issues identified by clinicians were related to accuracy; for example, sensitivity to movement was a common complaint which affected clinicians' ability to obtain a correct result while taking a reading [15,16]. Some clinicians also reported needing further support to get a stronger signal by fitting the probe correctly [16].

The device was found to be easy to use by clinicians in both high- and low- medical resource countries [18,19]. While a small number of clinicians reported experiencing initial difficulties, most said their skills, knowledge, and ability to use the pulse oximeter developed over time [16]. Usability issues identified by clinicians can be categorised as: 1) problems navigating the user interface of a phone oximeter app, 2) managing device battery life [16], and 3) alarm fatigue when nurses were monitoring patients in a ward setting [14]. In one study, despite high usability ratings from patients, clinicians reported that 36% of data obtained was invalid and many patients required phone calls for system 'clarifications'. Potential causes suggested by the authors of this study for invalid data include low literacy of patients, difficulty understanding the system's functioning, and difficulty keeping track of their everyday movements and charging the various devices (a heartrate accelerator and mobile phone were part of the larger system assessed) [12]. Overall, the included studies revealed that even clinicians who struggled with device usability, and observed patients struggling, were very accepting of the device.

Several additional benefits of pulse oximeters were mentioned by clinicians in studies. For example, the ability to gather interappointment data which could help augment existing care and prioritise patients' needs during consultations [4]. Clinicians also reported that having access to patient health data between appointments had the potential to facilitate timelier interventions and individualise care with regular contact and advice. Furthermore, symptom tracking could have a positive impact on patient self-management and support their adherence to treatment plans by improving awareness and knowledge of their condition. Some clinicians also reported that using pulse oximeters increased their own 'motivation to work' because people 'appreciated [their] work more' when the device enabled them 'to deliver an effective service' [16]. Finally, some clinicians appreciated the pulse oximeter's ability to offer protection from potential COVID-19 infection by mitigating need for contact [15].

3.8. Non-clinical perceptions of pulse oximeter

Overall, non-clinicians (i.e., patients and healthy volunteers) found the pulse oximeter easy to use and were highly satisfied with its performance [10–13]. Russell et al., [9] reported a high 'willingness to use'

Study	Questionnaire or Survey Tool
Areia et al., [21]	Borg CR-10 Scale (for assessing exertion and pain or discomfort while performing activities) Comfort Rating Scale (CRS)
Chaniaud et al., [22]	System Usability Scale (SUS)
Hudson et al.,[18]; Karlen et al., [19]	Mobile Phone Usability Questionnaire (MPUQ)
McGillion et al., [8]	Net Promoter Scale (NPS)
Russell et al., [9]	J.R. Lewis's Investigator After-Scenario Questionnaire (ASQ) Subject Device Usability Questionnaire (DUQ) adapted from Lewis's Post Study System Usability Questionnaire (PSSUQ)
Tang et al., [13]	100mm Visual Analogue Scale (VAS)
Chan et al., [17]; Chang et al., [10]; Faria et al., [12]; Harsha et al., [14]; Lopez Segui et al., [11]	Ad-hoc questionnaires

Fig. 3. Questionnaire or survey tools used.

the pulse oximeter device 'more than once per day for more than 1 month' (100%, n = 22). Overall, patient withdrawal from included studies was low and indicated a high satisfaction with care.

Phone Oximeters' were reported to improve user experience by providing an inexpensive, personalised and readily accessible solution for monitoring pulse oximetry remotely. However, no studies performed a comparison with the standard procedure of writing down results or reporting to a clinician over the phone. Participants in one study reported mixed usability results for daily symptom reporting with a phone oximeter [20]. Only half (45.5%) said they found the technology 'nice' or easy to use and suggested self-reporting interacted with their lifestyle, causing inconvenience or annoyance.

The most common user complaint from non-clinicians was an uncomfortable probe or probe cable [12–14]. Having a fingertip probe seemed to negatively impact a device's wearability, with participants reporting it as a hinderance, requiring removal to perform activities and affecting the total time the device was worn. Overall, participants reported a preference for smaller wrist-worn devices [21]. Other reasons for withdrawal from studies with pulse oximeters included too many false alarms triggered by the oximeter, annoying noises or beeps, restriction to movement, confusion with monitor malfunction, sleep disturbance, patients being allergic to Velcro, and patients suffering from carpal tunnel syndrome [14].

In Chaniaud, Metayer, Megalakaki and Loup-Escande [22], only 64.6% of participants were able to record their oxygen levels correctly, indicating room for improvement in the usability of the pulse oximeter. On average users made one error (mean = 0.99, SD = 0.92) and the three categories of error included: (1) did not position the oximeter the right way, (2) did not insert the finger as far as the sensor, and (3) removed the oximeter too early during the measurement. Context of use, specifically users' prior health and IT/computer knowledge, were identified as factors contributing to the usability of the pulse oximeter. A significant link (r = -0.263, P =.001) and statistical threshold ($X^2_{2,146}$ = 10.9, P =.004) were found for the effect of prior health knowledge on the number of errors made while using the device. This contrasts with findings from another study [18] investigating the user experience of clinicians, which reported that performance in usability testing was not significantly influenced by familiarity with the use of mobile phones or pulse oximeters.

4. Discussion

This scoping review provides an overview of what aspects of pulse oximeter UX have been investigated, what population characteristics are usually considered, and what clinical and non-clinical users think of the devices. Published research assessing UX of the pulse oximeter in a healthcare setting is scarce and only 16 studies were found that met the inclusion criteria for this review. These studies are heterogeneous by country, research area, user population, UX dimension, and method, which precludes any definite conclusions from being drawn about the factors which contribute to acceptance of pulse oximeters in an RPM context.

The COVID-19 pandemic has led to a sharp increase in studies focusing on pulse oximeters but outside of COVID management, pulse oximeters are also being used to: gather interappointment data to provide clinicians with a more holistic view of patients' health; as continuous vital sign monitoring systems to improve healthcare efficiency; and are being paired with mobile health apps to improve the usability of systems and increase accessibility to care.

This review identified several factors impacting patients' and clinicians' UX of pulse oximeters. Firstly, the perceived ease of use of the pulse oximeter – including setting up the device and taking a reading – was consistently positive for both patients and clinicians. The Motivation Model (MM) for assessing technology acceptance proposes that ease of use has an impact on user enjoyment and perceived system usefulness; therefore, positive results for the pulse oximeter are encouraging and

suggest high acceptability [23]. Wearability was another factor found to have an impact on UX of devices, and a preference for smaller devices without a fingertip probe was identified – although, a trade-off with device accuracy must be acknowledged. While existing technology acceptance models do not specify wearability as a contributing dimension, some like the Theory of Interpersonal Behavior (TIB) claim situational conditions can have an impact on technology adoption, therefore, it is important to investigate the potential influence of wearability on the acceptance of RPM devices [24].

Interestingly, the one aspect where clinicians and patients differed was in the impact of users' prior IT and health knowledge (i.e., digital and health literacy) on attitude towards the device. These factors appeared to influence patient experience but not clinician experience of the pulse oximeter, although more research is needed to understand how prior knowledge – and other aspects of context of use – impact the UX of pulse oximeters.

At present, there has been limited research investigating how attitude towards the pulse oximeter impacts actual use and acceptance of the pulse oximeter. Previous studies have shown that attitude towards a technology has a direct impact on technology adoption and acceptance and thus, attitude is a key element of most technology acceptance models [25]. The failure of studies to examine the link between attitude and uptake represents a significant gap in the literature. The review also highlighted the lack of research on the impact that usability of devices and overall user perceptions have on the accuracy of readings. The 36% of invalid data observed in one study [12] was viewed by authors to potentially be influenced by poor user experience. Other gaps we identified included a lack of research in how user training; *belief in* the device's effectiveness or accuracy; attitudes towards use; and potential opportunity costs impact UX of the pulse oximeter.

There are some unintended consequences which result from using the pulse oximeter that should be considered by service providers to optimise quality of care. These consequences can have a positive or negative impact on patient and clinician experiences and for this reason have been extracted and summarised by this review. Providers should be aware of unintended negative consequences to manage potential problems during patient care and leverage any positive consequences to optimise service quality and patient experience.

This review identified some reported benefits and drawbacks which result from using the pulse oximeter that should be considered by service providers to optimise quality of care. Reported benefits included for example, pulse oximeters acting as a motivator to empower patients in asserting greater control over their health, and pulse oximeters reducing the risk of future adverse effects occurring. Regular monitoring with the pulse oximeter can identify gradual decreases in blood oxygen saturation early and prevent further patient deterioration. Alarm systems connected to patients' pulse oximeters can allow clinicians in busy hospital wards to manage their time more efficiently and increase care quality. Additionally, pulse oximeter data can support clinicians to make better decisions about patient's health; for example, helping them to determine when to transfer virtual-hospital patients to the ED or ICU. Finally, pulse oximeters can motivate clinicians by allowing them to deliver a more effective service. Drawbacks of using the pulse oximeter reported by users included, for example, inconvenience (i.e., making time to take readings) and increased anxiety. Further investigation is needed to understand the level of impact these drawbacks have on UX of the pulse oximeter.

There is also a lack of research in how users pair devices with smartphone apps and integrate data, which is something that may have an impact on result accuracy and should be investigated further [17–20]. It is also worth noting that pulse oximeters are often used in conjunction with other RPM devices, and this may influence perceptions of the pulse oximeter. For example, patients with cardiovascular disease are frequently provided with a heart rate monitor and glucometer for monitoring at home as well as a pulse oximeter [10]. Several of the included studies assessed other devices in combination with the

oximeter and reported similar issues relating to device usability, wearability, and perceived effectiveness [4,5,8,9,10,11,12,21,22]. Understanding the interactions between different devices would be valuable as they are often used together in an integrated system to monitor the symptoms of disease. This research would be beneficial in improving the delivery of care in virtual hospitals.

Overall, future services in virtual care and RPM should be aware of these UX issues when designing their programs to minimise patient discomfort and improve quality of care.

5. Future directions

A greater in-depth investigation on user perceptions of pulse oximeters would provide valuable insight for the management of COVID-19 patients. This information could help us to better understand how to integrate RPM devices into current healthcare system and mainstream virtual hospitals. The investigation should examine whether the current service delivery systems are sufficient to support the integration of RPM technology. It should explore the following questions: How will introducing the pulse oximeter impact workflow for clinicians, as well as patient-clinician collaboration? How will the device impact the way patients access health services and manage their health? How do levels of technology and health literacy in users impact outcomes?

To carry out this investigation, an improvement in study design using a mixed method approach is required. Most studies in this review used a questionnaire or survey to assess user perceptions, however, survey results are subjective reports and should be supported by other methods such as usability testing or observation. Uniformity is also needed on definitions for acceptability and usability. Furthermore, previous studies have not used a theoretical framework to assess UX or user perceptions of the pulse oximeter. It is important to use a theoretical framework to guide this exploration because it will provide a systematic approach to ensure all aspects of device acceptability within a larger virtual care system are captured. 'Technology agnostic' tools like the SUS are validated but may omit important information that is specific to the system's context of use [26].

One of the limitations is the exhaustiveness of the scoping strategy in relation to the concept of "user perceptions". Our interpretation was influenced by a goal to understand different factors influencing user acceptance of the pulse oximeter in the form of a measure to collect unstructured, subjective feedback through a 'questionnaire', 'survey', 'focus group' or 'interview'. This interpretation means some relevant studies may have been excluded that examine user perceptions of pulse oximeters without collecting feedback using one of these methods. As we expect the number of studies to increase further in ensuing years as the effects of the pandemic continue to be felt, we suggest conducting an updated review in the future to include forthcoming research and see how perceptions have changed, and what new measures of perceptions have emerged, since the publication of this review. A systematic review would be of value to take a comprehensive approach to summarising how people perceive pulse oximeters and what impact this may have on the delivery and acceptance of virtual care.

6. Conclusion

This review is the first to summarise user perceptions of the pulse oximeter in a healthcare context. It showed that both patients and clinicians hold positive perceptions of the pulse oximeter and important factors to consider in designing user-focused services include: ease-of-use and wearability of devices; context of use including user's prior health and IT knowledge; attitude towards use and perceived effectiveness; impact on user motivation and self-efficacy; and finally, potential user costs like inconvenience or increased anxiety. With the rapid increase in research studies examining pulse oximeter use for RPM since COVID-19, a systematic review would be a useful next step to consolidate evidence and investigate the impact of these factors on pulse oximeter acceptance and effectiveness.

CRediT authorship contribution statement

Tamara Rosic: Data curation, Writing – original draft, Writing – review and editing, Visualisation; Formal analysis, Software, Investigation, Validation. **Neysa Petrina:** Conceptualisation, Methodology, Investigation, Writing – review and editing, Supervision, Validation. **Melissa Baysari:** Writing – review and editing. **Angus Ritchie:** Funding acquisition, Writing – review and editing. **Simon K. Poon:** Conceptualisation, Methodology, Investigation, Resources, Writing – review and editing, Supervision, Project administration, Funding acquisition, Validation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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