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DIGITAL PRACTICE IN PHYSIOTHERAPY

Remote physiotherapy in Finland and the development of a computer vision-based markerless human pose estimation application

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Digital Practice in Physiotherapy

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Thomas Hellstén

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Abstract

Ensuring equitable access to physiotherapy services presents a substantial challenge due to the aging of the population, the rising prevalence of chronic diseases, and the centralization of healthcare, rehabilitation, and social services in urban areas. Digital practice in healthcare has grown in recent decades, which has altered service delivery and enhanced accessibility by reducing barriers to healthcare services, including physiotherapy.

The main aim of this dissertation was to study and develop digital practice in physiotherapy as part of the rehabilitation provided by physiotherapists (PT). The dissertation comprises four scientific articles. The first and second studies were based on a cross-sectional web-based questionnaire, the third was a narrative review, and the fourth was a methodological study. Study I evaluated how suitable remote physiotherapy (RP) is for different disease groups, the proportion of practice time spent on RP before and during the COVID-19 pandemic, which method and what technology PTs use during RP, and the difference between public- and private-sector use of RP in Finland. In Study II, PTs perceptions and experiences of RP regarding suitability, implementation, use, and promoting and inhibiting factors in Finland were studied. Study III was a narrative review of recent computer vision (CV)-based markerless human motion analysis systems and their applicability for rehabilitation applications as a starting point for the development of our CV-based markerless human pose estimation (HPE) application. Study IV evaluated the reliability (intrarater repeatability) and criterion validity of a CV-based markerless HPE application (DensePose) for measuring hip and knee range of motion (ROM) among healthy participants.

The results showed that, according to Finnish physiotherapists, RP is better suited for clients with lung, heart, or musculoskeletal diseases than for clients with neurological diseases. The COVID-19 pandemic led to an increased use of RP in everyday practice; however, the overall practice time spent on RP remained limited, with only one out of ten physiotherapists using >20% of their everyday practice time on RP. The use of RP remains limited across different phases of the physiotherapy process, with its primary use being in follow-up. According to physiotherapists, RP is most appropriate for communication-based aspects, such as consultation, guidance, and counseling. The main factors promoting the use of RP are technology-related factors, followed by those related to the PTs themselves. RP was most frequently conducted using computers, tablets, or smartphones in real time. Based on the narrative review, CV-based markerless HPE can be performed with standard cameras that capture color and brightness for each pixel in an image or with a depth-sensing camera. It can then be categorized into two-dimensional (2D) and three-dimensional (3D) approaches. In our knee joint angle simulation, the error margin of ± 5° in the knee joint angle tolerated a 2.5 cm error margin at key points, with a knee angle of 45°. Our CV-based markerless HPE application (DensePose) showed highly repeatable results in hip joint ROM (active flexion, active extension, active inner rotation, and active outer rotation), and the correlation was very strong in three (active hip inner rotation, active hip outer rotation, and active knee flexion) out of five directions between the CV-based markerless HPE application and reference picture among healthy participants.

This dissertation highlights insights for PTs and organizations in planning and implementing RP in daily practice, particularly in areas where its benefits are well established. The successful adoption of CV-based markerless HPE requires rigorous validation of existing solutions across different physiotherapy settings. Moreover, efforts should prioritize user-friendly technologies, workflow integration, and targeted education and training for both healthcare professionals and rehabilitees to support integration into routine care.

Tiivistelmä

Kohtaamme merkittäviä haasteita yhdenvertaisen pääsyn varmistamiseksi fysioterapiapalveluihin, joita väestön ikääntyminen, kroonisten sairauksien lisääntyminen sekä terveydenhuollon, kuntoutuksen ja sosiaalipalvelujen keskittyminen kaupunkialueille aiheuttavat. Digitaaliset käytännöt terveydenhuollossa ovat lisääntyneet viime vuosikymmeninä, mikä on muuttanut palveluiden tarjontaa ja parantanut niiden saavutettavuutta vähentämällä terveydenhuollon esteitä.

Tämän väitöskirjan päätavoitteena oli tutkia ja kehittää digitaalisia käytänteitä fysioterapiassa osana fysioterapeuttien tarjoamaa kuntoutusta. Väitöskirja koostuu neljästä tieteellisestä artikkelista. Ensimmäinen ja toinen tutkimus olivat poikkileikkaustutkimuksia, kolmas tutkimus oli narratiivinen katsaus ja neljäs metodologinen tutkimus. Ensimmäinen tutkimus toteutettiin verkkopohjaisella kyselyllä työikäisille fysioterapeuteille Suomessa, jossa arvioitiin, kuinka hyvin etäfysioterapia soveltuu eri sairausryhmille, kuinka suuri osa fysioterapeuttien työajasta käytettiin etäfysioterapiaan ennen ja COVID-19-pandemian aikana sekä, mitä menetelmiä ja etäteknologioita fysioterapeutit käyttävät etäfysioterapiassa. Lisäksi selvitettiin julkisen ja yksityisen sektorin eroja etäfysioterapian käytänteissä Suomessa. Toinen tutkimus tarkasteli fysioterapeuttien näkemyksiä ja kokemuksia etäfysioterapiasta Suomessa, sen soveltuvuudesta, toteutuksesta sekä käyttöä edistävistä että estävistä tekijöistä. Kolmas tutkimus oli narratiivinen katsaus viimeaikaisiin konenäköön perustuviin markkerittomiin ihmisen liikeanalyysijärjestelmiin ja niiden sovellettavuuteen kuntoutuksessa. Narratiivinen katsaus toimi markkerittoman konenäön sovelluksen kehittämisen perustana. Neljäs tutkimus arvioi markkerittoman konenäkösovelluksen (DensePose) toistettavuutta (intrarater) ja kriteerivaliditeettia lonkan ja polven liikelaajuuksien mittaamisessa terveillä tutkittavilla.

Tulokset osoittivat, että suomalaiset fysioterapeutit arvioivat etäfysioterapia soveltuvan paremmin keuhko-, sydän-, tuki- ja liikuntaelinsairauksien fysioterapiassa kuin neurologisessa fysioterapiassa. COVID-19-pandemia lisäsi etäfysioterapian käyttöä päivittäisessä työssä, mutta kokonaisuudessaan etäfysioterapian käytetty työaika jäi vähäiseksi, vain yksi kymmenestä fysioterapeutista käytti yli 20 % päivittäisestä työajastaan etäfysioterapiaan. Etäfysioterapiaa käytetään eniten kuntoutujien seurannassa. Fysioterapeuttien mukaan etäfysioterapia soveltuu parhaiten kommunikaatioon, kuten konsultointiin, ohjaukseen ja neuvontaan. Etäfysioterapian käytön merkittävimmät edistävät tekijät liittyvät teknologiaan ja fysioterapeuttien asenteisiin. Etäfysioterapia toteutettiin yleisimmin tietokoneiden, tablettien tai älypuhelimien välityksellä reaaliaikaisesti.

Narratiivisen katsauksen perusteella konenäköön perustuva markkerittoman ihmisen asennon arviointi, voidaan toteuttaa tavallisilla kameroilla, jotka tallentavat värin ja kirkkauden kullekin pikselille tai syvyyskameroilla. Konenäköön perustuva markkerittoman ihmisen asennon arviointi voidaan jakaa kaksiulotteisiin (2D) ja kolmiulotteisiin (3D) lähestymistapoihin. Simuloidussa polvinivelkulmamittauksessa 45° polvikulmalla (±5° virhemarginaali) salli konenäölle 2,5 cm:n virhemarginaalin avainpisteissä. Kehittämämme markkerittoman konenäön sovellus (DensePose) mittasi toistettavasti lonkkanivelen liikkeitä (aktiivinen fleksio, aktiivinen ekstensio, aktiivinen sisäkierto ja aktiivinen ulkokierto) terveillä tutkittavilla. Lisäksi kolmessa liikesuunnassa (aktiivinen lonkan sisäkierto, aktiivinen lonkan ulkokierto ja aktiivinen polven fleksio) välillä havaittiin erittäin vahva korrelaatio markkerittoman konenäkösovelluksen ja kontrollikuvan välillä.

Tämä väitöskirja tarjoaa arvokasta tietoa fysioterapeuteille ja organisaatioille etäfysioterapian suunnitteluun ja toteuttamiseen erityisesti osa alueilla, joissa sen hyödyt ovat vakiintuneita. Konenäköön perustuvan markkerittoman ihmisasennon arvioinnin onnistunut käyttöönotto edellyttää olemassa olevien ratkaisujen perusteellista validointia eri fysioterapiaympäristöissä, niiden luotettavuuden ja pätevyyden varmistamiseksi. Lisäksi tulisi painottaa käyttäjäystävällisiä teknologioita, työnkulun integrointia sekä kohdennettua koulutusta ja perehdytystä sekä terveydenhuollon ammattilaisille että kuntoutujille, jotta teknologia saadaan osaksi vakioitua käytäntöä.

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List of abbreviations

AI artificial intelligence
CI confidence interval
COSMIN COnsensus-based Standards for the selection of health Measurement INstruments
CV computer vision
EU European Union
FIMEA Finnish Medical Agency
HPE human pose estimation
ICC intraclass correlation coefficient
ICT information and communication technology
MAE mean absolute error
MDC minimal detectable change
NHI National Health Insurance
OR odds ratios
PT physiotherapist
PCK percentage of correct key points
PCKh head-normalized percentage of correct key points
RGB red, green and blue
ROM range of motion
RP remote physiotherapy
SD standard deviation
SEM standard error of measurement
VR virtual reality
WOMAC Western Ontario and McMaster Universities Arthritis Index
3D three-dimensional
2D two-dimensional

Contents

List of original publications

This dissertation is based on the following publications:

I Hellstén, T., Arokoski, J., Sjögren, T., Jäppinen, A. M., & Kettunen, J. (2022). The current state of remote physiotherapy in Finland: cross-sectional web-based questionnaire study. *JMIR Rehabilitation and Assistive Technologies, 9*(2), e35569. https://doi.org/10.2196/35569

II Hellstén, T., Arokoski, J., Sjögren, T., Jäppinen, A. M., & Kettunen, J. (2023). Remote physiotherapy in Finland—suitability, usability and factors affecting its use. *European Journal of Physiotherapy, 25*(6), 378–387. https://doi.org/10.1080/21679169.2023.2233560

III Hellsten, T., Karlsson, J., Shamsuzzaman, M., & Pulkkis, G. (2021). The potential of computer vision-based markerless human motion analysis for rehabilitation. *Rehabilitation Process and Outcome, 10*. https://doi.org/10.1177/11795727211022330

IV Hellstén, T., Arokoski, J., Karlsson, J., Ristolainen, L., & Kettunen, J. (2025). Reliability and validity of computer vision-based markerless human pose estimation for measuring hip and knee range of motion. *Healthcare Technology Letters, 12*(1), e7002. https://doi.org/10.1049/htl2.70002

The publications are referred to in the text by their Roman numerals.

1 Introduction

Providing easily attained healthcare services for all is a significant challenge in society due to, among other reasons, the aging population (Scott Kruse et al., 2018) and the concentration of healthcare services in urban areas (Rausch et al., 2021). Digitalization in healthcare has increased and reshaped healthcare services in recent decades (Rausch et al., 2021), as it can improve access and reduce barriers to treatment, including physiotherapy (Martinsen et al., 2024). Physiotherapy is a profession with expertise in health, movement, mobility, and function (Physiotherapy, 2023). Digital practice in physiotherapy is an umbrella definition that describes healthcare services, support, and information provided remotely via information and communication technology (ICT; Physiotherapy, 2019). Digital practice in physiotherapy, in the form of remote physiotherapy (RP), was widely implemented at the time of the COVID-19 pandemic (Hawley-Hague et al., 2023a) and has altered how physiotherapists (PTs) can deliver services using digital health tools (Keel et al., 2023). This change offers opportunities to improve flexibility and access to physiotherapy (Martinsen et al., 2024), especially for individuals in rural areas (Rausch et al., 2021).

Digital practice in physiotherapy can be implemented using several different technological platforms, including telephones, smartphones, video conferencing, mobile applications, and web-based systems (Hawley-Hague et al., 2023b). Digital practice in physiotherapy makes interaction between rehabilitees (rehabilitee is defined as a patient, recovering individual, customer, or a group of them in this dissertation) and PTs in different locations possible, enabling connection through ICT technologies either in real time or not tied to time. These technologies can also offer feedback and support to rehabilitees during the physiotherapy process (Werneke et al., 2021). According to some studies, assessments in physiotherapy require hands-on interaction; as such, it is challenging to perform assessments using digital practice methods (Malliaras et al., 2021). However, there is some discussion that highlights the importance of developing digital practices to solve these challenges, which appear to be solvable (Hannink et al., 2022).

Digital practice in physiotherapy is implemented and followed up by a PT and has a clear goal, typically a beginning and an end, as in conventional physiotherapy (Salminen et al., 2016). However, for rehabilitees with, for example, a neurological disease such as cerebral palsy, there is usually a need for ongoing contact with physiotherapy throughout life (Cook et al., 2022).

The first aim of this dissertation was to study the current state of remote physiotherapy (RP) in Finland among PT. It did so by study how appropriate RP is for diverse disease groups, the amount of practice time used on RP before and during the COVID-19 pandemic, which method and what technology PTs use in the field of RP, and the difference between public and private sector use of RP in Finland. It enhanced understanding of PTs perspectives and experiences with RP in terms of its suitability, implementation, use, and the factors that promote or inhibit its adoption. Furthermore, it studied the potential of computer vision (CV)-based markerless human motion analysis for rehabilitation and the intrarater repeatability and criterion validity of a CV-based markerless human pose estimation (HPE) application for measuring active hip flexion, extension, inner rotation, outer rotation, and knee flexion. In this thesis the term "intrarater repeatability" was used when studying reliability of the repeated measurements with our CV-based markerless HPE application. The results of this dissertation have the potential to support healthcare providers and technology developers in enhancing the accessibility and quality of digital practice in physiotherapy in Finland and beyond.

2 Literature Review

2.1 Physiotherapy

Physiotherapy is a rehabilitation profession requiring expertise in health, movement, mobility, and function. Physiotherapy plays an essential role in the provision of health and welfare services, functioning both independently and collaboratively with various healthcare providers and practices across a wide variety of situations (World Physiotherapy, 2023). PT aids in the progress of a rehabilitee in active engagement in, for example, daily living in society by focusing on progress, maintenance, and restoration of their health, physical movement, and functional capability throughout their lives (Hynynen et al., 2016).

Over the years, physiotherapy has evolved from manual therapy to exercise therapy to support the physical functioning of rehabilitees (Sampath et al., 2016). Most of the central tasks PTs use in their daily practice are guidance and counseling, exercise therapy, manual therapy, and physical therapy. Other commonly used tasks are assessment (employment and functional assessment, assessment of movement, assessment of pain, assessment of the need for devices and equipment, and assessment of the ability to manage in the living environment), and corrective acts in the workplace. Physiotherapy extends its daily practice both to individual rehabilitees and groups in situations in which rehabilitees' proper functioning may be threatened by factors such as aging, pain, illness, dysfunction, or the environment (World Physiotherapy, 2023).

Physiotherapy follows the principles of physiotherapy science and incorporates research from various disciplines. Optimal outcomes can be realized through the adoption of an evidence-based approach, integrating the best available research data with the clinical experience of the PT and the perceptions of the rehabilitees undergoing physiotherapy (World Physiotherapy, 2023). Furthermore, PTs must understand rehabilitees' functional capacities and restrictions to be able to establish a physiotherapeutic diagnosis based on clinical reasoning (Hynynen et al., 2016).

The physiotherapy process guides the PT through the rehabilitee's intervention, based on professional knowledge. The physiotherapy process typically includes the following steps: examination/assessment, plan, implementation, final assessment, and follow-up (see Figure 1) (Hynynen et al., 2016).

The aim of assessment is to systematically assess, observe, and state the rehabilitee's functioning in sufficient detail to serve as the foundation for a suitable physiotherapy protocol and plan. However, to be able to treat a rehabilitee, the PT must have a strong knowledge base, problem-solving abilities, and clinical reasoning skills (Hynynen et al., 2016).

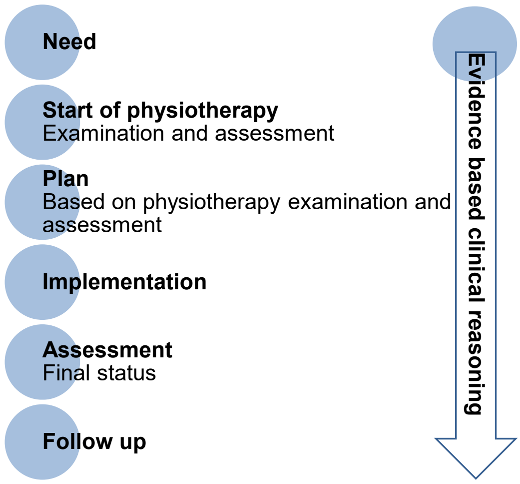

Figure 1 Workflow of the physiotherapy process (Hynynen et al., 2016).

2.2 Digital practice in physiotherapy

Ensuring convenient and equitable access to physiotherapy poses a notable challenge given the aging population, the rising prevalence of chronic diseases, and the concentration of health, rehabilitation, and social services in urban areas (Truter et al., 2014). Physiotherapy is undergoing a change in clinical practice due to digitalization, its potential in current health and welfare services (Laver et al., 2020), and the possible benefits for rehabilitees (Hawley-Hague et al., 2023a). The combination of physiotherapy and digital technology involves different terms, and the content may therefore remain unclear and superficial. Accordingly, World Physiotherapy proposes the following umbrella definition when PTs use digital technology in daily practice*: digital practice describes healthcare services, support, and information provided remotely via ICT* (World Physiotherapy, 2019). RP is another commonly used term to describe the use of ICT technology remotely in physiotherapy (Hawley-Hague et al., 2023a; Rausch et al., 2021; Salminen et al., 2016). In this dissertation, we use the term *digital practice in physiotherapy* or *RP* to describe how physiotherapy is delivered remotely using ICT.

Digital practice in physiotherapy can be categorized into different techniques based on the technology used, including audiovisual techniques (Hinman et al., 2024), mobile applications, activity trackers (Bezuidenhout et al., 2022), virtual reality (VR) (Peláez-Vélez et al., 2023), sensors that respond to touch and motion (Bakker et al., 2020), and CV (Song et al., 2024). However, the process should follow conventional physiotherapy when the rehabilitee and the PT work in the same physical place. This involves a physiotherapy intervention and interaction between the PT and the rehabilitee, starting with the PT conducting an interview, followed by a clinical analysis leading to a physiotherapeutic diagnosis, and concluding with a set goal and an intervention plan (Russell, 2009). Digital practice is used, for example, in physiotherapy assessment, treatment, education, and meetings with PTs (Reynolds et al., 2021). Other frequently used methods include subjective questionnaires and functional assessments, such as joint range of motion (ROM) assessment, education, self-massage, and mobilization (Malliaras et al., 2021).

When digital practice is used in physiotherapy, the rehabilitee and the PT are physically located in two separate places and communicate digitally using ICT technologies. Digital practice may encompass real-time online communication between a rehabilitee and a PT, where both parties are physically located in separate places, or not in real time communicating or sharing data at different times (Howard & Kaufman, 2018). Furthermore, digital practice can refer to digital technologies within physiotherapy that offer automated feedback and support to the rehabilitee (Capecci et al., 2018).

Some studies have found that digital practice in physiotherapy took a big step forward during the COVID-19 pandemic (Hawley-Hague et al., 2023a; Rausch et al., 2021). Whether digital practice or an alternative, the term *telerehabilitation* was introduced in the scientific literature in the late 1990s (Burns et al., 1998). Digital practice in physiotherapy can be a sustainable alternative to the delivery of physiotherapy services. However, rehabilitees are chosen at the PTs discretion based on their compatibility and commitment to digital practice (Reynolds et al., 2021). Accessing physiotherapy services may be a challenge for individuals in geographically remote areas or those who cannot visit a clinic individually, as well as in low- and middle-income countries where physiotherapy services are lacking (Hinman et al., 2024). Digital practice in physiotherapy can offer physiotherapy to rehabilitees remotely in their living spaces, thus improving access to physiotherapy services (at the PTs discretion) for rehabilitees with neurological diseases or older adults (Bezuidenhout et al., 2022). The objectives of incorporating digital practice into physiotherapy are to enhance the effective delivery of physiotherapy by improving accessibility to care and managing healthcare resources (World Physiotherapy, 2019). Digital practice has shown a higher attendance rate at therapy sessions than conventional physiotherapy for rehabilitees with chronic heart failure (Hwang et al., 2017). In addition, completion of exercise therapy at home may be higher when receiving digital practice compared to conventional physiotherapy (Nelson et al., 2020; Russell et al., 2011).

It has been found that the use of digital practice in physiotherapy is impracticable without additional education and training (Barton et al., 2022) in using it as a complement to conventional physiotherapy (Dierick et al., 2021) and unless the PT demonstrates a positive outlook toward it (Bezuidenhout et al., 2022).

2.2.1 Use of digital practice in physiotherapy

The COVID-19 pandemic meant that digital practice had to be integrated into the daily routines of PTs as part of their clinical practice (Bezuidenhout et al., 2022; Rausch et al., 2021). As discussed in the literature, the use of digital practice enabled PTs to maintain their regular clinical practice throughout the COVID-19 pandemic for rehabilitees who required physiotherapy but were unable to go to a hospital or clinic (Cottrell & Russell, 2020).

In Switzerland, the frequency of using digital practice in physiotherapy increased from 4.9% (prior to the COVID-19 pandemic) to 44.6% (during the COVID-19 pandemic) among PTs, and younger PTs (under age 45) used more digital practice than older ones. The two digital tools that PTs used most frequently were smartphone applications and online meeting tools. Digital practice was mostly delivered in individual physiotherapy settings (94.6%), and only a few PTs delivered digital practice in group settings. Digital practice was mainly used in rehabilitee education, treatment, and follow-up. During this time, most PTs did not view digital practice as an alternative to conventional physiotherapy, and many had no intention of continuing its use after the pandemic (Rausch et al., 2021).

Tsekoura et al. 2022 reported that 52.9% of PTs in Greece began to implement some form of digital practice in physiotherapy during the COVID-19 pandemic, but only 4 out of 10 intended to work remotely with digital practice after the pandemic. Furthermore, in a study in Ireland, 17% of PTs reported using digital practice in physiotherapy prior to the COVID-19 pandemic, and 4 out of 10 considered digital practice as a provisional method to physiotherapy (Reynolds et al., 2021). In a study in Sweden, PTs who worked with rehabilitees with neurological disease or older adults slightly increased their use of digital practice during the COVID–19 pandemic. Of the PTs in their study, 74% did not provide digital practice before the pandemic, and 51% provided it during the pandemic. The use of digital practice during the pandemic was 42% for rehabilitees with a neurology diagnosis and 40% for older adults; prior to the pandemic, it was 24% for rehabilitees with a neurology diagnosis and 22% for older adults. However, willingness to use digital practice was high among PTs. Only 1 PT out of 10 did not want to work at all with digital practice. Furthermore, approximately 40% of PTs believed that digital practice would enhance the quality of physiotherapy (Bezuidenhout et al., 2022). In contrast, in the United States, the use of digital practice (internet or phone) decreased in 2020 between the second and third quarters from 10% to 5%, and 37% of PTs implemented digital practice in their daily practice (Werneke et al., 2021).

In a multinational study, PTs working with rehabilitees with multiple sclerosis increased their use of digital practice by approximately 20% during the COVID-19 pandemic. However, most PTs have encountered various obstacles and challenges when using digital practice on a daily basis (Jonsdottir et al., 2023). In only France and Belgium, a few PTs reported a willingness to use digital practice, and half of the PTs believed they would never use digital practice (Dierick et al., 2021). Furthermore, in a multinational study by Malliaras et al. (2021), two-thirds of the health care professionals (in the cohort, 82.1% of PTs) reported that they had not used digital practice before the COVID-19 pandemic.

2.2.2 Current evidence of the effectiveness of digital practice in physiotherapy

PTs must apply effective, evidence-based physiotherapy methods that ensure both efficacy and patient safety in daily practice. Reported adverse events are minor in digital practice (Bini & Mahajan, 2017; Bourne et al., 2017; Chen et al., 2017; Hansen et al., 2020; Moffet et al., 2015; Odole & Ojo, 2014; Russell et al., 2011; Spindler et al., 2019; Turner et al., 2016). However, more knee pain is reported among rehabilitees with osteoarthritis in the knee than among control participants (Nelligan et al., 2021); it has been found that efficacy without training in digital practice may not be generalized to PT (Hinman et al., 2024).

For physiotherapy to be effectively delivered through digital practice, evidence indicative of its efficacy compared to conventional physiotherapy is essential. There is some indication that digital practice could be as effective as and comparable to conventional physiotherapy, such as in rehabilitees with chronic knee pain (Hinman et al., 2024), osteoarthritis in the knee (Nelligan et al., 2021; Odole & Ojo, 2014), total knee arthroplasty (Bini & Mahajan, 2017; Bradbury et al., 2024; Moffet et al., 2015; Russell et al., 2011), heart diseases (Spindler et al., 2019), multiple sclerosis (Turner et al., 2016), stroke (Chen et al., 2017), and chronic obstructive pulmonary disease (Bourne et al., 2017; Hansen et al., 2020). Most of these studies have been graded as good or high-quality studies based on the Physiotherapy Evidence Database (PEDro, n.d.).

In a high-quality randomized controlled trial (RCT) among rehabilitees with chronic knee pain by Hinman et al. (2024), conventional physiotherapy consisted mainly of five consultations that included individual exercise therapy and an activity plan. In the digital practice group involved in the study, physiotherapy comprised consultation through a computer screen and an individual digital-based training program. Although there were no differences between the digital practice and conventional physiotherapy groups in pain or physical function after the intervention, the rehabilitees in the digital practice group were more physically active at the 9-month follow-up, and their satisfaction, suitability, and engagement with physiotherapy were superior to conventional physiotherapy (Hinman et al., 2024).

In the RCT among rehabilitees with knee arthroplasty (Moffet et al., 2015), physiotherapy intervention comprised exercise therapy, prescription of home exercises, guidance in walking, and information on how to return to daily activities. In this study, digital practice was delivered through two-way audiovisual contact. In addition, there was no difference in this study between the groups in the Western Ontario and McMaster Universities Arthritis Index (WOMAC) scores, a six-minute walk test, or ROM in the knee joint (Moffet et al., 2015). In Bradbury et al. (2024) high-quality RCT, RP used instructional videos that included exercise therapy, accessible anytime on a smartphone or computer with internet connectivity. Physiotherapy was divided into different phases based on the time from knee arthroplasty surgery and the achievement of goals in the physiotherapy process. The phases were (1) knee ROM, (2) swelling reduction and gait training, and (3) muscle strengthening (Bradbury et al., 2024).

In an osteoarthritis knee RCT (Nelligan et al., 2021), the conventional physiotherapy group was given guidance and counseling about the importance of exercise and activity through a web-based platform. The intervention group received the same guidance and counseling, as well as additional home exercise therapy and automatic messages (inspiring exercises) through their mobile phones as the digital practice method. In this study, the intervention group had a better overall average knee pain score (numerical rating scale [NRS]) and better physical function (WOMAC) compared to the control group (Nelligan et al., 2021). In an RCT among rehabilitees with knee osteoarthritis, digital practice was delivered through mobile phones, and the PT observed participants during their exercise therapy program at home (Odole & Ojo, 2014). This study found that digital practice is an effective method in the management of rehabilitees with knee osteoarthritis and, in terms of quality of life, is in line with the rehabilitees in conventional physiotherapy groups (Odole & Ojo, 2014).

In an RCT among rehabilitees with stroke, audiovisual digital practice methods were used, and individual exercise therapy was delivered using the Bobath technique for the intervention and control groups. Functional gains were seen in both groups, with no differences between the groups (Chen et al., 2017).

Bourne et al. (2017) conducted an RCT among rehabilitees with chronic obstructive pulmonary disease. Digital practice was carried out using an online program with exercise therapy, guidance, and counseling. The results of the study showed that there were no differences in outcomes, such as in the 6-minute walk test, the chronic obstructive pulmonary disease Assessment Test (CAT) (measures the impact of chronic obstructive pulmonary disease on an individual's life and changes in this impact over time), quality of life, or safety issues between the digital practice group and the conventional pulmonary rehabilitation group. In their study, physiotherapy sessions consisted of exercise therapy and education (Bourne et al., 2017). Finally, in the Danish RCT on rehabilitees with chronic obstructive pulmonary disease (Hansen et al., 2020), audiovisual contact (computer) was used as the digital practice method, and physiotherapy comprised exercise therapy, guidance, and counseling. In this study, no difference in the main outcome, such as a 6-minute walk test, was reported between the conventional physiotherapy group and the digital practice group (Hansen et al., 2020). In addition to the effectiveness of physiotherapy interventions, several other factors may influence the use of digital practice as part of the treatment.

2.2.3 Advantages of digital practice in physiotherapy

Some studies have found evidence of the advantages that digital practice offers in physiotherapy (Barton et al., 2022; Damhus et al., 2018). Digital practice in physiotherapy increases the possibility of establishing connections between professionals and rehabilitees, regardless of geographical distance, and reduces waiting time (Damhus et al., 2018), travel costs, travel time (van Egmond et al., 2018), distance to get physiotherapy (Barton et al., 2022; Reynolds et al., 2021), and costs (Bradbury et al., 2024). It increases flexibility by allowing rehabilitees to schedule physiotherapy at their most convenient time (Salminen & Hiekkala, 2019) and offers seamless incorporation of exercise therapy into daily life (Barton et al., 2022; Cranen et al., 2017), the ability to monitor rehabilitees' progress (Galea, 2019), the chance to provide individual feedback (Lahtio et al., 2022), and easier access to the right experts in the physiotherapy field (Barton et al., 2022), and various options for the delivery of physiotherapy services (Reynolds et al., 2021).

Furthermore, digital practice can potentially achieve improved efficiency when PTs do not need to travel between clinics but can also focus on continually learning professional skills (World Physiotherapy, 2019; Reynolds et al., 2021). Digital practice can be more cost-effective than conventional physiotherapy when considering a wider societal view, such as including individual time and travel aspects in cost calculation. For a health organization, digital practice tends to lower total cost; however, there was no difference compared to conventional physiotherapy for osteoarthritis knee pain rehabilitees (Hinman et al., 2024).

PTs without experience in digital practice presume that conducting digital practice in physiotherapy would require a more innovative approach to exercise therapy compared to conventional methods, such as creating exercise suitable via a screen in real time (Damhus et al., 2018). Professionals have also pointed out other advantages of digital practice, such as the possibility of providing PT to rehabilitees with the most compromised health conditions or who face transportation challenges (Damhus et al., 2018; Inskip et al., 2017). Performing exercise therapy at home without exercise therapy equipment is seen by professionals as an advantage but also as a barrier among those who do not have experience in digital practice (Damhus et al., 2018). Furthermore, self-management for rehabilitees to exercise on their own has been seen as an advantage over manual or physical therapy included in physiotherapy sessions at a clinic (Malliaras et al., 2021).

The things that PTs require to implement digital practice (video conference) are a stable internet connection, a good working digital platform, and the appropriate hardware setup (computer, camera, microphone). Access to written or digital information, instructions, or videos for upcoming exercise therapy, and applications for exercise therapy are other central tasks. It is important for PTs to prepare themselves for possible technical problems and rehabilitee participation and engagement in the execution of digital practice (Bennell et al., 2021). Likewise, it has been reported that a well-functioning environment (lightning, physical environment, camera placing, and picture quality) for both PT and rehabilitee are important factors when implementing digital practice in daily practice (Reynolds et al., 2021).

2.2.4 Barriers to digital practice in physiotherapy

Various barriers hinder the broader implementation of digital practice in physiotherapy. These barriers include, among other things, the expertise of PTs in utilizing technical issues (Damhus et al., 2018; Reynolds et al., 2021), having the correct technical equipment, resistance to digital practice, and investment costs (Scott Kruse et al., 2018). Furthermore, a poor-quality environment for carrying out digital practice, including problems such as noise, a small space, poor camera angle and lightning (Bennell et al., 2021), and access to appropriate therapeutic equipment, are other barriers to implementing digital practice that have been reported by professionals (Malliaras et al., 2021). Infrastructure challenges, such as bandwidth capacity (Bennell et al., 2021; Hale-Gallardo et al., 2020; Malliaras et al., 2021; Reynolds et al., 2021) and issues with software and devices, have also been reported as barriers (Albahrouh & Buabbas, 2021; Barton et al., 2022; Tsekoura et al., 2022). Furthermore, a PTs age, level of education, computer skills (Scott Kruse et al., 2018), and lack of comprehensive training have been reported as obstacles (Albahrouh & Buabbas, 2021; Tsekoura et al., 2022). In addition, a rehabilitee's poor computer literacy has been noted as a barrier (Reynolds et al., 2021). It has also been reported that consultation in digital practice is more time-consuming than conventional physiotherapy consultation for rehabilitees with chronic knee pain (Hinman et al., 2024). However, Barton et al. (2022) reported that rehabilitees spent an equivalent amount of consultation time in digital practice and conventional physiotherapy; on the other hand, rehabilitees generally expected lower charges for digital practice (Barton et al., 2022; Dierick et al., 2021). Some PTs would not be willing to charge the full price for digital practice (Dierick et al., 2021).

Safety concerns during the sessions (Jonsdottir et al., 2023; Malliaras et al., 2021), such as the risk of rehabilitees falling during video conferencing (Bennell et al., 2021), not being sufficiently familiar with the digital tools (Jørgensen et al., 2021), and challenges with maintaining patient privacy, have been seen as barriers (Albahrouh & Buabbas, 2021; Jonsdottir et al., 2023; Reynolds et al., 2021; Tsekoura et al., 2022).

Hands-on activity has traditionally been essential in physiotherapy (Malliaras et al., 2021). Therefore, the absence of physical touch, e.g., in assessment (Bennell et al., 2021; Malliaras et al., 2021) and a limited possibility for physical examination (Reynolds et al., 2021) of the rehabilitee have been seen as barriers. Completing a comprehensive assessment during digital practice is challenging, as it lacks individual touch and is time-consuming (Reynolds et al., 2021). Furthermore, communication through the screen has been seen as a barrier (Malliaras et al., 2021). However, professionals have developed new communication techniques to perform physiotherapy on a screen (Damhus et al., 2018). It is important to be able to offer digital practice to the appropriate rehabilitee groups and to ensure that it is applied meaningfully. Difficulties in creating an individual connection with the rehabilitees through the screen (Damhus et al., 2018) and the feeling that professionals are observing the actions from outside the care with digital practice are further seen as barriers (Reynolds et al., 2021). The lack of a relationship between the rehabilitee and the PT is seen as a barrier, as it is challenging to create trust between the parties through digital practice (Malliaras et al., 2021).

2.3 Digital health tools in physiotherapy

Digital health tools, such as telephones, video conferencing (Cottrell & Russell, 2020), mobile applications (Sandal et al., 2021), VR (Peláez-Vélez et al., 2023), and CV (Cronin et al., 2023), include a diverse collection of digital items that can be used in physiotherapy. Digital health tools in physiotherapy can be defined as digital health technologies used in healthcare (physiotherapy) that remotely store, deliver, and analyze rehabilitee data and information, for example, using techniques that are not yet perceived as standard in physiotherapy (Keel et al., 2023). Digital health tools in physiotherapy can play a central role in enhancing clinical decision-making, delivery of physiotherapy practice management, and enable the capture, transmission, storage, and display of data and information (American Physical Therapy Association, 2022). Researcher have discussed, the adoption of digital health tools to become widespread and progressively more important (Keel et al., 2023). The field of digital health tools is broad and constantly developing. The digital tools used can be categorized, for example, as they are in Solomon and Rudin's (2020) study in Figure 2.

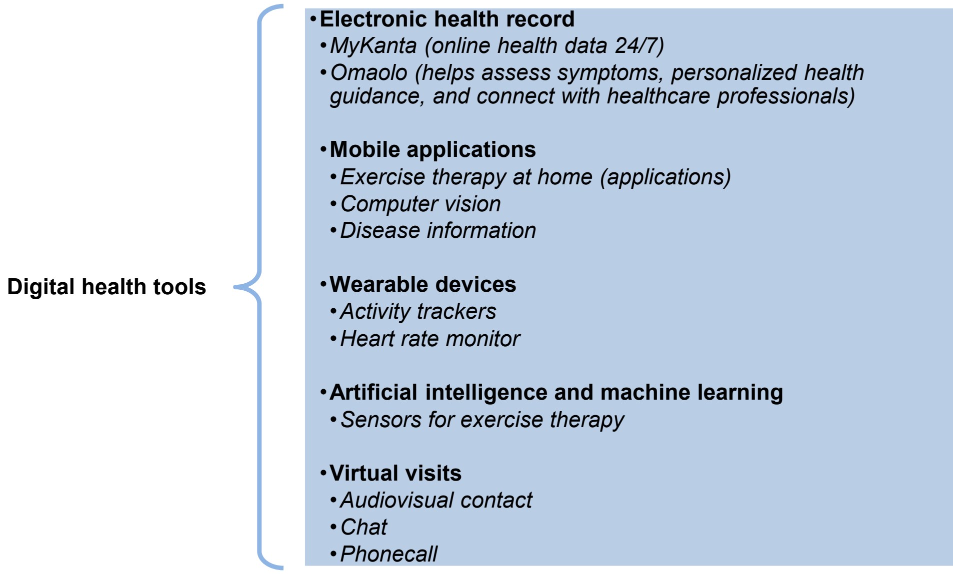

Figure 2 Modified overview by Solomon & Rudin (2020) of digital health tools. The cursive bullet points are examples of possible technology tools implemented in physiotherapy in Finland.

An electronic health record is characterized by elements such as digital storage of PT documentation, notes, test outcomes, and electronic reminders (Keyhani et al., 2008). Mobile applications can be used, for example, to develop and distribute exercise therapy at home, track a rehabilitee's progression in the physiotherapy process, and offer guidance and counseling (Keel et al., 2023). There is a broad range of commercial wearable devices available for monitoring physical activity (activity trackers; Jakicic et al., 2016) that enable collecting, transmitting, and analyzing extensive amounts of digital data concerning health and medical conditions (Klonoff, 2013). Artificial intelligence (AI) is a field of applied computer science in which computer algorithms are designed to carry out tasks that are generally linked to human intelligence (He et al., 2019). It is typically used in healthcare to gather relevant information from data and to support clinical reasoning (Murdoch & Detsky, 2013). In machine learning, the computer imparts knowledge via data without direct programming (He et al., 2019) and can automatically make estimates based on rehabilitee data. These estimates can be used, for example, to predict successful performance in exercises (Tack, 2019).

Virtual visits can comprise the use of audiovisual technology with a computer to follow up on rehabilitation progress in physiotherapy or to give instructions (Rausch et al., 2021).

Although this area has expanded, studies indicate that the integration of digital health tools into clinical practice in physiotherapy is still limited (Bezuidenhout et al., 2022; Button et al., 2018). In Switzerland and Greece, PTs have used easy-to-use and low-cost digital tools, such as smartphones and digital meeting platforms (Rausch et al., 2021; Tsekoura et al., 2022). In Bezuidenhout et al. (2022) study, the most frequently used digital health technology in Sweden was the telephone, followed by text messages and internet-based applications. In a study by Reynolds et al. (2021), over 80% of PTs reported using telephones or applications with visual contact, and over 35 different programs were mentioned in their study as being used in digital practice. In Dierick et al. (2021) study in France and Belgium, PTs reported the most frequent use of computers (41%), smartphones (30%), tablets (18%), and phones (11%). Telephones (38%) or audiovisual contact over the internet (23%) were most frequently used by PTs in Sri Lanka (Dissanayaka et al., 2022).

2.3.1 Regulatory issues

Digital health technology used in healthcare (medical devices) is governed by various national notified and regulatory authorities (Arandia et al., 2022). In the European Union (EU), every member nation possesses a national authority responsible for overseeing the regulatory adherence of medical devices (European Medicines Agency, n.d.). In Finland, the Finnish Medical Agency (FIMEA) ensures the regulatory compliance of medical devices and their operators (Huusko et al., 2023). It functions under the Ministry of Social Affairs and Health, conducting supervision in partnership with other EU authorities (FIMEA, n.d.). Regulations are designed to guarantee a high standard of health and safety for rehabilitees and users. Figure 3 presents most central regulatory authorities in different areas of the world (Arandia et al., 2022).

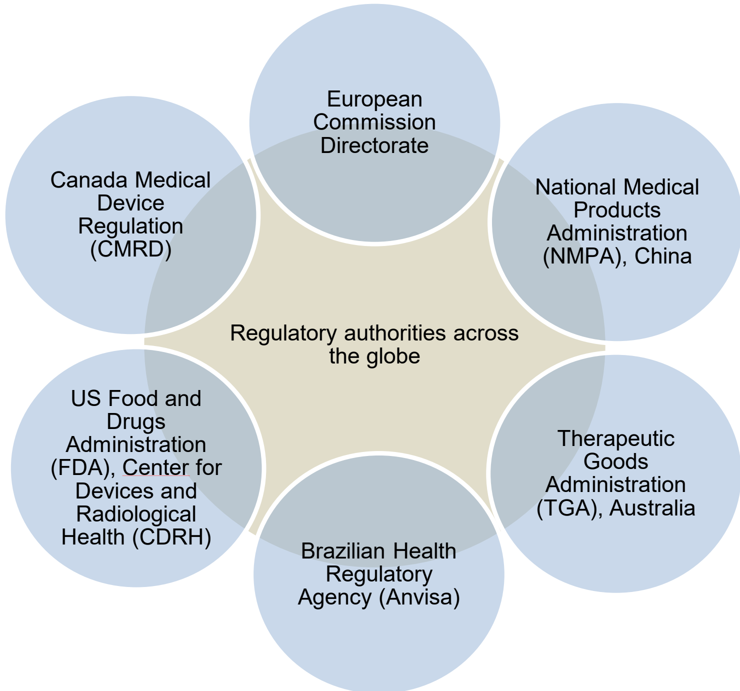

Figure 3 Most central regulatory authorities around the globe (Arandia et al., 2022).

In Europe, digital health technology tools in physiotherapy must meet the regulatory criteria for medical devices set by the European Parliament and Council (Regulation EU, 2017). The definition of a medical device by the EU is *"instrument, apparatus, appliance, software, implant, reagent, material or other article intended by the manufacturer to be used, alone or in combination, for human beings for one or more of the following specific medical purposes: A) diagnosis, prevention, monitoring, prediction, prognosis, treatment or alleviation of disease, and B) diagnosis, monitoring, treatment, alleviation of, or compensation for, an injury or disability"* (Regulation EU, 2017).

In the EU, medical devices must obtain a CE (Conformité Européenne) marking, showing that the medical device adheres to standards and has undergone evaluation in accordance with requirements (Regulation EU, 2017). Recent studies have found that the EU medical device regulation will enhance patient safety; however, it also has drawbacks, as the heightened expenses and administrative demands of medical devices are likely to affect the innovation capabilities of small companies. Consequently, some of these companies may choose to concentrate on products that are not classified as medical (Maresova et al., 2021). However, the medical device industry plays a vital role in the European economy, with more than

500,000 medical devices (for example, software apps, adhesive bandages, contact lenses, pacemakers, breast implants, and hip replacements) available on the EU market (European Commission, n.d.).

2.3.2 CV-based markerless HPE

Monitoring and evaluating human motion has been a topic of rigorous study for many years in digital practice (Zhou & Hu, 2008). There is a need for digital health technologies that can assess function in physiotherapy (Bezuidenhout et al., 2022). There are some indications that CV-based markerless HPE could be used, for example, to assess human posture (Hannink et al., 2022; Moreira et al., 2022), analyze functional movements (Cronin et al., 2023; Hannink et al., 2022), measure physical capacity (Mazéas et al., 2023), and evaluate balance tasks (Nalci et al., 2015).

CV-based human motion analysis typically employs marker-based techniques. This technique requires professionals to place physical markers on anatomical landmarks to collect kinematic data (Figure 4). This requirement imposes a significant limitation on motion analysis, as extensive technical preparations are necessary before the interventions (Zhou & Hu, 2008). It has been noted that motion analysis may be biased by professionals' ability to palpate anatomical landmarks (Moreira et al., 2022).

Figure 4 An illustration of marker-based CV, markers placed on the lateral malleolus of the fibula, lateral epicondyle of the femur, greater trochanter of the femur, and middle of the humeral head when analyzing hip extension.

A more feasible and user-friendly alternative is CV-based markerless motion analysis (Figure 5). In this analysis method, a rehabilitee requires a computing device (e.g., a smartphone) equipped with one or more cameras to perform an exercise (Colyer et al., 2018). The pose estimation system analyzes data from a camera picture frame to determine joint coordinates. This method can be applied in various settings, such as at home or in clinics (Sugiyama et al., 2023). It demands significantly less time, cost, and effort compared to a traditional optical motion capture system. CV-based markerless motion analysis comprises the following technical elements: a camera, a sequence of pictures of the human body's motion, and the HPE algorithm to detect key points of the body (Colyer et al., 2018).

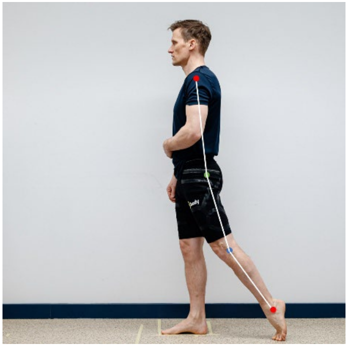

Figure 5 An illustration of CV-based markerless HPE key points: ankle joint, knee joint, hip joint, and shoulder joint when analyzing hip extension.

Standard two-dimensional (2D) cameras integrated into computing devices (e.g., smartphones, tablets, and laptop computers) can be used with CV-based markerless HPE. The first step in the technical process is to automatically detect a person in a video in real time (Colyer et al., 2018). There are different estimation algorithms for 2D human pose estimation; however, one well-known technique is DensePose (Guler et al., 2018). DensePose maps picture pixels that encode red, green, and blue (RGB) colors onto a three-dimensional (3D) surface model of the human body, using a 2D picture of a person. DensePose maps 2D (x, y) picture coordinates to 3D (x, y, z) surface coordinates of a human body, establishing dense correspondences for detailed HPE. DensePose is trained on a large dataset called DensePoseCOCO human pictures, and comprises approximately 50,000 manually annotated human pictures (Guler et al., 2018). DensePose takes one picture frame from a real-time video as input, adds dense correspondences, and produces an output picture marked with 2D coordinates of key points of the human body (Guler et al., 2018; Figure 6). These data metrics calculate various values, such as joint angles (Cronin et al., 2023).

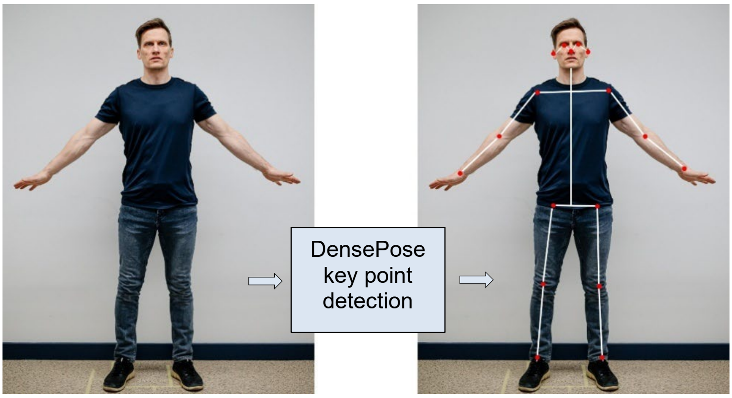

Figure 6 Illustration of the CV-based markerless HPE key point detection feature of DensePose.

2.3.2.1 Accuracy of measurement

Measurement is one of a PTs most-used key methods. Accurate measurement produces reliable and valid information about factors influencing a rehabilitee's functioning, such as the ROM of joints, balance, and walking speed. Digital health tools in physiotherapy can be useful at different stages of the physiotherapy process and in observing the outcomes of physiotherapy (Hynynen et al., 2016). PTs have considered the quality of their measurements in digital practice and have explored optimal ways to adjust their evaluation, treatment, and clinical reasoning in the field of digital practice (Reynolds et al., 2021). However, measurements must be accurate. The psychometric properties of measurements include information about their validity, reliability, and sensitivity to change (Valkeinen et al., 2014).

2.3.2.2 Validity

Validity is defined as *"the degree to which an instrument measures the construct(s) it purports to measure"* by the COnsensus-based Standards for the selection of health Measurement Instruments (COSMIN) steering board (Mokkink et al., 2010, p.743). Validity can be categorized into three different categories—construct validity, criterion validity, and content validity—with several subcategories. Construct validity evaluates the degree to which an instrument is consistent with a hypothesis, criterion validity evaluates whether an instrument meets a "gold standard," and content validity evaluates whether an instrument is an acceptable likeness of the construct to be measured (Mokkink et al., 2010).

When evaluating aspects of validity related to hypothesis testing, it is important to describe the structure of the measure being validated and its theoretical background. This further includes evaluating the extent to which the results of the measure are consistent with those of another measure believed to assess the same phenomenon (Valkeinen et al., 2014). In hypothesis testing, there are three different areas of validity: convergent validity, discriminant validity, and known-group validity. Convergent validity evaluates the extent to which the results of a measure are consistent with those of another measure believed to assess the same phenomenon. In a cross-sectional design, the results of the measure used should moderately or strongly correlate with another measure that has been validated for the same purpose (Valkeinen et al., 2014). Discriminant validity evaluates the extent to which the measure differs from measures assessing other phenomena; for example, the results of a measure assessing functioning in the lower limb should correlate better with the physical functioning section than with emotional well-being (De Vet et al., 2011; Valkeinen et al., 2014). Known-group validity evaluates the ability to distinguish between two or more groups, such as acute and chronic back pain patients (De Vet et al., 2011; Valkeinen et al., 2014).

2.3.2.3 Reliability

Reliability encompasses various concepts, such as objectivity, repeatability, reproducibility, stability, agreement, association, sensitivity, and precision (De Vet et al., 2011). It is defined as *"the degree to which the measurement is free from measurement error"* by the COSMIN steering board (Mokkink et al., 2010, p.743) and can be divided into three subgroups: measurement error, reliability, and internal consistency.

Measurement error is defined as *"the systematic and random error of a patient's score that is not attributed to true changes in the construct to be measured"* (Mokkink et al., 2010, p.743) and can be represented by the standard error of measurement (Terwee et al., 2007). The standard error of measurement indicates how much measurement error contributes on its own to the variation in the differences between repeated measurements. The higher the variance and the lower the reliability, the higher the standard error of measurement score (Valkeinen et al., 2014). Reliability (subgroup) is defined as *"the proportion of the total variance in the measurements which is because of 'true' differences among patients"* (Mokkink et al., 2010, p.743) and refers to repeated measurements in healthy participants yielding consistent measurement results over time (Terwee et al., 2007). Internal consistency is defined as *"the degree of the interrelatedness among the items"* (Mokkink et al., 2010, p.743) and is a measure of how well items in a questionnaire are correlated, indicating the ability to measure similar items with different questions. This is central for questionnaires that assess a single underlying concept using multiple items/questions (Terwee et al., 2007). Repeated measurement can be referred to as intrarater, which assesses the consistency of measurements performed by the same person, or between persons (interrater) (Valkeinen et al., 2014).

Although reliability is high, it is not sufficient, as the evaluation can be continually inconsistent. Therefore, the evaluation must also be valid to be accurate (Streiner et al., 2024).

3 Aims of the Study

The main aim of this dissertation was to examine and develop digital practice in physiotherapy as part of the rehabilitation provided by PTs. The dissertation comprised four constituent studies (Studies I-IV). In Studies I and II, the participants (662 out of 6525) were working-age PTs. Study III was a narrative review of the potential use of CV-based markerless motion analysis in rehabilitation as a starting point for the development of our CV-based markerless HPE application. In Study IV (methodological study), participants (n = 30) were 18 years of age or older and healthy. For this general aim, the study questions were as follows:

Study I	To determine how appropriate RP is for different disease groups, the proportion of practice time spent on RP before and during the COVID-19 pandemic, which method and what technology PTs use on RP, and the difference between public and private sector use of RP in Finland.
Study II	To increase knowledge of PTs perceptions and experiences of RP regarding suitability, implementation, use, promotion, and inhibiting factors in Finland.
Study III	To provide a narrative review of recent CV-based markerless human motion analysis systems and their applicability for rehabilitation.
Study IV	To evaluate the intrarater repeatability and criterion validity of a CV-based markerless HPE application (DensePose) for measuring hip and knee range of motion.

4 Materials and Methods

This dissertation comprises four studies. Figure 7 provides an overview of the study design.

STUDIES I and II Quantitative cross-sectional, web-based questionnaire

- Study I investigated PTs opinions of the current state of RP in Finland.
- Study II investigated PTs views on suitability, usability, and factors affecting the use of RP in Finland.

STUDY III Narrative review study

- Study III was a narrative review study of recent CV-based markerless human motion analysis applications and their applicability for rehabilitation. The accuracy, in terms of the ability to measure the knee angle, was analyzed using technical simulation.

STUDY IV Methodological study

- Study IV evaluated the intrarater repeatability and criterion validity of a CV-based markerless HPE application for measuring ROM in active hip flexion, extension, inner and outer rotation, and knee flexion.

Figure 7 Overview of the study design

4.1 Studies I and II: Design and participants

We conducted a quantitative cross-sectional study using a web-based questionnaire for both Study I and Study II. The participants were PTs of working age, recruited from the Finnish Association of Physiotherapists (n = 5905) and a private physiotherapy organization in Finland (n = 620). The questionnaire was distributed via email in March 2021 (Finnish Association of Physiotherapists) and May 2021 (private physiotherapy organization), along with an informational letter containing an electronic link to the survey. Respondents were given a 5-week period to complete the questionnaire, with two reminders sent: the first after one week and the second two weeks later.

The Finnish healthcare system comprises two complementary sectors, a public sector and a private sector, both of which are publicly funded. Significant differences exist between these two sectors, including the range of services offered, user fees, and waiting times, as well as differences in their financing mechanisms. The public sector is primarily funded through taxes and the National Health Insurance (NHI), while the private sector receives partial funding from the NHI, which covers approximately one-third of its costs (Vuorenkoski et al., 2008). Consequently, we conducted separate analyses for both sectors in Study I. Despite the differences between these two sectors, everyone undergoing rehabilitation is entitled to high-quality, equitable healthcare and rehabilitation services in Finland.

4.1.1 Questionnaire

A questionnaire was developed that incorporated items based on previous literature in the field of digital practice in physiotherapy (Caughlin et al., 2020; Damhus et al., 2018; Hakala et al., 2017; Hakala et al., 2021; Salminen & Hiekkala, 2019; Sjögren et al., 2016) and the insights of the research team and collaborators. This team included experts such as medical doctors, PTs, clinical specialists, researchers, and lecturers from a university hospital, a city health station, a university, a university of applied sciences, and a physiotherapy association. The questionnaire was piloted with 28 PTs from various fields and regions across Finland. During the pilot phase, we asked for feedback on issues such as unclear questions and suggestions for improvements. As a result, the wording was revised, and two questions were changed from mandatory to optional.

The questionnaire comprised 32 questions (31 closed and 1 open), organized into nine groups: background, suitability of RP, education in RP, current state of RP, selection of rehabilitees, suitability of RP for various physiotherapy tasks, facilities and devices for RP, methods and usage of RP, and implementation of RP (Appendix 1). PTs without experience in RP responded only to the first three groups (background, suitability of RP, and education in RP). Responses were automatically collected once a PT completed all the questions in a given group.

4.1.1.1 Study I

For Study I, the following five questions were utilized: the “suitability of RP for various diseases and patients with pain”, “how much practice time was spent on RP in the month before the survey,” “how much time was spent on RP just before the COVID-19 pandemic (early 2020),” “whether real-time or not tied to time methods were used in RP,” and “which of the following technology solutions do you use weekly in RP.” To study suitability of RP for various diseases and patients with pain, an 11-point numeric scale was employed (0 = not suitable at all, 10 = fully suitable). Categories included “musculoskeletal diseases,” “lung diseases,” “psychiatric diseases,” and “neurological diseases.” Since the majority of chronic pain patients have musculoskeletal disorders (James et al., 2018), they were included in the "musculoskeletal diseases" category. The numeric rating scale was chosen due to its familiarity and widespread use in physiotherapy (Hartrick et al., 2003).

4.1.1.2 Study II

For Study II, the following seven questions were included: the suitability of RP in different physiotherapy work tasks (consultation, guidance and counseling, exercise, assessment, and corrective activity in the workplace), the reasons for implementing RP, the method that PTs primarily put into practice in individual physiotherapy sessions, the three most central factors that promote or inhibit RP, the criteria for using RP, and the amount of education in the field of RP. With respect to the question about the suitability of RP in different physiotherapy tasks, we used an 11-point numeric scale (0 = not suitable at all, 10 = fully suitable) and grouped the questions into five themes (consultation, guidance and counseling, exercise, assessment, and corrective activity in the workplace). These themes were based on Finnish physiotherapy nomenclature, which comprises coded classifications related to physiotherapeutic services and physiotherapy work (Hynynen et al., 2016). A question regarding physiotherapeutic consultations was categorized under the consultation theme, questions concerning the type of guidance and counseling promoting proper functioning and the type of guidance, and counseling promoting the ability to work were categorized under the guidance and counseling theme. The exercise theme encompassed questions related to physical functioning exercises and movement exercises. The assessment theme included questions about the rehabilitee's employment status and functional assessment, assessment of movement, assessment of pain, assessment of the need for devices and equipment, and assessment of the ability to manage in their living environment. Lastly, the corrective activity in the workplace theme encompassed questions assessing the rehabilitee's ability to work.

To study the primary method PTs put into practice at various stages of the physiotherapy process when conducting individual physiotherapy, the question provided three answer alternatives: RP only, conventional physiotherapy only, or a combination of both methods. This study adhered to the physiotherapy process definition established by World Physiotherapy (2023). To investigate the overall factors that either promote or inhibit RP, we categorized them into three themes: PT-based, technology-based, and management-based. The PT-based factor theme included questions about the PTs attitude, competence, and experience with RP. The technology-based factor theme included questions related to the functionality of the hardware and software, as well as the quality of the internet connection. The management-based factor theme covered questions about education in RP, availability of technical support, facilities for RP, and allocation of work and time resources within RP. PTs could answer up to nine questions. If a PT answered one of the subtheme questions, then the response was incorporated into the corresponding theme. The proportional distribution of responses for the various themes was calculated based on what each PT answered in the questionnaire.

Regarding the criteria for utilizing RP, the questions were organized into six themes: functioning and performance, cultural factors, rehabilitees' wishes, economic factors, medical diagnosis, and patient safety. The functioning and performance theme encompassed questions about physical functioning and performance, psychic functioning and performance, social functioning and performance, and lastly, cognitive functioning and performance. The cultural factors theme included questions regarding language skills, various cultural factors, and the rehabilitees' age groups (children, youth, working-aged people, and the elderly). The rehabilitees' wishes theme encompassed questions related to the rehabilitees' difficulty in attending the appointment and the rehabilitees' wishes overall. The economic factors theme addressed questions concerning the potential to intensify physiotherapy by increasing rehabilitees' daily workloads and recommendations from the payer. Lastly, the questionnaire included questions pertaining to rehabilitees' medical diagnoses and patient safety. If the PT responded to any of the subtheme questions, then the response was included in the corresponding theme. The proportional responses regarding the criteria for using RP were calculated based on each PT answer in the questionnaire.

4.1.1.3 Terminations in Study I and II

RP was defined as a physiotherapy intervention that included remote technology, such as telephones, smartphones, computers, tablets, activity trackers, CV, VR, AI, or robotics, where the PT and the rehabilitee were physically in different places (Salminen et al., 2016). The "real-time" and "not tied to time" methods were defined as follows: a real-time method was online communication between rehabilitee and PT; a not tied to time method referred to remote technology used in physiotherapy that delivered automatic feedback and support to the rehabilitee (Capecci et al., 2018).

4.2 Study III design

A narrative literature review study was conducted to map existing literature in the field of CV-based markerless human motion analysis. The study followed the methodology of narrative review, as in Ferrari (2015). These steps include formulating research questions, identifying relevant studies, selecting the studies, charting the data, and summarizing and reporting the results (Ferrari, 2015). Accuracy with regard to the ability to measure the knee angle with CV-based markerless HPE was analyzed using technical simulation.

4.2.1 Search strategy

A collection of keywords agreed upon by the authors, given their expertise in this study, was used: accuracy, computer vision, markerless, pose estimation, physiotherapy, and rehabilitation. These keywords were combined and used in different sources to search for evidence. The sources included the PubMed, Google Scholar, Institute of Electrical and Electronics Engineers (IEEE), Association for Computing Machinery (ACM) key journals, existing networks, and relevant conferences. Inclusion criteria for the studies were studies published from 2001 to 2021 that involved a combination of keywords.

4.2.2 Technical simulation

In the technical simulation of the knee joint angle, the black markers in Figure 8 represent the "true" position of the hip, knee, and ankle joints, while the colored markers indicate the predicted positions (key points). The error margin for the estimated joint coordinates corresponds to the maximum deviation from the actual joint position within a defined circular region. The simulation randomly generated joint positions uniformly scattered within these error limits to calculate the knee angle. Repeating this process a number of times, the probability of accurately estimating the knee angle within our allowable error margin was ±5°. This was determined by dividing the number of knee angle estimates that fell within this margin by the total number of measurements.

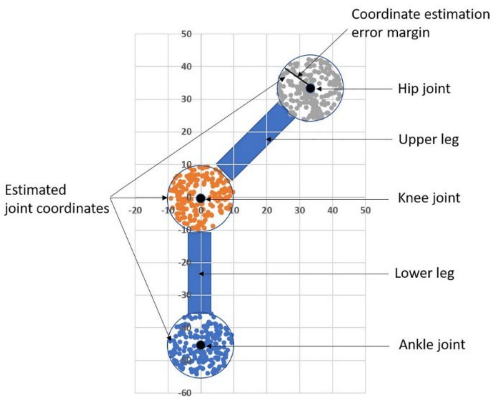

Figure 8 An illustration of a simulation calculating the level of accuracy for the knee joint angle. The figure is reproduced from Hellsten et al. (2021) from *Rehabilitation Process and Outcome* under the Creative Commons Attribution 4.0 International license (Study III)

4.3 Study IV design and participants

Study IV aimed to evaluate the intrarater repeatability and criterion validity of a CV-based markerless HPE application based on DensePose for measuring active hip flexion, extension, inner and outer rotation, and active knee flexion (Figure 9).

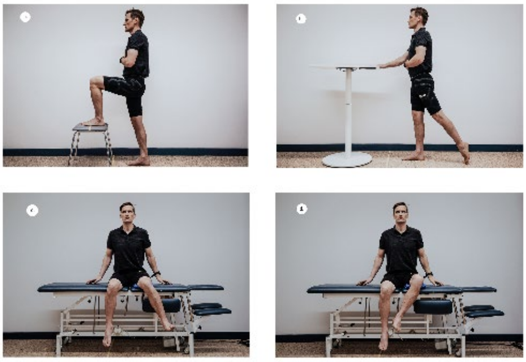

Figure 9 Measurement protocol: A) active flexion of hip and knee joint, B) active extension of hip joint, C) active inner rotation and D) outer rotation of hip joint. The figure is reproduced from Hellstén et al. (2025) from *Healthcare Technology Letters* under the Creative Commons Attribution 4.0 International license (Study IV)

Participants were recruited in April 2023 from Arcada University of Applied Sciences, Helsinki (students and staff). The inclusion criteria for participants were as follows: healthy voluntary participants who were 18 years of age or older, understood Swedish well enough to follow the instructions, and were capable of walking without assistance or aid. The exclusion criteria were participants with symptoms or pain in the lower limbs or lower back that necessitated a visit to a physician within the month preceding the study or a diagnosis of neurological disease. A total of 30 voluntary participants were enrolled in the study. There were 30 study participants, comprising 10 females and 20 males, aged 20–33 years (mean 22.9 years).

The study involved conducting measurements twice, with an interval of 24 hours between sessions, to assess the intrarater repeatability of our CV-based markerless HPE application. The criterion validity of the application was determined by comparing the joint angles automatically measured by the CV-based markerless HPE application with the corresponding reference picture frame. The reference picture frame was a direct capture from the web camera and corresponded to the exact same picture frame as the automatically measured CV-based markerless HPE application joint angle. See Section 4.3.2 for reference picture details.

4.3.1 CV-based markerless HPE application

Based on the results from Study III and the outcomes of technical testing, a CV-based markerless HPE application employing a single camera was developed for use in Study IV. This application was built on a human pose estimation system referred to as DensePose. See Section 2.3.2 for technical details about our CV-based markerless HPE application (DensePose).

To measure hip flexion and extension, the pixel coordinates of the knee, hip, and shoulder joints were first used to form a triangle. Using the law of cosines, the angle α was calculated between the hip–knee line and the hip–shoulder line. Lastly, the hip flexion and extension angle were calculated with the formula $\beta = 180 - \alpha$. The detailed key points and angles used for measuring hip flexion and extension are shown in Figure 10.

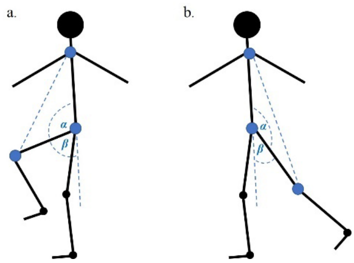

Figure 10 Key points and angles of interest for measuring hip A) flexion and B) extension. The angle is calculated as $\beta = 180 - \alpha$. Blue dots show key points from a lateral view: the middle of the knee joint, hip joint, and shoulder joint. The figure is reproduced from Hellstén et al. (2025) from *Healthcare Technology Letters* under the Creative Commons Attribution 4.0 International license (Study IV)

The knee angle was measured similarly to the hip; however, on this occasion, the hip, knee, and ankle key points were used to formulate a triangle, with α showing the angle between the hip–knee and knee–ankle lines (Figure 11).

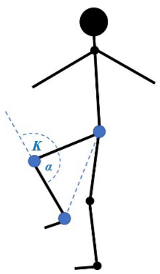

Figure 11 Key points and angles of interest for measuring knee ROM. The angle is calculated as β = 180 – α. Blue dots show key points from a lateral view: the middle of the ankle joint, knee joint, and hip joint. The figure is reproduced from Hellstén et al. (2025) from *Healthcare Technology Letters* under the Creative Commons Attribution 4.0 International license (Study IV).

To accurately measure the angle of inner and outer hip rotation θ, we ensured that the camera was positioned horizontally. Our CV application registered the pixel coordinates of the knee and ankle joints for each frame. A right-angle triangle was formed from the estimated knee and ankle joints and a vertical pixel line from the knee joint downward. Lastly, the rotation angle θ was calculated using trigonometrical functions. The key points and angles of interest observed while measuring inner and outer rotation in the hip joint are illustrated in Figure 12.

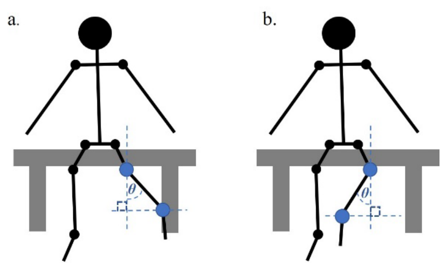

Figure 12 Key points and angles of interest for measuring hip A) inner rotation and B) outer rotation. Angle θ is calculated using trigonometrical functions. Blue dots show key points from the frontal view, the middle of the ankle joint, and the knee joint. The figure is reproduced from Hellstén et al. (2025) from *Healthcare Technology Letters* under the Creative Commons Attribution 4.0 International license (Study IV)

During the operation of the CV-based markerless HPE application, the estimated joints (key points), along with the angles of hip flexion, extension, rotation, and knee flexion, were displayed frame-by-frame on the screen in real time. A save button was provided, enabling the user to save the measured hip and knee angle to a log file at any moment, along with the corresponding video output frame on which the CV-based markerless HPE application measured the joint angles. These output frames were used as reference pictures for validating the hip and knee ROM measurements. During the test protocol, the positions of the computer, web camera, and participants were standardized. The measurement values were expressed in whole degrees. The computer used in the study was Acer Nitro 5, with an integrated webcam (720p resolution and 30 frames per second sampling). The test setup is illustrated in Figure 13.

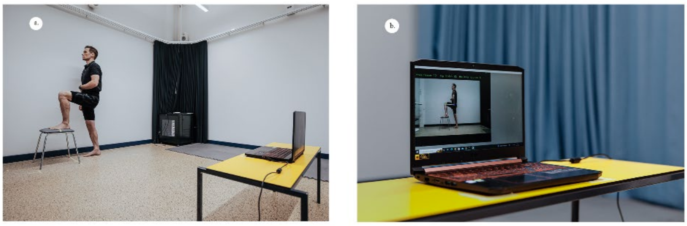

Figure 13 Photograph of A) test setup when a participant performs active hip flexion, and B) computer screen view of our CV-based markerless HPE application. The figure is reproduced from Hellstén et al. (2025) from *Healthcare Technology Letters* under the Creative Commons Attribution 4.0 International license (Study IV)

4.3.2 Reference picture

Each reference picture produced as a result of pressing the Save button in the CV-based markerless HPE application was a direct capture from the web camera. The key points identified by the CV-based markerless HPE application are not displayed in the reference picture. To calculate active hip flexion and extension, an experienced PT manually placed markers with precision. Markers were positioned on the reference picture on the left greater trochanter of the femur, lateral epicondyle of the femur, and middle of the humeral head. To calculate the active inner and outer rotation of the hip joint, markers were placed on the reference picture at the midpoint of the patella and the talocrural articular space. To calculate active flexion in the knee joint, markers were placed on the greater trochanter of the femur, lateral epicondyle of the femur, and lateral malleolus of the fibula. Lines were placed between markers to calculate the joint angles, as illustrated in Figure 14. The marker points were positioned according to bony landmarks used when using a universal goniometer in physiotherapy (Reese & Bandy, 2016). The measurement values are given in degrees with a precision of 1° intervals.

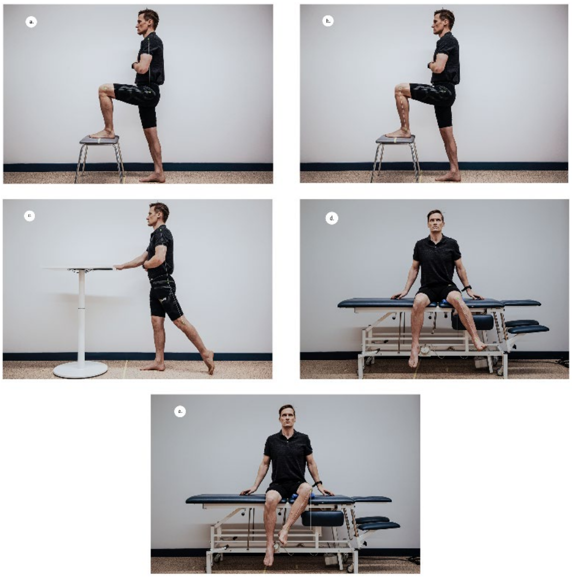

Figure 14 Reference picture with manually drawn markers for A) active flexion of hip, B) active flexion of knee joint, C) active extension of hip joint, D) active inner rotation, and E) outer rotation of hip joint. The figure is reproduced from Hellstén et al. (2025) from *Healthcare Technology Letters* under the Creative Commons Attribution 4.0 International license (Study IV).

4.3.3 Execution

4.3.3.1 Active flexion (hip and knee)

In the standing position, the instructions were as follows: "Bend your left hip and knee and lift your midfoot on the line on the chair. Keep your back and head straight. Look straight forward at the mark on the wall. Maintain this position for three seconds. I will just demonstrate the movement to you. Do you have any questions?" The test position is illustrated in Figure 9a. Once the participant had taken the position, the instructor counted down from 3 to 1, and the CV-based markerless HPE application recorded the joint angle for hip and knee flexion in a log file, along with a time stamp. Simultaneously, the reference picture was saved on a computer with an identical time stamp corresponding to the same picture frame used by the CV-based markerless HPE application to calculate the joint angles. The saving procedure was consistently followed for all measurements.

4.3.3.2 Active extension (hip)

For active extension, the instructions were as follows: "In standing position, touch the table slightly with your right hand to maintain balance. Place the palm of your left hand on your stomach. Extend your left hip so that your toes touch the floor. Do not bend your back, keep your head straight, and look forward at the mark on the wall. Maintain this position for three seconds. I will just demonstrate the required movement to you. Do you have any questions?" The test position is illustrated in Figure 9b.

4.3.3.3 Active inner and outer rotation (hip)

In active inner and outer rotations, the participant was in a sitting position. The instructions were as follows: "Rotate the left hip inward by bringing the left foot outward from the midline (Figure 9c) and then rotate the hip outward by bringing the foot toward the midline (Figure 9d). Keep your pelvis in place as you perform the movement. Maintain both positions for three seconds. I will just demonstrate the required movement to you. Do you have any questions?"

4.4 Ethical considerations

The studies followed ethical principles established by the Finnish National Board on Research Integrity: "Responsible conduct of research" (TENK, 2012) and "The ethical principles of research with human participants and ethical review in the human sciences in Finland" (TENK, 2019).

Studies I and II were granted ethical approval by the research ethics committee of the Faculty of Medicine at the University of Helsinki, Finland, in February 2021 (registration number 3/2021). Study IV was granted ethical approval by the same research ethics committee in January 2023 (registration number 1/2023). For Studies I and II, answering the questionnaire confirmed participation in the study. For Study IV, research permissions were received from Arcada University of Applied Sciences, Helsinki, Finland, in January 2023. Written consent was obtained from all voluntary participants before conducting the study.

4.5 Data Analysis

Statistical analyses (Studies I, II, and IV) were performed with the SPSS software (IBM Corp. Released 2022; IBM SPSS Statistics for Windows, Version 27.0 and 29.0. Armonk, NY), version 27.0 (study I and II), for Study IV, version 29.0 and Microsoft Excel, Version 19. Frequencies, proportions, mean, and standard deviations (SD) were used as descriptive statistics.

4.5.1 Study I

To study the differences between the public and private groups, chi-squared statistics and a Student's t-test were used. A value of $p < .05$ (2-tailed) was considered a statistically significant threshold.

4.5.2 Study II

To compute statistical differences among gender, age, experience working with RP, and population density (number of people per square kilometer) groups, chi-squared statistics and a Student's t-test were used. A two-tailed p-value threshold of less than .05 was considered statistically significant. To study factors affecting different reasons for using RP, we computed odds ratios (OR) and their 95% confidence intervals (CI) with binary logistic regression analysis.

4.5.3 Study III

Following the guidelines described in a narrative review by Ferrari (2015), the results were presented. Initially, basic information regarding the study's characteristics was collected. In the next phase, the data were charted and sorted according to key issues and themes to align with the aims of the study. Lastly, the study involved collating, summarizing, and reporting the results (Ferrari, 2015).

To study accuracy in the measurement of a theoretical knee joint angle in a technical simulation, the Percentage of Correct Keypoints (PCK) was used. PCK and its modified variant, head-normalized Percentage of Correct Keypoints (PCKh) (Andriluka et al., 2014), indicate a percentage value for the probability of correctly detecting a specific joint coordinate (Dang et al., 2019). Dividing the number of knee angle measurements (technical simulation) within the tolerable margin by the total number of measurements gives the probability of PCKh estimating the knee angle. A margin of ±5° degrees was used as a tolerable error margin, as universal goniometry, widely used in the healthcare sector by professionals, such as PTs, has demonstrated a measurement error of 6° when measuring joint angles in the lower extremities (Boone et al., 1978). The law of $K = 180 - a\cos\left(\frac{a^2-b^2-c^2}{-2ac}\right)$ was used to calculate the knee angle.

4.5.4 Study IV

To study intrarater repeatability, the first and second CV-based markerless HPE application measurements were used. Test–retest was assessed with the intraclass correlation coefficient (ICC) with a two-way random effect model and 95% CI. For ICC values, Landis and Koch's (1977) classification was used. Classification was as follows: 1.00–0.81 was considered almost perfect, 0.80–0.61 was considered substantial, 0.60–0.41 was considered moderate, 0.40–0.21 was considered fair, and 0.20–0 was considered slight (Landis & Koch, 1977). The standard error of measurement (SEM) was computed using the mathematical formula $SEM = S \times \sqrt{1 - ICC}$ for absolute reliability, where S represents the SD of scores from the first and second CV-based markerless HPE application measurement. Then, the minimal detectable change (MDC) was computed using the mathematical formula $MDC = SEM \times \sqrt{2} \times 1.96$ (Donoghue & Stokes, 2009).

Correlation between the CV-based markerless HPE application and the reference picture (first measurement) was established with Pearson's correlation analysis to compute the criterion validity, and the Bland–Altman plot analysis was employed to estimate the agreement between the two methods (Bland & Altman, 1986). The following classification was used for correlation analysis: 1.00–0.90 was considered very strong, 0.89–0.70 was considered strong, 0.69–0.50 was considered moderate, 0.49–0.30 was considered weak, and 0.29–0 was considered very weak (Hinkle et al., 2003).

5 Results

Specific results for each of the four studies in this dissertation are provided in their respective publications. In this section, key findings for the respective study are summarized, and new analyses that have not been published are included in Section 5.2 of the last chapter.

5.1 Study I

A total of 662 out of 6525 PTs (9.9%) responded to our questionnaire for Studies I and II. After excluding physiotherapy students, retired PTs, lecturers, and researchers, the final study sample comprised 579 of 6525 PTs, representing 8.9% of the total group. Of these, 482 (83.2%) were female with a mean age of 49.3 years (SD 11.9 years), and 97 (16.8%) were male with a mean age of 46.2 years (SD 12.2 years). Additionally, 440 out of 579 PTs (76%) had more than a decade of professional experience in the field. For Study I, we divided the PTs into the public and private sectors; there was no difference in the level of work experience among PTs over the two sectors. However, a greater proportion of PTs in the public sector reported a lack of work experience in RP compared to PTs in the private sector. Detailed information regarding the characteristics of the study participants is presented in Table 1.

Table 1 Characteristics of the study physiotherapists.

Modified and reproduced from Hellstén et al. (2022) from *JMIR Rehabilitation and Assistive Technology* under the Creative Commons Attribution 4.0 International License (Study I).

	Total group (n = 579)	Public sector (n = 152)	Private sector (n = 423)	*p* value
Age (years), mean (SD)				
Total	48.8 (11.9)	48.6 (11.9)	49.0 (11.9)	.73[a]
Female	49.3 (11.9)	49.3 (11.9)	49.3 (11.7)	.93[a]
Male	46.2 (12.2)	42.3 (10.3)	47.3 (12.3)	.15[a]
Time from physiotherapy degree (years), mean (SD)	22.3 (12.6)	21.4 (12.5)	22.7 (12.5)	.27[a]
Work experience in physiotherapy, n (%)				.47[b]
<1 year	18 (3.1)	7 (4.6)	10 (2.4)	
≥1 year and <5 years	65 (11.2)	17 (11.2)	47 (11.1)	
≥5 years and <10 years	56 (9.7)	12 (7.9)	43 (10.2)	
≥10 years	440 (76.0)	116 (76.3)	323 (76.4)	
Work experience in remote physiotherapy, n (%)				<.001[b]
No experience	210 (36.3)	77 (50.7)	130 (30.7)	
<1 year	209 (36.1)	26 (30.3)	162 (38.3)	
1 year to 2 years	135 (23.3)	26 (17.1)	109 (25.8)	
>2 to 4 years	13 (2.2)	1 (0.7)	12 (2.8)	
>4 years	12 (2.1)	2 (1.3)	10 (2.4)	

[a] *p* values are based on the Student's *t*-test.
[b] *p* values are based on the chi-squared test.

When the mean suitability score for RP was compared (ranging from 0, indicating "not suitable at all," to 10, indicating "fully suitable") across various connected disease groups between the public and private sectors, there were minor differences. The total group mean suitability "score" for lung diseases was 6.1 and for musculoskeletal diseases was 5.7, although the mean suitability "score" for lung diseases ($p = .02$) and musculoskeletal diseases ($p = .01$) was significantly higher in the public sector compared to the private sector. Across various diseases (subgroups), the mean suitability "score" for RP ranged from 2.1 for memory disorders to 6.6 for both hip or knee osteoarthritis and asthma. Furthermore, for 12 out of 21 subgroups, the suitability score was 5 or higher. However, only 9.7% (40 out of 411) of the PTs rated asthma, and 8.2% (37 out of 452) of the PTs rated hip or knee osteoarthritis as fully suitable for RP, with a suitability score of 10. In addition, 32.2% (134 out of 416) of the PTs thought RP was not suitable at all for individuals with memory disorders, as assessed with a suitability score of 0. More data relating to suitability scores in connected disease groups and subgroups can be seen in Table 2.

Table 2 Suitability scores of remote physiotherapy (RP) in different disease groups[a]

Modified and reproduced from Hellstén et al. (2022) from *JMIR Rehabilitation and Assistive Technology* under the Creative Commons Attribution 4.0 International license (Study I).

Connected disease groups and subgroups	**Total group, mean (SD)**	**Public sector, mean (SD)**	**Private sector, mean (SD)**	**Mean difference (95% CI)**	***p* value[b]**
Lung diseases	6.1 (2.4)	6.5 (2.1)	5.9 (2.5)	0.6 (0.1 to 1.1)	.02
Asthma	6.6 (2.5)	6.8 (2.3)	6.5 (2.5)	0.3 (–0.3 to 0.8)	.31
Chronic obstructive pulmonary disease	5.6 (2.6)	6.2 (2.2)	5.4 (2.7)	0.8 (0.3 to 1.3)	.003
Musculoskeletal diseases	5.7 (2.2)	6.1 (1.9)	5.6 (2.3)	0.6 (0.1 to 1.0)	.01
Knee and hip osteoarthritis	6.6 (2.5)	7.2 (2.1)	6.4 (2.6)	0.8 (0.3 to 1.2)	.001
Low back pain	5.9 (2.6)	5.9 (2.5)	5.9 (2.6)	0.0 (–0.5 to 0.5)	.98
Repetitive strain injury of the hand and forearm	5.9 (2.8)	6.5 (2.7)	5.6 (2.8)	0.9 (0.3 to 1.5)	.002
Tendon disorder of the shoulder	5.8 (2.7)	6.0 (2.6)	5.7 (2.7)	0.4 (–0.2 to 0.9)	.19
Rheumatoid arthritis	5.7 (2.5)	6.1 (2.3)	5.5 (2.6)	0.6 (0.1 to 1.2)	.02
Pain patient	5.2 (2.7)	5.3 (2.6)	5.1 (2.7)	0.2 (–0.4 to 0.8)	.50
Neck pain	4.8 (2.7)	4.7 (2.6)	4.8 (2.7)	–0.1 (–0.7 to 0.5)	.75
Psychiatric diseases	4.9 (2.7)	5.3 (2.6)	4.7 (2.7)	0.6 (0.0 to 1.2)	.06
Anxiety disorder	5.2 (3.0)	5.6 (3.1)	5.0 (3.0)	0.6 (0.0 to 1.3)	.045
Depression	5.0 (2.9)	5.3 (2.8)	4.8 (2.9)	0.5 (–0.2 to 1.1)	.15

Connected disease groups and subgroups	**Total group, mean (SD)**	**Public sector, mean (SD)**	**Private sector, mean (SD)**	**Mean difference (95% CI)**	***p* value**[b]
Personality disorder	4.7 (2.9)	4.9 (2.9)	4.6 (2.9)	0.4 (–0.2 to 1.0)	.23
Neurological diseases	3.3 (2.1)	3.3 (1.9)	3.3 (2.2)	0.1 (–0.5 to 0.4)	.81
Multiple sclerosis	4.4 (2.6)	4.3 (2.4)	4.4 (2.7)	–0.1 (–0.6 to 0.5)	.85
Parkinson disease	4.0 (2.6)	4.1 (2.5)	4.0 (2.6)	0.1 (–0.5 to 0.7)	.69
Cerebral infarction (e.g., stroke)	3.3 (2.6)	3.1 (2.4)	3.4 (2.6)	–0.2 (–0.8 to 0.3)	.45
Spinal cord injury	3.2 (2.7)	2.9 (2.3)	3.3 (2.8)	–0.5 (–1.1 to 0.1)	.09
Brain injury	3.2 (2.5)	2.9 (2.4)	3.2 (2.6)	–0.3 (–0.8 to 0.2)	.25
Memory disorder	2.1 (2.2)	2.3 (2.3)	2.0 (2.2)	0.3 (–0.2 to 0.8)	.21
Other					
Heart disease/failure	5.8 (2.7)	6.1 (2.5)	5.7 (2.8)	0.4 (–0.1 to 1.0)	.14
Cancer	5.2 (2.8)	5.3 (2.7)	5.2 (2.8)	0.1 (–0.5 to 0.7)	.75
Multimorbid patient	3.6 (2.6)	3.7 (2.6)	3.5 (2.7)	0.2 (–0.4 to 0.8)	.46

[a] Suitability score (0 = not suitable at all to 10 = fully suitable).

[b] *p* values are based on Student's *t* test.

Prior to the COVID-19 pandemic in early 2020, three-quarters of all PTs in the study responded that they did not allocate any of their daily practice time to RP. This was more common in the private sector than in the public sector, with 66.1% (41 out of 62) of public sector PTs versus 80.3% (171 out of 213) in the private sector responding to use of RP of their practice time ($p = .03$). Only a small number of PTs dedicated more than one-fifth of their practice time to RP. From early 2020 to spring 2021, the percentage of PTs utilizing RP significantly increased from 33.8% (21 out of 62) to 75.4% (46 out of 61; $p < .001$) in the public sector and from 19.7% (42 out of 213) to 76.6% (163 out of 213; $p < .001$) in the private sector. In 2021, the proportion of PTs who did not use RP was 24.6% (15 out of 61) in the public sector and 23.5% (50 out of 213) in the private sector, showing no statistically significant difference between the groups ($p = .86$). Detailed findings are presented in Table 3.

Table 3 Proportion of physiotherapists who used remote physiotherapy (RP) before (early 2020) and during the COVID-19 pandemic (spring 2021).

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Proportion of practice time (%)	Total group, n (%)	Public sector, n (%)	Private sector, n (%)	*p* value[a]
Before COVID-19 pandemic				.03
0	212 (76.8)	41 (66.1)	171 (80.3)	
1–20	60 (21.7)	19 (30.6)	40 (18.8)	
>20	4 (1.4)	2 (3.2)	2 (0.9)	
During the COVID-19 pandemic				.20
0	65 (23.7)	15 (24.6)	50 (23.5)	
1–20	177 (64.6)	35 (57.4)	142 (66.7)	
>20	32 (11.7)	11 (18.0)	21 (9.9)	

[a] *p* values are based on chi-squared tests.

The real-time method was the most frequently used method in both the public sector (46 out of 66, 69.7%) and the private sector (157 out of 213, 71.7%) when studying methods and equipment utilized for individual RP. Conversely, only a small number of PTs used methods not tied to time, with similar tendencies for group RP sessions (data not shown). Across all PTs in the study, the most used technological devices were computers or tablets (229 out of 290, 79%), smartphones (149 out of 290, 51.4%), and traditional phones for voice calls (51 out of 290, 17.6%). The percentage of PTs using computers or tablets for RP was significantly greater in the private sector (183 out of 221, 82.8%) than in the public sector (46 out of 68, 67.6%; $p = .01$). However, a greater proportion of PTs in the public sector utilized traditional phones than those in the private sector (18 out of 68, 26.5% versus 33 out of 221, 14.9%; $p = .04$). Other technologies, such as VR, CV, or AI, were seldom used. Detailed information can be seen in Table 4.

Table 4 Methods and equipment used in remote physiotherapy (RP) on a weekly basis.

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	Total group, n (%)	Public sector, n (%)	Private sector, n (%)	*p* value[a]
Method				.47
Real-time method	203 (71.0)	46 (69.7)	157 (71.7)	
Method not tied to time	11 (3.8)	1 (1.5)	10 (4.6)	
Real-time method and method not tied to time	25 (8.7)	5 (7.6)	20 (9.1)	
Equipment				
Computer/tablet	229 (79.0)	46 (67.6)	183 (82.8)	.01
Smartphone	149 (51.4)	33 (48.5)	116 (52.5)	.58
Phone	51 (17.6)	18 (26.5)	33 (14.9)	.04
Activity tracker[b]	18 (6.2)	3 (4.4)	15 (6.8)	.58
Others[c]	10 (1.7)	1 (1.5)	9 (4.1)	.76

[a] *p* values are based on chi-squared tests.
[b] For example, pedometer and accelerometer.
[c] Exergame, television application, virtual reality, computer vision, artificial intelligence, robotics, smart textile, or augmented reality.

5.2 Study II

When the suitability "score" (ranging from 0, indicating "not suitable at all" to 10, indicating "fully suitable") was examined for RP across various physiotherapy tasks in the physiotherapy process, the score ranged from 3.8 for corrective activity in the workplace to 7.6 for consultation, guidance, and counseling. Among the PTs, 24.9% (59 out of 237) assigned a perfect score of 10 to consultation and 18.5% (44 out of 238) awarded guidance and counseling a full suitability "score" of 10 when considering the use of RP. Conversely, 16.3% (32 out of 196) of the PTs rated RP as not suitable at all (a score of 0) for corrective activity in the workplace. A PT with at least one year of experience using RP in daily practice indicated that it is more appropriate for all tasks, except for corrective action in the workplace, when compared to those with less experience with RP (all *p*-values < .05). More detailed results can be seen in Table 5.

Table 5 Suitability score (0 = not suitable at all to 10 = fully suitable) for remote physiotherapy (RP) in different physiotherapy tasks.

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	Consultation, mean (SD), n = 237	**Guidance and counseling, mean (SD), n = 238**	**Exercise, mean (SD), n = 237**	**Assessment, mean (SD), n = 178**	**Corrective activity in the workplace, mean (SD), n = 196**
Total group	7.6 (2.4)	7.6 (1.9)	6.1 (2.6)	4.3 (2.3)	3.8 (2.8)
Gender					
Female	7.7 (2.3)	7.7 (2.0)	6.1 (2.6)	4.3 (2.3)	3.8 (2.8)
Male	7.5 (2.6)	7.4 (1.9)	6.0 (2.5)	4.1 (1.9)	3.5 (2.5)
Mean difference (95% CI)[a]	0.2 (-0.6 to 1.1)	0.2 (-−0.5 to 1.0)	0.0 (−0.9 to 1.0)	0.3 (−0.7 to 1.2)	0.3 (−0.8 to 1.4)
Age					
<45 years	7.6 (2.4)	7.8 (1.7)	6.1 (2.4)	4.2 (2.3)	3.9 (2.7)
≥45 years	7.6 (2.4)	7.5 (2.1)	6.1 (2.7)	4.4 (2.3)	3.7 (2.8)
Mean difference (95% CI)[a]	0.0 (-0.6 to 0.6)	0.3 (−0.2 to 0.8)	0.0 (−0.7 to 0.7)	−0.2 (−0.9 to 0.5)	0.2 (−0.5 to 1.0)
Experience of working with RP					
<1 years	7.3 (2.5)	7.3 (2.0)	5.6 (2.5)	4.0 (2.2)	3.7 (2.7)
≥1 years	8.0 (2.1)	8.0 (1.8)	6.6 (2.5)	4.7 (2.3)	3.9 (2.9)
Mean difference (95% CI)[a]	−0.7 (−1.3 to −0.1)*	−0.7 (−1.2 to −0.2)*	−1.0 (−1.6 to −0.4)*	−0.7 (−1.4 to −0.1)*	−0.3 (−1.1 to 0.5)
Population density					
[b]5 Smallest	7.5 (2.0)	7.7 (1.5)	6.3 (2.4)	4.8 (2.2)	3.8 (2.9)
[b]5 Greatest	7.7 (2.4)	7.7 (2.0)	6.2 (2.5)	4.5 (2.2)	3.9 (2.7)
Mean difference (95% CI)[a]	−0.2 (−1.3 to 0.9)	0.1 (−0.9 to 1.0)	0.1 (−1.1 to 1.2)	0.4 (−0.9 to 1.7)	−0.1 (−1.6 to 1.3)

[a] 95% CI = 95% confidence intervals.
[b] Finland is divided into 19 regions.
[*] $p < 0.05$; *p*-values are based on the chi-squared test.

Half of the PTs indicated that the main reason for implementing RP was either due to the “wish of the rehabilitee” or as “one alternative among many.” Experience in adopting RP was linked to the reason for working with it. A greater proportion of PTs with at least one year of experience using RP in daily practice referred to the "wish of the rehabilitee" as a reason compared to those with less experience in RP (62.8% versus 39.6%, $p = .001$). After adjusting for factors such as gender, age, and population density, PTs with at least one year of RP experience were more likely to choose "wish of the rehabilitee" (OR 2.6, 95% CI 1.4–4.6, $p = .002$). Similarly, a larger proportion of more experienced PTs indicated "improves accessibility" as a reason for selecting RP compared to those with less experience (48.1% versus 33.1%, $p = .015$). However, when adjusted for gender, age, and population density, no significant difference was found between the groups (OR 1.6, 95% CI 0.9–2.9, $p = .12$). More results can be found in Table 6.

Table 6 Reasons why physiotherapists implement remote physiotherapy (RP) depending on the characteristics of the physiotherapist or population density.

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	Wish of rehabilitee, % (n)[a]	**One alternative among many, % (n)[a]**	**Improves accessibility, % (n)[a]**	**Employer requires it, % (n)[a]**	**Interest in implementing RP, % (n)[a]**	**[b] Other, % (n)[a]**
Total group (n = 283)	50.2 (142)	48.4 (137)	39.9 (113)	15.2 (43)	10.2 (29)	15.5 (44)
Gender						
Female n = 242	49.2 (119)	49.6 (120)	39.3 (95)	14.5 (35)	11.2 (27)	15.3 (37)
Male n = 41	56.1 (23)	41.5 (17)	43.9 (18)	19.5 (8)	4.9 (2)	17.1 (7)
Age						
<45 years n = 109	52.3 (57)	50.5 (55)	43.1 (47)	18.3 (20)	9.2 (10)	12.8 (14)
≥45 years n = 174	48.9 (85)	47.1 (82)	37.9 (66)	13.2 (23)	10.9 (19)	17.2 (30)
Experience of working with RP						
<1 years n = 154	39.6 (61)*	46.1 (71)	33.1 (51)*	16.2 (25)	8.4 (13)	16.9 (26)
≥1 years n = 109	62.8 (81)*	51.2 (66)	48.1 (62)*	14.0 (18)	12.4 (16)	14.0 (18)
Population density						
[c]5 smallest n = 31	38.7 (12)	58.1 (18)	41.9 (13)	19.4 (6)	12.9 (4)	12.9 (4)
[c]5 biggest n = 182	50.5 (92)	45.6 (83)	37.9 (69)	13.7 (25)	8.8 (16)	18.1 (33)

[a] Subjects with positive (yes) response; percent (n).

[b] To save social costs, increase equality, deepen therapy relationships, reduce physical/mental load, and increase number of contacts with rehabilitee.

[c] Finland is divided into 19 regions.

*$p < 0.05$, values are based on a chi-squared test.

When the study methods that PTs predominantly implemented during different phases in physiotherapy were examined, it was found that conventional (face-to-face) physiotherapy was the most frequently employed approach at every phase in the individual physiotherapy process. Of all the PTs, 72.5% in Study II indicated a preference for conventional (face-to-face) physiotherapy. In contrast, only 7.2% of

PTs reported using only RP, and 20.2% favored combining both methods. PTs who primarily used RP tended to implement it more frequently during the follow-up phase (23.9%, n = 56). However, a relatively small number of PTs reportedly used RP during other phases of the physiotherapy process. Detailed results can be seen in Figure 15.

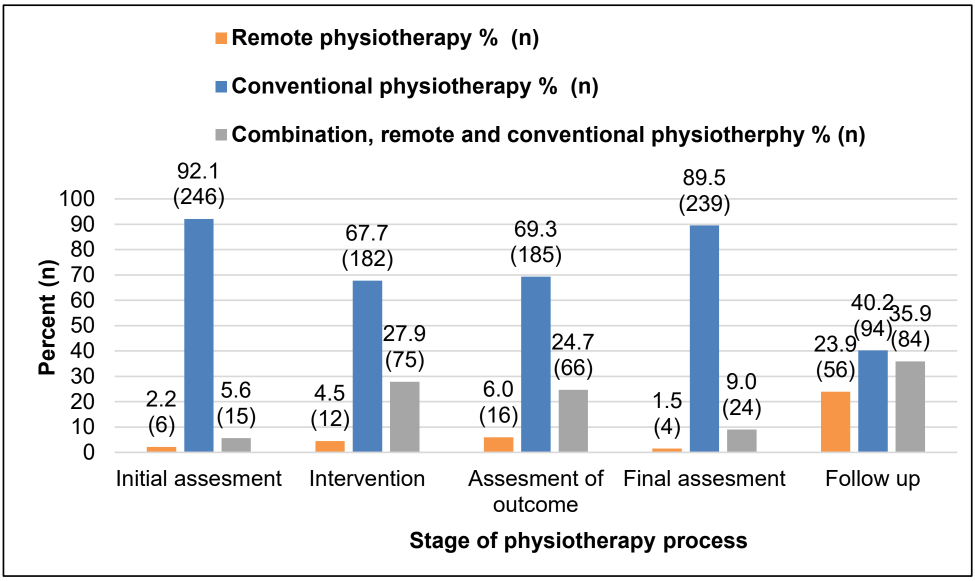

Figure 15 Proportion of physiotherapists choosing primarily remote physiotherapy (RP), conventional physiotherapy, or a combination of both at different stages of the physiotherapy process. The figure is modified and reproduced from Hellstén et al. (2023) from *European Journal of Physiotherapy* under the Creative Commons Attribution 4.0 International license (Study II).

According to the PTs, factors related to technology (84.5%) most strongly promoted the use of RP. Factors related to PTs are also highly influential, with 76.5% of PTs indicating their importance. In contrast, only half of the PTs considered factors related to management to promote the use of RP.

Two out of three PTs indicated that technology-related factors inhibited the use of RP. A greater percentage of PT with less than one year of experience using RP identified technology as an inhibiting factor, compared to those with more experience (86.6% versus 70.2%, respectively; $p = .001$). Conversely, PTs with less than one year of experience in using RP were more likely to note management-related factors as inhibiting compared to those with more experience in RP (63.3% versus 45.6%, respectively; $p = .002$). In addition, a greater percentage of male than female PTs noted that factors related to PT inhibited the use of RP (72.2% versus 61.0%, respectively; $p = .007$).

When studying all PTs concerning the subthemes, the three most frequently mentioned factors that promoted the use of RP were the functionality of hardware and software (71.0%), a PTs positive attitude toward RP (58.0%), and having a working internet connection (39.4%). A greater percentage of younger PTs (<45 years) reported a more favorable attitude toward promoting the use of RP compared to their counterparts (≥45 years, 65.9% versus 53.9%, respectively; p = .011). PTs with less than one year of experience working with RP emphasized the importance of education in promoting its use more than those with more experience (22.1% versus 13.4%, respectively; p = .045).

The three most frequently cited inhibiting factors for RP that PTs mentioned in subthemes included lack of functional hardware and software (56.1%), a negative attitude toward RP (37.6), and the lack of a stable internet connection (34.9%). PTs with at least one year of experience working with RP were more likely to report the lack of functional hardware and software (67.8% versus 55.8%, respectively; p = .031) and the lack of a stable internet connection (53.7% versus 36.5%, respectively; p = .002) as obstacles, compared to those with less experience. Conversely, PTs with less than one year of experience more frequently identified the need for education and competence related to RP as barriers than their more experienced counterparts (29.8% versus 11.4%, respectively; p = .001 for education and 21.0% versus 12.1%, respectively; p = .039 for competence). Detailed results can be seen in Table 7.

Table 7 Factors promoting or inhibiting the implementation of remote physiotherapy (RP).

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	All subjects % (n)	Gender % (n); female / male	Age % (n); < 45 / ≥ 45 years	Experience of working with RP% (n); < 1 / ≥ 1 year	Population density % (n); 5 smallest /5 greatest
Promoting factors					
Physiotherapist-based factors	76.5 (390)	75.9 (327) / 79.7 (63)	77.8 (137) / 75.7 (253)	76.2 (138) / 81.2 (121)	81.8 (54) / 74.4 (233)
Attitude	58.0 (296)	57.1 (246) / 63.3 (50)	65.9 (116) / 53.9 (180)*	57.5 (104) / 64.4 (96)	66.7 (44) / 56.9 (178)
Competence	32.7 (167)	31.8 (137) / 38.0 (30)	27.8 (49) / 35.3 (118)	31.5 (57) / 29.5 (44)	34.8 (23) / 32.3 (101)
Experience of working with RP	8.0 (41)	7.4 (32) / 11.4 (9)	6.3 (11) / 9.0 (30)	8.8 (16) / 9.4 (14)	12.1 (8) / 7.0 (22)
Technology-based factors	84.5 (431)	84.7 (365) / 83.5 (66)	85.8 (151) / 83.8 (280)	89.5 (162) / 89.9 (134)	80.3 (53) / 84.3 (264)
Functionality of hardware and software	71.0 (362)	71.5 (308) / 68.4 (54)	68.2 (120) / 72.5 (242)	74.6 (135) / 77.9 (116)	66.7 (44) / 70.0 (219)
Internet connection	39.4 (201)	39.7 (171) / 38.0 (30)	43.8 (77) / 37.1 (214)	45.3 (82) / 67 (45.0)	36.4 (24) / 43.1 (135)
Management-based factors	56.3 (287)	56.8 (245) / 53.2 (42)	54.5 (96) / 57.2 (191)	54.7 (99) / 45.0 (67)	48.5 (32) / 55.9 (175)
Education	20.0 (102)	18.8 (81) / 26.6 (21)	20.5 (36) / 19.8 (66)	22.1 (40) / 13.4 (20)*	22.7 (15) / 18.8 (59)
Technical support	16.1 (82)	16.9 (73) / 11.4 (9)	12.5 (22) / 18.0 (60)	13.8 (25) / 11.4 (17)	7.6 (5) / 16.9 (53)
Facilities	9.4 (48)	8.4 (36) / 15.2 (12)	13.1 (23) / 7.5 (25)*	8.8 (16) / 9.4 (14)	10.6 (7) / 10.2 (32)
Work-time resources	22.2 (113)	23.9 (103) / 12.7 (10)*	21.6 (38) / 22.5 (75)	19.9 (36) / 17.4 (26)	21.2 (14) / 20.4 (64)
Inhibiting factors					
Physiotherapist-based factors	63.5 (324)	61.0 (263) / 77.2 (61)*	66.5 (117) / 62.0 (207)	61.3 (111) / 54.4 (81)	75.8 (50) / 61.7 (193)*
Attitude	37.6 (192)	36.0 (155) / 46.8 (37)	44.3 (78) / 34.1 (114)*	38.1 (69) / 40.3 (60)	45.5 (30) / 35.8 (112)
Competence	21.8 (111)	20.4 (88) / 29.1 (23)	22.7 (40) / 21.3 (71)	21.0 (38) / 12.1 (18)*	24.2 (16) / 22.7 (71)
Experience of working with RP	22.5 (115)	20.4 (88) / 34.2 (27)*	15.9 (28) / 26.0 (87)*	18.2 (33) / 11.4 (17)	30.3 (20) / 20.1 (63)

	All subjects % (n)	Gender % (n); female / male	Age % (n); < 45 / ≥ 45 years	Experience of working with RP% (n); < 1 / ≥ 1 year	Population density % (n); 5 smallest /5 greatest
Technology-based factors	69.5 (355)	69.1 (298) / 72.2 (57)	67.7 (226) / 73.3 (129)	70.2 (127) / 86.6 (129)*	69.7 (46) / 70.9 (22)
Functionality of hardware and software	56.1 (286)	56.1 (242) / 55.7 (44)	56.3 (99) / 56.0 (187)	55.8 (101) / 67.8 (101)*	54.5 (36) / 56.2 (176)
Internet connection	34.9 (178)	35.3 (152) / 32.9 (26)	44.3 (78) / 29.9 (100)*	36.5 (66) / 53.7 (80)*	36.4 (24) / 37.4 (117)
Management-based factors	58.0 (296)	59.9 (258) / 48.1 (38)	55.1 (97) / 59.6 (199)	63.0 (114) / 45.6 (68)*	57.6 (38) / 59.4 (186)
Education	24.5 (125)	24.8 (107) / 22.8 (18)	23.3 (41) / 25.1 (84)	29.8 (54) / 11.4 (17)*	25.8 (17) / 23.6 (74)
Technical support	19 (97)	21.1 (91) / 7.6 (6)*	15.9 (28) / 20.7 (69)	18.2 (33) / 19.5 (29)	18.2 (12) / 19.2 (60)
Facilities	9.2 (47)	8.8 (38) / 11.4 (9)	10.8 (19) / 8.4 (28)	9.4 (17) / 13.4 (20)	4.5 (3) / 12.1 (38)
Work-time resources	20.6 (105)	21.6 (93) / 15.2 (12)	17.6 (31) / 22.2 (74)	22.1 (40) / 14.8 (22)	25.8 (17) / 20.1 (63)

*$p < 0.05$, values are based on chi-squared test.

Of the PTs, no more than 18.6% (59 out of 318) indicated that their workplaces had established predefined criteria for the use of RP. Among these PTs (n = 59), the majority (68%, 40 out of 59) noted that RP was primarily used according to the rehabilitee's wish to do so, whereas the fewest (14%, 8 out of 59) noted that RP was used due to cultural considerations. Detailed results are presented in Figure 16.

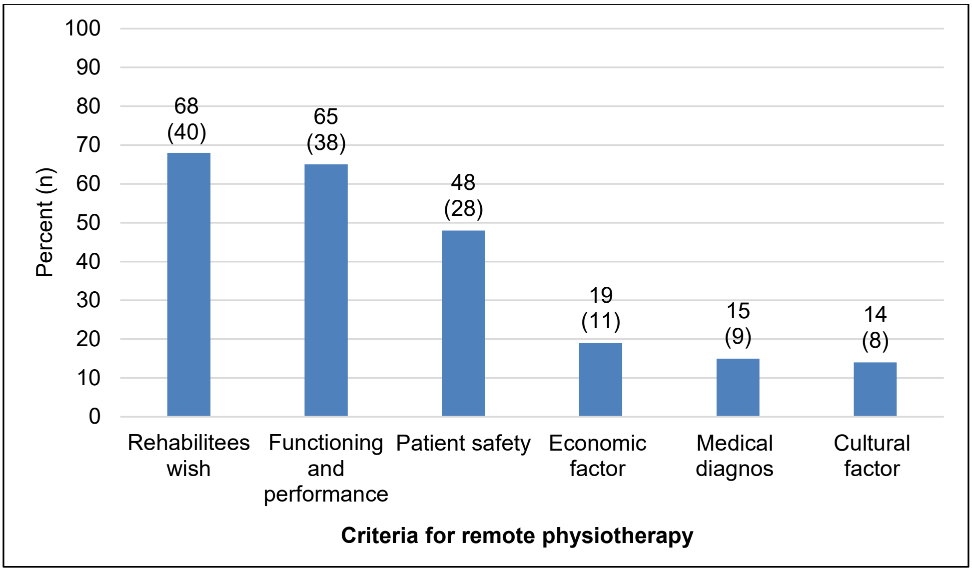

Figure 16 Proportion of physiotherapists choosing criteria for remote physiotherapy (RP). The figure is modified and reproduced from Hellstén et al. (2023) from *European Journal of Physiotherapy* under the Creative Commons Attribution 4.0 International license (Study II).

Among the PTs in Study II, 62.4% (309 out of 495) reported not having participated in any RP education in the past year. Overall, a higher percentage of female PTs participated in RP education compared to male PTs (40%, 167 out of 417 versus 24.3%, 19 out of 78, respectively; p =.010). Additionally, PTs with at least one year of experience working with RP were more likely to have attended RP education in the past year than those with less experience (58.0%, 83 out of 143 versus 43.8%, 78 out of 178, respectively; p = .013). Furthermore, just 8.9% (44 out of 495) of PTs reported having completed entry-level courses in RP.

In this paragraph, we present unpublished results based on the cross-sectional web-based questionnaire. When we examined the reasons for implementing RP, the proportion of PTs choosing "the rehabilitee's wish" was higher in the private sector (55.4%, 118 out of 213) than in the public sector (39.0%, 23 out of 59; p = .03. The proportion of PTs who were "not interested in RP" was higher in the private sector (92.5%, 197 out of 213) than in the public sector (83.1%, 49 out of 59; p = .04). When study methods that PTs predominantly implemented during follow-up in physiotherapy, conventional physiotherapy was more frequently used in the private sector than in the public sector (38.0% versus 15.3%, respectively; p = .01). There were no differences between these two sectors when we compared RP and the combination of RP and conventional physiotherapy in the follow-up phase. In the view of the PTs, only 2.1% (6 out of 283) responded that they could observe exercise therapy as well as conventional physiotherapy with RP. However, of the PTs

(66.8%, 189 out of 283) strongly agreed or agreed that they could motivate rehabilitees with RP as well as in conventional physiotherapy.

5.3 Study III

As shown by the results of the narrative review, CV-based markerless HPE systems can be used with standard cameras that capture the color and brightness for each pixel in an image or with depth-sensing cameras (Colyer et al., 2018). CV HPE systems can be categorized into 2D and 3D approaches. The 2D system calculates the (x, y) coordinates of each joint in an image, while in the 3D pose estimation, the system determines the (x, y, z) coordinates (Bengio et al., 2013). In recent years, several methods have been proposed for 2D pose estimation. Early methods relied on handcraft features, such as the histogram of oriented gradients (HOG; Wang & Li, 2013) and edgelet (Eichner & Ferrari, 2010). However, these techniques struggled to accurately detect body parts. As a result, machine learning methods have developed and are rapidly advancing to address these limitations (Dang et al., 2019). A common technique for the 2D pose estimation of an individual comprises direct regression and heatmap-based methods (Dang et al., 2019). In direct regression, key body points are identified in a single step. One of the earliest solutions utilizing deep learning and direct regression of HPE is DeepPose, which is based on deep neural networks (DNN; Toshev & Szegedy, 2014). A heatmap-based approach estimates the probability of a joint being present at each pixel. One commonly used technique for 2D estimation involves generating heatmaps for joints using the stacked hourglass technique (Newell et al., 2016).

OpenPose is a widely used technical method for estimating the poses of several individuals in the same picture. It serves as the basis for advancements in CV-based markerless HPE. Its widespread use is largely due to its ability to identify up to 25 key points in the human body, which makes it highly used in CV-based markerless HPE analysis. During the opening stage, the OpenPose system takes an original image as input to predict the potential locations of key points (joint locations) within the image. The incorporation of part affinity maps (PAF) in the OpenPose image model allows for linking body parts to specific individuals within the image. This method makes OpenPose a bottom-up approach, enabling it to deliver real-time pose estimation, regardless of the number of individuals present in the image (Cao et al., 2019).

5.3.1 Knee angle measurement simulation

A key challenge faced by CV-based markerless HPE methods is their level of accuracy, which has hindered their widespread adoption in the field of biomechanics (Colyer et al., 2018; Pavlakos et al., 2018). The measurement of the knee joint angle is an example of this, as shown in Figure 17.

Figure 17 An illustration of a CV-based markerless HPE application (OpenPose) measuring the knee joint. The figure is reproduced from Hellsten et al. (2021) from *Rehabilitation Process and Outcome* under the Creative Commons Attribution 4.0 International license (Study III).

The CV-based markerless HPE application first estimated the coordinates (key points) of the hip, knee, and ankle joints. These coordinates created a triangle, as illustrated in Figure 18. To estimate all corner angles, the law of cosine was used after determining the Euclidean distance between each pair of coordinates. The angle of interest was K, and its calculation used the following equation: $K = 180 - \alpha\cos\left(\frac{a^2-b^2-c^2}{-2ac}\right)$

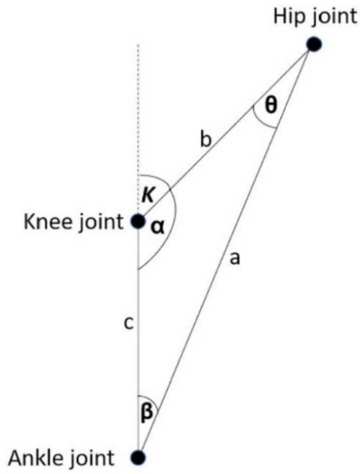

Figure 18 Once the coordinates of the hip, knee, and ankle joints have been estimated, the knee angle K is calculated using the law of cosines. The figure is reproduced from Hellsten et al. (2021) from *Rehabilitation Process and Outcome* under the Creative Commons Attribution 4.0 International license (Study III).

For an average male, the length of the upper leg (distance between the hip and knee) is around 46 cm, for the lower leg (distance between knee and ankle), it is around 45 cm (Aitken, 2021), and for the head height, it is around 20 cm (Vasavada et al., 2008). In practical terms, the application of PCKh at 0.5 indicates that the error margin for the estimated joint coordinates is 10 cm, which is based on the head height (Andriluka et al., 2014; Dang et al., 2019). In a simulation with a knee angle of 45°, using this parameter with 1,000 knee angle simulation measurements indicates that the probability of measuring the knee angle within a margin of ±5° is only 25%. An error margin of ±5° in this scenario tolerates an error margin of no greater than 2.5 cm, which corresponds to a PCKh value of approximately 0.1. Figure 8 illustrates this.

5.3.2 Performance and accuracy

Studies presented by Slembrouck et al. (2020) and Gu et al. (2018) used OpenPose to detect 2D coordinates of human joints. Gu et al. (2018) studied the performance and accuracy of OpenPose in calculating lower limb angles by tracking joint coordinates from adults in gait when using a single RGB camera recording at 30 Hz. A state-of-the art commercial multicamera system was used to validate the computed lower limb angles. Most of the frames showed an error of 10° or less, demonstrating accuracy comparable to that of a marker-based depth camera system. Slembrouck et al. (2020) used triangulation with 2D joint coordinates detected by OpenPose from multiple camera angles. These coordinates were further refined into 3D joint coordinates before least-square triangulation. The authors claimed that their system could track the poses of multiple individuals in real time at a frame rate of 20–25 frames per second. In their study, the lower parts of the body joint coordinates were detected with a standard deviation from 9.6 mm to 23.7 mm.

Nakano et al. (2020) studied CV-based markerless HPE motion (OpenPose) with multiple synchronized video cameras (3D) to compare the accuracy of CV marker-based HPE motion during walking, countermovement jumping, and ball throwing tasks performed by only two participants. Mean absolute errors (MAE) were used to assess the difference in joint positions between the two methods. Approximately 47% of all the measurements had an MAE of less than 20 mm, and 80% of the measurements had an MAE of less than 30 mm. Schmitz et al. (2014) conducted a comparison between the accuracy of CV-based markerless motion analysis of a single camera and CV marker-based motion analysis with ten cameras. They used six different jig postures designed to simulate a human leg. To measure abduction and adduction angles, a digital inclinometer with a precision of 0.1° was employed. Both the marker-based and the markerless systems were calculated as the average of 30 frames. The marker-based system provided slightly more accurate estimates for abduction, while the markerless system was more accurate for adduction; however, the differences were minimal within ± 0.5°.

5.3.3 Use of CV-based markerless HPE in rehabilitation

Several CV-based markerless HPE real-time monitoring tools for rehabilitation have been proposed in the literature. Nalci et al. (2015) conducted an analysis of the balance of single leg stance with both eyes open and closed, using CV-based markerless techniques (dynamic vision sensor cameras). These results were compared in their informal study with those obtained from a gold-standard balance board, which measured sway. Dorado et al. (2019) introduced a CV-based system (ArthriKin) for rehabilitees with rheumatoid arthritis, which enabled real-time supervision and feedback for rehabilitees performing exercise therapy at home. Baptista et al. (2019) developed a home-based training system meant for stroke patients with a two-way linked application, one for the rehabilitee and one for the therapist. The rehabilitee side application used MicrosoftKinect, which provides real-time visual feedback and tracks the rehabilitees' home exercise therapy. CV-based applications have also been designed to track objects for rehabilitees with arm and wrist injuries (Peer et al., 2013) and upper extremity therapy in the home environment (Chen et al., 2018). Furthermore, Salisbury et al. (2018) presented a CV-based smartphone application to analyze vestibular rehabilitation in real time, and Khan et al. (2018) used CV-based experimental methods to analyze the body movements of rehabilitees in real time. Rammer et al. (2018) proposed a system for conducting CV-based markerless HPE motion analysis of manual wheelchair maneuvering. However, their system utilized at least two MicrosoftKinect sensors (hardware devices with cameras and microphones) to capture motion data. Mehrizi et al. (2018) developed and validated CV-based markerless HPE designed to evaluate 3D joint kinematics during symmetrical lifting tasks with two optical cameras from two distinct angles.

5.4 Study IV

A total of 30 participants (10 females and 20 males) were involved in Study IV. The study participants were young, healthy adults aged between 20 and 43 years (mean 22.9 years). For more detailed information, see Table 8.

Table 8 Characteristics of the study participants.

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Participants (n)	Age, years; mean (SD)	Length; (cm)[a]; mean (SD)	Weight (kg)[b]; mean (SD)	BMI[c]; mean (SD)
Total (30)	22.9 (2.8)	177.5 (10.6)	77.3 (14.1)	24.4 (2.9)
Female (10)	22.9 (3.8)	165.8 (3.7)	66.2 (9.2)	24.1 (4.0)
Male (20)	22.9 (2.2)	183.3 (7.6)	82.9 (12.8)	25.6 (2.7)

[a] cm: Centimeter

[b] kg: Kilogram

[c] BMI: Body mass index (kg/m2)

The results demonstrated nearly perfect intrarater repeatability for the CV-based markerless HPE application when all movement directions of the hip joint were assessed, including active flexion, active extension, active inner rotation, and active outer rotation. The ICC values for these measurements were consistently high in the hip joint, ranging from 0.93 to 0.82. The highest ICC values (0.93) were observed in active hip inner rotation, while the lowest ICC values (0.74) were found in active knee flexion. SEM values were slightly low, ranging from 0.6 for active hip inner rotation to 1.0 for active knee flexion. The MDC score was the lowest for active hip inner rotation (1.6), and the highest for active hip outer rotation (3.2). More detailed results can be seen in Table 9.

Table 9 The intrarater repeatability of a CV-based markerless HPE application in hip and knee joints.

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Movement direction	ICC[a] (95%CI[b])	SEM[c]	MDC[d]
Hip			
Active flexion	0.82 (0.63–0.92)	0.8	2.1
Active extension	0.82 (0.62–0.91)	0.8	2.1
Active inner rotation	0.93 (0.86–0.97)	0.6	1.6
Active outer rotation	0.83 (0.61–0.92)	0.8	3.2
Knee			
Active flexion	0.74 (0.45–0.87)	1.0	2.7

[a] ICC: Intraclass correlation coefficient

[b] CI: Confidence interval

[c] SEM: Standard error of measurement

[d] MDC: Minimal detectable change

The correlation between the CV-based markerless HPE application and the reference pictures, indicated by Pearson's *r* value, ranged from 0.99 to 0.85 and was very strong in three of the five movement directions measured. The strongest correlation was found in active hip inner rotation, while the weakest correlation was found in active hip extension. The mean difference in degrees between the two methods was smallest for active hip internal rotation, −0.9°, with one outlier beyond the limits of agreement. The highest mean difference, −2.1°, occurred in active knee flexion, which also had one outlier beyond the limits of agreement. Detailed results are provided in Figures 19 and 20.

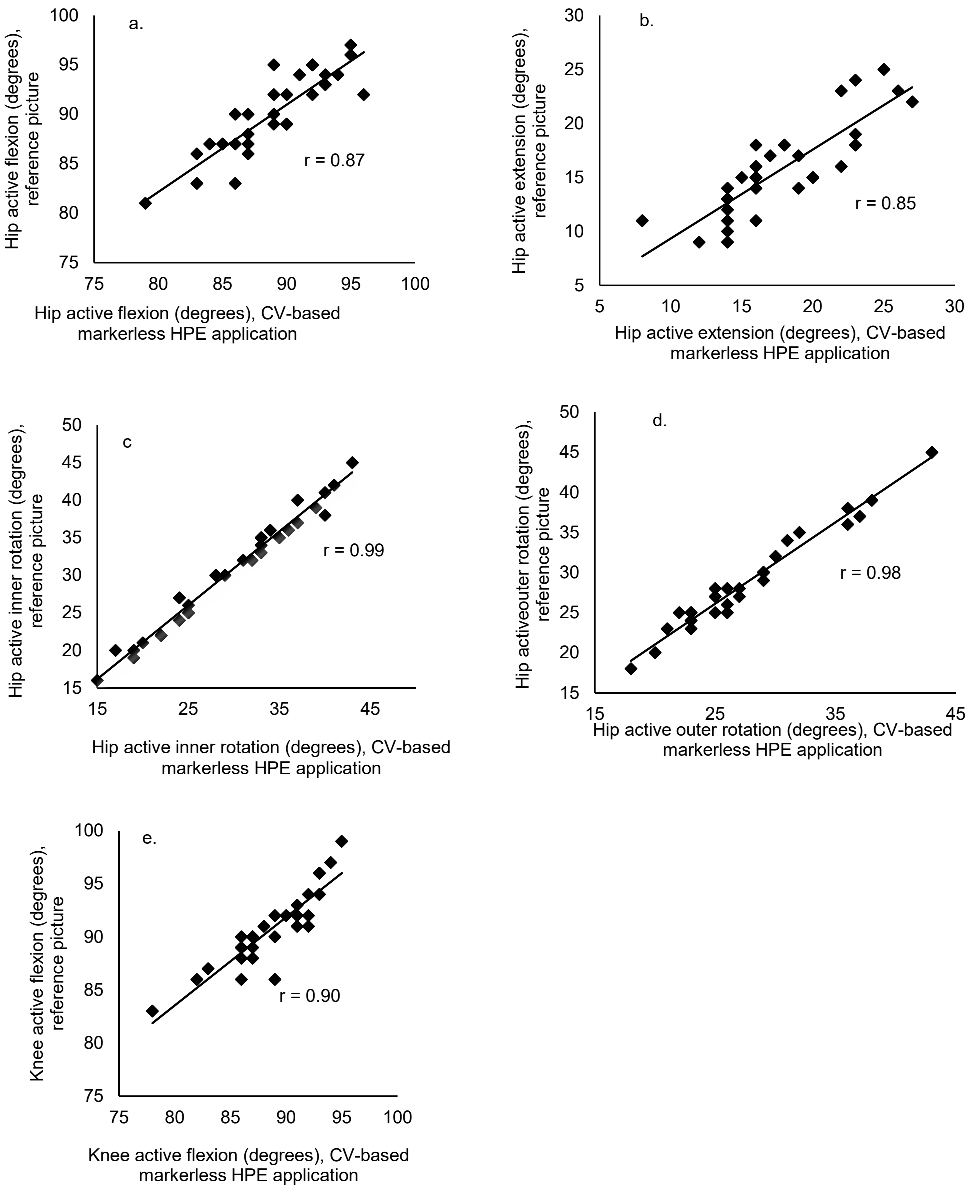

Figure 19 Correlation between our CV-based markerless HPE application and the reference picture for A) hip active flexion, B) hip active extension, C) hip active inner rotation, D) hip active outer rotation, and E) knee active flexion; r = Pearson's correlation coefficient. The figure is modified and reproduced from Hellstén et al. (2025) from *Healthcare Technology Letters* under the Creative Commons Attribution 4.0 International license (Study IV).

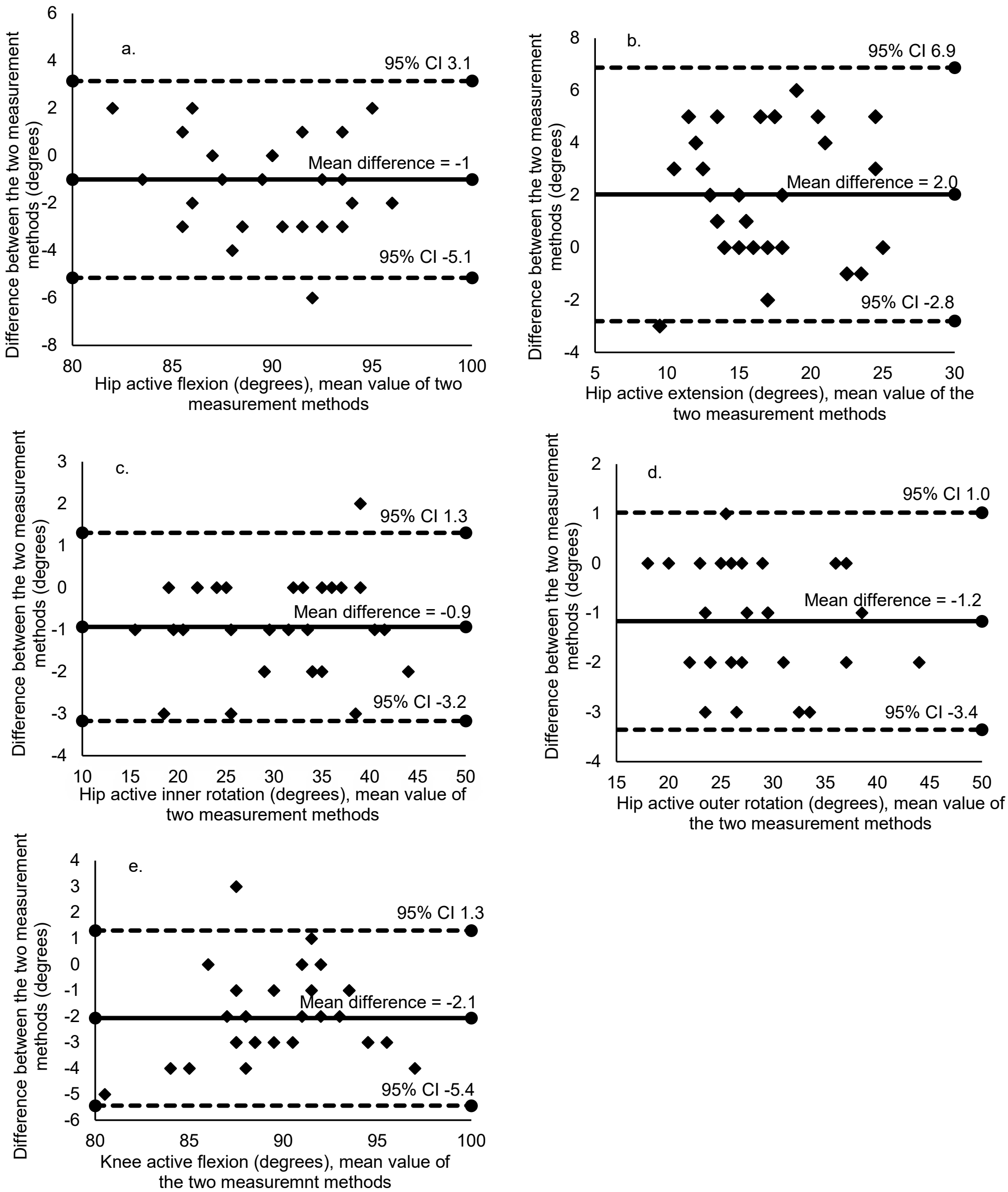

Figure 20 Bland–Altman plots for A) hip active flexion, B) hip active extension, C) hip active inner rotation, D) hip active outer rotation, and E) knee active flexion. The outer lines represent 95% limits of agreement. The middle line represents the mean of the differences between the two measurement methods. The figure is modified and reproduced from Hellstén et al. (2025) from *Healthcare Technology Letters* under the Creative Commons Attribution 4.0 International license (Study IV).

6 Discussion

6.1 RP in clinical practice in Finland (Study I)

Based on PTs opinions in Finland, RP is more suitable for rehabilitees with lung, heart, or musculoskeletal disorders than for those with neurological disorders, memory disorders, or spinal cord injuries, where verbal communication, as guidance and advice, plays an important role in physiotherapy. Research has shown that RP is comparable to conventional physiotherapy for rehabilitees, among others, with stroke (Rintala et al., 2019), cardiac diseases (Laustsen et al., 2020), chronic respiratory diseases (Cox et al., 2021), chronic obstructive pulmonary disease (Cerdán-de-Las-Heras et al., 2021), multiple sclerosis (Rintala et al., 2018), hip and knee arthritis (Kloek et al., 2018), total knee and hip replacement (Bettger et al., 2020; Hoogland et al., 2019), anterior cruciate ligament reconstruction (Levinger et al., 2017), and chronic shoulder pain (Pak et al., 2023). Hawley-Hague et al. (2023a) studied the use of RP in different clinical areas in the United Kingdom. In their study, RP was most frequently used in musculoskeletal diseases (58.3%), trauma and orthopedics (16%), and neurology (15.4%). According to Hawley-Hague et al. (2023a) and Rausch et al. (2021), RP is primarily used for providing guidance and advice for rehabilitees; other PTs in Norway (Martinsen et al., 2024) rated the suitability of RP as a "score" of 6 (SD 2.1) on an 11-point numeric rating scale (0 = very unsuitable or strongly disagree, 10 = very suitable or strongly agree). Overall, PTs generally feel that RP is especially suitable for the rehabilitation of diseases for which RP has been found to be an evidence-based alternative to conventional physiotherapy. However, when planning physiotherapy, it is important to take the current state of the disease into account. For instance, RP may be appropriate in the early stages of neurological conditions, when hands-on therapy is not yet critical, or at a later stage for rehabilitees with lung disorders, when aerobic exercise therapy is essential and can be delivered remotely. In general, the understanding of RP as either an alternative or a complement to conventional physiotherapy for various health conditions remains limited.

A rapid implementation of RP was observed in Finland during the COVID-19 pandemic in hospitals and clinics. Before the COVID-19 pandemic, 4 out of 5 PTs in the private sector did not use RP, compared to 2 out of 3 in the public sector. While the use of RP remains relatively low, there was an increase in the number of PTs who reported incorporating RP into their daily practice between early 2020 and spring 2021. The percentage of PTs who reported not using RP dropped to just over 20% in both the private and public sectors in Finland. The rise in RP usage observed in our study aligns with the findings of Rausch et al. (2021) in Switzerland, who reported an increase from 4.9% before the COVID-19 pandemic to 44.6% during the pandemic. In the UK, the proportion of PTs delivering RP during the COVID-19 pandemic was reported to be approximately 30%–50%, varying based on the clinical area, type of physiotherapy, purpose of the consultation, and the rehabilitee groups (Hawley-Hague et al., 2023a). In Norway, almost half (46.2%) of PTs offered RP in their daily practice in early 2023 for rehabilitees with musculoskeletal disorders; however, only 10.2% used RP daily (Martinsen et al., 2024). Furthermore, in Kuwait, half of the studied PTs reported they never used RP in daily practice during the COVID-19 pandemic (Albahrouh & Buabbas, 2021), and in the US, more than 9 out of 10 pediatric PTs reported they had never provided RP before the COVID-19 pandemic. However, in the middle of 2020, almost 1 out of 2 PT reported using RP (Hall et al., 2021). In contrast, in Jonsdottir et al. (2023), a multinational study (nine countries) among rehabilitees with multiple sclerosis, the use of RP did not increase during the COVID-19 pandemic.

In Finland, one possible reason for the rapid adoption of RP at the onset of the COVID-19 pandemic could be that the Social Insurance Institution of Finland temporarily restricted conventional physiotherapy, forcing clinics and hospitals to shift to RP. Before the pandemic, RP was more commonly used in the public sector than in the private sector, likely due to strategic decisions made by public organizations. However, companies in the private sector, being generally smaller and more agile, may have been able to implement RP more quickly. In addition, more complex data security and protection systems in the public sector might have slowed the adoption of RP in these settings. In Norway, PTs in the private sector offer RP more often than in the public sector (Martinsen et al., 2024). This difference was not seen in our study in 2021. Swiss PTs under the age of 45 were found to use RP more frequently than their older counterparts (Rausch et al., 2021), as willingness to use RP was highest among PTs aged 35–50 (Albahrouh & Buabbas, 2021). However, in our study, no similar correlation between age and RP usage was observed.

In our study, most PTs used real-time methods, some used methods not dependent on real-time interaction and some used both. Physiotherapy has traditionally been a hands-on profession, making it potentially difficult for PTs to achieve the same standards with RP as they would with conventional physiotherapy. In some countries, insurance companies may be unwilling to cover RP services; however, this is not a concern in Finland, where PTs have the autonomy to choose between conventional physiotherapy and RP. It is important to note that real-time methods, which are the most commonly used form of RP, still provide direct interaction between the rehabilitee and the PT using a digital platform. While RP offers the potential to enhance effectiveness with methods not dependent on real-time interaction, its use remains infrequent. However, the benefits and drawbacks of these methods need to be evaluated through high-quality interventional studies. Applying RP may require modifications in work routines, as in the opinion of PTs, insufficient working hours to implement RP, and inadequate training in RP act as barriers toward RP; however, RP contributes to flexibility in the delivery of physiotherapy (Martinsen et al., 2024). RP should not be seen as a replacement for the necessary in-person contact between the PT and the rehabilitee (Spindler et al., 2019), nor should it completely replace conventional physiotherapy (Damhus et al., 2018; Rausch et al., 2021).

A computer or tablet emerged as the most frequently selected medium for communication. This aligns with previous research indicating that PTs favor real-time communication methods using video technologies over other platforms (Hawley-Hague et al., 2023a; Martinsen et al., 2024; Rausch et al., 2021; Reynolds et al., 2021; Werneke et al., 2021). Furthermore, the emphasis lies not on the method or technology itself but on the opportunities the method offers within the physiotherapy process. Rehabilitees who are either uninterested in or unfamiliar with technology tend to prefer more traditional physiotherapy approaches compared to those who are enthusiastic and recognize the benefits of technology, believing that RP could provide adequate support (Anttila et al., 2019). Furthermore, PTs who had already provided RP rated the suitability of all technologies significantly higher compared to those PTs who did not offer RP (Martinsen et al., 2024).

In our study, nearly 75% of the PTs either had no experience or had less than one year of experience with RP, which can influence its use. Previous studies have shown that work experience is linked to how convenient PTs perceive RP to be in clinical practice (Lawford et al., 2018) as per experience in RP (Martinsen et al., 2024). Although RP use remains infrequent, PTs have expressed a high level of willingness to adopt RP (Bezuidenhout et al., 2022; Martinsen et al., 2024). To facilitate the integration of RP into everyday practice, it is important to focus not only on professional training and skill development (Damhus et al., 2018; Rausch et al., 2021) but also on addressing common technical issues (Martinsen et al., 2024). In contrast, declining hardware and software costs, increasing ICT speeds, and ongoing technological advancements all contribute positively to the adoption of RP (Levy et al., 2015).

6.2 PTs perspectives and experience on RP in Finland (Study II)

Our findings indicated that RP is primarily used for consultations, guidance, counseling, and exercise therapy purposes; this is consistent with the studies by Martinsen et al. (2024), Hawley-Hague et al. (2023a), Malliaras et al. (2021) and Rausch et al. (2021). An interesting observation is that compared to those with less experience, PTs with greater experience in RP consider it more suitable for various physiotherapy tasks. Although there were no statistically significant differences across the various physiotherapy tasks, the suitability scores were consistently higher among more experienced RP users compared to those with less experience. This is in line with the study by Martinsen et al. (2024), who found that experience with RP is linked to suitability for using different digital technologies. This suggests that PTs gain expertise through hands-on experience, which influences their approaches to using RP. This response is understandable given the rapid implementation of RP during the COVID-19 pandemic, in which PTs may have faced challenges in meeting the standards of conventional physiotherapy through RP.

Achieving optimal results in physiotherapy involves an evidence-based approach that integrates the best available research, PTs clinical expertise, and rehabilitees' perceptions. Verbal communication for guidance and counseling is an essential component of the physiotherapy process (World Physiotherapy, 2023); in addition, our study suggests that RP is currently most effective for these types of tasks, and should be part of the physiotherapy process. PTs have expressed high confidence in treating rehabilitees with RP methods (Martinsen et al., 2024). However, research has also shown that RP can be used for assessment, including observing balance, gait, joints' ROM (Cottrell & Russell, 2020; Malliaras et al., 2021), self-reported palpation, performance on specialized tests (Malliaras et al., 2021), and questionnaires (Truter et al., 2014).

In the opinion of the PTs in our study, the main reason for implementing RP was the rehabilitees' wish to use it as one alternative physiotherapy method among many; they also stated RP improves accessibility. PTs did not, however, mention cost savings, promoting equality, or enhancing therapy relationships as the main reasons. Although earlier studies have highlighted RP's benefits, such as improved access to therapy for rural rehabilitees and reduced travel and waiting times (Damhus et al., 2018; Odole et al., 2020; Turolla et al., 2020), and cost-effectiveness (Cottrell et al., 2018), as well as deepening therapist-patient relationships (Pastora-Bernal et al., 2017), our findings did not note these aspects. Studies have shown that few PTs had service specifications or standard operating procedures for delivering RP, and even fewer had established rehabilitee criteria for RP Hawley-Hague et al., 2023a). This may be due to the rapid implementation of RP during the COVID-19 pandemic, in which PTs focused on practical solutions to continue providing physiotherapy. However, it is essential for PTs to recognize that patients unfamiliar with or uninterested in RP might still require conventional physiotherapy (Anttila et al., 2019).

Physiotherapy has traditionally been characterized by hands-on methods and close, in-person interactions between the rehabilitee and the PT. Current knowledge regarding the suitability of RP across the different stages of physiotherapy remains limited. In our research, conventional physiotherapy was predominantly applied throughout all stages, with particular emphasis on the initial and final assessment of rehabilitees. RP tends to be employed mainly during follow-up, while its use in other stages of the physiotherapy process is infrequent. This suggests that PTs often prefer to see rehabilitees individually, either in clinics or hospitals, during some phase of the physiotherapy process. However, RP is increasingly regarded as an essential factor in a PTs professional role, though its integration into practice often depends on the PTs willingness (Hynynen et al., 2016) and confidence in utilizing RP within the physiotherapy process (Damhus et al., 2018; Malliaras et al., 2021). However, most PTs believe that RP cannot fully replace direct, in-person interactions between the rehabilitee and the PT (Rausch et al., 2021; Spindler et al., 2019). RP is primarily employed in physiotherapy for activities such as guiding rehabilitees through exercise therapy (Damhus et al., 2018) and during follow-up (Polastri et al., 2022), findings that have also been observed in our study.

In our study, technology-related factors were identified as the most effective in promoting the use of RP, followed by factors related to PTs and management. For RP to be successful, both PTs and rehabilitees require learning new skills and adopting a new mindset. Additionally, RP requires functional, user-friendly technological tools. Although younger people tended to be more familiar with using technology, we found that younger PTs with less experience were generally less positive about adopting RP compared to their older counterparts. Interestingly, prior experience with RP did not emerge as a key factor in encouraging its use. Previous studies have identified several factors that encourage the use of RP, including the growing flexibility of physiotherapy in daily practice (Turolla et al., 2020), flexibility in how physiotherapy is offered (Martinsen et al., 2024), and the development of new professional skills (Damhus et al., 2018). In addition, benefits such as the ability to follow up on rehabilitees' progress (Galea, 2019; Rintala et al., 2022), provide individualized feedback (Lahtio et al., 2022), integrate guidance, counseling, and exercise therapy into daily life, and offer flexible exercise therapy hours for rehabilitees (Cranen et al., 2017) have been discussed. While previous research has mostly explored promoting and inhibiting factors through qualitative approaches, we employed a quantitative, cross-sectional, web-based questionnaire to study these factors. As a result, our study provides valuable new insights into the use of RP in Finland, which, with some caution, may be generalized.

Several obstacles inhibit the widespread use of RP. Our study found that technology-related factors strongly inhibited the use of RP, particularly among PTs with less experience in this area. Similarly, Damhus et al. (2018) noted that a lack of technical support and concerns among PTs about resolving technical problems were barriers to the use of RP. Since technical issues frequently arise when using digital tools, these barriers need to be addressed before RP can be widely implemented. Other obstacles include PTs competence with technology, resistance to RP adoption, the financial cost of acquiring RP equipment (Scott Kruse et al., 2018), limitations in physical space for RP, and infrastructure issues, such as insufficient bandwidth capacity (Hale-Gallardo et al., 2020). An interesting finding in our study was that the same factors both promoted and inhibited the use of RP. This suggests that technology-related, PT-related, and management-related factors are all crucial for the successful implementation of RP. However, the overall understanding of these promotional and inhibitory factors remains limited, highlighting the need for higher quality research to explore these aspects further.

Our study also revealed a notable gap in education related to RP, a finding consistent with Jonas et al. (2019) and Martinsen et al. (2024), despite the introduction of RP as early as the late 1990s (Burns et al., 1998). The results indicate that in Finland, the use of RP is mostly learned through practice rather than education in the field. However, RP should follow an evidence-based approach, integrating the best available research, clinical expertise of PTs, and an understanding of rehabilitees' rehabilitation needs. It is central for PTs to recognize both their competencies and limitations when aiming to implement RP effectively in daily practice. Additionally, our study highlights the lack of a clear, evidence-based reason for using RP. For instance, only two out of ten PTs reported that their workplaces had established predefined criteria for using RP. A similar tendency was seen in the study by Hawley-Hague et al., 2023a.

6.3 Use of CV-based markerless HPE in rehabilitation (Study III)

Our findings in the narrative review indicate that CV-based markerless HPE systems can be used with standard cameras integrated into computer or mobile devices (Colyer et al., 2018) and categorized into 2D and 3D approaches (Bengio et al., 2013). In 2D pose estimation, the system identifies the position of each joint using two-dimensional coordinates (x, y), whereas 3D pose estimation extends this by incorporating depth information to compute three-dimensional coordinates (x, y, z) for each joint (Bengio et al., 2013). A major limitation of CV-based markerless HPE methods is their accuracy, which remains a hinder to their widespread integration and adoption within the field of biomechanics (Colyer et al., 2018; Pavlakos et al., 2018). Performance and accuracy of CV-based markerless HPE has been evaluated among others in walking (Gu et al., 2018, Nakano et al., 2020), pose of multiple individuals (Slembrouck et al., 2020), jumping, ball throwing (Nakano et al., 2020) and in simulation of human leg abduction and adduction (Schmitz et al., 2014). Furthermore, some CV-based markerless HPE systems for real-time monitoring in rehabilitation settings have been proposed in the literature as supervision for rehabilitees with rheumatoid arthritis (Dorado et al., 2019), home-based training system meant for stroke patients (Baptista et al., 2019), balance on one leg (Nalci et al., 2015), track objects for rehabilitees with arm and wrist injuries (Peer et al., 2013) and therapy for upper extremity (Chen et al., 2018). Lastly, manual wheelchair maneuvering (Rammer et al., 2018) and lifting task has been proposed (Mehrizi et al.,2018).

The proposed systems in the narrative review demonstrate potential use of CV-based markerless HPE in rehabilitation, as they require only a computing device in combination with one or more cameras. However, thorough testing in different rehabilitee groups and diverse settings is essential before it can be integrated into daily practice.

6.4 Measurement accuracy of CV-based markerless HPE for measuring hip and knee ROM (Study IV)

The results showed almost perfect intrarater repeatability in active hip flexion, active hip extension, and active hip inner and outer rotation, and substantial intrarater repeatability in active knee flexion. In our study, the ICC values were high in active hip flexion, extension, and inner and outer rotation, and slightly lower in knee flexion. MDC values were relatively high (>2°) in four out of five directions; however, it can be stated this is acceptable in clinical settings when compared to a universal goniometer (Boone et al., 1978). Despite the test-retest measurement difference more than 6 degrees among healthy subjects were rare, it highlights the need to conduct the measurements carefully.

The correlations between the CV-based markerless HPE application and the reference picture joint angles were very strong in over half of the joint angles and strong in two out of five. In knee flexion, the CV-based markerless HPE application values tended to be more minor than in the reference picture. This finding should be studied in detail. Studies have shown that PTs have greater confidence in using RP to treat rehabilitees compared to their confidence in evaluating and diagnosing rehabilitees, both in acute conditions and chronic conditions requiring musculoskeletal care (Martinsen et al., 2024). It has been found that RP can be challenging for healthcare professionals, such as PTs, when hands-on methods are required (Rausch et al., 2021), for example, during the evaluation of joints' ROM.

The key challenge, however, is ensuring that the professionals and the technology can accurately and reliably measure and analyze rehabilitees' movements.

Further, the results of our study indicate very strong (1.00-0.90) correlation, between the CV-based markerless HPE application and the reference picture among healthy participants in hip active inner and outer rotation, and in knee active flexion, in active hip flexion and extension, the correlations were strong (0.89-0.70). Clinicians, such as PTs and physicians, measure regular rehabilitees' ROM to follow up on the treatment process, for example, after a knee arthroplasty (Calatayud et al., 2017). To obtain an exact joint angle, a radiograph image needs to be taken, which has been found to be the gold standard when measuring knee joint angle (Brosseau et al., 1997; Gogia et al., 1987). However, the radiograph measure is not always acceptable because exposure to radiation (Frane et al., 2020). Further, joint angles with radiograph can be measured with different medium as analog films as from diverse digital screens (Lohman et al., 2011). The CV-based markerless HPE application algorithm may have difficulty localizing the joints (key points) to estimate accurate angles in hip flexion and extension; this explains its inferior accuracy in active hip flexion and extension, as Wang et al. (2023) also discussed.

Various methods and tools are used to measure hip or knee joint ROM, with universal goniometry being the most commonly employed method by healthcare professionals in daily practice (Cibere et al., 2008). However, this method is less precise than radiographic measurements (Boone et al., 1978; Brosseau et al., 1997); therefore, it was not selected as a reference for CV-based markerless HPE application in our study. Moreover, marker-based CV systems, which require one or more cameras, were not used in our study due to the significant financial costs and impracticality of daily use in healthcare settings.

As a reference for the CV-based markerless HPE application's measured angles, a simple and reliable method—photographic measurement (Kouyoumdjian et al., 2012) was used. The reference picture was exact the same picture frame from which the CV-based markerless HPE application analyzed the joint angle. Although it was not possible to palpate bony landmarks for markers in the reference picture, they were visually estimated by an experienced PT. Moreover, the study did not measure knee extension restrictions, as the participants were healthy, young, and free of acute lower limb injuries. However, reduced knee extension can weaken quadriceps contraction (Hancock et al., 2018) and normal knee function, which is typical in conditions such as knee osteoarthritis (Liikavainio et al., 2008). Therefore, the ability of the CV-based markerless HPE application to measure joint ROM among rehabilitees should be studied in the future.

Evaluating and documenting conditions such as hip or knee joint stiffness after an injury using RP methods can be challenging. Correct documentation is essential (e.g., joint angles), as it directly impacts rehabilitees' care (Adane et al., 2019) and is also used to assess healthcare costs and gather statistics (Lorkowski et al., 2021). In this context, CV-based markerless HPE technology can have potential for future use in RP, analyzing joint ROM, as it only requires a device with a camera, nor expertise of healthcare professionals. Furthermore, CV-based markerless HPE offers the possibility of more frequent measurements, which can enhance rehabilitee motivation and add to the treatment process (Hynynen et al., 2016). To encourage the widespread adoption of CV-based markerless HPE applications, efforts should focus on developing intuitive software interfaces, ensuring seamless integration with existing clinical workflows, and conducting thorough validation in diverse settings. Furthermore, providing robust training resources for healthcare professionals and delivering effective rehabilitee education will be essential to support their incorporation into routine care prior to daily practice implementation.

6.5 Strengths and limitations

Each study included in this dissertation has unique strengths. In Studies I and II, it is the substantial number of PTs (662) who participated in the survey, despite the response rate of 9.9%. The participants were recruited from all municipalities across Finland and included PTs with varying levels of work experience, both short and long, in physiotherapy. Our sample is somewhat representative of the broader Finnish physiotherapy workforce, where 82% of employed PTs are female, with an average age of 44.8 years, and generally have long clinical experience.

Studies III and IV are a result of a multidisciplinary collaboration between healthcare professionals (physicians and PTs) and engineering experts, which has been discussed as central to the development processes of health technologies (Wang et al., 2023). In Study III, the primary strength of the narrative review lies in its focus on studies targeted at CV-based markerless HPE in rehabilitation being closely matched as a starting point for our development of the CV-based markerless HPE application. An extensive and thorough search strategy was formulated in several meetings with the research group. The strength of Study IV is the number of participants (n=30) involved in the study. Efforts were made to minimize errors by conducting the measurements in an optimal, controlled environment at a clinic. Furthermore, a bright room with an ideal lighting setup, as well as precisely positioned computers, web cameras, and participant test positions, helped ensure accuracy and consistency in the measurements.

The studies presented in this dissertation also have certain limitations. First, the survey data (Studies I and II) were collected in Finland, which may limit the generalizability of our findings to other countries where PTs may have more experience with RP or may work in different healthcare systems. The proportion of respondents from the private sector was higher than that of the overall private sector physiotherapy workforce in Finland. Some PTs in the private sector also belong to the Finnish Association of Physiotherapists, which could have allowed them to respond to the questionnaire twice. To avoid this overlap, we included a recommendation in the information letter asking participants not to submit responses more than once. Furthermore, while we do not know the reasons for the overrepresentation of private sector PTs, we conducted separate analyses of data from the private and public sectors. The PTs who completed the entire questionnaire, including the section on experience with RP, were, on average, slightly younger than those who only responded to the first three question groups (background, suitability of RP, and education in RP). This observation aligns with the findings of Rausch et al. (2021), but it may limit the generalizability of the results. Another limitation may be the potential for nonparticipation bias. We recruited PTs from both the Finnish Association of Physiotherapists and a private physiotherapy organization, but since the data were collected anonymously, we were unable to analyze whether there were significant differences between responders and no responders, or how these differences might have affected the results. A further limitation may be the use of a questionnaire that has not been scientifically validated. We did not use a specific theoretical model when designing the questionnaire, and we relied on a web-based format, which often resulted in a low response rate (Eysenbach, 2004). However, the questionnaire covered key areas from the Non-Adoption, Abandonment, Scale-up, Spread, Sustainability (NASSS) framework (Greenhalgh et al., 2017). The questionnaire was developed through consensus within a broad expert group based on key literature in the field, and underwent pilot testing.

In Study III, the data were both clinically and technically heterogeneous. Clinical heterogeneity was observed between participants (e.g., health status), the diversity of the technologies used, and the outcomes measured. The primary limitation of this narrative review was that we did not evaluate the quality of the included studies, which could have been low, and affected the results.

In Study IV, joint angles were measured using the same test order throughout, which might have influenced the results. Although varying the test order could have reduced this limitation, it was not done for practical reasons. Another limitation of this study was that the participants were all healthy, young, and within the normal body mass index. Lighting conditions were found to significantly affect the CV-based markerless HPE application's ability to detect and accurately localize body key points (markers) to calculate joint ROM. Furthermore, the joint angles were measured while the participants were in a standing position due to the lack of training data in the DensePose-COCO dataset for individuals in other positions. In the future, such technical challenges should be addressed before CV-based markerless HPE can be widely integrated into daily practice in the healthcare sector. Finally, a limitation of this study was the lack of radiographic imaging, which is regarded as the gold standard for measuring ROM. However, ethical concerns related to radiation exposure and resource limitations prevent its use. Future research could explore noninvasive imaging alternatives, such as ultrasound or advanced magnetic resonance imaging techniques, to enhance the validation of CV-based markerless HPE applications.

6.6 Implications for future directions

Because the COVID-19 pandemic led to the rapid adoption of RP (Study I), future studies should analyze whether RP adoption was a momentary occurrence. Greater focus should be placed on increasing the use of evidence-based RP practices within clinical settings. RP is mostly practiced through a "learning by doing" approach, and professional education in this field is at a low level (Study II). RP should be guided by an evidence-based framework to enhance its effectiveness and reliability. Generally, information on RP as an alternative or as part of conventional physiotherapy for diverse diseases is still incomplete. RP can be used in daily practice with various methods (i.e., the real-time method, method not tied to time, or a combination of these two methods); however, in the future, the benefits and limitations of these methods should be evaluated through high-quality interventional studies.

A key priority for future research is the rigorous testing of some of the most promising CV-based markerless HPE algorithms within physiotherapy applications. Initial testing could focus on 2D applications and then progress to more advanced 3D movement analyses. In addition, future research should aim to develop machine learning-based calibration methods suitable for CV-based markerless HPE, specifically for physiotherapy purposes. Although CV-based markerless HPE holds the potential for analyzing joint ROM in the hip and knee joint (Study IV), thorough testing is essential before it can be integrated into daily practice. Lastly, most CV-based markerless HPE training data analyze individuals in an upright (standing) position; however, this kind of technical challenge should be considered before CV-based markerless HPE can be implemented in healthcare.

7 Conclusion

As shown by Study I, according to Finnish physiotherapists, RP is better suited for clients with lung, heart, or musculoskeletal diseases than for clients with neurological diseases. Although the use of RP by PTs increased during the COVID-19 pandemic, it remains relatively uncommon in daily practice. PTs primarily use computers, tablets, or smartphones and use real-time methods for RP, while other technological tools and methods are less frequently used.

Study II demonstrated that RP differs in physiotherapy tasks. According to the PTs in our study, RP is most suitable for communication, such as consultation, guidance, and counseling. While conventional physiotherapy is most commonly used at all stages of the physiotherapy process, RP is primarily applied during follow-up, with limited use in other stages of the physiotherapy process. The main factors promoting the use of RP are technology-related factors, followed by those related to PTs themselves in the PTs daily practice. However, education in the field of RP remains limited (in 2021), and PTs have reported the infrequent use of established criteria for the implementation of RP in daily practice.

In Study III, we presented some approaches for the use of 2D and 3D CV-based markerless HPE in rehabilitation. The study results suggest that some recent CV-based markerless HPE systems have already achieved adequate accuracy in detecting and localizing key points for the purpose of joint angle estimation. However, in our knee joint angle simulation, the margin of error of ± 5° in the knee joint angle tolerates a 2.5 cm margin of error at key points, with a knee angle of 45°.

In Study IV, our CV-based markerless HPE application demonstrated highly repeatable results in active hip joint movements, including flexion, extension, internal rotation, and external rotation. MDC values were relatively high across all directions; nonetheless, they were acceptable for healthcare professionals when assessing joint ROM (hip and knee) in daily practice. Lastly, the results of our study indicate that our CV-based markerless HPE application is a valid method to measure active hip and knee ROM among healthy participants.

The findings in this dissertation highlight the evolving contribution of RP, and may help PT and organizations in planning, developing, and integrating these methods into daily practice.

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Appendices

Appendix 1. Etäfysioterapiakysely

Etäfysioterapialla tarkoitetaan tässä kyselytutkimuksessa fysioterapian järjestämistä etäteknologian (esim. puhelimen, älypuhelimen, tietokoneen, tablettitietokoneen, aktiivisuusmittarin, konenäön, tekoälyn, virtuaalitodellisuuden tai robotiikan) avulla niin, että fysioterapeutti on fyysisesti eri paikassa kuin kuntoutuja. Käsitteellä ”kuntoutuja” tarkoitetaan potilasta, asiakasta tai ryhmää.

Vaikka sinulla ei olisikaan kokemusta etäfysioterapiasta, toivomme, että vastaat ”Etäfysioterapian soveltuvuus” ja ”Etäfysioterapiaan liittyvä koulutus” osioiden kysymyksiin, jotka ovat tämän kyselyn alussa heti taustatietokysymysten jälkeen.

Vastausohjeita:
Vastaa kysymyksiin valitsemalla omaa tilannettasi tai mielipidettäsi parhaiten kuvaava vaihtoehto. Eräiden kysymysten kohdalla on erikseen täydentäviä vastaamisohjeita. Kyselyn lopussa on avoin kysymys, johon voit vastata omin sanoin.

Ajastasi ja yhteistyöstäsi kiittäen

Tutkimusryhmä

TÄSTÄ ALKAVAT VARSINAISET KYSYMYKSET

TAUSTATIEDOT

1. Syntymävuotesi.

Vuosi

2. Sukupuolesi.

Nainen
Mies
Muunsukupuolinen
En halua vastata

3. Valmistuin fysioterapeutiksi/lääkintävoimistelijaksi.

Mikäli olet päivittänyt lääkintävoimistelijatutkintosi ammattikorkeakoulututkinnoksi, niin merkitse alla olevaan kysymykseen valmistumisvuotesi ammattikorkeakoulusta.

Vuosi

4. Mikä on korkein suorittamasi tutkinto?

Valitse korkein tutkinto, jonka sinä olet suorittanut tutkintonimikkeestä välittämättä.
(Valitse vain yksi seuraavista.)

Opistoasteen tutkinto, (esim. lääkintävoimistelija/fysioterapeutti/ erikoislääkintävoimistelija)
Alempi ammattikorkeakoulututkinto, (esim. fysioterapeutti AMK)
Alempi yliopistotutkinto, (kandidaatin tutkinto)
Ylempi ammattikorkeakoulututkinto, (YAMK)
Ylempi yliopistotutkinto, (maisterin tutkinto)
Jatkotutkinto, lisensiaatti
Jatkotutkinto, tohtori
Jokin muu, mikä____________
En halua vastata

5. Oletko nykyään?

Kokopäivätyössä
Osa-aikatyössä (myös osa-aikaeläkeläiset)
Opiskelija
Eläkkeellä
Työtön tai lomautettu
Hoitamassa omaa kotitaloutta tai perheenjäseniä
Varusmies- tai siviilipalvelussa

Sairauslomalla
Äitiys-, isyys- tai vanhempainlomalla
Hoitovapaalla
Vuorotteluvapaalla
Muu, mikä
En halua vastata

6. Pääasiallinen työ.

Mikäli työskentelet useammassa kuin yhdessä organisaatiossa, valitse pääasiallinen työpaikkasi.

Valitse sopivin vaihtoehto
(Valitse vain yksi seuraavista)

Yliopistollinen keskussairaala
Muu keskussairaala kuin yliopistollinen keskussairaala
Terveyskeskus
Työterveyshuolto
Yksityinen lääkäriasema/yksityinen sairaala tai fysioterapiayritys
Kuntoutuslaitos
Yrittäjä
Koulutus- ja/tai tutkimusorganisaatio
Kolmas sektori
Muu mikä:
En halua vastata

7. Työpaikkasi maakunta.

Ahvenanmaa
Etelä-Karjala
Etelä-Pohjanmaa
Etelä-Savo
Kainuu
Kanta-Häme
Keski-Pohjanmaa
Keski-Suomi
Kymenlaakso
Lappi
Pirkanmaa
Pohjanmaa

Pohjois-Karjala
Pohjois-Pohjanmaa
Pohjois-Savo
Päijät-Häme
Satakunta
Uusimaa
Varsinais-Suomi
En halua vastata

8. Työtehtäväsi.

Mikäli työskentelet useammassa kuin yhdessä työtehtävässä, valitse pääasiallinen tehtäväsi.
Valitse sopiva vaihtoehto
(Valitse vain yksi seuraavista)

Fysioterapeutin tehtävä toisen palveluksessa
Itsenäinen ammatinharjoittaja (ei alaisia)
Esimies toisen palveluksessa
Yrittäjä (vähintään yksi alainen)
Tutkija
Lehtori/opettaja
Muu mikä:
En halua vastata

9. Työkokemus fysioterapeuttina.

Huomioi työkokemuksessasi myös mahdolliset työvuotesi lääkintävoimistelijan tehtävissä.
Valitse sopiva vaihtoehto
(Valitse vain yksi seuraavista)

Alle vuoden
Vuosi – alle 5 vuotta
5 vuotta – alle 10 vuotta
Vähintään 10 vuotta

10. Työkokemuksesi etäfysioterapiasta.

Ei ole kokemusta
Kokemusta on, mutta alle vuoden

1-2 vuotta
Yli 2 vuotta, mutta korkeintaan 4 vuotta
Yli 4 vuotta

Etäfysioterapian soveltuvuus

Tässä osiossa kysymme mielipiteitäsi etäfysioterapian käytöstä ja koulutuksesta. Vaikka sinulla ei ole kokemusta etäfysioterapiasta tällä hetkellä toivomme, että vastaat ”Etäfysioterapian soveltuvuus” sekä myös ”Etäfysioterapiaan liittyvä koulutus” osion kysymyksiin.

11. Arvioi asteikolla 0 – 10 seuraavien ryhmien osalta, kuinka hyvin mielestäsi fysioterapia soveltuu tai ei sovellu toteutettavaksi etäfysioterapiana.

(ei sovellu ollenkaan 0 ------------ soveltuu täysin 10)
Voit halutessasi siirtyä seuraavaan kysymykseen (12).

Ahdistuneisuushäiriö (esim. paniikkihäiriöt tai sosiaalisten tilanteiden pelko)
Aivoinfarkti (esim. aivoverenkiertohäiriö)
Aivovamma
Alaselkäkipu (esim. epäspesifisi selkävaiva tai iskiasoire)
Astma
Depressio
Keuhkoahtaumatauti
Kipupotilas
Käden ja kyynärvarren rasitussairaudet (esim. epikondyliitti tai rannekanavaoireyhtymä)
Mielenterveyden häiriöt
MS-tauti
Monisairas potilas
Niskakipu (esim. paikallinen niskakipu, säteilevä niskakipu tai retkahdusvamma)
Nivelreuma
Muistisairaus (esim. Alzheimerin tauti)
Olkapään jännevaiva (esim. kiertäjäkalvosimen jännevaiva)
Parkinsonin tauti
Polven tai lonkan nivelrikko
Selkäydinvamma
Sydänsairaus
Syöpäsairaus

12. Valitse seuraavista kolme keskeisintä tekijää, mitkä mielestäsi edistävät etäfysioterapian toteuttamista työpaikallasi. Mikäli tekijöitä on alle kolme, merkitse vain ne.

Vaikka työpaikallasi ei toteuteta etäfysioterapiaa vastaa kysymykseen arviosi perusteella.

Fysioterapeuttien myönteinen asenne etäfysioterapiaa kohtaan
Riittävä etäfysioterapiakoulutus
Fysioterapeutin riittävä etäfysioterapiaosaaminen
Fysioterapeutin etäfysioterapiakokemus
Kollegoiden tuki
Etäfysioterapiassa käytettävien laitteiden ja ohjelmistojen toimivuus
Toimiva internet-yhteys
Toimiva tekninen tuki
Toimivat fyysiset tilat
Riittävät työaikaresurssit etäfysioterapian toteuttamiseksi
Muu mikä

13. Valitse seuraavista kolme keskeisintä tekijää, mitkä mielestäsi vaikeuttavat etäfysioterapian toteuttamista työpaikallasi. Mikäli tekijöitä on alle kolme, merkitse vain ne.

Vaikka työpaikallasi ei toteuteta etäfysioterapiaa vastaa kysymykseen arviosi perusteella.

Fysioterapeuttien kielteinen asenne etäfysioterapiaa kohtaan
Riittämätön etäfysioterapiakoulutus
Fysioterapeutin heikko etäfysioterapiaosaaminen
Fysioterapeutilla ei ole kokemusta etäfysioterapiasta
Kollegoiden tuen puute
Etäfysioterapiassa käytettävien laitteiden ja ohjelmistojen toimimattomuus
Heikko internet-yhteys
Puutteelliset fyysiset tilat
Riittämätön tekninen tuki
Riittämättömät työaikaresurssit etäfysioterapian toteuttamiseksi
Muu mikä

Etäfysioterapiaan liittyvä koulutus

14. Olen osallistunut fysioterapeutin peruskoulutuksessa etäfysioterapiaa käsittelevään koulutukseen.

Olen
En ole

14.1 Jos vastasit ”olen” edelliseen kysymykseen, kuinka monta opintopistettä (1 op =27h) etäfysioterapiaan liittyvä koulutus oli yhteensä?

alle 0,5
0,5 – 1
Yli 1 – 2
Yli 2

15. Olen edellisen vuoden aikana osallistunut etäfysioterapian täydennyskoulutuksiin yhteensä.

En lainkaan
Alle 3h
3h - 6h
yli 6h - 2pv
yli 2pv - 5pv
yli 5pv

16. Olen suorittanut erikoistumiskoulutuksen etäfysioterapiasta (vähintään 30 op esimerkiksi Etäratkaisut kuntoutumisen tukena -erikoistumiskoulutus).

Olen
En ole

Mikäli vastasit kysymyksessä kymmenen, että sinulla ei ole kokemusta etäfysioterapiasta kyselysi tallentuu tämän kysymyksen jälkeen, kun painat seuraava painiketta. Mikäli sinulla on vähänkin kokemusta etäfysioterapiasta (esimerkiksi toteuttajana, tutkijana, suunnittelijana, tms.), niin ole hyvä ja jatka vastaamista.

Etäfysioterapian nykytila

Tässä osioissa kysytään etäfysioterapian nykytilasta työpaikallasi. Vaikka et tällä hetkellä tekisi fysioterapeutin kliinistä työtä, niin toivomme kuitenkin, että vastaat kysymyksiin. Tässä kyselymme loppuosiossa on 16 kysymystä.

17. Työpaikallani on yhteisesti sovittu, että panostamme etäfysioterapiaan.

[Pitää täysin paikkansa / Pitää osittain paikkansa / Ei pidä ollenkaan paikkansa / Ei koske minua, ei mielipidettä]

18. Työpaikallani etäfysioterapiassa käytettävät laitteet ja ohjelmistot toimivat hyvin kokonaisuutena.

[Täysin samaa mieltä/ Jokseenkin samaa mieltä/ Jokseenkin eri mieltä/ Täysin eri mieltä / Ei koske minua, ei mielipidettä]

Kuntoutettavien valinta

19. Työpaikallani on yhteisesti sovitut kriteerit, joilla kuntoutujat valitaan etäfysioterapiaan

[Kyllä/ Ei]

19.1 Mikäli vastasit "kyllä" edelliseen kysymykseen, mitä valintakriteereitä käytätte työpaikallasi valitessanne kuntoutujia etäfysioterapiaan? (Valitse korkeintaan viisi mielestäsi keskeisintä kriteeriä.)

Lääketieteellinen sairausdiagnoosi
Fyysinen toimintakyky (mm. liikkeiden hallinta ja näkö ja kuulo)
Psyykkinen toimintakyky (mm. kyky vastaanottaa ja käsitellä tietoa)
Sosiaalinen toimintakyky (mm. vuorovaikutus)
Kognitiivinen toimintakyky (mm. hahmottaminen ja muisti)
Potilasturvallisuus
Kieleen ja kielitaitoon liittyvät tekijät
Kulttuuriin liittyvät tekijät
Kuntoutujan esittämä toive
Kuntoutujan ikä / ikäluokka (lapset, nuoret, työikäiset, ikääntyneet)

Kuntoutujan vaikea tulla paikan päälle vastaanotolle
Fysioterapian tehostuminen lisäämällä kuntoutujien määrää työaikana
Fysioterapian/kuntoutuksen maksajatahon suositus
Jokin muu kriteeri, mikä:
Etäfysioterapian vaiheet

20. Mitkä seuraavista fysioterapiaprosessin vaiheista toteutat etäfysioterapiana ja kuinka hyvin se mielestäsi soveltuu etäfysioterapiana toteutettavaksi?

Vaikka et toteuta jotakin fysioterapiaprosessin vaihetta etäfysioterapiana, vastaa kuitenkin sen toteuttamisen soveltuvuudesta etäfysioterapiana. Voit halutessasi siirtyä seuraavaan kysymykseen (21).

Kyllä - Ei
(ei sovellu ollenkaan 0 ------------ soveltuu täysin 10)

Arvio toiminta- ja työkyvystä (arvio kuntoutujan fyysisten, psyykkisten ja sosiaalisten edellytysten toteutumisesta toiminta ja työkyvyn ylläpitämiseksi arkielämän asettamissa vaatimuksissa)
Arvio liikkumisesta (arvio kuntoutujan liikkumiseen, tuki- ja liikuntaelimistöön ja liikkeisiin liittyvistä toiminnoista ja rakenteista)
Arvio kivusta (arvio kuntoutujan kivun kokemuksesta toimintakykyyn ja elämänlaatuun vaikuttavana tekijänä sekä kipuaistimusten tunnistamisesta)
Terveyttä ja toimintakykyä edistävä ohjaus ja neuvonta (tuetaan kuntoutujaa suuntaamaan voimavarojaan terveytensä ja toimintakykynsä edistämiseen ja toimintarajoitteiden tunnistamiseen ja hallitsemiseen sekä itsenäiseen harjoitteluun)
Työkykyä edistävä ohjaus ja neuvonta (ylläpidetään ja edistetään kuntoutujan toimintakykyä työssä, työympäristössä ja työyhteisössä)
Toimintakyvyn harjoittaminen (terapeuttisen harjoittelun muoto, jossa käytetään aktiivisia ja toiminnallisia menetelmiä kuntoutujan toimintakyvyn harjoittamiseksi kotona)
Liikkumisen harjoittaminen (terapeuttisen harjoittelun muoto, jossa käytetään aktiivisia ja toiminnallisia menetelmiä kuntoutujan aistitoimintojen ja tahdonalaisiin liikkeisiin liittyvien toimintojen harjoittamiseksi)
Apuvälinetarpeen arviointi
Arvio elinympäristössä selviytymisestä (palvelu, joka sisältää kuntoutujan asuin- ja elinympäristön arvioinnin sekä mahdollisen kirjallisen suosituksen asuin- ja elinympäristössä tarvittavista muutostöistä)
Arvio työssä selviytymisestä

Korjaava toiminta työpaikalla (parannetaan työn ja työolosuhteiden terveellisyyttä ja turvallisuutta kuntoutujan työpaikalla)
Fysioterapeuttinen konsultointi (fysioterapeutin antama asiantuntija-apu kuntoutujan fysioterapiaan liittyvissä kysymyksissä)

Etäfysioterapian tilat ja välineet

21. Etäfysioterapiaa varten työpaikallani on tila, jossa ovat valmiina etäfysioterapian toteuttamiseksi tarvittavat tietotekniset välineet (esim. tietokone tai virtuaalilasit).

Kyllä on
Ei ole

22. Mitä seuraavista etäteknologisista välineistä ja sovelluksista käytät viikoittain etäfysioterapiassa? (Voit valita useamman vaihtoehdon.)

En tee tällä hetkellä fysioterapeutin kliinistä työtä
Puhelin
Älypuhelin
Tietokone ml. tablettitietokone
Televisiosovellutus (sovelluksen/ohjelman toiminta televisiossa)
Aktiivisuusmittari (esimerkiksi askel- ja kiihtyvyysmittari)
Konenäkö (esimerkiksi tietokone analysoi nivelten liikkeet)
Älyvaate (esimerkiksi lihasten sähköistä aktiivisuutta mittaavat vaatteet)
Virtuaalitodellisuus (VR, virtual reality) (virtuaalitodellisuus voi simuloida jotakin todellista ympäristöä tai se voi luoda täysin kuvitteellisen ympäristön. Esim. tietokoneen luoma kolmiulotteinen maailma, esimerkiksi virtuaalilasit)
Lisätty todellisuus (AR, augmented reality) (järjestelmä, jossa keinotekoista tietokoneella tuotettua tietoa, kuten kuvaa, ääntä, videota, tekstiä tai GPS-informaatiota, on lisätty näkymään todellisessa ympäristössä)
Pelillistetty fysioterapia (exergame, kuntopelit) (esimerkiksi pelikonsoli tai muu vastaava tekniikka/laitteisto ja niiden sovellukset)
Tekoäly (esimerkiksi ”oppivat” ohjelmat)
Robotiikka (esimerkiksi kävelyrobotti tai yläraajan toimintoja avustava robotti)
Muu, mikä?

Etäfysioterapian menetelmät ja käyttö

23. Käytätkö reaaliaikaisia menetelmiä ja / tai ajasta riippumattomia menetelmiä etäfysioterapiassa?

Reaaliaikainen menetelmä: Kuntoutujan ja fysioterapeutin reaaliaikainen yhteys toisiinsa etäteknologiaa hyödyntävien sovellusten avulla.
Ajasta riippumaton menetelmä: Kuntoutuja toteuttaa omatoimisesti etäteknologian avulla fysioterapiaintervention, joka on ajasta ja paikasta riippumatonta.

Yksilöfysioterapiassa; kyllä – ei - ei koske minua
Ryhmäfysioterapiassa; kyllä – ei - ei koske minua

Käytän reaaliaikaisia menetelmiä
Käytän ajasta riippumattomia menetelmiä

24. Kuinka paljon olet käyttänyt kyselyä edeltäneen kuukauden aikana työajastasi etäfysioterapiaan?

0%
1 - 20%
21 - 40 %
41 - 60 %
61 - 80 %
81 - 100 %
En tee tällä hetkellä fysioterapeutin kliinistä työtä

24.1 Kuinka paljon tästä etäfysioterapiaan käyttämästäsi työajasta on ryhmämuotoista etäfysioterapiaa?

0%
1 - 20%
21 - 40 %
41 - 60 %
61 - 80 %
81 - 100 %

25. Muistele työtäsi ennen Korona-aikaa (vuoden 2020 alun tammi-helmikuussa); kuinka paljon käytit työajastasi tuona aikana etäfysioterapiaan?

0%
1 - 20%
21 - 40 %
41 - 60 %
61 - 80 %
81 - 100 %
En tehnyt tuolloin fysioterapeutin kliinistä työtä

Etäfysioterapian toteutus

26. Miten toteutat ensisijaisesti seuraavat yksilöfysioterapian vaiheet?

Fysioterapian yhdistelmämallilla tarkoitetaan tässä etäteknologiaa hyödyntävän fysioterapian ja kasvokkain tapahtuvan fysioterapian yhdistelmää.

etäfysioterapiana / kasvokkain / fysioterapian yhdistelmämallilla / ei koske minua

Kuntoutujan alkututkimus
Fysioterapian käytännön toteutus
Fysioterapiajakson aikainen arviointi
Fysioterapiajakson loppututkimus
Fysioterapiajakson jälkeinen seuranta

27. Videoyhteyden välityksellä voin havainnoida kuntoutujan terapeuttista harjoittelua yhtä hyvin kuin kasvokkain tapahtuvassa fysioterapiassa.

[Täysin samaa mieltä/ Jokseenkin samaa mieltä/ Jokseenkin eri mieltä/ Täysin eri mieltä / Ei koske minua, ei mielipidettä]

28. Voin motivoida kuntoutujaa etäfysioterapiassa yhtä hyvin kuin kasvokkain tapahtuvassa fysioterapiassa.

[Täysin samaa mieltä/ Jokseenkin samaa mieltä/ Jokseenkin eri mieltä/ Täysin eri mieltä / Ei koske minua, ei mielipidettä]

29. Miten etäfysioterapia kirjataan potilastietojärjestelmään? (Voit valita useamman vaihtoehdon.)

Vapaamuotoisesti (fysioterapeutin vapaata tekstiä)
Rakenteisesti (kirjataan valtakunnallisesti yhtenäisten tietorakenteiden avulla käyttämällä koodistoja ja luokituksia)
Tietoa ei kirjata
Liitetiedostona (esimerkiksi videotallenne tai lomake)
Jokin muu tapa, mikä?
En osaa sanoa

30. Kun ajattelet tyypillistä työviikkoasi, kuinka usein sinulla tai kuntoutujalla on teknisiä ongelmia, jotka hankaloittavat etäfysioterapian toteuttamista?

Teknisellä ongelmalla tarkoitetaan tässä yhteydessä heikkoa kuva- tai ääniyhteyttä, internetyhteyden katkeamista, tietokoneen teknistä ongelmaa tai vastaavaa ongelmaa, joka hankaloittaa tai estää etäfysioterapian toteuttamisen.

Päivittäin
Muutamana päivänä viikossa, mutta ei päivittäin
Kerran viikossa
Muutaman kerran kuukaudessa tai harvemmin
Ei käytännössä koskaan
Ei koske minua

31. Miksi toteutat etäfysioterapiaa?

Valitse seuraavista kolme keskeisintä syytä toteuttaa etäfysioterapiaa. Mikäli sinulla on alle kolme syytä, merkitse vain ne.

En toteuta etäfysioterapiaa
Säästää fysioterapian yhteiskunnallisia kustannuksia
Lisää tasa-arvoa terveydenhuollossa
Parantaa fysioterapian saavutettavuutta
Syventää fysioterapeutin ja kuntoutujan välistä terapiasuhdetta (esim. tasavertaista kommunikointia, ohjausta ja keskustelua)
Etäfysioterapia kiinnostaa fysioterapian toteutusmuotona
Vähentää työni fyysistä kuormittavuutta
Vähentää työni henkistä kuormittavuutta

Kuntoutujan toive
Voin ottaa vastaan samassa ajassa useamman kuntoutujan kuin perinteisessä kasvokkain tapahtuvassa fysioterapiassa
Työnantaja edellyttää
Yksi vaihtoehtoinen tapa toteuttaa fysioterapiaa muiden tapojen joukossa
Muu, mikä?

32. Mitä muuta haluaisit kertoa etäfysioterapiasta (esimerkiksi koulutus, toteutus, kuntoutujan näkökulma)

Avoin kysymys

Appendix 2. Original publications, Study I-IV

FACULTY OF MEDICINE

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