A FUNCTIONALITY DESIGN FRAMEWORK FOR ELDERLY-CENTRIC DIGITAL SELF-MANAGEMENT SYSTEMS TO ENHANCE OLDER ADULTS' MOTOR HEALTH

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A functionality design framework for elderly-centric digital self-management systems to enhance older adults' motor health

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CERTIFICATE OF ORIGINALITY

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Abstract

With ageing, individuals commonly experience motor degradation, reducing independence and quality of life. Advanced technologies have accelerated the development of digital healthcare solutions, enabling older adults to self-manage their motor health. Previous research on digital self-management systems mainly focused on single functionality, such as assessments or sensor-based exercises. Few have combined diverse functionalities to develop optimal designs that enhance motor health and confidence in older adults. Moreover, previous studies highlighted the systems' usability but ignored users' desirability, leading to abandonment or rejection. Consequently, a limited framework has been developed to guide the elderly-centric design of digital self-management systems.

To improve the accessibility and usability of digital self-management systems and enhance older adults' motor health, this research developed a functionality design framework based on macroergonomic analysis and design methods. Firstly, literature reviews were used to synthesise digital self-management systems and their design frameworks. Cross-sectional surveys and semi-structured interviews with older adults and physiotherapists further explored their obstacles, perceptions, and needs regarding digital self-management of motor health. Based on the motor health self-management situation analysis and the root definition of functionality structure, an initial functionality design framework for the elderly-centric digital self-management systems was developed. A digital self-management system was then designed and tested via usability test and a pilot randomised controlled trial, validating the feasibility of the framework. The results led to further enrichment of the framework.

The results showed that older adults reported positive attitudes towards education, evaluation and exercise functionalities. Perceived vulnerability, perceived severity, maladaptive response rewards, response costs, perceived ease of use, and task-technology fit significantly influence older adults' behavioural intention to use digital self-management systems. Functions including data collection, analysis, updates, feedback, info search, and activity reminders were also presented to influence older adults' behavioural intention. Additionally, physiotherapists provided valuable insights in combining optical sensors and wearable inertial sensors with the three-meter timed up and go test, five sit-to-stand test, and Berg balance test to capture older adults' lower back, knee, and foot motions. Stretching, aerobic exercise, strength, balance, and functional task training were suggested as exercises in digital self-management systems. A functionality design framework was thus developed, identifying education, evaluation, and exercise functionalities as the fundamental structure, while considering their content, technology, and material design strategies.

In the usability test and pilot randomised controlled trial, older adults showed greater perceived usefulness of the designed digital system on motor health management. The system also achieved a “good” usability. The education, evaluation, and exercise functionalities all had positive effects on motor health-related outcomes (Education: handgrip strength, GSE; Evaluation: 3TUG; Exercise: 3TUG). However, each functionality presented a different effect size in diverse domains of motor health. Therefore, a comprehensive digital functionality strategy was further updated in the functionality design framework.

The findings enhanced understanding of motor health management and older adults’ needs for digital self-management systems. The elderly-centric functionality design framework can guide the design of accessible, usable and practical digital healthcare systems, and enhance theoretical knowledge of macroergonomics and age-centric design strategies.

Keywords: Motor health, Older adults, Digital healthcare systems, Self-management, Design framework

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CHAPTER 1: INTRODUCTION

1.1. Research Background

Over the past few decades, technological advances and increased personal wealth have significantly improved human life expectancy (Prajapati & Sharmila, 2023). As a result, the proportion of older adults aged 60 years and above is projected to reach one in six globally by 2030. Due to physiological degradation with ageing, older adults often experience declines in motor health, such as sarcopenia, reduced gait speed and standing balance, joint stiffness and reduced proprioceptive acuity (Davoudi et al., 2024). Therefore, motor impairments are highly prevalent among older adults, affecting approximately 15%, 26%, and 48% of individuals aged 65-74 years, 75-85 years, and 85 years and older, respectively (Remillard et al., 2022).

Previous studies have revealed that motor health impairments significantly contribute to diverse health problems (Lieberz et al., 2022; Remillard et al., 2022; Tang et al., 2022). For example, older adults with motor impairments experience lower physical activity levels and a poorer quality of life than those with good motor health (Lee & Tak, 2023). Additionally, motor impairments increase the risk of falls, negatively impact mental well-being, and reduce the likelihood of ageing in place and access to medical services (Lieberz et al., 2022). Therefore, maintaining motor health is crucial for healthy ageing, as it positively affects older adults' physical and mental health, ability to live independently, and social participation (Tang et al., 2022).

Older adults traditionally rely on care services from hospitalists, physiotherapists, nurses, care workers, and family members (Anderson & Knickman, 2001). Due to the giant care burden and complex requirements, older adults' motor health management has brought considerable challenges and financial burdens to individuals, health systems, and society in the era of global ageing (Lee & Tak, 2023). Hence, innovative solutions are crucially needed to provide superior motor health management services at an affordable price.

Recently, the advancement of sensor technology, the Internet of Things, and artificial intelligence has boosted various gerontechnologies to help monitor and manage older adults' motor health and quality of life (Chen et al., 2022; Mao, Zhang, et al., 2024). These technologies cater to the needs and interests of older adults, as well as enable individuals to adjust health behaviours according to their environments, enhance gait, balance and muscle strength, and delay the degradation of physical capacity. Through sensor-based gait monitoring, balance assessment, and physical exercise interventions (as shown in Figure 1) (Cieślik et al., 2023; Goher & Fadlallah, 2020; Zhong & Rau, 2020), the digital motor health management systems empower older adults to self-manage their motor health and make decisions on health behaviours (Wald et al., 2019). These sensor technology-based digital motor health management systems also allow older adults to care in place instead of going to healthcare facilities, such as rehabilitation centres or hospitals.

Moreover, physiotherapists and care workers can assess older adults' motor performance and provide timely interventions based on the feedback of the digital health management systems (Majumder et al., 2017). These systems, equipped with non-invasive and unobtrusive sensors, offer cost-effective and viable alternatives to traditional motor health management approaches. However, despite the various digital motor health management systems, few of them considered stakeholders' perceptions and requirements. The current digital motor health systems primarily focus on technology, overlooking the usability and desirability for older adults and clinical motor management processes.

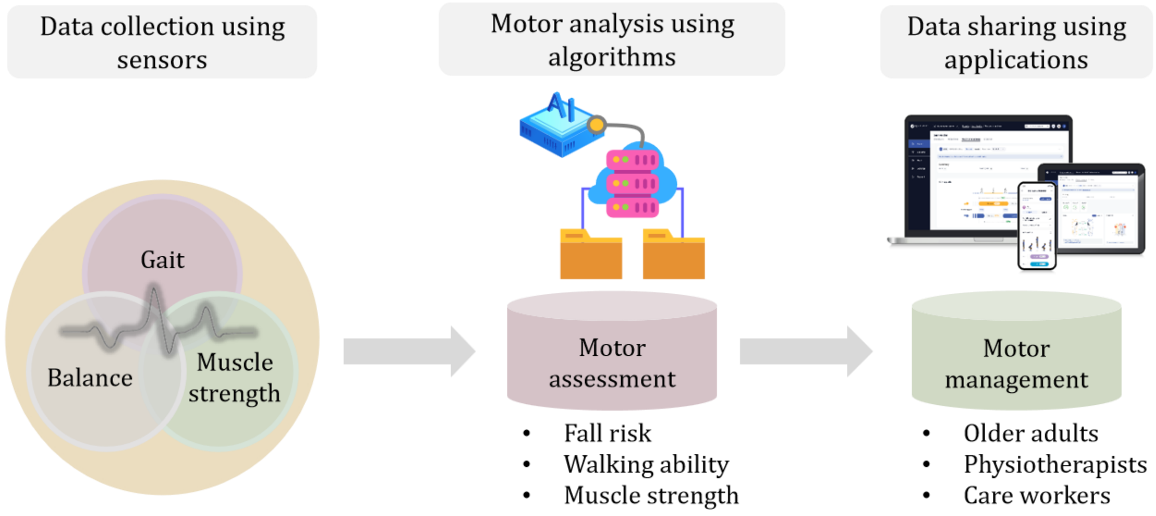


Figure 1. The digital motor health management systems

As older adults increasingly prefer to age in place, the World Health Organisation emphasises the potential of digital self-management systems to support the home-based management of multiple health conditions (Lanfear & Harding, 2023). In this situation, older adults' adherence to digital healthcare systems is crucial for the efficiency and effectiveness of these systems. Due to the lack of user-centric design strategies in the functionality design of digital self-management systems, around half of the users abandoned the digital systems after 30 days of use. This number increased to more than 60% after 90 days (H. Wang et al., 2022). Thus, understanding older adults' home-based motor health processes in practice, as well as their preferences and requirements in daily motor self-management, is crucial for digital self-management system design to improve systems' usability, accessibility and effectiveness.

In addition, the functionality of digital healthcare systems was identified as referring to a digital health intervention using digital technology to achieve health objectives (Organization, 2019). Previous research suggests that education, evaluation, and intervention functionalities are core components of digital self-management systems (Devan et al., 2019; Moreno-Ligero et al., 2023). Notably, the typical intervention for motor health self-management is physical exercise. There is numerous evidence on the effectiveness of sensor-based physical exercises in improving motor health (Mao, Zhang, et al., 2024). Previous studies have also investigated the design and accuracy of digital motor assessment systems (Díaz et al., 2019; Zhao et al., 2023). However, most of them have focused on a single functionality rather than comprehensively considering the interaction among diverse functionalities. Consequently, it remains uncertain which functionality combination is most beneficial for older adults' motor health management.

As the motor management in older adults is complex and dynamic, a system-specific, exploratory, and interactionist approach is expected to gain a deep insight into the components of the digital self-management system, the interactions among different components, and their effects on the quality of motor management. Systems thinking, defined as "*a discipline for seeing wholes, as a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static*" (Zhang & Ahmed, 2020), provides a holistic systems view to help recognise human and technology as components of the dynamic systems of motor management. Particularly, macroergonomic analysis and design methods have been widely used to develop problem-solving solutions for digital healthcare systems. In this method, map and role analysis tools were applied to analyse the health management process and relationships between different components, offering deep insights into the opportunities for effective and efficient design solutions.

In this context, this thesis endeavoured to develop a functionality design framework for an elderly-centric digital self-management system based on systems thinking. By exploring older adults' perceptions and requirements, physiotherapists' clinical experience and perspectives on the functionality of digital motor health self-management systems, motor health self-management systems and digital problem-solving paths were analysed and identified to guide the development of the functionality design framework.

To evaluate the feasibility of the framework, a digital self-management system for motor health was designed to conduct task-based usability tests and a pilot randomised controlled trial. After evaluating the usability and effect of different functionalities among older adults, the functionality design framework was further updated and expected to guide human-computer interaction researchers and digital healthcare system developers to design accessible, usable and effective digital healthcare systems. Through an evidence-based design framework, the developed digital healthcare systems can cater to older adults' requirements and improve their motor ability and quality of life.

1.2. Aim and Research Objectives

This thesis aimed to develop a functionality design framework for elderly-centric digital self-management systems and enhance older adults' motor health and quality of life through design. The framework provides evidence-based, context-sensitive design strategies to enhance the usability and effectiveness of digital self-management systems. To achieve this aim, five objectives were identified as follows:

1) **Objective 1**: To explore older adults' perceptions, attitudes, required functions and preferred content design for different functionalities of digital motor health self-management systems, providing insights for the development of an elderly-centric functionality framework.
2) **Objective 2:** To investigate physiotherapists' clinical experience and perspectives on motor health management, and their suggestions on the functionality design for digital motor health self-management systems, providing clinical guidance and practical insights for the functionality framework and avoiding design misalignment with clinical needs.
3) **Objective 3:** To develop a functionality design framework for elderly-centric digital

motor health self-management systems. The framework identified the design elements and principles for different functionalities in digital self-management systems based on the motor health self-management situation analysis, providing digital self-management problem-solving paths and guiding the development of a digital motor health self-management system.

4) **Objective 4:** To evaluate the feasibility of the developed functionality design framework by designing a digital self-management system, quantifying its usability, as well as the effectiveness of included functionalities and the synergies when functionalities are integrated. This objective was expected to provide evidence-based insights into the intervention strategies and duration design in the functionality framework.
5) **Objective 5:** To update the proposed functionality design framework for elderly-centric digital self-management systems, guiding the development of accessible, desirable, usable, and effective digital self-management systems.

1.3. Research Questions

Three questions were raised based on the research aim and objectives. In detail, Objective 1 and Objective 2 contributed to Question 1. Objectives 3 evoked Question 2, Objectives 4 and 5 raised Question 3, as shown in the following:

1) **Question 1**: What are the primary stakeholders' (including older adults and physiotherapists) perceptions and requirements on the functionality design (content, technology, materials, functions, interface design features of different functionalities) for digital self-management systems used for older adults' motor health management?
2) **Question 2**: What design elements and principles for different functionalities

should be included in the proposed functionality design framework for elderly-centric digital self-management systems to empower older adults during their daily motor health management?

3) **Question 3**: What is the feasibility of the proposed functionality design framework for the elderly-centric digital self-management system, including usability and the effect of diverse functionalities on older adults' motor health self-management?

1.4. Research Significances

1.4.1. Practical Implication

There are two practice implications of this thesis:

1) Deepen understanding regarding the motor self-management process, the attitudes and requirements of older adults: Chapters 4 to 5 performed questionnaires and semi-structured interviews with older adults and physiotherapists, and Chapter 6 analysed the motor health self-management situation analysis and developed the digital problem-solving paths. The findings facilitate the design of clinical-based and elderly-centric functionality for digital motor health self-management systems.
2) Provide insights into the usability and effectiveness of each functionality in improving older adults' motor health and self-management ability: Chapters 7 and 8 developed a digital motor health self-management system and further validated its usability and effectiveness through task-based usability test and a pilot randomised controlled trial. The findings can help human-computer interaction designers, healthcare professionals, and digital healthcare researchers select and adopt appropriate digital functionality to enhance older adults' motor health-related outcomes and quality of life.

1.4.2. Theoretical Implication

There are two theoretical implications of this thesis:

1) Establish an elderly-centric functionality design framework for digital motor health self-management systems: Chapters 4 to 9 developed a framework as guidance for the further design of digital self-management systems with accessibility, usability, desirability and effectiveness. This framework promotes comprehensive and user-centric design approaches that consider the dynamic nature of motor care processes and the specific needs of older adults. Based on the framework, future designers and researchers can create innovative and effective digital healthcare systems to improve health management and quality of life in older adults.
2) Enhance the knowledge of macroergonomics regarding digital motor management systems. Chapters 4 to 9 provide a holistic view of the dynamic motor care process and identify the relationships and interactions between different functionalities, such as education, assessment and physical exercise functionalities in the framework, contributing to the sociotechnical systems theory and models that address the complexities and dynamics of healthcare.

1.5. Research Structure

As shown in Figure 2, six studies were conducted for this thesis. Chapter 2 reviewed the related literature on motor health in older adults, digital motor health management systems, the related design framework, and systems thinking. Specifically, a meta-analysis examining the effectiveness of sensor technology-based systems in enhancing gait and balance was conducted in Chapter 2. Chapter 3 introduced the methodology, which included both qualitative and quantitative methods. Chapters 4 and 5 conducted Studies 1 and 2 to identify the personal and clinical requirements of older adults in motor self-management by exploring the perceptions of older adults and the perspectives of physiotherapists. Based on the findings from Chapters 4 to 5, Chapter 6 employed systems thinking to visualise the current motor self-management situation and identify the challenges. Digital problem-solving paths were further developed to create an initial functionality design framework for elderly-centric digital self-management systems. Chapters 7 and 8 conducted studies 3 and 4 to evaluate and validate the feasibility of the proposed functionality design framework through a task-based usability test and a pilot randomised controlled trial. Based on the findings from Chapters 7 to 8, Chapter 9 further updates the proposed functionality design framework for elderly-centric digital self-management systems used for the motor health management of older adults.

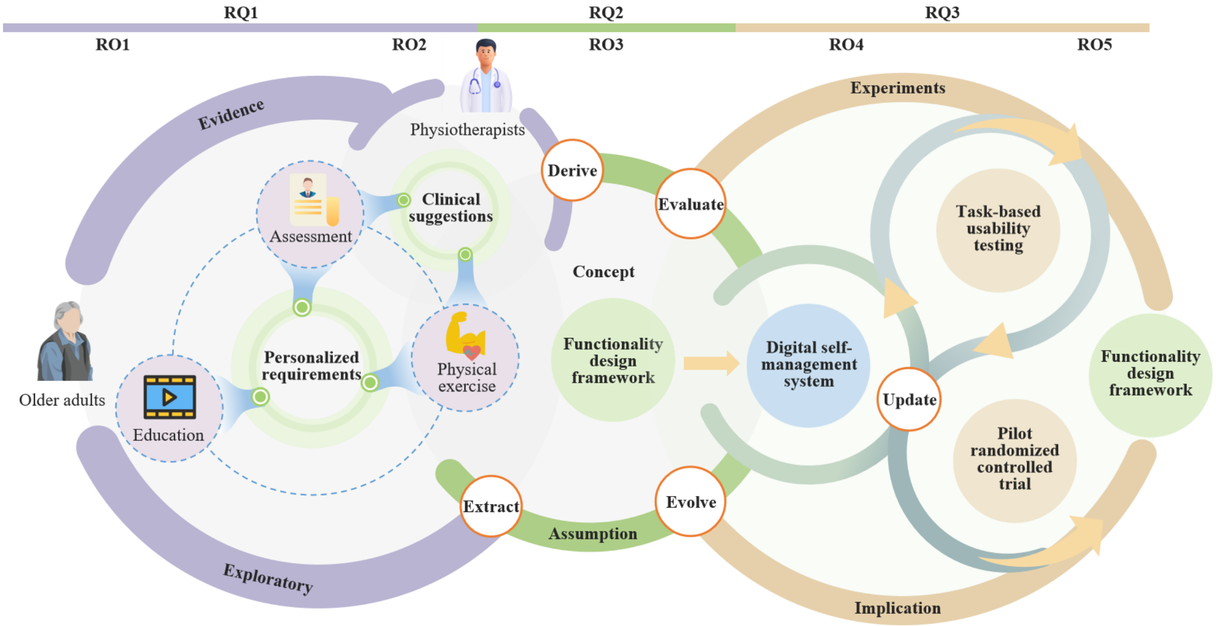


Figure 2. Research studies of this thesis

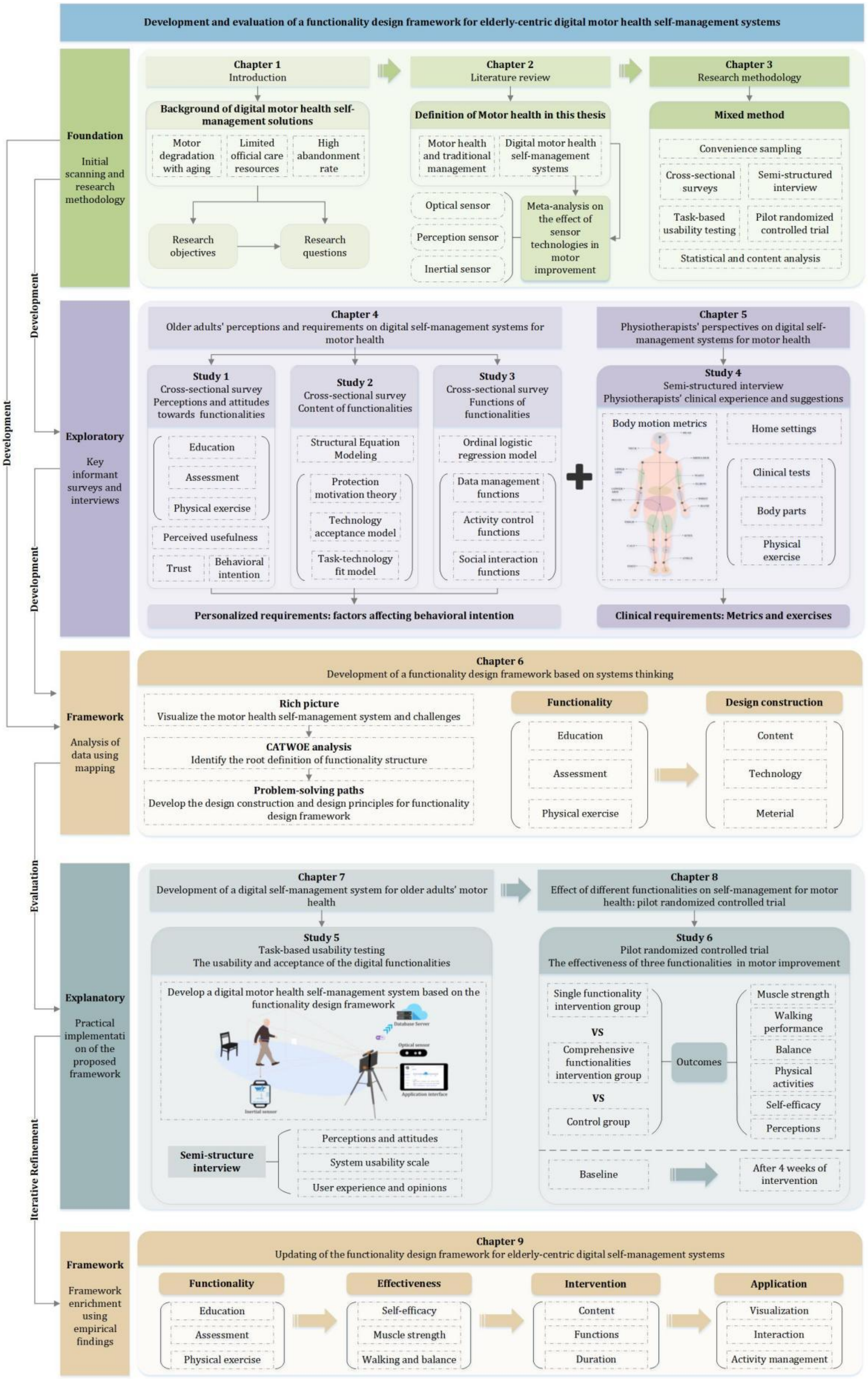


Figure 3. Research flowchart of this thesis

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

The purpose of this chapter is to provide a comprehensive review, synthesis, assessment and analysis of previous research on motor health management in older adults. The chapter begins with an overview of the theoretical framework within which the research questions were formulated and reviewed. It then provides a description of the key terms and definitions used throughout the study. Based on the existing literature, this chapter explores current intervention strategies aimed at supporting motor function (particularly gait and balance) in older adults. Given the multifaceted nature of motor function decline and motor issues in older adults, it is natural that approaches to assessment and intervention are varied. In order to support effective management of motor health, this study seeks to explore systems and tools that can help protect and improve motor health.

Concurrently, the chapter explores the multifaceted area of motor function and age-related impairments in older adults, while exploring the potential for maintaining and improving fitness through intervention strategies. The review compares and summarises existing technologies, including sensor-based assessments, motion tracking systems, and rehabilitation platforms, outlining their respective strengths and limitations in real-world and clinical applications. To integrate these approaches into relevant theoretical constructs, the chapter draws on models of motor control, neuroplasticity, embodied cognition, ecological dynamics, and functional task analysis. The chapter also integrates frameworks from gerontology, behaviour change theory, and motivational psychology to illustrate the unique challenges faced by ageing populations. A synthesis of this literature provides a structured foundation for the research questions, methodological decisions, and intervention design of this study.

2.2. Definitions in Motor Management

Motor:

Human motor health is defined as the integrity and optimal performance of the neuromuscular system, which encompasses the physiological components responsible for initiation, coordination (Voelcker-Rehage, 2008). Motor health encompasses the functional capacity of skeletal muscle, the integrity of peripheral and central neural circuits, and also includes the dynamic interaction between cognitive planning and motor execution (Ashendorf et al., 2009). Exercise health is a key determinant of physical autonomy and psychosocial well-being, especially for older adults with a high prevalence of motor problems (Ketcham & Stelmach, 2004).

Motor skills refer to the execution of purposeful movements. They are usually categorised into upper and lower limbs, with the former requiring precise control (e.g., writing, fastening buttons) and the latter requiring a broader range of motor patterns (e.g., walking, postural maintenance) (Kraft et al., 2015). These processes are characterised by adaptation to repetitive practice and training in response to feedback and task-specific training.

Gait:

Gait difficulty is a common problem in older adults with motor impairments, and gait impairments can be costly to treat and can also lead to increased morbidity and mortality in older adults (Brach & VanSwearingen, 2013). Gait is a complex, coordinated task that places demand on the muscular, skeletal, cardiorespiratory, cognitive, and neurological systems. Changes in gait occur due to a variety of factors such as age and stroke (Woollacott & Tang, 1997).

Balance:

Balance is a fundamental part of the assessment of motor performance; balance implies that a person can maintain an upright posture, adapt to distractions, and perform dynamic tasks such as walking (Granacher et al., 2011). After a stroke, postural control tends to be impaired due to disruptions in sensory, reflex modulation, and downward motor pathways, which can lead to an increased risk of falls and decreased motor ability (Lesinski et al., 2015). Studies have shown that stroke survivors exhibit abnormal muscle synergies and delayed or diminished postural responses, especially when there is external interference during standing or gait (Salzman, 2010).

Muscle strength:

Muscle strength plays an important role in generating the processes of gait propulsion, postural stabilisation, and the strength needed to recover from imbalance (Moreland et al., 2004). Strength of lower extremity musculature is often closely associated with reduced walking speed, asymmetrical stride length, and poor balance recovery (Hughes et al., 2001). Deficits in muscle strength often coexist with impaired motor coordination, thus complicating motor rehabilitation outcomes.

2.3. Motor Health in Older Adults

2.3.1. Motor Health

Ageing causes motor control and functional abilities to decline over time. This decline usually manifests itself in gait and balance impairments, factors that have a significant impact on the ability of older adults to perform activities of daily living (ADLs) and maintain independent living (Seidler et al., 2010). Age-related motor decline results from both the deterioration of the central nervous system and the loss of muscle mass, strength, and peripheral nerve conduction. These combined deficits impair motor control, increase fall risk, and reduce independence.

Ageing involves a progressive loss of muscle mass and strength (sarcopenia), impaired sensory function and reduced neuromuscular coordination. These changes collectively reduce the physical capacity of older individuals and heighten their risk of negative health outcomes (Dallaire et al., 2021). Physical and physiological decline often results in impaired gait, balance and muscle strength. These problems are prevalent among older adults and are associated with an increased risk of falls, loss of independence and reduced quality of life. Epidemiologic data suggest that approximately one in three people aged 70 and older has an abnormal gait (M. Y. Osoba et al., 2019). Age affects about 13% of people aged 65 to 69, and this percentage rises sharply to nearly 46% among those aged 85 and older. At the same time, older people's muscle strength is weakening, with an estimated average decline of about 3% per year, which significantly increases the risk of falls and reduces functional independence (Freiberger et al., 2020). This negative physical change places a considerable burden on the economy, healthcare systems, and society at large, primarily because of the increased complexity and level of care needed for those affected individuals.

Impairments in gait and balance have been widely recognised as key factors contributing to the risk of falls in older adults. They are often early indicators of declining motor ability and functional independence (M. Y. Osoba et al., 2019). For example, decreased walking speed is often associated with impaired balance and lower extremity function (Figueiro et al., 2011). An increase of one standard deviation in stride length variability was linked to a more than fivefold elevation in fall risk. Additionally, a similar increase in swing time variability corresponded to over a twofold heightened likelihood of experiencing a fall (M.

Y. Osoba et al., 2019). Decreased muscle strength impairs balance control, which can greatly increase the likelihood of falls, especially in older adults (Freiberger et al., 2020). Recent epidemiologic studies have shown that about one in three adults aged 65 and older falls at least once a year. Falls account for more than half (about 55.8%) of all accidental deaths in this population. This risk increases with age: about 40 per cent of people over 75 years of age suffer fall-related injuries, and this number rises to nearly 50 per cent among older adults aged 80 years and over. These data highlight the urgent need to develop effective fall prevention strategies for older persons (Bruyere et al., 2005). Falls in older people can have a range of adverse consequences, including physical injuries such as fractures and head trauma, as well as psychological effects such as fear of falling and loss of self-efficacy. These consequences typically result in reduced motor ability, diminished ability to participate in daily routines, and loss of confidence in maintaining balance independently. These limitations can seriously compromise overall quality of life, increase dependence on health and social care services, and place significant emotional and physical strain on family members and caregivers (Shen et al., 2016). Therefore, accurate and timely monitoring of gait and balance deficits is critical for healthcare professionals and physical therapists to assess functional motor health and design targeted and effective interventions to support quality of life for older adults.

2.3.2. Risk Factors of Motor Impairments

The causes of motor performance deficits in older adults are often due to a gradual decline in the functioning of the central and peripheral nervous systems and degeneration of the neuromuscular system (Immonen, 2020). Older adults typically exhibit impaired coordination and greater difficulty maintaining balance and stability in gait, among other problems. These impairments can seriously affect their ability to perform basic activities of daily living, further compromising the quality of life of older adults (Xu, 2014). Gait and balance are two major factors in motor function impairments that are strongly associated with fall risk, and falls continue to be the leading cause of injury in the ageing population. During the motor function impairment process, a significant proportion of falls result in moderate to severe physical injuries, leading to reduced motor health and a significant reduction in quality of life. Other potential risk factors include prolonged task completion times in a variety of activities (household activities, exercise, etc.) and significant decreases in movement speed. This often means that older adults prioritise precision of movement over speed due to physical constraints.

More serious motor disorders, including those such as amyotrophic lateral sclerosis, are manifested in older adults as muscle weakness, atrophy, and autonomic dysfunction (Tomlin et al., 2025). Similarly, other movement disorders (e.g., Parkinson's disease, essential tremor, dystonia, and ataxia) impair motor control through basal ganglia or cerebellar dysfunction, leading to symptoms such as stiffness, involuntary movements, or impaired motor initiation. Impaired motor health typically diminishes an individual's ability to perform daily living activities, reduces older adults' sense of participation in social and occupational roles, and decreases older adults' quality of life. Protecting motor health is therefore critical to maintaining functional independence, especially in an ageing population.

Age is a factor in motor health, and age-related declines in exercise capacity are well documented; however, regular participation in physical activity has been shown to mitigate neuromuscular degeneration. Other factors include diet, sleep hygiene and stress management, which play a contributing role in maintaining nerve and muscle vitality (Brustio et al., 2018). In addition, systemic and neurological diseases such as stroke, multiple sclerosis, and diabetes-related neuropathy can trigger secondary motor dysfunction.

2.4. Motor Health Management

2.4.1. Traditional Clinical Tests

Traditional clinical assessments of motor function impairments around balance, gait, and functional motor ability use standardised tests that provide quantitative metrics and observations (Wales et al., 2016). The Berg Balance Scale (BBS) is widely used to assess static and dynamic balance through functional tasks such as standing, turning and walking (Patrizio et al., 2021). The Three Meters Timed Up-and-Go test (3TUG) evaluates basic motor health by measuring the time taken to stand from a chair, walk three meters, turn, and return (Patrizio et al., 2021). The Five Sit-to-Stand test (5STS) provides an indication of lower extremity strength and transitional movements in older adults. 5STS essentially consists of measuring how quickly a person can stand up from a chair five times without using arm support (Patrizio et al., 2021). The Activities-Specific Balance Confidence Scale (ABC) is a scale used to measure an individual's confidence in performing daily activities without losing balance (Patrizio et al., 2021). In terms of comprehensive gait analyses, the Functional Gait Assessment (FGA) examines dynamic walking in a variety of conditions, such as head turning and obstacle navigation. At the same time, the Balance Evaluation System Test (BESTest) categorises balance deficits, including anticipatory postural adjustments and sensory orientation (Wales et al., 2012). In addition, the Tinetti assessment estimates fall risk by combining gait and balance tasks, while the Romberg test assesses the proprioceptive contribution to postural stability by comparing balance with eyes open and eyes closed (Wales et al., 2012). In conclusion, these assessment tests allow for a multifaceted evaluation of movement and balance, which is essential for the assessment of motor health and intervention therapy in older adults.

2.4.2. Sensor-Based Tests

Instrumented Laboratory-Based Tests primarily use high-precision motion capture systems and grip strength meters for quantitative analysis of motor performance (Lodha et al., 2016). These systems provide kinematic and kinetic data, and the data obtained from the trials allow for detailed analysis of gait, balance, and upper limb movement. Handgrip strength measures the resting maximum grip strength of the hands of older adults (both left and right-handed) to assess balance and symmetry. These laboratory-based methods can be used as a standard for validating new assessment tools and interventions, which are essential in motor assessment among older adults due to their high reliability and accuracy.

Wearable sensor-based systems also offer a portable and cost-effective option for assessing motor health in real-world environments (Chen et al., 2022). Wearable watches often contain sensor units, and inertial measurement units (IMUs), which include accelerometers and gyroscopes, are widely used to capture movement patterns such as gait speed, gait symmetry, and postural transitions (Howcroft et al., 2016). These devices enable continuous monitoring of older adults during various activities, such as household tasks and outdoor exercise, providing relevant data (steps, speed, etc.) for longitudinal analysis of motor function and early detection of decline (Baig et al., 2019). Other wearable devices, including wearable pressure sensors integrated in insoles, can assess balance and gait through plantar pressure distribution (Choi et al., 2021). In addition, smart textiles and EMG wearables can further extend the range of monitoring by monitoring muscle activity during dynamic tasks (Bezold et al., 2021). These wearable sensor-based systems can support remote health monitoring and personalised rehabilitation by providing actionable metrics to seniors and physical therapists.

2.4.3. Interventions for Motor Health

Pharmacologic interventions have long played an important role in controlling motor dysfunction in older adults, especially in the treatment of motor disorders (De Spiegeleer et al., 2018). However, traditional pharmacological interventions tend to ignore the early warning stage of frail and disabled elderly patients due to motor problems (Valencia et al., 2016). Subjects in traditional studies tend to be multimorbid, pharmacologic, and age-related physiologic decline, and are underrepresented in studies assessing older adults with motor problems (Seidler et al., 2010). As a result, there is growing concern about the external validity of pharmaceutical interventions when applied to older populations with varying degrees of motor problems.

Conventional indicators such as height, weight or lifestyle habits are often used as benchmarks for interventions for older adults (Rubenstein et al., 2001). These interventions combined with indicators can have an impact on motor outcomes that can be assessed (Sato et al., 2024). Consequently, related studies have emphasised the importance of patient-centred outcomes such as self-reported health status, functional independence, and reduction of falls for older adults (Sato et al., 2024).

Drug therapies initially developed for motor problems have shown adjunctive efficacy for motor health. Acetylcholinesterase inhibitors (AChEIs) have been used to study their effects on gait and fall risk (Portlock et al., 2023). These pharmacological interventions may modulate motor performance by enhancing executive function and attentional control (Ruangritchankul et al., 2021).

A systematic review and meta-analysis investigated the effects of cholinesterase inhibitors (ChEIs) on gait and balance in older adults, which can reduce stride length or stride variability (Chen et al., 2021). Individualised approaches should be taken when treatments using pharmacological interventions are targeted at older adults (Portlock et al., 2023). Pharmacologic interventions can play an important role in the treatment of older adults at risk for falls, and medication replacement interventions can reduce falls by up to 70% (Cooper & Burfield, 2009). The effectiveness of traditional pharmacologic interventions for movement disorders in older adults is mixed and often depends on the underlying aetiology and the cognitive reserve of the patient.

Physical exercise therapy interventions are the primary non-pharmacological intervention for older adults. Physical exercise therapy included walking and gait training, task-oriented motor training, hand and grip strengthening, balance training, and functional strengthening activities (Forkan et al., 2006). Walking training mainly consists of task-oriented motor training, which is designed for older adults to improve their ability to plan routes while walking (Brach & VanSwearingen, 2013). The brain needs to plan routes and synchronise movements while the older adults are walking, which makes the training process have a positive influence on the brain. The motor sequence learning exercise is designed to improve the gait speed of older adults; the training content is to complete a series of formulated movements faster than the usual speed (Bateni, 2012). In addition, Tai Chi and Ba Duan Jin are often used to improve motor coordination and balance in older adults as a physical therapy intervention (Lin et al., 2023).

2.5. Digital Self-Management Systems for Older Adults’ Motor Health

2.5.1. Functionalities of Digital Self-Management Systems

Self-management is an individual’s ability to manage symptoms, treatment regimens, and the physical and psychological aspects (Barlow et al., 2002). With the rise of mobile and wearable technologies, digital self-management systems have emerged as promising tools to enhance older adults’ engagement and autonomy in long-term care. The demand for populations with chronic pain, musculoskeletal disorders, and age-related decline in physical function fosters the development of digital self-management system technologies.

Numerous systematic reviews evaluating digital health interventions among older adults reported benefits, including improved quality of life, reduced pain intensity, and decreased functional disability (Arntz et al., 2023; Varma et al., 2016). They have emphasised the potential and importance of digital self-management systems as alternatives to traditional healthcare professional-oriented interventions. Notably, according to previous research on digital self-management systems for chronic diseases and physical health, education, monitoring and assessment, as well as treatment, have been identified as the core functionalities supporting self-health management among older adults (Devan et al., 2019; Moreno-Ligero et al., 2023). These three functionalities have been frequently reported in empirical and review studies for digital self-management systems, reflecting their central roles in enhancing users' knowledge, enabling continuous evaluation of health conditions, and facilitating behaviour or exercise-based interventions. Therefore, this thesis focuses on these three core functionalities (education, assessment and physical exercise) to develop a functionality design framework for digital self-management systems aimed at improving motor health among older adults, as shown in Figure 4. Other technology features set, such as data management features, activity control features, and social interaction features (Suh & Li, 2022), were considered as sub-functions of the three core functionalities. Specifically, the functionality in this thesis was identified as "What the system can do to deliver the digital health intervention", and the function was identified as "What specific actions or processes the system performs to support the functionality".

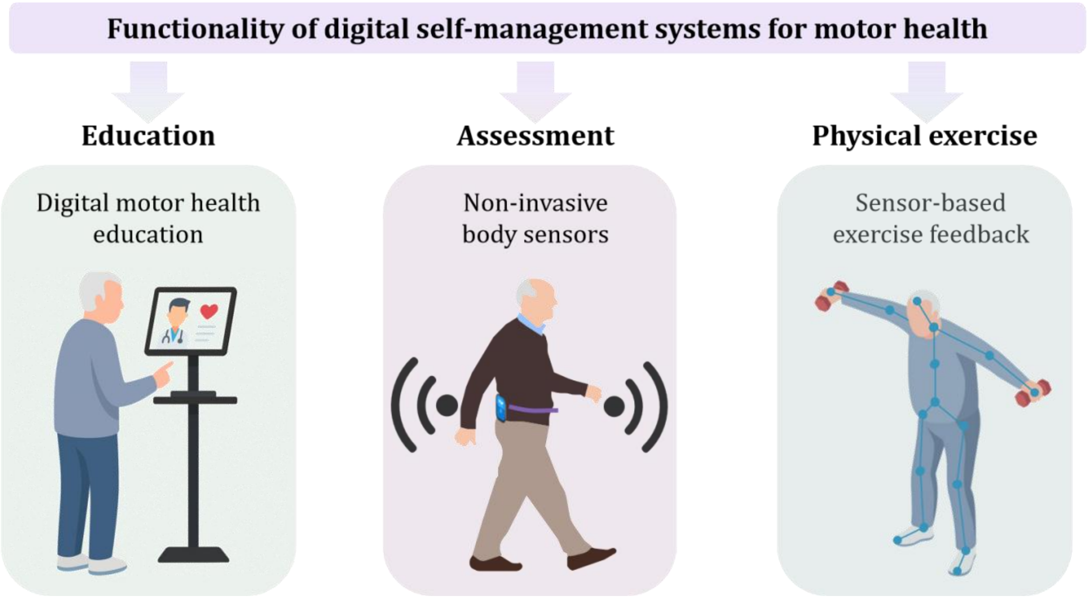


Figure 4. Typical functionalities of digital self-management systems in older adults

Digital education aims to enhance older adults' knowledge of their condition, which includes treatment options and self-care techniques. Older adults are typically educated via mobile applications or web-based portals. These modules often combine textual, visual, and video content on how to improve health literacy and treatment adherence. Older adults can be empowered to engage in their own exercises with greater confidence after digital education (Safari et al., 2020; van Olmen, 2022). The multimedia nature of digital education also enables personalised learning and flexibility, especially for older adults and individuals with motor limitations.

Sensor-integrated assessment, which enables real-time, objective monitoring of a user's physical capabilities. Utilising motion sensors such as accelerometers, gyroscopes, or cameras, the system captures biomechanical data (e.g., joint angles, balance, gait) during specific tasks. Embedded algorithms or AI-driven models were adopted for signal processing, and then quantitative feedback will be generated on movement quality, range of motion, or functional decline (Alhussein & Hadjileontiadis, 2022). Such feedback mechanisms are valuable for personalised exercise adaptation, and they can support older adults in remote monitoring and progress tracking.

Digital self-management systems embed exercise modules by real-time motion capture and feedback. Users can be guided through rehabilitation exercises during monitoring by wearable or contactless sensors. These systems have the advantages of immediate feedback on posture, speed, and accuracy. Most importantly, digital self-management systems allow for correction and encouragement of proper technique (Doyle et al., 2019). Furthermore, the integration of gamification elements and progress dashboards can improve user motivation. Importantly, evidence suggests that sensor-guided digital exercise interventions can be as effective as traditional in-person therapy for improving motor outcomes (Kim et al., 2025).

2.5.2. Sensor Technologies of Digital Self-Management Systems

Although diverse sensor technologies have been used for digital assessment and physical exercise systems, it remains uncertain which technology is more effective in improving older adults' motor health. Therefore, based on the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (Higgins & Green, 2008), this study conducted a meta-analysis to investigate the effect size of optical, perception and wearable sensors.

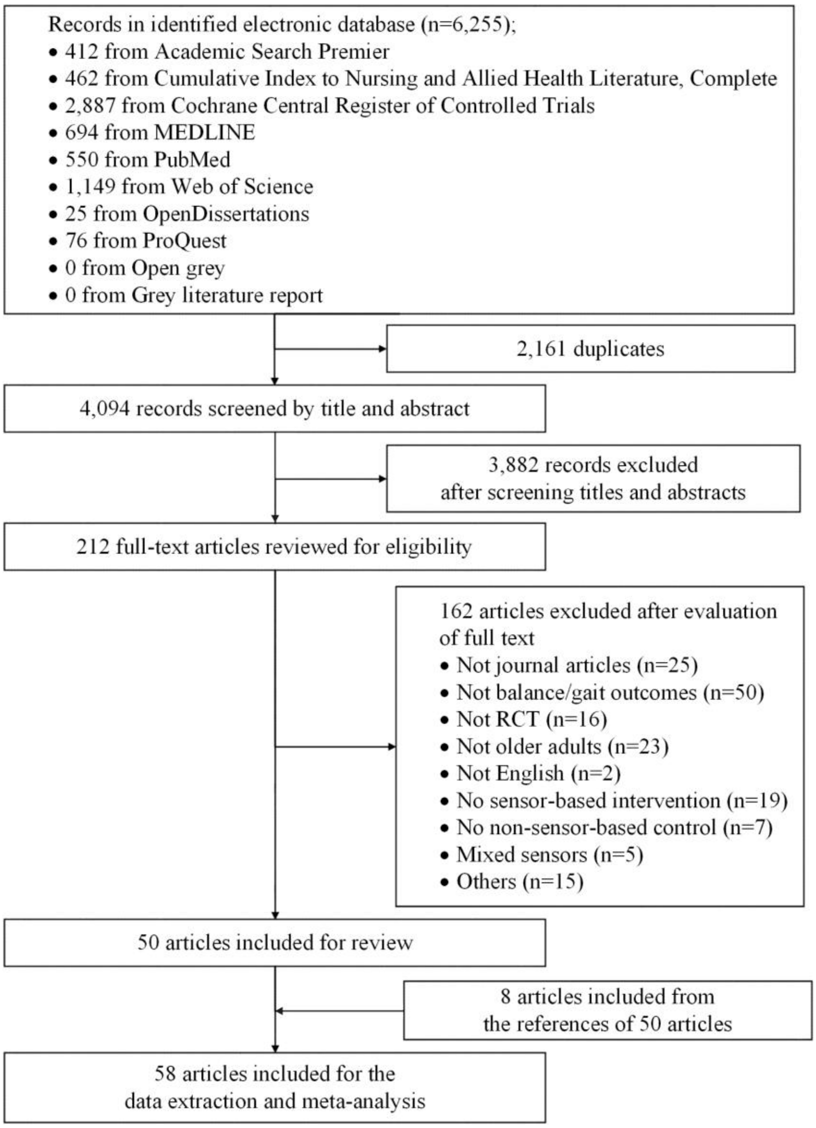


Figure 5. The flow of the literature search and selection process

In detail, a total of 58 articles from ten databases were included according to the inclusion criteria: a) were RCTs; b) compared the use of sensor-based technology with non-use of the technology for gait and/or balance performance; c) examined older adults with an average age > 60 years; d) were published in peer-reviewed journals; and e) were written in English. Review articles, case studies, commentary letters, and studies with only qualitative data analyses were excluded. The literature search and selection process are shown in Figure 5. The characteristics of the sensor-based intervention groups in the included studies are shown in Table 1.

Table 1. The characteristics of the sensor technologies in the included studies

Sensor type	Devices	Article number	Biofeedback
Optical sensor	Kinect	22	Whole-body motion
	Undefined infrared sensors	2	Whole-body motion
	Web camera	1	Whole-body motion
	Smartphone camera	1	Whole-body motion
	BTS NIRVANA VR system	1	Whole-body motion
Perception sensor	Wii balance board	19	Feet pressure
	A step mat	1	Feet pressure
	Tymo system	1	Feet pressure
	A pressure-sensitive electronic mat	1	Feet pressure
	Biorescue platform	1	Feet pressure
	Impact dance platform	1	Feet pressure
	Dividat senso-step training platform	1	Feet pressure
Wearable sensor	Oculus VR headset and two controllers	1	The motion of head and hands
	HTC Vive headset and two controllers	1	The motion of head and hands
	VR glasses with smartphone	1	The motion of head
	Smartphone -accelerometers and gyroscopes	2	The motion of torso at the lower back
	Inertial sensors - a tri-axial accelerometer, gyroscope and magnetometer	2	The motion of shank, thigh and lower back

Conventional functional assessments, including the Timed Up and Go (TUG) test, normal gait speed, Berg Balance Scale (BBS), 6-Minute Walk Test (6MWT), and Falling Efficacy Scale-International (FES-I), were used as the assessment outcomes reflecting gait and balance performance. The effectiveness of sensor-based interventions (optical sensors (OPTS), perception sensors (PCPS), and wearable sensors (WS)) was analysed compared with control groups (non-treatment intervention and traditional physical exercise intervention).

The effect size of each trial was assessed using the mean differences (MD) in outcomes, with 95% confidence intervals, based on suggestions provided in previous meta-analysis studies (Grissom & Kim, 2005). The heterogeneity of the studies was evaluated using the inconsistency test (I^2). An I^2 value less than 40% was considered to indicate low heterogeneity. Random-effects models were used to pool the effect sizes for trials with high levels of heterogeneity. Egger's regression tests were used to assess publication bias when more than 10 trials evaluated the outcomes, with $p < 0.05$ indicating the presence of publication bias. The analysis was performed using Comprehensive Meta-Analysis 3.0 (Biostat, Inc., Tampa, FL, USA) with significance levels predetermined at $p < 0.05$. The results are shown in Table 2.

The results revealed that sensor-based interventions with biofeedback are statistically more effective than traditional physical exercises in improving older adults' gait and balance performance, as determined by the TUG test, normal gait speed, BBS, 6MWT, and FES-I scores. In the subgroup meta-analyses of sensor-based intervention groups, the sensor technologies were divided into OPTS, PCPS, and WS. The results showed that OPTS with the biofeedback of whole-body motion or PCPS with the biofeedback of foot pressure were more effective than traditional physical exercise intervention groups in improving gait and balance performance (except for TUG test scores for PCPS) in a mixed population of older adults. The OPTS are applicable for gait training, and PCPS are suited for balance interventions. However, participants' age and health status potentially affected the effectiveness of sensor-based interventions on 6MWT. Sensor-based interventions tended to present greater efficacy among young-old adults and individuals with Parkinson's disease than among other participants. Optical sensors can be used to perform balance assessments for walking in older adults. They can improve the quality of life of older adults by capturing their movements for test and intervention training (Penteridis et al., 2017). Advanced wearable devices (WDs) can help physiotherapists to understand and manage physiological parameters and exercise steps of older adults in real time based on transmitted data.

Table 2. Meta-analysis of the effects of sensor-based interventions versus control groups

Intervention group	No. of trials	I^2	$p(I^2)$	MD	95% CI	p
TUG						
All group	34	67.851%	0.000	-1.132	-1.500, -0.764	0.000
All group*	25	0.000%	0.609	-0.448	-0.641, -0.255	0.000
OPT sensor	15	76.900%	0.000	-1.486	-2.139, -0.833	0.000
OPT sensor*	11	5.700%	0.389	-0.681	-0.964, -0.399	0.000
PCP sensor	15	40.524%	0.035	-0.682	-1.052, -0.312	0.000
PCP sensor*	11	0.000%	0.894	-0.226	-0.499, 0.048	0.106
WS	5	41.281%	0.146	-1.255	-2.757, 0.246	0.101
WS*	3	0.000%	0.535	-0.490	-1.474, 0.493	0.328
Normal gait speed						
All group	16	92.106%	0.000	7.681	3.540, 11.822	0.000
All group*	11	30.415%	0.141	4.272	3.268, 5.275	0.000
OPT sensor	9	95.324%	0.000	7.539	1.428, 13.651	0.016
OPT sensor*	8	31.821%	0.163	4.244	3.089, 5.399	0.000
PCP sensor	3	76.063%	0.002	7.375	1.644, 13.105	0.012
PCP sensor*	2	62.907%	0.067	4.382	0.321, 8.444	0.034
WS	4	0.000%	0.902	6.682	-1.480, 14.844	0.109
BBS						
All group	22	85.336%	0.000	3.091	2.002, 4.179	0.000
All group*	19	72.179%	0.000	2.133	1.213, 3.052	0.000
OPT sensor	14	89.717%	0.000	3.619	2.099, 5.139	0.000
OPT sensor*	12	79.343%	0.000	2.325	0.993, 3.657	0.001
PCP sensor	8	12.916%	0.329	1.938	1.181, 2.695	0.000
PCP sensor*	7	19.977%	0.277	1.874	1.098, 2.650	0.000

Table 2. Meta-analysis of the effects of sensor-based interventions versus control groups

Intervention group	No. of trials	I^2	*p*(I^2)	MD	95% CI	*p*
6MWT						
All group	14	41.657%	0.024	30.834	22.224, 39.443	0.000
All group*	11	20.287%	0.233	22.671	16.847, 28.495	0.000
OPT sensor	8	48.723%	0.029	37.574	23.020, 52.129	0.000
OPT sensor*	6	28.995%	0.197	25.166	13.158, 37.175	0.000
PCP sensor	6	15.524%	0.304	22.774	16.275, 29.274	0.000
PCP sensor*	5	19.782%	0.284	21.904	15.244, 28.563	0.000
FES-I						
All group	8	54.587%	0.015	-1.750	-2.504, -0.996	0.000
All group*	6	0.000%	0.539	-1.185	-1.502, -0.868	0.000
OPT sensor	4	0.000%	0.420	-3.418	-4.661, -2.176	0.000
OPT sensor*	3	0.000%	0.852	-2.036	-3.940, -0.133	0.036
PCP sensor	4	21.390%	0.273	-1.173	-1.494, -0.852	0.000
PCP sensor*	3	23.654%	0.269	-1.161	-1.482, -0.839	0.000

Note: *: the control groups with traditional physical exercise interventions only; OPT: optical; PCP: perception; WS: wearable sensors; MD: mean difference; I^2: inconsistency test.

2.5.3. Design Frameworks of Digital Self-Management Systems

Digital self-management systems are beginning to be used to address issues related to motor management and repair, especially for older adults (Spreadbury et al., 2022). Digital self-management systems can provide interventions for both self-motor and non-motor symptoms to improve quality of life (Park et al., 2022). With the development of artificial intelligence technology, the moral and ethical challenges of digital healthcare have become a concern for researchers. Attitudes towards digital health self-management systems for managing self-exercise, particularly among older people, were explored through interviews and questionnaires. Older people's previous experience with the relevant technology tended to correlate with their willingness to accept it (Garcia Reyes et al., 2023). For example, the protection of privacy issues, both in questionnaires emphasised issues including the need to have and synthesise information about multiple situations and be able to provide professional advice to caregivers (Codreanu & Florea, 2015). Privacy issues are necessary for healthcare professionals and healthcare services to communicate with providers. As digital self-management systems are used for motor assessment and training, privacy concerns should be adequately addressed; as multiple operators may observe online information on multiple chronic conditions during questionnaire surveys, the protection of privacy concerns and the use of the data should be adequately considered (Singh et al., 2019). Previous studies have focused on exploring rehabilitation for digital self-management systems based on intervention training, medication, and flexible sensors. However, there is a lack of a systematic design framework for the functionality design of digital self-management systems for older adults. The management of digital self-management systems through system thinking for older adults requires further investigation.

Around the 1960s, Barry Richmond coined the concept of systems thinking as "*the art and science of making reliable inferences about behaviours by developing an increasingly deep understanding of underlying structure*", signalling a change from a more linear cause-and-effect analysis to a more comprehensive understanding of complex systems (Ratter, 2012). The limits of mathematical models in capturing holistic views and addressing sociotechnical challenges prompted the development of general systems theory, which captures the entirety of a system instead of just its constituent parts (Zhang & Ahmed, 2020). Bertalanffy identified general systems theory's universal language and laws, providing the foundation for its applicability to many disciplines (Zhang & Ahmed, 2020).

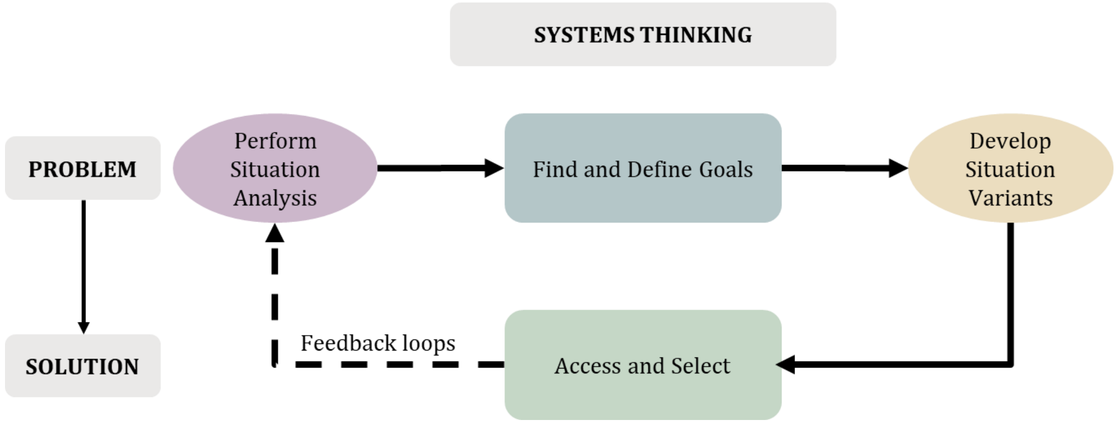


Figure 6. The process of systems thinking

Systems thinking offers a comprehensive framework for comprehending and managing the complexities of linked systems, which has changed techniques in several domains, including the social sciences, engineering, business, computer science, and healthcare (Arnold & Wade, 2015). In general, the application of systems thinking in various domains underscores its importance in tackling complex, interrelated issues through an integrative, comprehensive approach. For example, healthcare professionals can better understand the intricate connections among different actors and factors within health systems by considering them as complex adaptive systems (Adam & de Savigny, 2012). Based on systems thinking, healthcare systems have successfully improved the planning, analysis, and practice by finding the leverage points (Jackson & Sambo, 2020). Considering the dynamic, frequently unpredictable nature of health systems, there is a raised awareness of the necessity of systems thinking.

Traditional healthcare methods have frequently ignored the interconnectedness of health issues, resulting in disjointed and occasionally ineffectual interventions. Compared to reductionist methods, which reduce complicated interactions to linear, controllable results, systems thinking emphasises the relationships and interactions within systems (Powell & Mustafee, 2017). One prominent systems thinking approach in healthcare is macroergonomics, derived from sociotechnical systems theory. Macroergonomics is a "whole systems" approach with top-down, middle-out, and bottom-up concepts to improve the design of work systems for the quality of patient care and the well-being of multi-stakeholders (Carayon et al., 2013). Specifically, the approach emphasises the system elements' interactions and subsystems' relationships rather than considering just the system elements. Therefore, macroergonomics has been widely used to explore the interactions with complex, dynamic, and innovative healthcare systems, such as digital healthcare (Carayon et al., 2013).

Macroergonomic Analysis and Design (MEAD) was identified as a robust method in macroergonomics to investigate interactions between components of large systems. However, recognising the labour-intensive nature of MEAD, a modified approach focusing solely on analysis steps was developed (Murphy et al., 2018), as shown in Figure 7. This modified MEAD comprises four key steps: initial scanning of the organisation, key informant interviews, analysis of data using mapping, and validation of systems analysis. By engaging with stakeholders at multiple levels, modified MEAD overcomes the challenges of understanding various components and levels of large sociotechnical systems. Therefore, this study developed the functionality design framework based on the guidance of MEAD.

Based on the MEAD approach, the proposed framework emphasised the understanding of human-computer interaction from a systemic perspective. The framework concerns beyond user interfaces to broader contextual elements, such as user roles, health management flows, environmental constraints, and clinical requirements. Following the MEAD process, the thesis first reviewed existing literature and technical materials to identify core functionalities and technical solutions for digital motor health self-management among older adults. Subsequently, cross-sectional surveys and interviews were conducted to explore practical needs, usage experiences, and challenges in motor health management among multiple stakeholders, including older adults and physiotherapists. After data analysis, motion health management processes in existing communities were visualised through rich diagrams to highlight systemic bottlenecks. An initial functionality design framework was then proposed to address the identified challenges directly. The feasibility of the initial framework was further validated and updated through usability test and a pilot randomised controlled trial.

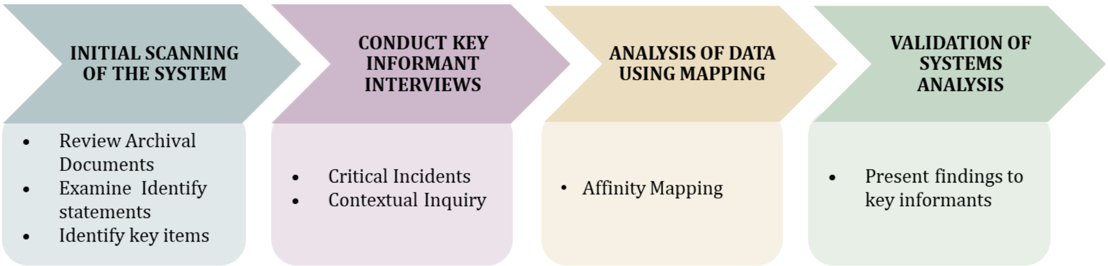


Figure 7. The Macroergonomic Analysis and Design method

2.6. Summary and Research Gap

Thus far, most existing studies on digital motor health self-management systems have primarily focused on their intelligent technologies. Initially, researchers explored how to provide sensory assistance in mobility aids to older adults through obstacle detection and navigation (Arefin et al., 2021). As the importance of gait assessment in older adults became more prominent, further research started to concentrate on gait pattern classification and the detection of abnormal gait (Wade et al., 2015). Various intelligent systems have been developed based on gait information to estimate human walking intentions, balance performance, and fall risks (Anikwe et al., 2022). Despite the variety and feasibility of digital motor health self-management systems, older adults had limited knowledge of technology. They tended to abandon the technology over time due to the ignorance of their requirements and preferences (Martinho et al., 2020).

Although previous studies have increasingly highlighted the importance of tailoring intelligent motor management systems to users' needs and preferences (Martinho et al., 2020), there is a lack of research on incorporating a user-centric design strategy into the development of digital motor health self-management systems. There is also little understanding of the attitudes and needs of older adults regarding the digital motor health self-management systems. The existing studies also had limited clinical consideration on the interactions and adaptations among older adults, intelligent care systems, and environments, leading to a lack of comprehensive understanding of the dynamic motor care process and requirements (Martinho et al., 2020).

Furthermore, most existing digital motor health self-management systems focus on a single digital functionality, such as motor assessment (Zhou et al., 2024) or sensor-based physical exercise (Mao et al., 2024). They ignored the integration of different functionalities during the motor self-management process. Therefore, it remains uncertain which functionality is more effective in improving motor health-related outcomes. Consequently, limited functionality design frameworks have been developed for digital motor health self-management systems.

In this context, based on the literature review and MEAD, the initial scanning of the motor management systems was conducted. Motor management systems should maintain a delicate balance and consider the diverse perceptions and perspectives of multiple stakeholders involved in the processes. During the design phase, it is essential to recognise the motor self-management process and healthcare actions as they considerably affect motor health-related outcomes. Thus, Chapter 4 and Chapter 5 further conducted the key informant interviews and questionnaires among older adults and physiotherapists; Chapter 6 analysed the motor self-management system based on systems thinking and identified the digital self-management problem-solving paths; Chapter 7 designed and evaluated a digital motor health self-management system based on the design elements and principles for different functionalities in Chapter 6; Chapter 8 conducted a pilot randomized controlled trial to quantify the effect size of each functionality in improving specific motor health-related outcomes; Chapter 9 proposed an elderly-centric functionality design framework for digital motor health self-management systems.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Mixed Method

Based on the theory of post-positivism, this thesis employs mixed methods throughout all stages of the research. The concept of “mixed methods” was coined by Campbell and Fiske in 1959 (Campbell & Fiske, 1959). Since all methods have limitations, there are some inertial biases in a single method (Creswell & Creswell, 2017). This issue may be addressed by combining multiple methods in a research study, which is a mixed-methods study. Increasingly, scholars have been prompted to adopt multiple approaches to data collection based on this concept. Ten years later, mixed approaches, which combine several methods such as observation and conventional surveys, gained popularity in research design for collecting both qualitative and quantitative data (Sieber, 1973). The basic usage principle of mixed methods is that it is better to understand the research issue than to rely on a single approach (Robins et al., 2008). In general, quantitative methods are employed to validate and test hypotheses using established conceptual models, thereby explaining and deepening the understanding of factors that contribute to specific successful actions. Meanwhile, qualitative methods are employed to explore the nature, reasons, and strategies of evidence-based practice (Teddlie & Tashakkori, 2003). Since this thesis draws on theories of rehabilitation, human factors, and user-centric design, different question-led approaches were employed to ensure the reliability and validity of the results. For example, the understandings and suggestions of physical therapists on digital self-management systems for motor health were impossible to quantify. In this case, the qualitative data and qualitative analysis were better for this study. However, when measuring the effect of digital self-management on the improvement of motor health and self-management ability, quantitative data and quantitative analysis were used, making the approach scientific and appropriate. Thus, mixed methods were employed in this thesis to investigate the more complex aspects and relationships between motor health self-management and digital self-management systems in older adults. Moreover, data triangulation was introduced as a critical approach in the data collection process to explore and verify uniform findings across different data sources (Lougen, 2009). According to the research gap and main research question, five objectives were further defined to address different sub-questions in this thesis. Based on the inherent nature of the research questions (exploratory, explanatory, descriptive, or predictive), the appropriate research strategies were determined.

3.1.1. Cross-Sectional Surveys

To explore the perceptions and requirements of older adults regarding the digital motor health management system, quantitative methods were employed in Chapter 4 to collect data from this population. The purely qualitative approach overlooks the social and cultural context of the participants in the study. Therefore, researchers consider the results of qualitative methods as having low reliability (Sallee & Flood, 2012). Additionally, regarding the research methods, a smaller sample size may limit the application to a broader population (Lam, 2015). Compared with qualitative methods, quantitative methods can generalise the results to the whole population due to a larger sample size with random sampling (Carr, 1994). The positivist paradigm enhances the trustworthiness of the results (Powers & Powers, 2015). Furthermore, the data analysis using quantitative methods is more time-saving with statistical software such as SAS, SPSS, and MATLAB (Connolly, 2007). In addition, triangulation methods can prevent criticisms from researchers that the results of studies are simply the product of a single method, source, or investigator bias (Bowen, 2009). Thus, three cross-sectional surveys were employed in Chapter 5 to investigate older adults' perceptions and requirements for the functionalities of digital motor health self-management systems.

A cross-sectional survey, a type of observational study collecting data from a population or a representative subset at a single point in time (Levin, 2006), helps examine perceptions, attitudes, behaviours, or needs within the target group. The quality of collected data is high because participants are more honest in the questionnaire than in interviews, which can help decrease bias (Marshall, 2005). Cross-sectional surveys enable researchers to collect data from a larger sample size in a relatively short period, thereby enhancing the generalizability of the findings. Additionally, cross-sectional surveys are efficient for identifying associations or correlations between variables, such as age, digital literacy, and attitudes towards health technologies. Given the exploratory nature of "Question 1: What are main stakeholders' (including older adults and physiotherapists) perceptions and requirements on the functionality design (content, technology, materials, functions, interface design features of different functionalities) for digital self-management systems used for older adults' motor health management?" and the need to gather a broad range of older adults' feedback to develop a user-centric digital motor health self-management system, the cross-sectional survey method provides an appropriate and practical research tool in this thesis.

3.1.2. Semi-Structured Interview

Although cross-sectional surveys were used to explore older adults' perceptions and requirements on digital motor health self-management systems, their feedback commonly lacks insight into clinical motor requirements and design strategies, such as motor metric extraction, physical exercise design, and motor rehabilitation strategies. As many older adults have limited professional knowledge of motor health management, it is challenging for them to fully comprehend the clinical needs related to motor assessment and physical exercise. Thus, the interpretivism-based qualitative approach was used in Chapter 5 to explore and answer the "Question 1: What are main stakeholders' (including older adults and physiotherapists) perceptions and requirements on the functionality design (content, technology, materials, functions, interface design features of different functionalities) for digital self-management systems used for older adults' motor health management?" from the side of physiotherapists, as this method can holistically insight into human experience in particular scenarios (Denzin & Lincoln, 2002).

Interviews allow researchers to gather in-depth and detailed data by asking open-ended questions and encouraging reflective responses (Lazar et al., 2017). As for the interviews, there are three generally used types: structured interviews, semi-structured interviews, and unstructured interviews. Structured interviews have predetermined questionnaires for the participants and limit the "depth" of the follow-up responses (Denzin, 2008). An unstructured interview has no organisation and no predetermined ideas, which may not be easy to participate in and can be time-consuming (May, 1991). Compared to structured and unstructured interviews, semi-structured interviews include several key points and questions that can prompt the identification of topics to be explored. Furthermore, this method enables participants, including both interviewees and interviewers, to elaborate on their ideas or responses (Gill et al., 2008). The healthcare field has the highest frequency of utilisation using the semi-structured interview method (Gill et al., 2008). One possible reason is that the semi-structured interview provides participants with guidance on the conversation's content, allowing many to benefit from it. Another possible reason is the outstanding flexibility of this method, particularly in comparison to structured interviews. Therefore, a semi-structured interview was adopted in Chapter 5 to explore physiotherapists' work experiences and perspectives on digital motor health self-management systems.

3.1.3. Task-Based Usability Test

After developing the digital motor health self-management system, it is necessary to evaluate its usability and verify the desirability of the design elements. Task-based usability test is often carried out as a late-stage activity, focusing on evaluating the final design products. Moreover, by employing representative users and tasks, task-based usability test provides insights into how individuals interact with systems and rectify functional issues (Lazar et al., 2017).

In detail, task-based usability test asks participants to perform a series of fundamental tasks based on typical usage scenarios. This method enables researchers to observe the interaction process between users and the system in a step-by-step manner. It also helps researchers identify specific problems that arise during system usage. (Rubin & Chisnell, 2008). Compared with interviews or questionnaires, task-based test provides more direct and observable evidence of system performance. It can detect errors, confusion, or unexpected actions in real-time (Nielsen, 1994). Task-based usability test has been widely used for evaluating digital healthcare systems (Lazar et al., 2017). It provides valuable feedback for improving both the interface and the functional design. Therefore, this method was applied in Chapter 7 to evaluate the usability of the designed digital motor health self-management system. The findings were used to answer, "Question 3: What is the feasibility of the proposed functionality design framework for the elderly-centric digital self-management system, including usability and the effect of diverse functionalities on older adults' motor health self-management?" and guide accessible and age-friendly digital healthcare system design.

3.1.4. Pilot Randomised Controlled Trial

Although the usability and acceptance of the designed digital self-management system were evaluated by task-based usability test, the effectiveness of the designed system and the effect size of each functionality remained uncertain. Thus, a pilot randomised control trial was conducted in Chapter 8 to address Research Question 3: What is the feasibility of the proposed functionality design framework for an elderly-centric digital self-management system, including usability and the effect of diverse functionalities on older adults' motor health self-management?

Pilot randomised control trials, a small-scale experimental design before conducting a full-scale study, are commonly used to assess system feasibility, participant adherence, intervention design, and preliminary results (Leon et al., 2011). Randomised grouping helps control confounding variables and improves the validity of causal inferences compared to single-group before-and-after designs or observational studies (Hariton & Locascio, 2018). In this study, participants were randomly assigned to eight groups. The intervention group used the different functionalities of the designed digital self-management system for motor health management. The control group received no treatment. More detailed information is presented in Chapter 8.

3.2. Sampling and Participants

Convenience sampling is the predominant sampling method used in social science research (Daniel, 2011). The sample recruitment is based on the convenience of the scholars and the method of selection. In general, respondents are selected because they are in the right place at the right time and have the right conditions to meet the requirements of the experiment (Dawson & Trapp, 2001). Convenience sampling is commonly used in clinical studies, which is why I chose it to investigate the effect of virtual reality on gait and balance. Specifically, older adults who meet the study's inclusion criteria are recruited (Nongkynrih, 2012). The advantage of this sampling method is that it is the most common and straightforward, and because it does not require listing all demographic elements, it not only saves time but also reduces the cost of the experiment. Thus, the convenience sampling method was applied to recruit participants in Chapters 4, 5, 7, and 8.

According to previous studies on cross-sectional surveys, for populations larger than 100,000, a sample size of 96 is enough to achieve a 95% confidence level with a 10% margin of error (Müller et al., 2014). Thus, a total of 109, 465 and 472 older adults were analysed in the three cross-sectional surveys in Chapter 4, respectively. In addition, as a previous study suggested that the interviews regarding workplace research should include 15~60 participants (Saunders & Townsend, 2016), twenty physiotherapists were included in the semi-structured interview in Chapter 5. Hwang and Salvendy suggested that the optimal sample size for usability test is around ten participants (Hwang & Salvendy, 2010). However, Lewis believed that each researcher could identify the appropriate sample size of participants, depending on the accuracy, problem discovery goals, and available participants (Lewis, 2006). Considering the expected number of discovered problems and resource costs, the task-based usability test in Chapter 7 included around twenty older adults via a convenience sampling method. Furthermore, twelve participants per group are generally considered sufficient for a pilot randomised controlled trial to assess feasibility and preliminary effects (Julious, 2005). Given the attrition rate of 20%, 15 participants were recruited for each group in the pilot randomised controlled trial. Thus, a total of 120 older adults were included in Chapter 8.

3.3. Analysis Technique

3.3.1. Content Analysis

Content analysis, a qualitative method extracting data from the audio recorded during the open-ended questions, was used as the primary approach to explore physiotherapists' perspectives on digital-based motor health management, and older adults' attitudes to the designed digital self-management system. The content analysis process provides a more rigorous structure for analysing data related to the stakeholders' perspectives. It rigorously defines the data coding process to distil some of the hard-to-distinguish categories into easily understood themes (Thomas, 2003). Four main steps are included in the content analysis (Graneheim & Lundman, 2004). Firstly, the core data chains were identified by reading the relevant literature. Then, these core data chains were distilled into simple concepts. Higher logical levels were aggregated into these concepts, and finally, themes were formed. The themes were expressions of the apparent content of the data and the underlying content of the text. Content analysis can facilitate the formation of data on physiotherapists' and older adults' opinions on digital motor health self-management systems into subcategories relevant to the design of the functionality.

3.3.2. Statistical Analysis

Regarding the methods of analysis in the cross-sectional survey and experimental study, statistical analysis belonging to quantitative methods was adopted. The process of data analysis is not influenced by the experimental observer, which can reduce the subjective impact of the analysis. Moreover, a large amount of information from different domains can be analysed simultaneously (Queirós et al., 2017). In the statistical analysis process, a normality test is typically conducted first to assess whether the data follow a normal distribution. Based on the results, parametric or non-parametric tests are selected for subsequent analysis on correlation, comparison, or regression.

In detail, descriptive statistics, including measures such as the mean, standard deviation, and percentage, were used to summarise participants' demographic information and outcomes. The Shapiro-Wilk test was used to check data normality. Moreover, Friedman's tests were used to compare older adults' perceptions and attitudes towards the functionality of digital self-management systems. Paired-samples T-test (for normal outcomes) or Wilcoxon signed-rank tests (for non-normal outcomes) were used to compare pre- and post-intervention outcomes. In addition, one-way analysis of variance (ANOVA) or the Kruskal-Wallis H Test was used to test the difference in outcome change between the control and intervention groups. Furthermore, ordinal logistic regressions or partial least squares structural equation modelling was used to identify the factors affecting older adults' behaviour intention to use the digital motor health self-management system and the effectiveness of the system.

3.4. Summary of the Methodology Framework

Chapter 3 elaborated the methodology of this thesis. Based on the post-positivistic paradigm, the mixed method combining qualitative and quantitative methods, including semi-structured interviews, cross-sectional surveys, task-based usability test, and a pilot randomised controlled trial, was used to develop and evaluate the functionality design framework for elderly-centric digital self-management systems. The illustration of the methodology in this thesis is shown in Figure 8.

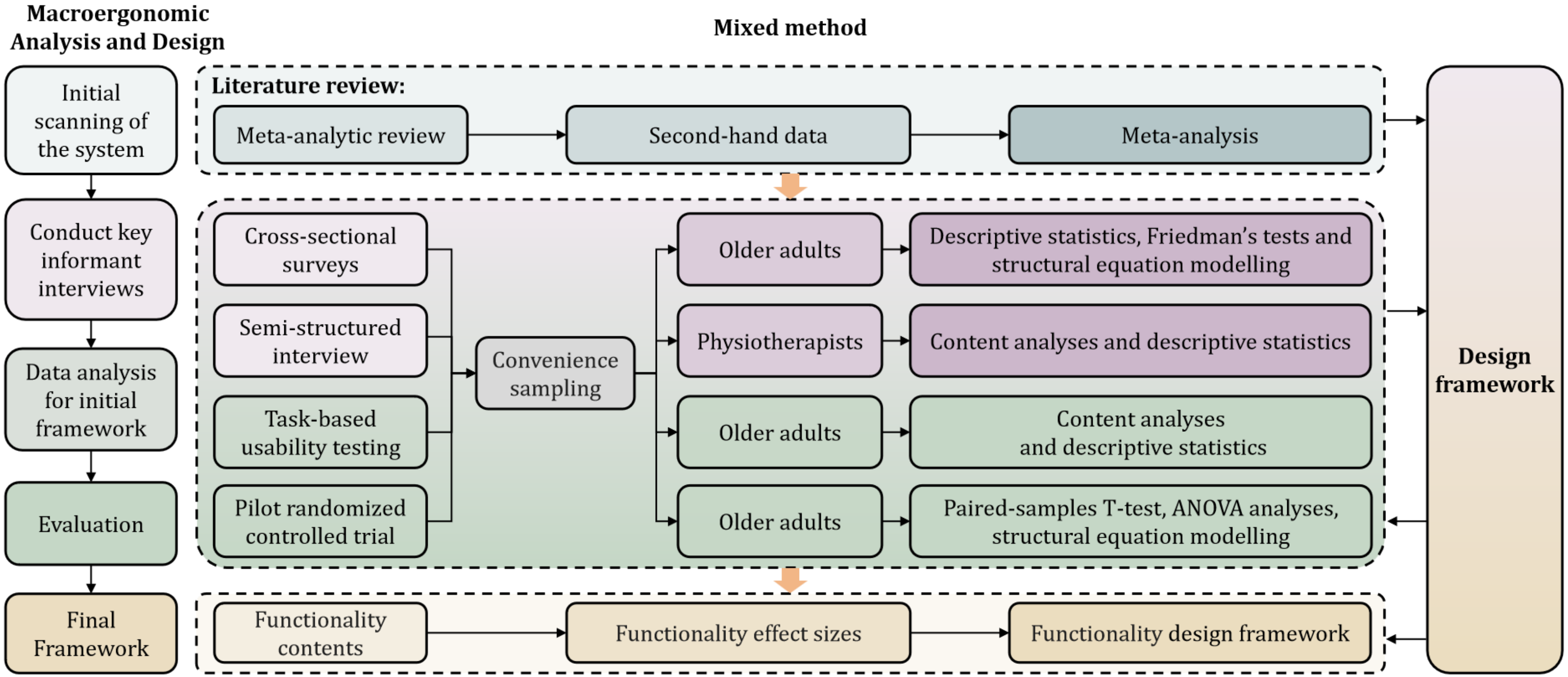


Figure 8. The illustration of the methodology in this thesis

CHAPTER 4: OLDER ADULTS' PERCEPTIONS AND REQUIREMENTS ON DIGITAL SELF-MANAGEMENT SYSTEMS FOR MOTOR HEALTH

4.1. Introduction

Due to limited official healthcare resources and an increased ageing population, the World Health Organisation emphasises the potential of digital self-management strategies to support the home-based management of physical health and quality of life (Lanfear & Harding, 2023). With the development of advanced technologies, such as the Internet of Things, sensors, and artificial intelligence algorithms (Ghosh et al., 2018; Mao et al., 2023), diverse digital self-management healthcare systems have been designed and developed for motor health education (Dispennette et al., 2019), motor health monitoring and assessment (Zhou et al., 2024), and sensor-based physical exercise (Mao, Zhang, et al., 2024). For instance, some digital self-management systems combined different types of sensors, including motion, environmental, and biometric sensors, to observe older adults’ movements, daily activities, and vital signs (Stavropoulos et al., 2020). These digital systems enable older adults to track their motor health and engage with physical exercise, enhancing their control over themselves and their ability to self-manage, allowing them to have healthy, active ageing and ageing in place (Blandford, 2019; Moon et al., 2020).

Despite advances in the variety of digital self-management systems for motor health, older adults tended to abandon them after a short time and refused to use them long-term due to limited user-centric design strategies (Greenhalgh et al., 2017). Previous studies have focused more on the functional design of digital self-management systems, often overlooking older adults' perceptions and preferences regarding the visualisation of content and required functional features. Thus, this study aimed to answer "Question 1: What are main stakeholders' (including older adults and physiotherapists) perceptions and requirements on the functionality design (content, technology, materials, functions, interface design features of different functionalities) for digital self-management systems used for older adults' motor health management?" by exploring older adults' perceptions, attitudes and requirements on the education, assessment and physical exercise functionalities, identifying the demographic information, content and function features affecting older adults' willingness to use the digital self-management systems for motor health. The research results are expected to provide knowledge for user-centric design strategies and promote the application and adoption of digital health management systems among older adults, thereby improving their motor health, quality of life, and well-being.

4.2. Methods

4.2.1. Survey Design

Three cross-sectional surveys were conducted to explore older adults' perceptions, attitudes and requirements on functionalities of digital self-management systems for motor health, as shown in Figure 9.

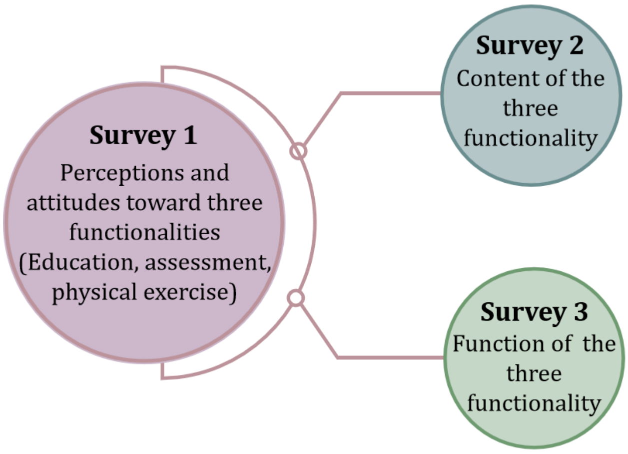


Figure 9. The research structure of surveys

The first survey included nineteen questions to explore older adults' perceived usefulness and acceptance regarding three functionalities of digital self-management systems. In detail, the first part involved seven demographic items, including gender, age, education levels, living arrangement, monthly income, health status, and fall history in the last year. The second part included twelve questions using a five-point Likert scale (1 = strongly disagree; 5 = strongly agree) to quantify older adults' perceived usefulness of the functionalities (including education, assessment and physical exercise) in self-managing motor health and increasing motor health knowledge, as well as trust in and willingness to use the three specific functionalities (Jokisch et al., 2022).By integrating the theory of protection motivation, the task-technology fit model, and the technology acceptance model, the second survey aimed to identify the factors affecting older adults' acceptance of digital self-management systems for motor health and further develop the content of three functionalities. In addition to the demographic information (gender, age, education levels, living arrangement, monthly income, health status), sixteen hypotheses (H) were identified, and the proposed research model is shown in Figure 10.

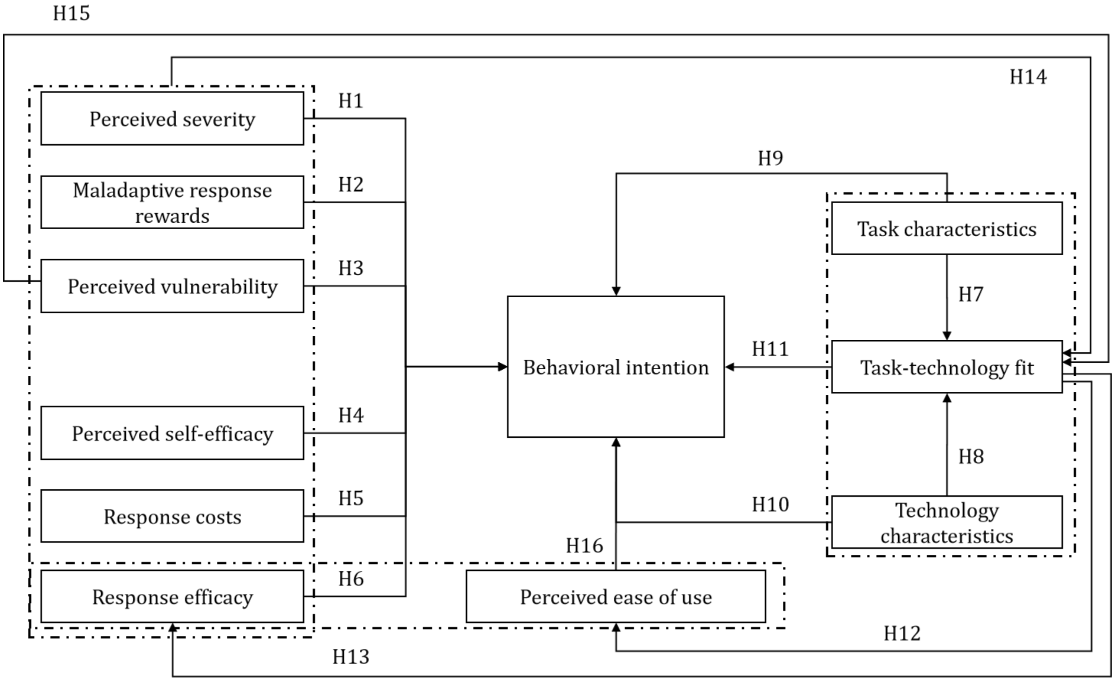


Figure 10. The proposed research model

The protection motivation theory, a widely used educational framework in health education, suggests that individuals' motivation to engage in protective behaviours depends on both threat appraisal and coping appraisal (Ong et al., 2023). Threat appraisal includes the perceived severity of the health threat, the perceived vulnerability to the threat, and the anticipated rewards of continuing maladaptive behaviours. In contrast, coping appraisal involves the perceived efficacy of the recommended protective behaviour, the individual's self-efficacy in performing the behaviour, and the perceived costs associated with the behaviour (Rakhshani et al., 2024). The task-technology fit model emphasises the alignment between task requirements and technological capabilities in determining technology effectiveness (Yu & Chen, 2019). It suggests that a better fit between task needs and system features leads to higher usage and improved performance. The Technology Acceptance Model is a foundational framework for understanding users' acceptance of information systems (H. Wang et al., 2022). In the model, perceived usefulness and perceived ease of use shape users' attitudes and influence their intention to use the system. The sources and scale items of the questionnaires are shown in Table 3. A 5-point Likert scale from 1 ("strongly disagree") to 5 ("strongly agree") was used to measure the proposed research model.

Table 3. Questionnaire items for the proposed research model

Constructs	**Items**
Perceived vulnerability (PV) (Zhang et al., 2020)	PV1: I am at risk of suffering from motor health problems, such as falls. PV2: It is likely that I will suffer motor health problems. PV3: It is possible for me to suffer motor health problems.
Perceived severity (PS) (Zhang et al., 2020)	PS1: If I suffer from motor health problems, then it would be severe. PS2: If I suffer from motor health problems, then it would be serious. PS3: If I suffer from motor health problems, then it would be significant.
Maladaptive response rewards (MRR) (Ruthig, 2016)	MRR1: Being physically inactive allows me to conserve energy. MRR2: Being physically inactive allows me to save time for doing other things that I enjoy. MRR3: Being physically inactive helps ensure that I won't strain, injure, or overexert myself.
Perceived self-efficacy (PSE) (Plotnikoff & Higginbotham, 2002)	PSE1: Be able to have adequate physical exercise even when you have many demands at work or many home duties. PSE2: Be able to have adequate physical exercise even though you are feeling depressed. PSE3: Be able to have adequate physical exercise even if you have to do it by yourself.

	PSE4: Be able to have adequate physical exercise even when you become bored with the activities.
	PSE5: Be able to have adequate physical exercise even if you can’t notice improvement in your fitness.
	PSE6: Be able to have adequate physical exercise even if you feel a little tired.
Response efficacy/Perceived usefulness (RE) (Zhang et al., 2020)	RE1: The digital self-management system works in solving these motor health problems.
	RE2: The digital self-management system is effective in solving these motor health problems.
	RE3: In the digital self-management system, solving these motor health problems is more likely to be guaranteed.
Response costs (RC) (Ruthig, 2016)	RC1: Physical exercise makes me too tired.
	RC2: Physical exercise takes too much time.
	RC3: Physical exercise leads to less time for family/friends.
	RC4: Physical exercise makes me looking awkward.
	RC5: Physical exercise costs too much.
Task characteristics (TC) (Yu & Chen, 2019)	TC1: I need to obtain intuitive feedback on my motor health level.
	TC2: I need to conduct the following learning to improve my self-management level for motor health.
	TC3: I need to display my motor health status and interact with others.
	TC4: I need to manage my motor health management goals.
Technology characteristics (TEC) (Yu & Chen, 2019)	TEC1: The digital self-management system provides anytime and immediate services.
	TEC2: The digital self-management system provides scientific and instructional services.
	TEC3: The digital self-management system provides private and social services.
Task-technology fit (TTF) (Yu & Chen, 2019)	TTF1: In helping me to manage motor health, the functions of digital self-management system are appropriate.
	TTF2: In helping me to manage motor health, the functions of digital self-management system are sufficient.
	TTF3: In general, the functions of the digital self-management system fully meet my motor health management needs.
Perceived ease of use (PEOU) (H. Wang et al., 2022)	PEOU1: Learning to use this digital self-management system is easy for me.
	PEOU2: I find it easy to get the digital self-management system to do

	what I want them to do. PEOU3: It is easy for me to become skilful at using the digital self-management system. PEOU4: I find the digital self-management system easy to use.
Behavioural intention (BI) (H. Wang et al., 2022)	BI1: I intend to use this digital self-management system when I need it in the future. BI2: I predict that I will use this digital self-management system in the future. BI3: I plan to use this digital self-management system in the future.

To explore older adults' attitudes and requirements regarding the functions of the three functionalities in the digital self-management system, a third survey was conducted based on a set of digital technology features (Suh & Li, 2022). The technology feature set includes data management features, activity control features, and social interaction features, totalling 12 features. The first part of the survey collected demographic information, including gender, education, living arrangement, monthly income, health status, and experience with digital motor management systems. The second part involved 12 questions regarding the perceived usefulness of the function features and one question on older adults' willingness to use the digital self-management system. The 13 questions were measured with a 5-point Likert scale from 1 ("strongly disagree") to 5 ("strongly agree").

To ensure the suitability and clarity of the questions, two designers and one human factor expert reviewed the surveys. After incorporating their suggestions, several improvements were made to the surveys. Following a preliminary assessment, the final version of the surveys was deemed appropriate for older adults and capable of eliciting precise answers to the research questions. Older adults

4.2.2. Participants

Older adults with familiarity using digital devices were recruited as participants in this study. The inclusion criteria for participants were: 1) aged 60 years or above; 2) able to use electronic communication devices. The exclusion criteria were: 1) aged below 60 years, and 2) with limited technological proficiency or internet access. All participants gave their informed consent. The Institutional Review Board of The Hong Kong Polytechnic University approved this study.

4.2.3. Data Collection

The data were collected through three large-scale cross-sectional surveys. Participants were recruited through a third-party management service platform (www.wjx.com), a widely used online survey platform in China. Non-probability and convenience sampling method was used to recruit older adults. The platform distributed the survey link through its user database, which includes individuals who have voluntarily participated in surveys and research activities.

Moreover, to ensure high-quality collected data and eliminate duplicate entries, the survey responses were configured to prevent multiple submissions from the same IP address and to verify unique respondent identifiers. The demographic features of respondents, including gender, age group, and region, were also recorded for subsequent data checking. After collecting the data, several quality control procedures were also implemented. Firstly, responses were excluded: 1) their completion time was excessively short (less than one-third of the median duration); 2) any items were unanswered. Then, the characteristics of responses were manually reviewed in accordance with the inclusion and exclusion criteria for participants. Finally, responses with outliers were also excluded based on the boxplot analysis and manual inspection. Data validation was also conducted through internal consistency and construct validity test. For multiple-item measures, Cronbach's α coefficients and item loadings of confirmatory factor analysis exceeded 0.7, indicating adequate reliability and construct validity.

4.2.4. Data Analysis

Descriptive statistics were first applied to obtain an overview of participants' demographic information, perceptions, attitudes and requirements. Then, Friedman's tests were used to compare older adults' perceptions and attitudes towards the three functionalities of digital self-management systems for motor health. Post hoc pairwise comparisons were conducted using the Bonferroni correction to adjust the significance level in cases where a significant difference was found. Ordinal logistic regressions were performed to assess the impact of demographic information on perceptions and attitudes, as well as the impact of perceptions on older adults' intention to use the digital self-management system. All statistical analyses were performed with IBM SPSS v26 (SPSS Inc.; Chicago, IL, USA). A significance level of $p < 0.05$ was set in all statistical analyses. In addition, a partial least squares structural equation modelling was used to test the proposed research model with SmartPLS 3.0 (SmartPLS GmbH, Boenningstedt, Germany). The internal consistency reliability, convergent validity, and discriminant validity were assessed to verify the model. Internal consistency was considered acceptable when Cronbach's α coefficients exceeded 0.7 (H. Wang et al., 2022). Convergent validity was confirmed when all item loadings were above 0.7, and both composite reliability and average variance extracted values were higher than 0.7 and 0.5, respectively (H. Wang et al., 2022). The structural model was evaluated by estimating path coefficients and test their significance using a bootstrapping procedure with 5000 resamples. Additionally, coefficients of determination (R^2) were calculated to reflect the amount of variance explained by the predictor factors (H. Wang et al., 2022).

4.3. Results

4.3.1. Demographic Information of Participants

Table 4 presents the demographic characteristics of the 109 valid respondents (female = 33; mean age = 64.50 ± 4.50 years) from the first survey. Approximately half of the participants were aged between 60 and 64 years old (56.0%) and had achieved an undergraduate degree (51.4%). The majority of older adults (78%) lived with their family members. Three-fifths of the participants had a moderate monthly income or over. Around 60% of older adults had chronic diseases, such as diabetes, asthma, and hypertensive disorders. Additionally, one in seven participants reported experiencing falls in the past year.

Table 4. The demographic information of the first survey (n=109)

Characteristics		**Number (percentage %)**
Gender	Female	33 (30.3%)
	Male	76 (69.7%)
Age	60~64 age	61 (56.0%)
	65~69 age	31 (28.4%)
	70~74 age	15 (13.8%)
	75~80 age	2 (1.8%)
Education	Primary or below	2 (1.8%)
	Junior secondary	14 (12.8%)
	Secondary	34 (31.2%)
	Undergraduate	56 (51.4%)
	Postgraduate or above	3 (2.8%)
Living arrangement	Alone	19 (17.4%)
	With family members	85 (78.0%)
	With relatives	2 (1.8%)
	In care institutions	3 (2.8%)
Monthly income	Low	22 (20.2%)
	Moderate	45 (41.3%)
	High	29 (26.6%)
	Extremely high	13 (11.9%)
Health status	Chronic diseases	64 (58.7%)
	No diseases	45 (41.3%)
Fall history	None	94 (86.2%)
	At least one time	15 (13.8%)

Table 5 presents the demographic characteristics of the 465 valid respondents (female = 204; mean age = 63.40 ± 3.15 years) from the second survey. Approximately half of the participants were male (56%). The majority (about 80%) were educated to secondary level or above. Approximately 90% of older adults lived with their family members and had at least one chronic disease.

Table 5. The demographic information of the second survey (n=465)

Characteristics		**Number (percentage %)**
Gender	Female	204(43.9%)
	Male	261(56.1%)
Education	Primary or below	22(4.7%)
	Junior secondary	80(17.2%)
	Secondary	213(45.8%)
	Undergraduate	142(30.5%)
	Postgraduate or above	8(1.7%)
Living arrangement	Living alone	39(7.6%)
	Living with family members	420(90.9%)
	Living with relatives	1(0.2%)
	Living with caregivers	3(0.6%)
	In care institutions	2(0.4%)
Monthly income	Low	64(13.8%)
	Moderate	206(44.3%)
	High	152(32.7%)
	Extremely high	43(9.2%)
Health status	Chronic diseases	406(87.3%)
	No diseases	59(12.7%)

Table 6 presents the demographic characteristics of the 473 valid respondents (female=210; mean age = 63.43 ± 3.03 years) in the third survey. Around 96% of the participants were aged between 60 and 70 years, with a male-to-female ratio of approximately 1:1. Four-fifths of the participants had secondary education or above. The majority lived with family members at home (90%) and had chronic diseases (88%). Approximately 10% of participants came from low-income backgrounds. All participants had experience using digital motor management systems, and half of them used smartphone-based exercise applications.

Table 6. The demographic information of the third survey (n=473)

Characteristics		**Number (percentage %)**
Gender	Female	210(44.4%)
	Male	263(55.6%)
Education	Primary or below	24(5.0%)
	Junior secondary	82(17.3%)
	Secondary	186(39.3%)
	Undergraduate	172(36.3%)
	Postgraduate or above	9(1.9%)
Living arrangement	Living alone	36(7.6%)
	Living with family members	430(90.9%)
	Living with caregivers	4(0.8%)
	In care institutions	3(0.6%)
Monthly income	Low	58(12.2%)
	Moderate	211(44.6%)
	High	157(33.1%)
	Extremely high	47(9.9%)
Health status	Chronic diseases	418(88.3%)
	No diseases	55(11.6%)
Digital motor management systems usage experience	Smartphones	305(55.7%)
	Smart watches	10(1.8%)
	Smart exercise bands	53(9.7%)
	Smart exercise garments	17(3.1%)
	Exergaming devices (such as Wii Balance Board or Xbox)	104(19.0%)
	Smart gym equipment	59(10.8%)

4.3.2. Older adults' Perceived Usefulness and Behavioural Intention towards the Functionalities

Figure 11 shows older adults' perceived usefulness of three functionalities (education, assessment and physical exercise) in self-managing motor health. All three functionalities received positive recognition from the recruited older adults, with the education functionality achieving the highest score, averaging 3.56. According to the results of Friedman's tests, there was no statistically significant difference in older adults' perceived usefulness of functionalities in self-managing motor health (*p*=0.061). The result indicates that education, assessment, and physical exercise are all important for motor health management, which highlights the necessity of providing a comprehensive solution that integrates all three functionalities.

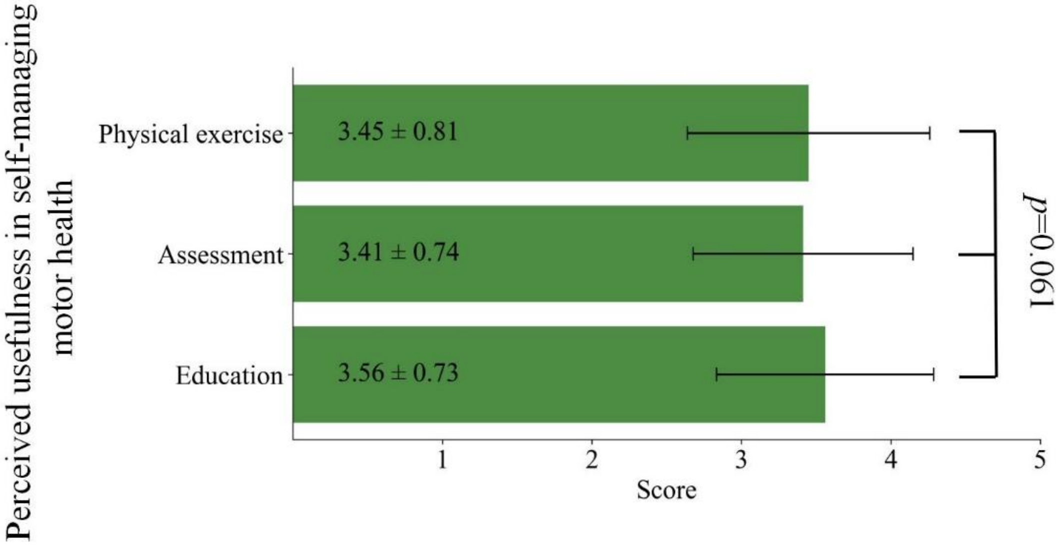


Figure 11. Perceived usefulness in self-managing motor health

As shown in Figure 12, no statistically significant differences existed in older adults' perceived usefulness of education, assessment, and physical exercise in increasing motor health knowledge (*p*=0.449). Older adults also showed positive attitudes towards the usefulness of the three functionalities, with an average score of around 3.6. These findings reveal that older adults emphasise the complementary value of each functionality in supporting their understanding of motor health. Therefore, digital self-management systems should involve all three functionalities.

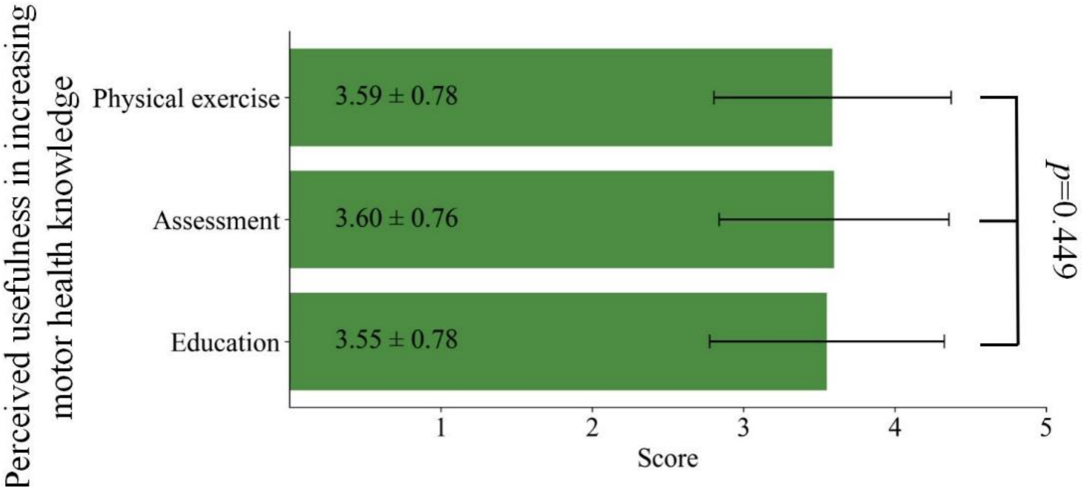


Figure 12. Perceived usefulness in increasing motor health knowledge

In terms of older adults' trust in the content of education, assessment and physical exercise, they tended to believe the results and visualised contents in the three functionalities, with average scores exceeding 3.2 (see Figure 13). There is also no statistically significant difference in older adults' trust in the three functionalities (p=0.084). However, older adults seem to be more likely to believe the assessment results (Score=3.36±0.78), suggesting that they consider the assessment feedback to be objective or credible.

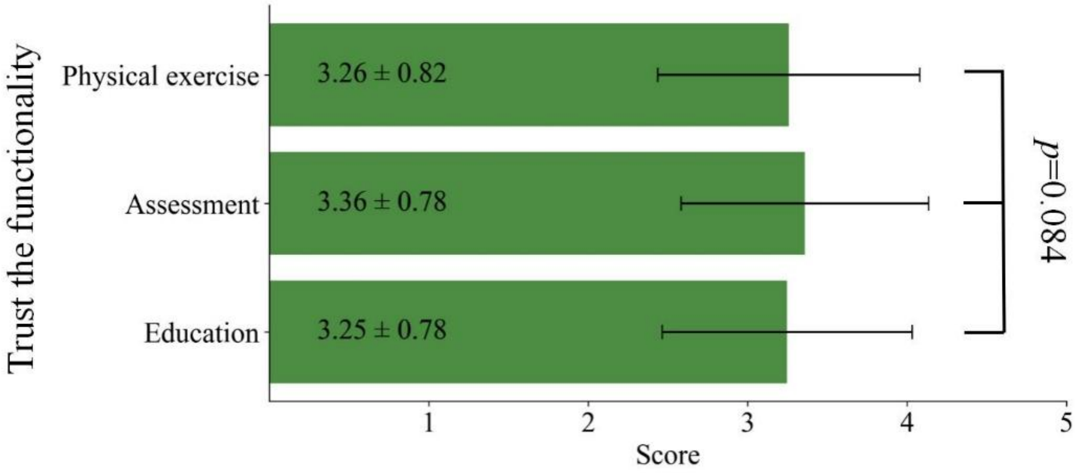


Figure 13. Older adults' trust in the content of the three functionalities

As shown in Figure 14, older adults expressed a willingness to use education, assessment, and physical exercise functionalities if they have opportunities to use them in the future. Based on the p-value of Friedman’s tests, no statistically significant differences existed in participants’ willingness to use the three functionalities (p =0.706). The balanced willingness towards the three functionalities suggests that older adults have a similar level of acceptance for education, assessment and physical exercise in the digital self-management systems for motor health. Therefore, digital self-management systems that integrate these functionalities can encourage more comprehensive participation from older adults in motor health management, without the risk of reduced user acceptance.

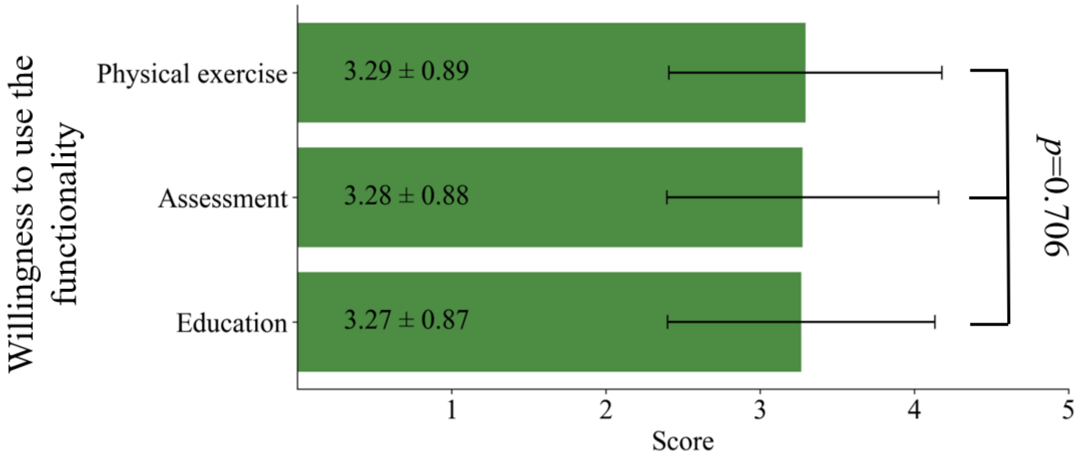


Figure 14. Older adults' willingness to use the three functionalities

As shown in Figure 15, older adults tended to have a positive attitude towards the usefulness of the functions in helping self-managing motor health (3.91±0.83). The activity control features (4.08±0.74) achieved the highest score, followed by the data management function features (4.07±0.70) and social interaction function sets (3.68±0.91). In detail, older adults were more likely to believe that data analysis, performance feedback, and activity reminders can help enhance self-management for motor health. Data analysis provides motor health assessment and physical exercise analysis, helping older adults understand changes in their motor capabilities and physical exercise performance, thereby adjusting their self-management plans to promote motor health. Performance feedback can offer personalised guidance based on an individual's physical exercise performance, helping them maximise the effectiveness of physical exercise and reduce the risk of accidents such as injuries or falls. Activity reminders include reminders about physical exercise and health behaviours, helping older adults develop personalised health behaviour programs and establish regular exercise habits.

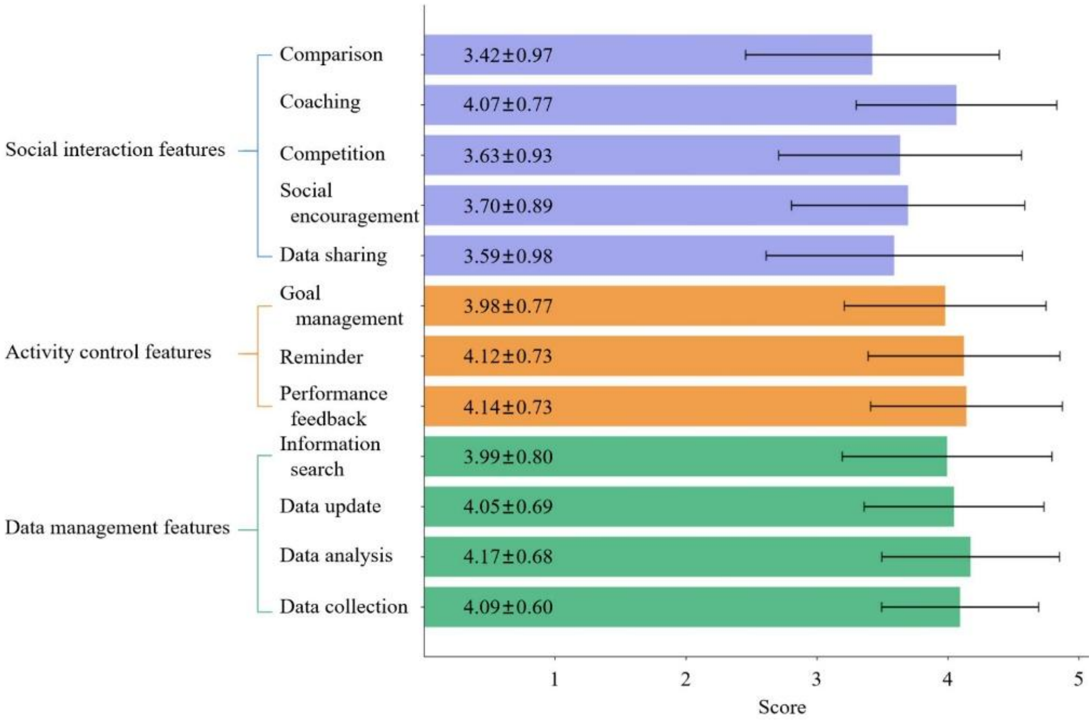


Figure 15. Older adults' perceived usefulness of function features

4.3.3. Factors Affecting Older Adults' Intention to Use the Digital Self-Management Systems

Table 7 shows the results of the ordinal logistic regression model for the first survey. Demographic information showed no significant effect on the perceived usefulness of the education and physical exercise functionalities in self-managing motor health (all *p*-values> 0.05). However, compared to older adults living with relatives, those living in care institutions tended to believe that assessment functionality could significantly help them self-manage their motor health (OR = 333.33, $\chi^2 = 7.31$, $p = 0.01$). The findings emphasise the importance of context in the use of digital health management systems among older adults. Institutional settings may or may not limit older adults' opportunities for individual autonomy and personalised health feedback. Thus, the assessment functionality serves as an important tool for regaining control over motor health and enhancing self-management by providing structured feedback and progress tracking. Conversely, individuals living with family members benefit from informal supervision and encouragement, reducing reliance on formal assessment tools.

Table 7. The impact of demographic information on the perceived usefulness of three functionalities in self-managing motor health

Demographic information	**Education**		**Assessment**		**Physical exercise**	
	P	**OR (95% CI)**	***P***	**OR (95% CI)**	***P***	**OR (95% CI)**
Gender (Reference=Male)						
Female	0.29	1.79 (0.61, 5.28)	0.08	0.41 (0.15, 1.10)	0.61	1.32 (0.46, 3.74)
Age (Reference=75~80 years)						
60~64 years	0.49	0.33 (0.01, 7.78)	0.15	0.10 (0.00, 2.36)	0.27	0.17 (0.01, 3.97)
65~69 years	0.88	0.77 (0.03, 19.43)	0.24	0.14 (0.01, 3.68)	0.37	0.23 (0.01, 5.73)
70~74 years	0.54	2.88 (0.10, 86.49)	0.56	0.37 (0.01, 10.65)	0.96	1.09 (0.03, 34.88)
Education (Reference=Postgraduate and above education)						
Primary education or below	0.20	16.74 (0.23, 1220.48)	0.97	0.93 (0.01, 58.44)	0.36	0.13 (0.00, 9.86)
Junior secondary education	0.83	1.38 (0.08, 25.15)	0.49	0.37 (0.02, 6.26)	0.16	0.11 (0.00, 2.41)
Secondary education	0.16	7.07 (0.46, 109.51)	0.86	1.26 (0.09, 17.62)	0.59	0.46 (0.03, 7.99)
Undergraduate education	0.14	7.04 (0.53, 94.44)	0.43	2.76 (0.23, 33.78)	0.75	1.56 (0.10, 25.03)
Living status (Reference=Living in elderly care institutions)						
Living alone	-	-	0.11	0.08 (0.00, 1.75)	0.79	1.46 (0.09, 25.18)
Living with family members	-	-	0.20	0.15 (0.01, 2.74)	0.44	2.86 (0.20, 40.57)
Living with relatives	-	-	0.01	0.00 (0.00, 0.2)	0.27	0.11 (0.00, 5.66)
Income (Reference= Extremely high)						
Low	0.52	0.54 (0.08, 3.51)	0.37	2.23 (0.38, 13.00)	0.58	1.73 (0.25, 12.17)
Moderate	0.64	1.48 (0.28, 7.71)	0.93	0.93 (0.21, 4.04)	0.90	0.90 (0.17, 4.82)
High	0.06	0.21 (0.04, 1.06)	0.21	0.39 (0.09, 1.70)	0.11	0.27 (0.05, 1.36)
Health status (Reference=No diseases)						
Chronic diseases	0.28	0.59 (0.23, 1.53)	0.89	0.94 (0.40, 2.23)	0.26	1.67 (0.69, 4.07)
Fall history (Reference=fall at least one time)						
None	0.26	2.53 (0.50, 12.73)	0.77	1.24 (0.30, 5.23)	0.28	2.27 (0.52, 9.94)

Notes: ORs in table are based on model reference groups; some textual descriptions present inverse comparisons for clarity.

As shown in Table 8, similar results of the ordinal logistic regression model were observed regarding the perceived usefulness in increasing motor health knowledge. Only older adults living in care institutions significantly tended to believe that assessment functionality could help them increase motor health knowledge (OR = 75.79, $\chi2 = 4.04$, $p = 0.04$), compared to those living with relatives. The remaining demographic information showed no statistically significant impact on older adults' perceived usefulness of the three functionalities in increasing motor health knowledge.

Table 8. The impact of demographic information on the perceived usefulness of three functionalities in increasing motor health knowledge

Demographic information	**Education**		**Assessment**		**Physical exercise**	
	P	**OR (95% CI)**	***P***	**OR (95% CI)**	***P***	**OR (95% CI)**
Gender (Reference=Male)						
Female	0.27	1.81 (0.64, 5.17)	0.37	0.64 (0.24, 1.7)	0.40	1.56 (0.55, 4.37)
Age (Reference=75~80 years)						
60~64 years	0.81	0.68 (0.03, 15.49)	0.28	0.17 (0.01, 4.42)	0	0 (0, 0)
65~69 years	0.90	1.22 (0.05, 29.28)	0.36	0.21 (0.01, 5.84)	0	0 (0, 0)
70~74 years	0.37	4.73 (0.16, 143.17)	0.71	0.51 (0.02, 16.76)	-	0 (0, 0)
Education (Reference=Postgraduate and above education)						
Primary education or below	0.61	0.32 (0, 24.24)	0.16	0.05 (0, 3.37)	0.11	0.03 (0, 2.25)
Junior secondary education	0.52	0.37 (0.02, 7.58)	0.15	0.11 (0.01, 2.2)	0.26	0.18 (0.01, 3.7)
Secondary education	0.93	1.13 (0.07, 18.93)	0.41	0.31 (0.02, 5.1)	0.64	0.5 (0.03, 8.56)
Undergraduate education	0.92	1.14 (0.08, 17.15)	0.99	1.03 (0.07, 14.67)	0.92	1.15 (0.08, 17.69)
Living status (Reference=Living in elderly care institutions)						
Living alone	-	-	0.10	0.08 (0.00, 1.65)	-	-
Living with family members	-	-	0.31	0.22 (0.01, 4.03)	-	-
Living with relatives	-	-	0.04	0.01 (0.00, 0.9)	-	-
Income (Reference= Extremely high)						
Low	0.83	1.22 (0.20, 7.41)	0.11	4.37 (0.71, 27.03)	0.53	1.80 (0.28, 11.5)
Moderate	0.64	1.45 (0.31, 6.77)	0.50	1.68 (0.37, 7.64)	0.59	1.54 (0.32, 7.50)
High	0.65	0.71 (0.16, 3.15)	0.81	0.83 (0.19, 3.63)	0.44	0.55 (0.12, 2.50)

Health status (Reference=No diseases)						
Chronic diseases	0.56	0.76 (0.31, 1.89)	0.81	1.11 (0.46, 2.67)	0.49	1.37 (0.56, 3.32)
Fall history (Reference=fall at least one time)						
None	0.40	1.97 (0.40, 9.59)	0.48	1.69 (0.40, 7.13)	0.64	1.45 (0.31, 6.79)

Table 9 presents the results of the ordinal logistic regression model regarding older adults' trust in the content and results of the three functionalities. Compared to individuals with a healthy status, older adults with chronic diseases were more likely to trust assessment (OR = 2.75, χ^2 = 5.70, p = 0.02) and physical exercise functionalities (OR = 2.65, χ^2 = 5.46, p = 0.02), respectively. There was no statistically significant effect of the remaining demographic information on the trust of older adults in the three functionalities.

As shown in Table 10, only gender exhibited a statistically significant effect on older adults' willingness to use the physical exercise functionally (OR = 2.57, χ^2 = 4.07, p = 0.04). Women were 2.57 times more likely than men to use the physical exercise functionality in digital self-management systems for motor health. Other demographic information had no statistically significant effect on the trust of older adults in the three functions (all p-values> 0.05). This finding indicates gender-based differences in motor health behaviour and technology-assisted physical exercise interventions.

Table 9. The impact of demographic information on older adults' trust in the content of the three functionalities

Demographic information	**Education**		**Assessment**		**Physical exercise**	
	P	**OR (95% CI)**	***P***	**OR (95% CI)**	***P***	**OR (95% CI)**
Gender (Reference=Male)						
Female	0.82	1.12(0.45,2.78)	0.59	0.78(0.32,1.92)	0.84	1.10(0.45,2.69)
Age (Reference=75~80 years)						
60~64 years	0.85	0.75(0.04,15.20)	0.35	0.24(0.01,4.87)	0.52	0.37(0.02,7.41)
65~69 years	0.52	0.36(0.02,7.74)	0.26	0.17(0.01,3.68)	0.41	0.27(0.01,5.79)
70~74 years	0.30	0.18(0.01,4.40)	0.16	0.10(0.00,2.45)	0.36	0.23(0.01,5.40)
Education (Reference=Postgraduate and above education)						
Primary education or below	0.70	2.19(0.04,114.89)	0.66	0.40(0.01,21.63)	0.35	0.15(0.00,7.77)
Junior secondary education	0.54	2.31(0.16,33.72)	0.68	1.76(0.12,26.39)	0.72	0.62(0.04,9.00)
Secondary education	0.76	1.48(0.12,18.05)	0.88	0.83(0.07,10.39)	0.36	0.31(0.03,3.80)
Undergraduate education	0.35	3.10(0.29,33.15)	0.65	1.75(0.16,19.28)	0.73	0.66(0.06,7.07)
Living status (Reference=Living in elderly care institutions)						
Living alone	0.63	1.91(0.14,26.23)	0.81	0.72(0.05,10.14)	0.50	0.40(0.03,5.79)
Living with family members	0.43	2.67(0.23,30.94)	0.87	1.23(0.10,14.53)	0.57	0.48(0.04,5.84)
Living with relatives	0.93	0.85(0.02,34.74)	0.69	0.47(0.01,19.55)	0.42	0.21(0.01,8.98)
Income (Reference= Extremely high)						
Low	0.83	1.21(0.23,6.40)	0.54	1.67(0.32,8.68)	0.92	1.09(0.21,5.61)
Moderate	0.87	1.13(0.28,4.63)	0.46	1.69(0.42,6.75)	0.86	0.88(0.22,3.53)
High	0.92	1.08(0.26,4.38)	0.92	1.07(0.27,4.23)	0.80	0.83(0.21,3.30)
Health status (Reference=No diseases)						
Chronic diseases	0.18	1.74(0.77,3.96)	0.02	2.75(1.20,6.32)	0.02	2.65(1.17,5.98)
Fall history (Reference=fall at least one time)						
None	0.85	1.13(0.30,4.22)	0.56	1.48(0.39,5.52)	0.88	1.10(0.30,4.07)

Table 10. The impact of demographic information on older adults' willingness to use the three functionalities

Demographic information	**Education**		**Assessment**		**Physical exercise**	
	P	**OR (95% CI)**	***P***	**OR (95% CI)**	***P***	**OR (95% CI)**
Gender (Reference=Male)						
Female	0.83	0.91(0.37,2.20)	0.93	1.04(0.43,2.53)	0.04	2.57(1.03,6.42)
Age (Reference=75~80 years)						
60~64 years	0.86	0.76(0.04,14.11)	0.91	0.84(0.04,16.23)	0.88	1.26(0.07,23.81)
65~69 years	0.48	0.34(0.02,6.74)	0.45	0.31(0.02,6.35)	0.89	0.81(0.04,16.10)
70~74 years	0.31	0.20(0.01,4.39)	0.39	0.25(0.01,5.72)	0.75	0.60(0.03,13.33)
Education (Reference=Postgraduate and above education)						
Primary education or below	0.51	0.27(0.01,12.72)	0.83	0.66(0.01,30.66)	0.32	0.14(0.00,6.57)
Junior secondary education	0.38	3.27(0.23,46.25)	0.19	5.95(0.42,84.94)	0.92	0.87(0.06,12.10)
Secondary education	0.56	2.09(0.18,24.68)	0.52	2.25(0.19,26.52)	0.50	0.43(0.04,5.03)
Undergraduate education	0.28	3.65(0.35,38.17)	0.17	5.21(0.50,54.49)	0.92	0.89(0.09,9.12)
Living status (Reference=Living in elderly care institutions)						
Living alone	0.67	1.76(0.13,23.57)	0.76	0.66(0.05,8.92)	0.77	0.68(0.05,9.22)
Living with family members	0.60	1.92(0.17,21.78)	0.69	0.61(0.05,6.91)	0.87	0.81(0.07,9.37)
Living with relatives	0.95	0.89(0.02,35.27)	0.44	0.23(0.01,9.27)	0.54	0.31(0.01,12.37)
Income (Reference= Extremely high)						
Low	0.55	1.64(0.33,8.24)	0.96	0.96(0.19,4.92)	0.63	1.49(0.29,7.54)
Moderate	0.60	1.44(0.37,5.57)	0.91	0.92(0.23,3.65)	0.81	1.18(0.30,4.63)
High	0.75	1.24(0.32,4.77)	0.60	0.69(0.18,2.71)	0.34	1.94(0.49,7.61)
Health status (Reference=No diseases)						
Chronic diseases	0.62	1.22(0.55,2.70)	0.58	1.25(0.56,2.77)	0.07	2.09(0.94,4.66)
Fall history (Reference=fall at least one time)						
None	0.68	0.76(0.21,2.79)	0.85	1.13(0.31,4.13)	0.62	1.39(0.38,5.09)

Table 11 shows the results of internal reliability and convergent validity of the partial least squares structural equation modelling in the second survey. The values of Cronbach’s alpha and composite reliability were all greater than 0.7, reflecting a good internal reliability of the proposed research model. The factor loadings for each construct item exceeded 0.7, and the average variance extracted values were all higher than 0.5. The results indicate that the proposed research model has acceptable convergent validity.

Table 11. The internal reliability and convergent validity of structural equation modelling

Variables	**Items**	**Factor loading**	**Cronbach's alpha**	**Composite reliability**	**Average variance extracted**
Maladaptive response rewards	MRR1	0.87	0.80	0.88	0.71
	MRR2	0.86			
	MRR3	0.80			
Perceived ease of use	PEOU1	0.86	0.85	0.90	0.70
	PEOU2	0.72			
	PEOU3	0.87			
	PEOU4	0.89			
Response efficacy	RE3	0.88	0.84	0.90	0.758
	RE4	0.87			
	RE5	0.87			
Response costs	RC1	0.83	0.74	0.85	0.66
	RC2	0.81			
	RC3	0.80			
Perceived self-efficacy	PSE1	0.77	0.78	0.86	0.61
	PSE2	0.79			
	PSE3	0.78			
	PSE4	0.77			
Perceived severity	PS1	0.95	0.93	0.96	0.88
	PS2	0.94			
	PS3	0.94			
Task-technology fit	TTF1	0.82	0.72	0.84	0.64
	TTF2	0.79			
	TTF3	0.80			
Task characteristics	TC1	0.84	0.86	0.90	0.70
	TC2	0.85			
	TC3	0.80			

	TC4	0.86			
Technology characteristics	TEC1	0.89	0.86	0.91	0.78
	TEC2	0.87			
	TEC3	0.89			
Perceived vulnerability	PV1	0.95	0.93	0.96	0.88
	PV2	0.93			
	PV3	0.93			
Behavioural intention	BI1	0.84	0.78	0.87	0.69
	BI2	0.82			
	BI3	0.83			

Table 12 presents that the square root of the average variance extracted for each construct was all higher than its correlation coefficients with the other constructs, showing desired discriminant validity.

Table 12. Square roots of average variance extracted (in bold) and correlations among the constructs

Variables	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Behavioural intention	**0.83**										
Maladaptive response rewards	-0.34	**0.84**									
Perceived ease of use	0.48	-0.19	**0.84**								
Response efficacy	0.54	-0.21	0.42	**0.87**							
Response costs	-0.34	0.55	-0.20	-0.19	**0.81**						
Perceived self-efficacy	0.39	-0.34	0.46	0.25	-0.35	**0.78**					
Perceived severity	0.65	-0.22	0.33	0.51	-0.20	0.30	**0.94**				
Task-technology fit	0.55	-0.23	0.47	0.64	-0.26	0.35	0.43	**0.80**			
Task characteristics	0.60	-0.18	0.43	0.47	-0.15	0.33	0.54	0.47	**0.84**		
Technology characteristics	0.63	-0.18	0.43	0.49	-0.21	0.31	0.60	0.48	0.64	**0.88**	
Perceived vulnerability	0.59	-0.19	0.29	0.45	-0.21	0.24	0.58	0.39	0.48	0.50	**0.94**

Figure 16 and Table 13 show the results of hypothesis test and the effects of the constructs on behavioural intention to use the digital self-management systems. Except for the H4 and H6, the remaining proposed hypotheses were supported in the research model. The perceived severity (H1: $\beta=0.231$, $p<0.001$), maladaptive response rewards (H2: $\beta=-0.084$, $p=0.02$), perceived vulnerability (H3: $\beta=0.178$, $p<0.001$), response costs (H5: $\beta=-0.093$, $p=0.01$), task characteristics (H9: $\beta=0.136$, $p=0.002$), technology characteristics (H10: $\beta=0.153$, $p<0.001$), task-technology fit (H11: $\beta=0.113$, $p=0.003$), and perceived ease of use (H16: $\beta=0.106$, $p=0.005$) significantly influenced behavioural intention, respectively. In addition, the perceived severity (H14: $\beta=0.128$, $p=0.015$), perceived vulnerability (H15: $\beta=0.103$, $p=0.034$), task characteristics (H7: $\beta=0.219$, $p<0.001$), and technology characteristics (H8: $\beta=0.214$, $p<0.001$) were important antecedents of the task-technology fit. At the same time, the task-technology fit was also a significant determinant of response efficacy (H13: $\beta=0.637$, $p<0.001$) and perceived ease of use (H12: $\beta=0.472$, $p<0.001$).

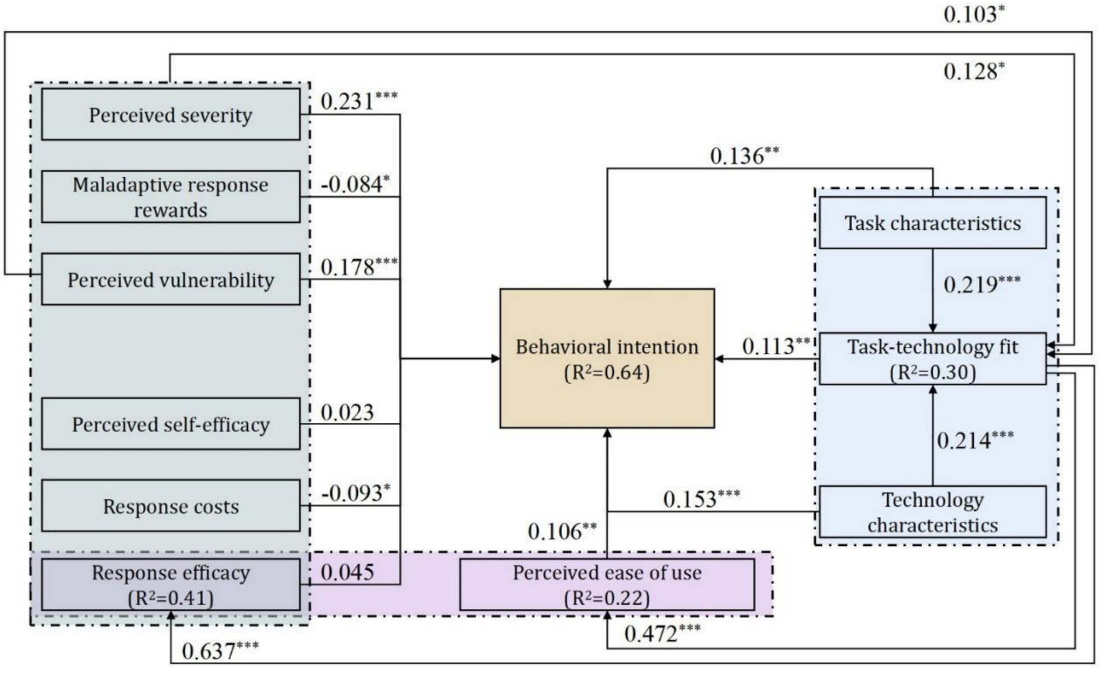


Figure 16. The results of the structural model (***$p<0.001$; **$p<0.01$; *$p<0.05$)

As shown in Table 13, maladaptive response rewards and response costs showed significantly negative effects on older adults' behavioural intention to use the digital self-management systems for motor health. Perceived severity yielded the largest total positive effect (0.255) on older adults' behavioural intention, followed by the perceived vulnerability (0.198) and task-technology fit (0.192). Response efficacy and perceived self-efficacy showed no significant total effect on behavioural intention.

Table 13. The direct, indirect and total effects of constructs on behavioural intention

Constructs	**Direct effect**	**Indirect effect**	**Total effect**
Maladaptive response rewards	-0.084*	-	-0.084*
Perceived ease of use	0.106**	-	0.106**
Response efficacy	0.045	-	0.045
Response costs	-0.093*	-	-0.093**
Perceived self-efficacy	0.023	-	0.023
Perceived severity	0.231***	0.024*	0.255***
Task-technology fit	0.113**	0.079**	0.192***
Task characteristics	0.136**	0.042**	0.178***
Technology characteristics	0.153***	0.041**	0.136***
Perceived vulnerability	0.178***	0.02	0.198***

Notes: ****p*<0.001; ***p*<0.01; **p*<0.05

Table 14 shows the results of the ordinal logistic regression model for the third survey. The greater the perceived usefulness of function features such as data collection (OR= 2.24, χ^2 = 22.40, p < 0.001), data analysis (OR= 1.66, χ^2 = 11.46, p < 0.001), data updating (OR= 1.34, χ^2 = 4.12, p = 0.04), information search (OR= 1.33, χ^2 = 5.57, p = 0.02), performance feedback (OR= 1.54, χ^2 = 10.54, p = 0.001), and activity reminders (OR= 1.85, χ^2 = 22.56, p < 0.001) in supporting motor self-management, the more likely older adults were to express a willingness to use digital self-management systems for motor health. On average, a one-unit increase in perceived usefulness was associated with a 124%, 66%, 34%, 33%, 54%, and 85% greater likelihood that older adults would intend to use digital self-management systems, respectively. In terms of other function features, there was no significant impact of their perceived usefulness on older adults' willingness to use digital self-management systems for motor health.

Table 14. The impact of perceived usefulness of functionality features on older adults' willingness to use digital self-management systems for motor health

Functionality Features	χ^2	***P***	**OR**	**95% CI for OR**
Data collection	22.40	<0.001	2.24	(1.60, 3.12)
Data analysis	11.46	<0.001	1.66	(1.24, 2.22)
Data update	4.12	0.04	1.34	(1.01, 1.78)
Information search	5.57	0.02	1.33	(1.05, 1.69)
Performance feedback	10.54	0.001	1.54	(1.19, 2.00)
Reminder	22.56	<0.001	1.85	(1.44, 2.39)
Goal management	0.23	0.63	1.06	(0.83, 1.36)
Data sharing	0.65	0.42	1.09	(0.89, 1.33)
Social encouragement	0.91	0.34	0.90	(0.72, 1.12)
Competition	0.70	0.40	0.91	(0.74, 1.13)
Coaching	3.56	0.06	1.26	(0.99, 1.60)
Comparison	3.85	0.05	0.81	(0.66, 1.00)

4.4. Discussions

Older adults in this study presented similar positive attitudes towards the perceived usefulness of education, assessment, and physical exercise functionalities in self-managing motor health, and expressed a willingness to use digital self-management systems for motor health in the future. This consistent recognition across different functionalities suggested that older adults have recognised the potential of digital technologies to support their autonomy and physical health in daily activities (Ienca et al., 2021). However, different from previous research findings (Liu & Tao, 2022; Petr Balog et al., 2023), which highlighted significant influences of demographic factors such as age, gender, or education level on older adults' acceptance and engagement with digital healthcare devices, this study found that demographic information appeared to have a negligible effect on older adults' perceptions, attitudes, and behavioural intentions regarding the three functionalities.

The perceived severity, maladaptive response rewards, perceived vulnerability, response costs, task characteristics, technology characteristics, task-technology fit, and perceived ease of use have a significant effect on older adults' behavioural intention to use the digital self-management systems for motor health. Previous research has emphasised the role of perceived severity and vulnerability in motivating health-related behaviours (Ong et al., 2023). However, Dickinson et al suggested that many older adults underestimate the seriousness of falls and motor impairments, especially for individuals without fall experience (Dickinson et al., 2011). Limited older adults recognised motor health problems as a medical issue requiring professional attention (Dickinson et al., 2011). Moreover, maladaptive response rewards, such as the perceived convenience of avoiding physical exercise or maintaining the current lifestyle, can discourage proactive behaviour for motor health management (Ong et al., 2023). Moreover, response costs also play a significant role in encouraging older adults to perform health behaviours. Older adults can better address the perceived severity if they perceive less response costs of physical exercise or fall prevention strategies (Taheri-Kharameh et al., 2020). Thus, education functionality included the contents of these domains, motivating older adults to perform health behaviours and enhance self-management for motor health.

A strong task-technology fit can increase the likelihood of digital self-management systems adoption among older adults (Yu & Chen, 2019). When functionalities align well with older adults' actual needs and daily routines, the increased perceived usefulness and engagement encourage older adults to use the digital systems to manage their motor health. In addition, perceived ease of use is also a key predictor of technology adoption (H. Wang et al., 2022). Older adults with low technical familiarity or declining cognitive abilities are often intimidated by complex interfaces (Liu et al., 2021). Therefore, user-centric design strategies, including intuitive navigation, adaptive feedback, and simplified interaction, are critical to promoting widespread adoption of the digital self-management systems.

Furthermore, this study found that the functions of data collection, data analysis, data updating, information search, performance feedback, and activity reminders significantly impact older adults' willingness to use the digital self-management systems for motor health. Additionally, considering the task characteristics of managing motor health goals, a function feature of goal management was included. Thus, a total of 7 function features were integrated into the three functionalities in Chapters 6 and 7.

Based on the above-mentioned findings, a unified system design method was adopted in the subsequent Chapters 6 and 7, focusing less on demographic segmentation and more on universal usability, functional alignment, and evidence-based behavioural motivators, as seen in Figure 17. This approach simplifies the system development process and enhances scalability and deployment efficiency in real-world environments such as community centres, clinics, or long-term care facilities.

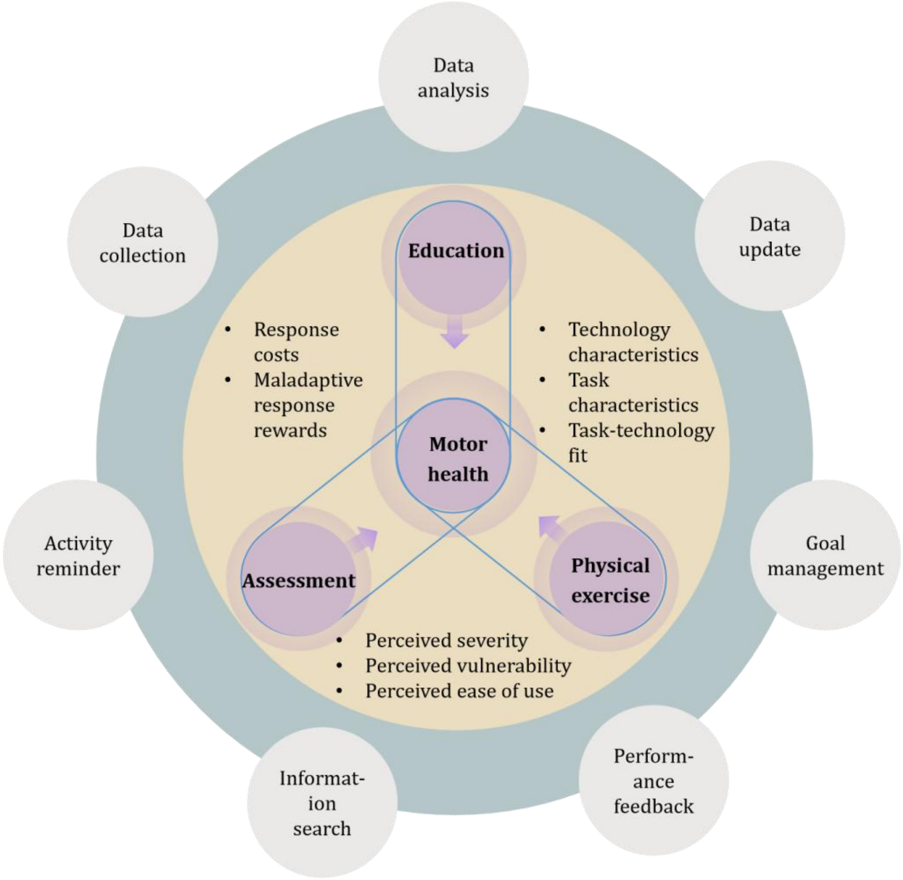


Figure 17. The identified content and functions for three functionalities in the digital self-management systems

4.5. Summary

This Chapter conducted three surveys to explore older adults' perceptions and requirements on the functionalities of digital self-management systems for motor health. Older adults generally had positive attitudes to the perceived usefulness of education, assessment and physical exercise functionalities. They also expressed trust and willingness to use these functionalities to manage their motor health. The content of the functionalities should be designed to increase older adults' perceived severity and vulnerability to motor impairments, as well as reduce the response costs and maladaptive response rewards associated with physical exercise and health behaviours. The digital self-management system's task and technology characteristics, along with a strong task-technology fit, should also be optimised to ensure functional alignment with older adults' requirements. High perceived ease of use is another important consideration in supporting effective interaction and promoting sustained use among older adults. Moreover, the three functionalities should include the functional features of data collection, data analysis, data updating, information search, performance feedback, and activity reminders to fit older adults' requirements for digital self-management systems. The findings in this Chapter were further used to develop the design elements and principles in Chapter 6.

CHAPTER 5: PHYSIOTHERAPISTS' PERSPECTIVES ON DIGITAL SELF-MANAGEMENT SYSTEMS FOR MOTOR HEALTH

5.1. Introduction

Recent advancements in information and sensor technologies have enabled more accessible and practical methods for motor health assessment among older adults (Howcroft et al., 2017; Latorre et al., 2019). Particularly, wearable and optical sensors have emerged as cost-effective and non-invasive devices for capturing gait and balance data across diverse environments (Latorre et al., 2019). Numerous studies have investigated the potential of sensor-based data collection and motor assessment during traditional clinical motor tests (Howcroft et al., 2017; Shahzad et al., 2017). By combining statistical methods or artificial algorithms, these studies were expected to automatically assess older adults' motor performance, reduce physiotherapists' work burden and achieve home-based motor assessment.

Despite promising progress, few digital motor assessment systems have been applied in practice due to a lack of consideration from the side of physiotherapists and limited explanation of results (Beauchet et al., 2017; Das et al., 2022). Consequently, there is a lack of understanding of the workflow of clinical motor assessment and interventions, as well as the critical gait or balance metrics for motor assessment. Therefore, this study aimed to address the following research question from a clinical perspective: "Question 1: What are the main stakeholders' (including older adults and physiotherapists) perceptions and requirements on the functionality design (content, technology, materials, functions, interface design features of different functionalities) for digital self-management systems used for older adults' motor health management?" A semi-structured interview was conducted with physiotherapists to gain insights into the clinical practices and processes of motor assessment and physical exercise interventions, and to explore their perspectives and suggestions on the use of digital self-management systems for promoting motor health in older adults. The findings are expected to bridge the gap between clinical expertise and technological development.

5.2. Methods

5.2.1. Semi-structured Interview Design

According to previous studies and the conceptual model of digital healthcare systems (Lee et al., 2022; Nwankwo et al., 2021), the semi-structured interview referred to demographic information, workflow of motor assessment and physical exercise treatments, perceptions on the application of digital self-management systems in daily motor health management, suggestions and concerns regarding the digital self-management systems. After the pilot interview with two physiotherapists, two experts assessed the clarity and validity of the items and provided appropriate modifications. The final construct of the semi-structured interview is shown in Table 15.

Table 15. The design of semi-structured interviews with physiotherapists

Dimension	Items
Demographic information	Age
	Gender
	Education
	Educational background
	Work experience duration
	Work institutes
Motor assessment	Workload
	Work process
	Clinical tests
	Critical body parts and metrics of gait balance, and muscle strength for motor health assessment (five-point Likert scale: 1 = strongly disagree; 5 = strongly agree)
	Difficulties
Motor health treatments (Physical exercise)	Workload
	Work process
	Physical exercise programs
	Considerations
Perceptions on digital self-management systems	Potential usefulness of digital self-management system in aiding motor assessment (five-point Likert scale: 1 = strongly disagree; 5 = strongly agree)
	Trust the assessment results of digital self-management systems for motor assessment (five-point Likert scale: 1 = strongly disagree; 5 = strongly agree)
	Willingness to use digital self-management systems for motor assessment
Suggestions and concerns regarding digital self-management systems	Suggested home-based interventions
	Issues of digital self-management systems in remote motor management

5.2.2. Participants

Physiotherapists with certificates were recruited as participants in this study. The participants were included if they: 1) obtained a physical therapist certificate, and 2) had experience in treating motor impairments among older adults (over 60 years). According to a previous study on interviews with physiotherapists (Nwankwo et al., 2021), a sample size of 20 is enough for data saturation. Verbal consent was obtained from all participants prior to the interviews. The Institutional Review Board of The Hong Kong Polytechnic University approved this procedure. Informed consent was sought and obtained from each participant. Confidentiality and anonymity of the data were assured.

5.2.3. Data Collection

The participants were recruited using convenience sampling methods. Each physiotherapist was invited to conduct a single online semi-structured interview via Zoom. The semi-structured interviews, which lasted around 60 minutes, were video recorded by a professional researcher following the final design of the semi-structured interview.

5.2.4. Data Analysis

The recorded conversations were transcribed into content data. The quantitative data regarding perceptions were also extracted from the texts. Both content analysis and statistical analysis were used in this study. Categories and themes were identified by coding the texts. The content analysis involved grouping and assigning descriptive codes, category labels, and interpretations to words, phrases, sentences, or whole paragraphs related to the motor management process and perceptions. Statistical analyses, such as descriptive analyses and the Wilcoxon paired test, were used to analyse demographic information and physiotherapists' perceptions of the digital self-management systems.

5.3. Results

5.3.1. Demographic Information of Participants

Twenty physiotherapists (female=6; mean age = 32.80±4.20 years) were included in the data analysis of this study. The demographic information of the 20 participants is shown in Table 16. Men accounted for the majority of participants (70%). All participating physiotherapists had a bachelor's degree or higher, with 65% having completed graduate studies. The majority of the included physiotherapists (95%) had received formal training in rehabilitation science, and fifteen held qualifications in physical therapy. On average, physiotherapists had 9.6 years of professional experience (standard deviation (SD) = 4.5), with individual experience ranging from 6 to 19 years. Additionally, approximately 70% of the included physiotherapists were employed by elderly care centres.

Table 16. The demographic information of 20 physiotherapists (n=20)

Demographic information		**Number (percentage)**
Gender	Female	6 (30%)
	Male	14 (70%)
Education	Undergraduate	7 (35%)
	Postgraduate or above	13 (65%)
Educational background	Rehabilitation Science	19 (95%)
	Physical Therapy	15 (75%)
	Clinical Medicine	4 (20%)
	Nursing	1 (5%)
	Chinese Medicine	1 (5%)
Work experience duration	1~5 years	3 (15%)
	6~10 years	10 (50%)
	11~15 years	5 (25%)

	Above 16 years	2 (10%)
Work institutes	Elderly care centres	14 (70%)
	Public hospitals	3 (15%)
	Private rehabilitation clinics	3 (15%)

5.3.2. Physiotherapists’ Clinical Experience on Motor Health Management Among Older Adults

As shown in Table 17, almost all physiotherapists (95%) reported that they have provided motor health management services in older adults’ homes. All physiotherapists (100%) also worked in institutional settings such as elderly centres or clinics. There was a considerable variation in the duration of motor health assessments, ranging from 5 minutes to 60 minutes. The average duration of motor health assessment was 26.18 minutes. The duration of physical exercise treatments also showed a considerable variation, ranging from 5 to 80 minutes, lasting an average of 38.61 minutes. Traditionally, the included physiotherapists conducted motor health assessments for older adults approximately once every 14 weeks.

Table 17. Motor assessment and physical exercise in clinical practice

Motor care information		Min	Max	Number (Percentage)/Mean (SD)
Workplace	Older adults’ home	-	-	19(95%)
	Institutes	-	-	20(100%)
Assessment time/minutes		5	60	26.18(14.31)
Physical exercise time/minutes		5	80	38.61(18.30)
Traditional assessment duration/week		4	48	14.10 (11.74)

The commonly used clinical tests (Berg balance scale (BBS), Three Meters Timed Up and Go test (3TUG), Five Times Sit to Stand Test (5STS), Activities-Specific Balance Confidence Scale (ABC), Functional Gait Assessment (FGA), Balance Evaluation Systems Test (BESTest), walking test, Tinetti test, Romberg test) for motor assessment by physiotherapists are shown in Figure 18. Physiotherapists emphasised that assessing older adults' gait and balance ability is a multifaceted process involving various factors, such as assessment methods, reference scores, individual circumstances, and therapist experience. BBS was the most frequently selected one with a frequency of 20, followed by 3TUG, 5STS, and the walking test, with frequencies of 16, 15, and 13, respectively. The remaining tests were less selected. Physiotherapists selected the Berg balance scale (BBS) test due to its comprehensive assessment of balance, ease of administration, and proven sensitivity in identifying balance impairments. As the gold standard for balance assessment (Klima & Hood, 2020), BBS rated balance on a scale of 0 to 56, where a change of 3 to 4 points was considered standard for improvement or deterioration. The Five Times Sit to Stand Test (5STS) typically assesses changes in older adults' motor ability by comparing the number of repetitions. In the Three-Meter Timed Up and Go test (TUG), a 5 to 10-second increase in completed time may indicate a decline in older adults' motor ability, while step count and turning phase should also be considered. In the Romberg and Walking tests, performance during the test and gait were the primary consideration, rather than time or scores.

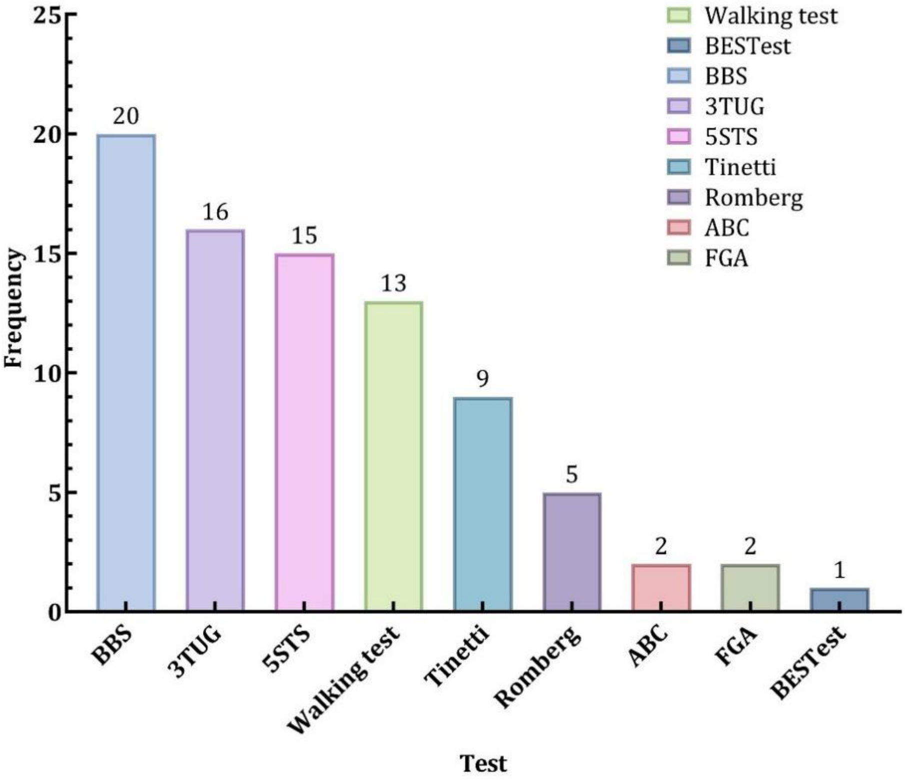


Figure 18. The clinical tests used for motor assessment

As shown in Table 18, 15 parts were identified to investigate physiotherapists' clinical understanding of the reference value and features of these body parts for motor health assessment. Based on the results, there were some variabilities in which body parts and joints were considered important for gait and balance assessment in older adults. The five most recommended body joints and points were the pelvis (17), knee (14), foot (13), waist (10), and ankle (9).

Physiotherapists reported that the movement of the shoulders and elbows can affect arm swing during walking, which can affect gait and balance. The shoulder has minimal impact on gait and balance compared to the waist and pelvis.

Moreover, if older adults use a walking aid, such as a cane or walker, physiotherapists will further examine the hands and spine to ensure that the person can adequately control the aid. The waist and spine are essential for examination for movement and limitations that could affect gait and balance. Its shape, stiffness, and flexibility can affect older adults' ability to rotate their torso during walking. The waist affects spinal alignment and provides stability during walking. Any pain or conditions affecting the waist, such as nerve compression, can also affect gait and balance.

The pelvis is a crucial body part for gait and balance assessment. It connects and stabilises the lower limbs to the spine and supports the body's weight, affecting stability and support during walking. The movement of the pelvis during walking can affect older adults' COM and increase the risk of falls. Thus, symmetry and balance of the pelvis are important for gait and balance. The stability and support the pelvis provides during walking contribute to maintaining balance and good posture.

> *'They often have problems with their lumbar spine, leading to the pelvis walking at an incorrect angle.'* (PT4)

> *'If the muscles surrounding the pelvis are well-controlled, their overall centre of gravity, balance, and gait will naturally improve.'*(PT10)

The strength and condition of the abdominal muscles also affect balance. The strength and condition of the abdominal muscles contribute to the core muscles. Muscles around the pelvis, including those in the buttocks and abdomen, must be controlled to maintain balance and good posture. The hip joint's strength and flexibility, including its range of motion, are also important, and any issues with the COM can cause the person to lean forward or to one side.

> *'A wider hip joint or feet clamped together will affect their base support stability."* (PT6)

> *'I would generally look at the overall range of the hip joint, including internal and external rotation, and an aspect that few people pay attention to is the range of extension.'* (PT5)

The size, strength, and height of the thigh muscles contribute to the overall strength and stability of the lower body and are important for maintaining balance. The thigh muscles work with other lower-body muscles, such as the hips, knees, and lower legs, to support the body during walking. It is important to examine the thighs for any muscle weakness or loss of strength that could impact motor health.

> *'If the thigh is lifted too high or too low, it can affect the gait, possibly due to insufficient strength.'* (PT13)

The condition, characterised by the ability to bend, straighten, twist, or experience instability of the knee joint during walking, affects gait and balance. Assessing the knee joint for excessive bending or deformities while standing or walking is important. The condition of the knees, including any degeneration or inflammation, can affect gait and balance. The PT may examine the degree of flexion or extension of the knee joint and check for deformities or signs of muscle atrophy.

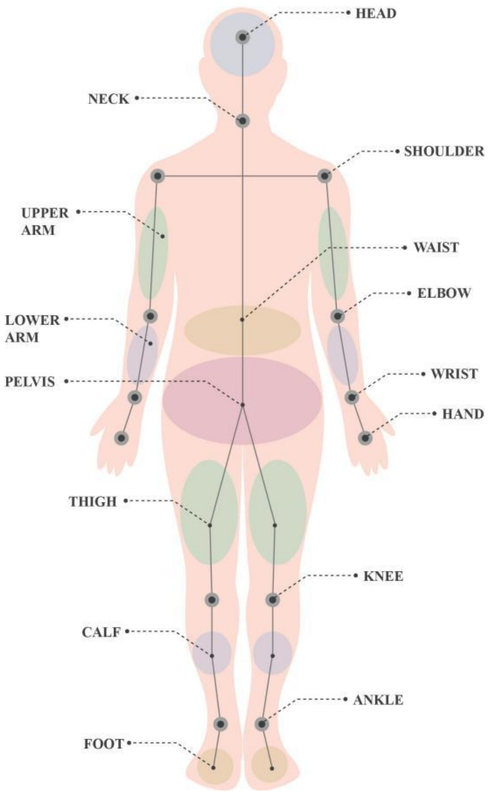
> *'The knee joint should be examined for swelling, as inflammation is common in older adults. If normal, check the range because this can affect the hip area and posture, such as whether it can be straightened. How well they can bend and straighten affects balance and gait.'* (PT7)

Any signs of muscle atrophy or swelling in the lower legs can affect the ability to generate force when stepping, affecting gait and balance. The tension or tightness of the muscles in the lower legs, including the calves and shins, must be symmetrical and in good condition to maintain balance and stability during walking. The lower leg muscles, ankle joint, and feet are always considered whole for gait and balance assessment.

The mobility and stability of the ankle joint and the condition of the feet play a vital role in maintaining support and mobility during walking, which is necessary for maintaining balance. Any issues with the ankle joint, such as inflammation, degeneration, inward rolling, or flattening of the foot arches, increase the risk of falls. The support provided by the feet is important for balance, too, and any deformities or issues with the feet can affect gait and balance.

> *'Check for conditions like pronation, which could be due to flat feet or previous habits of twisting injuries. This could lead to some pronation when walking. If there is pronation while walking, naturally, it can cause twisting in the knee joint.' (PT15)*

Table 18. Critical body parts for motor health assessment



Body parts	Number	Percentage (%)
Head	1	5%
Shoulder	2	10%
Elbow	1	5%
Waist	10	50%
Pelvis	17	85%
Thigh	8	40%
Knee	14	70%
Calf	8	40%
Ankle	9	45%
Foot	13	65%

Figure 19 depicts the vital metrics for motor health assessment. Stride considerably affected motor assessment from the perspective of physiotherapists, with the highest mean value and standard deviation (SD) (3.85±0.75). Turning speed, with the highest mean value (3.85±0.67), the SD of turning speed was smaller than that of the stride, which shows there are smaller differences between most values and the mean. Secondly, gait rhythm was regarded as a second vital metric for motor assessment, with a mean and SD (3.80±0.77). Hallux valgus and foot declination were seen as the smallest impact of all the parameters, with a mean and SD (3.10±0.64).

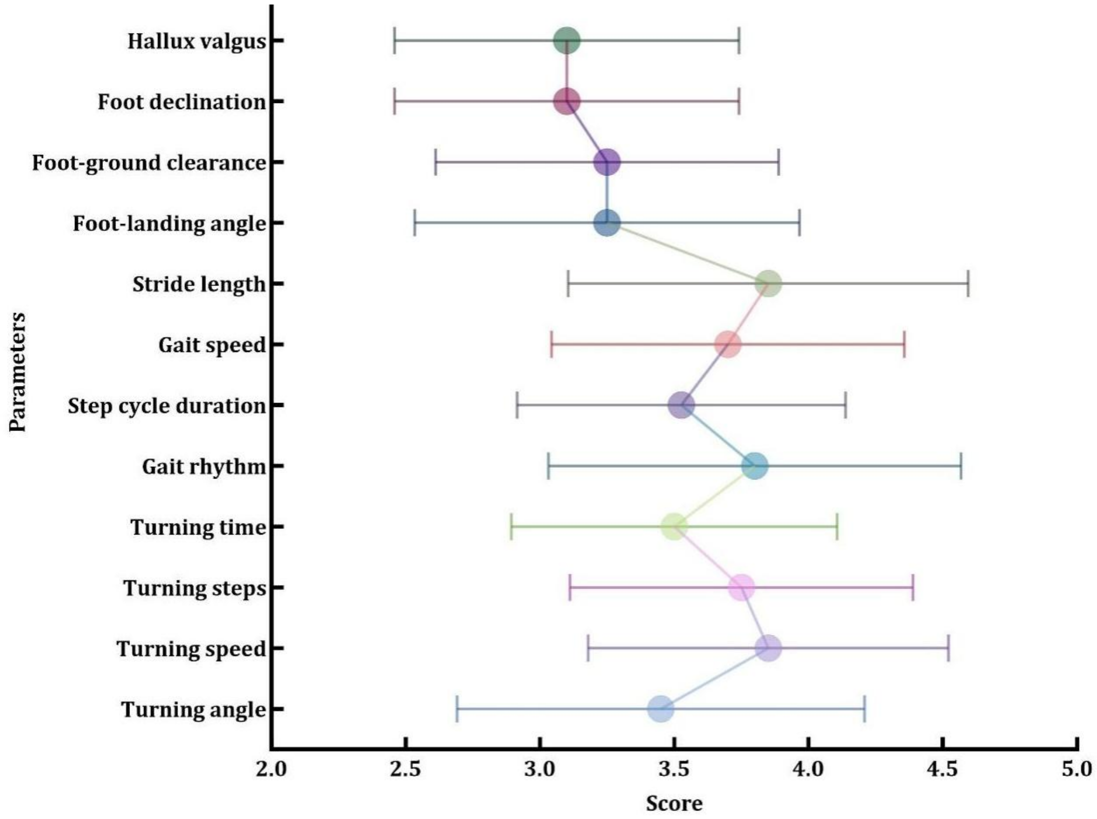


Figure 19. The vital metrics for motor health assessment

5.3.3. Physiotherapists' Suggestions on Digital Self-Management Systems for Motor Health

Figure 20 shows physiotherapists' perception of the importance of the metrics in motor health assessment. Among these metrics, the centre of gravity information was regarded as the most important parameter, with a mean of 4.15 and an SD of 0.49. Besides, pacing information (e.g., rhythm, foot clearance, etc.), and patient gait balance history record performed an essential role in motor assessment with a mean of 4.05 and SD of 0.60. In addition, muscle control information was recognised for its significant role in motor assessment, with a mean score of 4.00 (SD = 0.97). Other parameters, such as body joint angles, sway motion, plantar pressure, and physiological signals, were also noted but received relatively more moderate or variable importance scores. These findings reflect a preference for biomechanical and performance-based metrics in evaluating motor health among older adults.

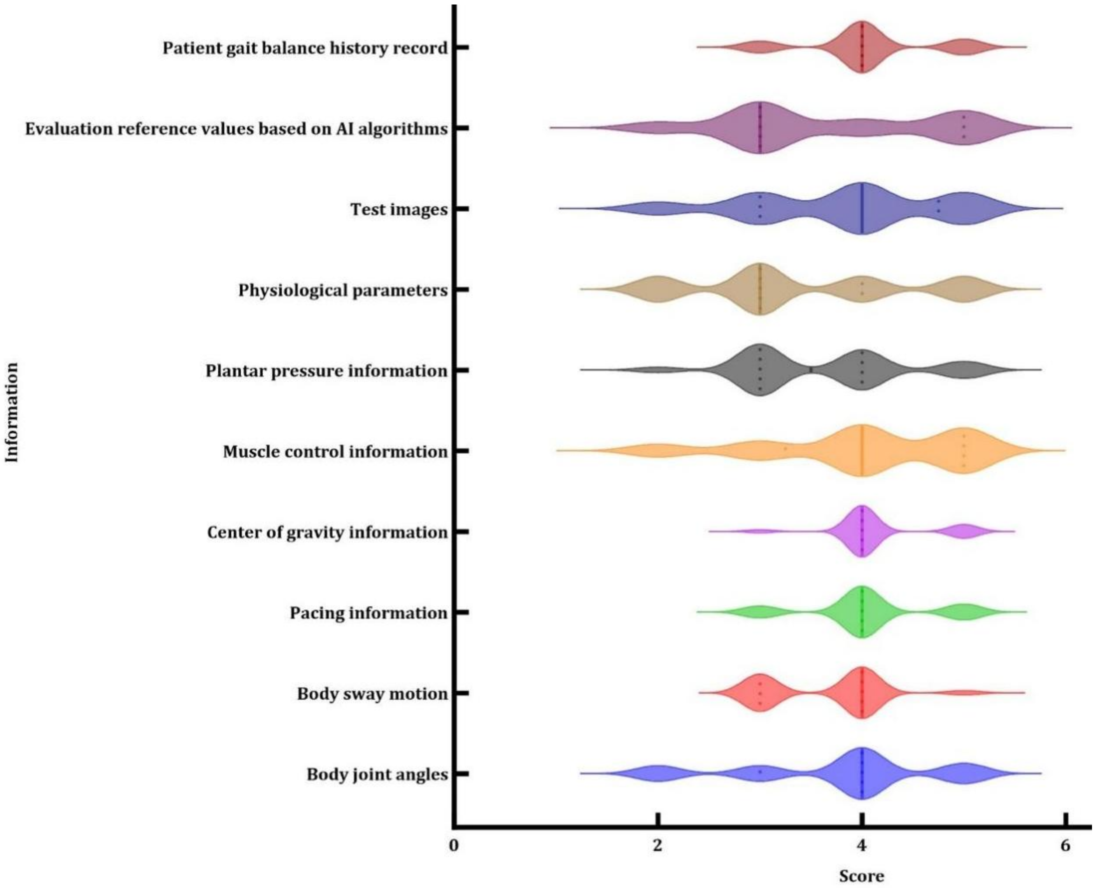


Figure 20. The critical metrics for motor health assessment

Figure 21 shows the issues concerned by physiotherapists for digital self-management systems. It can be extracted that older adults' safety was the most concerning issue (4.90±0.45). Exercise precision among older adults was the second issue for digital self-management systems, with a mean and SD of 4.20±0.70. Besides, the feedback accuracy of the systems was also important for STMMS (3.95±0.89). However, privacy was treated as the smallest issue (3.40±0.99).

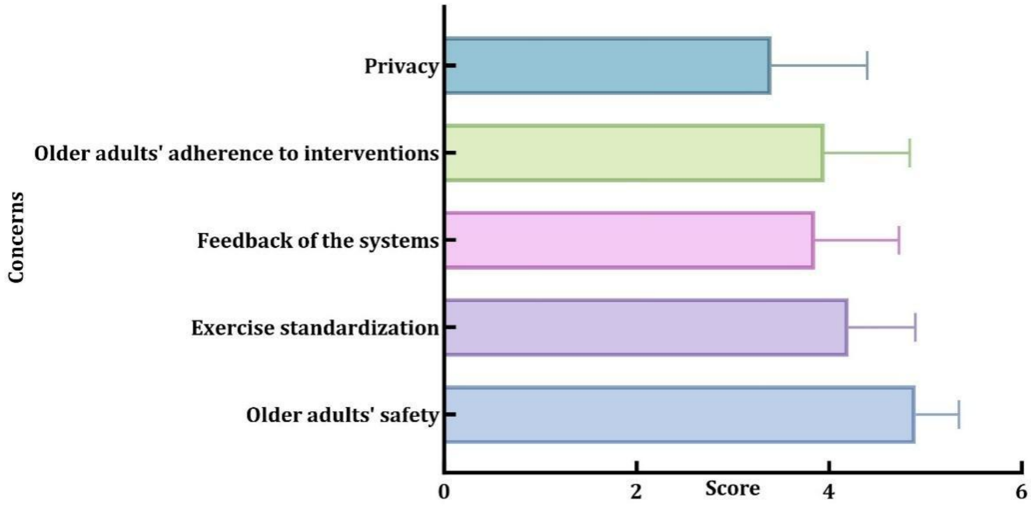


Figure 21. The issues concerned by physiotherapists for digital self-management systems

Figure 22 shows physiotherapists' perceptions of digital self-management systems in terms of trust and willingness to use them. Overall, the distribution of responses indicates that both trust in the systems' assessment results and willingness to use them are relatively high, with most responses concentrated above the 50% threshold. Specifically, the distribution of trust scores is more concentrated, indicating that physiotherapists maintained consistent levels of trust in the digital self-management systems for motor health. In contrast, the distribution of willingness to use is more widespread, with one outlier approaching 0%. Thus, while many physiotherapists were willing to use digital tools, a small number may have reservations or be constrained by specific circumstances, affecting their willingness to use them.

Figure 22. Physiotherapists' perceptions of the digital self-management systems

Figure 23 shows the results of Wilcoxon paired test on physiotherapists' suggested motor assessment duration between traditional motor health assessments and digital system-based motor health assessments. There was a statistically significant difference between the traditional motor assessment and digital system-based assessment (p=0.002). With the help of digital self-management systems, the suggested duration of motor health assessment was reduced from once every 14 weeks to once every 10 weeks. Notably, physiotherapists also highlighted the current limitations in motor management resources for older adults, as well as the potential of digital systems to support motor health management.

‘In fact, it is a matter of resources. If there are sufficient resources, it would be best to assess motor health once a week, but that is not possible.’ (PT1)

‘Currently, I conduct motor health assessments every three months because we lack sufficient physiotherapists, and the number of patient cases has skyrocketed. I hope that AI can help, which I think would be better.’ (PT8)

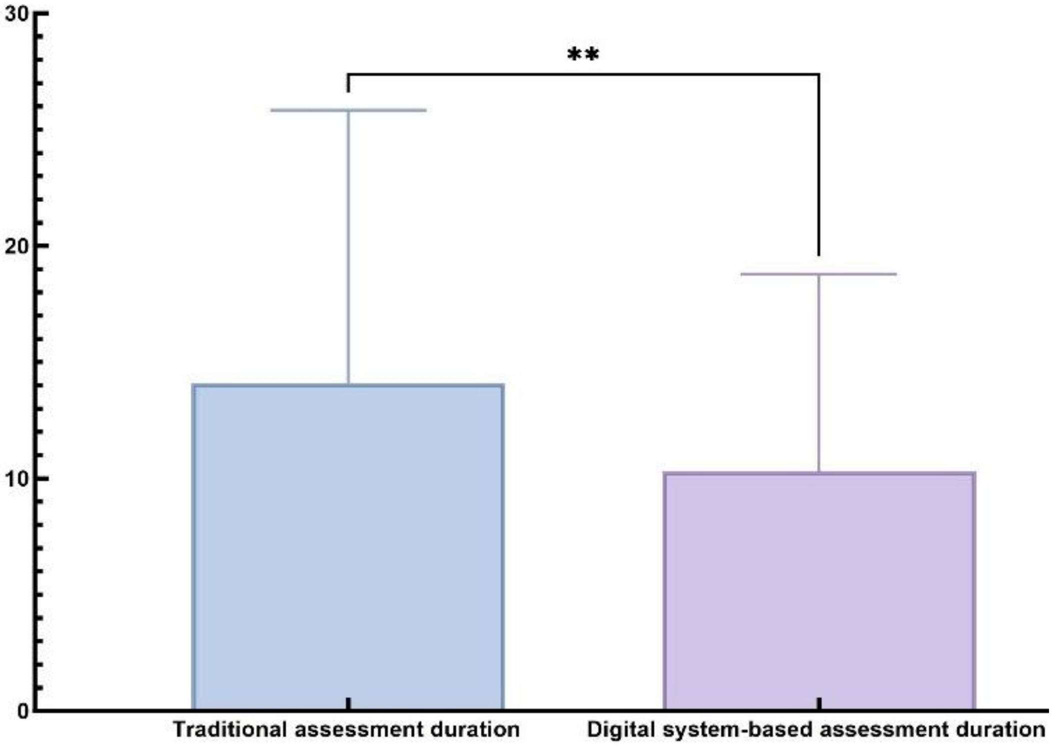


Figure 23. The duration of the motor health assessment

Table 19 shows the recommended physical exercise for older adults in home settings. Five categories of physical exercise (stretching, strength training, aerobic exercises, balance training, and functional task-oriented training) were commonly recommended for older adults to conduct at home. The selection of exercises was highly individualised and typically based on older adults' physical capacities (e.g., range of motion, muscle strength, and balance), functional demands, medical history, and environmental constraints. Physiotherapists also emphasise that muscle atrophy, joint stiffness, or mild balance disorders are also common in healthy older adults. Therefore, personalised intervention strategies should be developed based on an individual's physical health condition. In addition, physiotherapists recognized the potential and usefulness of digital self-management systems in helping older adults perform physical exercise at home.

> *'I usually start with their muscle strength and balance; if they can't stand independently, I won't give standing exercises.'* (PT1)

> *'Healthy older adults still tend to have some degree of muscle weakness or tightness, so we commonly do simple muscle test and range assessments before prescribing exercises.'* (PT13)

> *'It may be able to play videos demonstrating certain exercises, allowing older adults to review them at home at any time, thereby reducing the workload of physiotherapists.'* (PT14)

Table 19. Recommended home-based physical exercise

Exercise type	Purpose	Common examples/tools
Stretching	Improve flexibility, reduce stiffness, prevent contracture	Calf stretches, hamstring stretches, and upper limb motion
Strength training	Enhance muscle power and support daily activities	Quadriceps exercises, resistance bands
Aerobic exercises	Improve cardiovascular fitness and	Walking, stepping, cycling

	endurance	
Balance training	Reduce fall risk, improve postural control	Single-leg stance, Otago program
Functional task training	Improve the ability to perform activities of daily living and real-life tasks	Sit-to-stand, stair climbing, carrying groceries

Table 20 shows the difficulties and challenges mentioned by physiotherapists during motor health management for older adults. Physiotherapists reported that Hong Kong's dense living environment limits traditional motor health assessments. Sensor-based technologies, such as wearable inertial sensors and compact pressure sensors, can effectively mitigate these limitations and enhance the feasibility of home-based assessments (Edriss et al., 2024). Recent studies have highlighted the portability and flexibility of these technologies, which enable accurate assessments in small or confined spaces (Díaz et al., 2019).

Table 20. Challenges identified by physiotherapists in motor management

Challenges	**Descriptions**	**Quotations**
Non-technical challenges		
Environmental constraints	Limited space for assessments Lacking access to essential equipment	*'For elderly individuals who require home visits, their homes are usually relatively small, which may not allow for the necessary distance the assessment requires.'* (PT15) *'We may use a mobile phone to record the individual's gait and then thoroughly analyse it later to evaluate any potential issues.'* (PT6)
Safety concerns	Fall risk without assistance	*'Safety remains paramount for older adults. While it is important to push their limits, there is a fear of causing harm or injury.'* (PT18)
Patient cooperation	Cognitive, hearing, or comprehension issues Cultural discomfort with physical contact	*'Especially for elderly individuals experiencing cognitive decline, they may not fully understand or comprehend what is being communicated to them or the reasons behind the assessments being*

		suggested.' (PT3) *'Older adults often feel capable of walking and moving independently, questioning the need for additional assessments.'* (PT1)
Technical challenges		
Assessment method selection	Choosing appropriate methods for patients with multiple comorbidities	*'With multiple issues such as joint and back problems, knee complications, and the presence of a stroke or other neurological conditions, there are various overlapping concerns.'* (PT8)
Lack of standardisation	Inconsistent assessment methods Low generalizability of clinical tests	*'Individuals may have difficulty squatting down and may not meet the standard criteria. Despite this, they may have good walking abilities, rarely experience falls, and can climb mountains or stairs without issues. The best approach is to examine each component separately to gain a more comprehensive understanding.'* (PT9)

Safety is a primary concern when assessing older adults at risk of falls. Wearable sensors can enhance safety by providing real-time monitoring and fall detection during clinical tests and daily activities, enabling immediate interventions (Montesinos et al., 2018). Systems like G-STRIDE, integrating inertial sensors for continuous gait monitoring, have proven effective in identifying individuals with fall risks (García-Villamil et al., 2021). Additionally, it is challenging to engage older adults with cognitive impairments or cultural barriers in performing tasks accurately. Sensor-based instruments offer a less intrusive and more interactive approach to improve patient adherence (Jourdan et al., 2021). Wearable systems with user-friendly interfaces make the assessment process more accessible and acceptable for older adults (Zhao et al., 2023).

The diversity and overlapping of chronic diseases make it difficult for physiotherapists to identify a reliable and sensitive clinical test for gait and balance assessment. Furthermore, the minimal clinically important difference of a single test varies across diseases, complicating the selection of a universal tool. Recent research suggests that continuous monitoring of daily activities using sensor technologies can provide a more comprehensive evaluation (Ilg et al., 2024). This approach captures subtle changes in gait and balance that might be missed in clinical scenarios. Physiotherapists have also shown that current clinical tests can't accurately reflect an individual's actual motor functional abilities. Although sensor-based technology can provide objective and continuous data, there are still a few standardised protocols for specific tests and digital motor biomarkers, which limit their effectiveness and clinical practicality.

5.4. Discussions

From the perspective of physiotherapists' clinical practice in motor health management, older adults require ongoing and home-based assessment and physical exercise to maintain daily activity independence. However, the primary care resources for older adults remain significantly underserved, particularly in terms of providing routine motor assessments and personalised physical exercise plans. Therefore, technology-based solutions, such as digital self-management systems for motor health, can reduce the workload of physiotherapists and encourage motor care services to be delivered in community and home settings. The suggested design elements for motor evaluation and exercise functionalities by physiotherapists are shown in Figure 24.

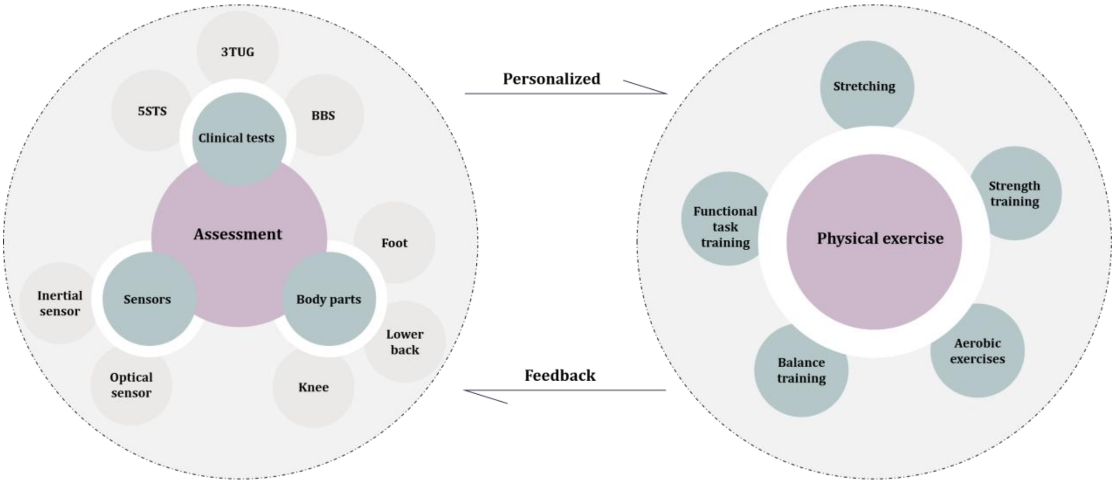


Figure 24. Physiotherapists' recommendations on assessment and physical exercise functionalities

In detail, traditional clinical tests for motor assessment tend to require intensive physiotherapist resources and time in primary care. Instruments providing objective and diverse indicators have been developed to assess motor performance based on clinical tests. For example, the accelerometer installed on shoes was verified to outperform the shoe pressure sensor and hip accelerometer in terms of the accuracy of predicted BBS (Tang et al., 2019). Inertial sensors were also commonly used to assess motor ability based on 5STS, TUG, and Walking tests (Montesinos et al., 2018; Tang et al., 2019). The lower back and shins were suggested as positions achieving excellent predictive performance (Montesinos et al., 2018).

With the development of wearable sensor-based gait and balance assessment, muscle status is typically assessed using surface electromyography sensors that detect and record the electrical signals generated by the underlying skeletal muscles during motion (Díaz et al., 2019). This technology offers a non-invasive method for assessing muscle activation patterns and fatigue, enabling physiotherapists to localise muscle injuries and identify the physiological mechanisms underlying gait and balance disorders (Mazzetta et al., 2019). Moreover, body coordination and centre of mass (COM) are commonly assessed by inertial or pressure sensors in instrumented tests (Díaz et al., 2019; Ilg et al., 2024). A previous study suggested that two-minute walking and 30-second standing tests with three inertial sensors (one at the pelvis and two on the feet) are reliable in assessing body coordination performance (Scott et al., 2007). The inertial sensors placed at the sternum or lower back were considered the optimised combination of assessing COM (Díaz et al., 2019).

The speed of the waist and spine and their jerk of turning during postural transitions, such as sit-to-stand, were significant objective biomarkers for identifying individuals with fall risk (Horak & Mancini, 2013). These instrument-based biomarkers from inertial sensors can help physiotherapists quantify the gait and balance performance and diagnose presymptomatic disease, tailoring individual treatments or prescriptions to prevent severe motor degeneration. Anticipatory postural adjustments, typically assessed by the force plate under the feet, have been verified to be highly associated with the mediolateral amplitude of accelerometers on the pelvis (Horak & Mancini, 2013). The smaller amplitude of accelerometers indicated bradykinetic anticipatory postural adjustments and a delayed onset of stepping. The subtle posture changes detected by sensors aid in the diagnosis and treatment of diseases like Parkinson's and Stroke. In addition, older adults with balance impairments tended to adopt hip motions to compensate for posture imbalance (M. Osoba et al., 2019). Based on assessments using inertial sensors, individuals with balance disorders exhibited significantly greater motion angles in both the medial-lateral and anterior-posterior directions.

In lower body strength assessments, such as the 5STS test, the movement of the thighs is particularly indicative of functional capacity (Doheny et al., 2013). Notably, a higher spectral edge frequency and greater variability in acceleration signals, especially in the anterior-posterior and medial-lateral directions, are associated with an increased risk of falls (Doheny et al., 2013). As muscle strength is difficult to measure in daily scenarios, motion sensors combined with clinical tests can assist in assessing thigh strength by quantifying thigh movement as assessment metrics. Moreover, conventional joint protractors can only measure the static angles of the knees. It is difficult for physiotherapists to quantify knee rotation during walking. Advanced techniques, such as strain gauges and inertial or optical sensors, have been developed to measure the dynamic and kinematic motion of the knee (Edriss et al., 2024). Compared with other positions, such as the thigh and feet, time-domain features extracted from the inertial signals of the lower legs achieved the best accuracy in identifying the walking patterns of participants with neurological disorders (Hsu et al., 2018). The angular velocity of lower legs during walking also significantly contributed to the recognition of fallers from non-fallers (Montesinos et al., 2018). Moreover, the decreased foot clearance also indicates shuffling among individuals with Parkinson's disease (Schlachetzki et al., 2017).

5.5. Summary

This chapter conducted semi-structured interviews among physiotherapists to obtain their professional suggestions for the functionality design of digital self-management systems. In summary, the current number of registered physiotherapists is insufficient to meet the growing demand for motor health assessments and physical exercise interventions among older adults. In this context, digital self-management systems offer a promising solution by empowering older adults to manage their motor health at home. These systems have the potential to improve older adults' motor ability, enhance their independence, and ultimately contribute to a higher quality of life. In detail, sensor technologies were suggested to combine with multiple clinical assessments (e.g., 3TUG, 5STS), providing quantified metrics of gait, balance and muscle strength performance. Inertial sensors placed at the lower back provide an effective measurement of the centre of mass, which is an essential metric for assessing gait and balance. Besides, upper body motion measured by inertial or optical sensors provides assessment metrics for static postural swing. The core body motion combined with clinical tests like the 5STS and BBS achieves great performance in measuring individuals' postural transitions and balance ability. The lower body motion metrics are related to the gait and posture coordination during dynamic activities. By combining multiple sensor signals from different body parts, we can better understand older adults' motor ability, enabling earlier detection of fall risk and more targeted therapeutic interventions. The findings provided insights into the design elements and principles developed in Chapter 6.

CHAPTER 6: DEVELOPMENT OF A FUNCTIONALITY DESIGN FRAMEWORK BASED ON SYSTEMS THINKING

6.1. Introduction

Motor health self-management is a complex process involving individual physical function, personal motivation, professional support, and the living environment (Bassola & Lusignani, 2017; Park et al., 2022). Without continued support from healthcare professionals like physiotherapists, older adults tend to have difficulties in doing regular and proper physical exercise, managing pain and maintaining motor health (Wicks et al., 2023). However, limited time and resources in clinical practice often hinder physiotherapists from delivering sustained and individualised motor care. In this context, digital self-management systems offer a promising alternative to support older adults in managing their motor health independently and continuously.

Despite the growing number of digital self-management devices for chronic disease and health management, few of them have a thorough consideration of the practical challenges encountered by older adults and clinicians in real-life settings. Additionally, there remains a lack of system-level thinking in this field. Most existing solutions focus on isolated parts of the problem, such as exercise instruction (Mao, Zhang, et al., 2024), balance assessment (Zhou et al., 2024), or user interface design (Liu et al., 2021). However, they ignored the interconnections among different parts of the motor self-management process, such as physical ability, healthcare access, and personal beliefs.

Systems thinking, an approach for examining dynamic relationships within a system, provides a structured way to understand the interconnections between different components of the motor health self-management process, as well as how changes in one area affect other areas (D. H. Meadows, 2008). This approach is particularly valuable in healthcare systems, where challenges are often complex and involve multiple stakeholders. By identifying feedback loops, interdependencies, and potential points of failure, systems thinking helps explain why motor health self-management may not succeed and highlights opportunities for more effective, system-level design (Morgan et al., 2024). Thus, this chapter used systems thinking tools (e.g., rich picture, CATWOE analysis) to analyse the current motor health self-management system and develop a functionality design framework for digital self-management systems.

Rich pictures are visual tools used in systems thinking to represent the key elements, relationships, and issues within a complex situation (Suryani et al., 2024). In this chapter, the motor health self-management system was first analysed from both the older adults' and the physiotherapists' perspectives. It includes key actors (older adults, physiotherapists), resources (devices, space, information), and the major barriers experienced in practice, such as limited space, low motivation or unclear instructions. This helps to understand the relationships and pain points in the system.

CATWOE analysis, a structured technique within Soft Systems Methodology (SSM), helps define a system by examining its purpose, structure, and constraints from multiple stakeholder perspectives (Checkland, 2000; Pidd, 1997). CATWOE analysis consists of six elements, including customers, actors, transformation process, worldview, owners, and environmental constraints, which together provide a comprehensive view of how a system operates and for whom it operates. By identifying who benefits or is affected (customers), who performs the activities (actors), what transformation the system is intended to achieve, and the underlying rationale or values (worldview), CATWOE clarifies both the intended functionalities and the justification for the system's existence (Suryani et al., 2024). It also recognises who holds authority over the system (owners) and what external factors may limit or shape its implementation (environmental constraints). Based on the CATWOE analysis of the motor health self-management system, problem-solving paths were further identified to support a more robust design framework for digital self-management systems.

According to the above-mentioned analyses, this study aimed to address the following research question from a systems thinking perspective: "Question 2: What design elements and principles for different functionalities should be included in the proposed functionality design framework for elderly-centric digital self-management systems to empower older adults during their daily motor health management?" By applying systems thinking tools, this chapter seeks to provide a clearer understanding of the real-world challenges in motor health self-management and to offer a practical framework for designing more effective, user-centric digital self-management systems that enhance older adults' self-management skills, improve their motor health, and improve their quality of life.

6.2. Motor Health Self-Management Situation Analysis

Based on the findings in Chapters 4 and 5, a rich picture analysis was conducted to comprehensively visualise and capture the complex context of older adults' self-management of motor health, as shown in Figure 25. As a standard tool of systems thinking, rich pictures are widely used to represent systems from the perspectives of multiple stakeholders (Checkland, 2000). Thus, in this chapter, the rich picture was developed from the perspectives of both older adults and physiotherapists, capturing motor self-management components and relationships and identifying the cultural, behavioural, and environmental barriers that influence motor health self-management. Differing from linear causal logic, this rich picture involved a dynamic feedback loop providing a holistic understanding of the complexity of the motor health self-management system.

In the motor health self-management system, older adults were expected to take primary responsibility for their motor health. However, in current clinical practice, physiotherapists remain the primary decision-makers, while older adults often play a passive role in the process due to limited health literacy. For example, older adults mainly relied on motor assessments from physiotherapists in official institutions, such as hospitals, resulting in insufficient and delayed motor health assessments.

When motor impairments, such as falls or injuries, occurred among older adults, physiotherapists shifted motor assessments to participants' homes. However, due to space limitations, it is difficult for physiotherapists to conduct traditional clinical tests and supervise older adults performing physical exercise. Consequently, older adults are typically advised to engage in physical exercise independently. As older adults become less active with age, they tend to abandon physical exercise due to feelings of frustration and a lack of motivation. As a result, they commonly experienced further deterioration of motor health and finally sought professional support from physiotherapists again. This negative cycle of current motor health self-management ultimately contributes to increased demand for primary care services and places additional strain on healthcare resources.

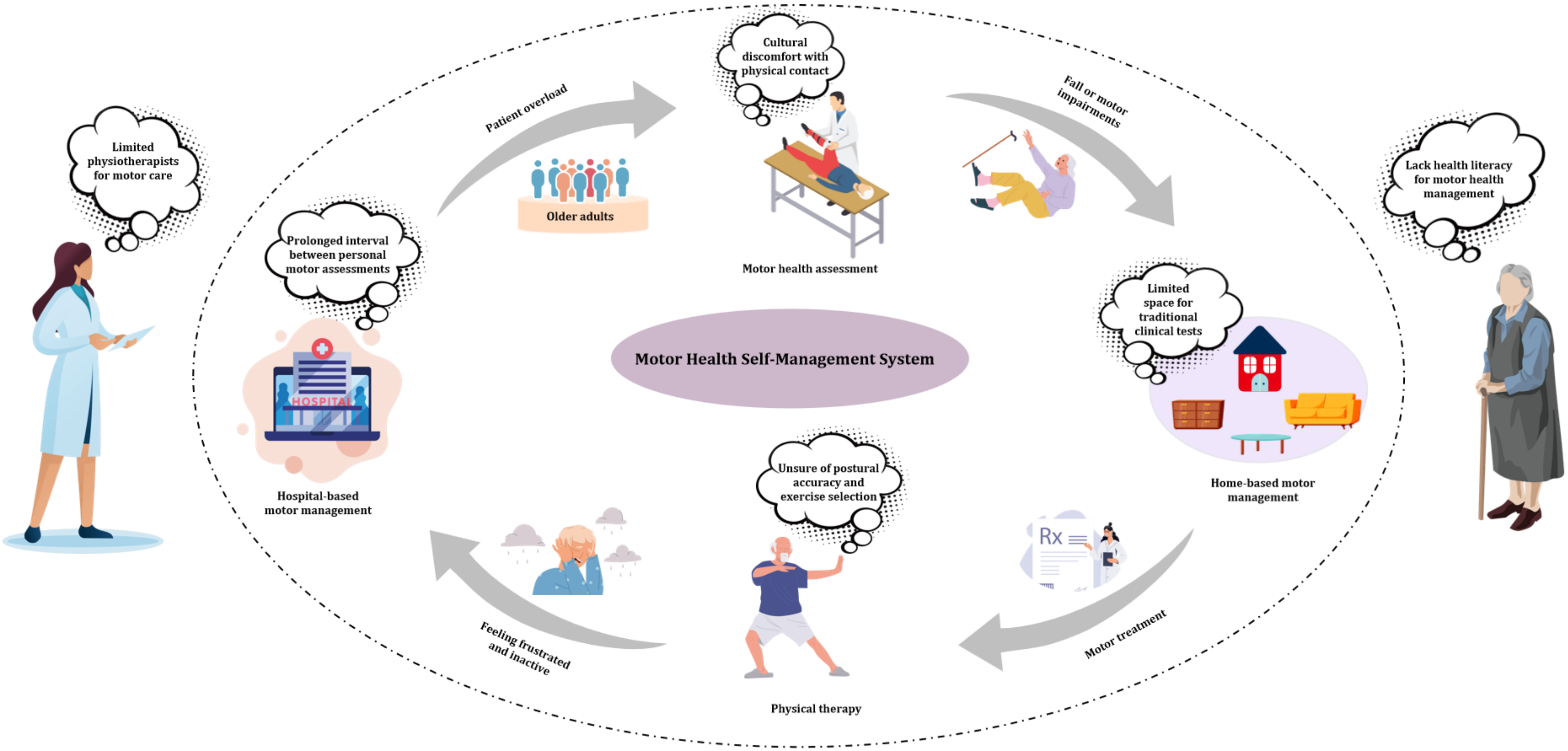


Figure 25. The rich picture of the motor health self-management system

The rich picture highlights the disconnections among different components of the motor health self-management system and their negative impact on both motor health outcomes and the overall care burden. For example, although physical exercise is a key component of motor health self-management, older adults often reduce their participation due to concerns about maintaining accurate posture and the risk of injury. This phenomenon can be attributed to a lack of physical exercise skills or to a lack of immediate feedback on exercise standardisation. This disconnection between feedback needs and timely support is particularly problematic when there is no access to detect and correct issues at an early stage, reflecting systemic failures to maintain continuity and support in self-management, and highlighting the interdependence between the barriers faced by users and providers.

As older adults often have limited motivation and feedback on physical exercise at home, they prefer to receive physical exercise treatments under the supervision of physiotherapists in healthcare institutions (Forbes et al., 2024). However, as indicated in Chapter 5, the average duration of each exercise session was approximately 40 minutes. Thus, older adults have limited resources to engage in consistent, guided physical exercise within the traditional motor health self-management system. As shown in the rich picture, infrequent follow-ups and long assessment intervals reduce opportunities for timely, personalised care. Due to the lack of regular communication, physiotherapists have limited knowledge of patients' home exercise progress, and older adults find it difficult to obtain feedback on their exercise efforts. This leads to uncertainty, poor exercise compliance, and a decline in motor health.

Additionally, certain contextual factors further limit older adults' ability to participate in physical activities and to maintain self-management of motor health. For instance, based on the findings in Chapter 5, some older adults felt psychological discomfort with physical contact, reducing their willingness to participate in face-to-face physical therapy assessments. Consequently, these older adults often missed opportunities for early detection and intervention of motor-related problems. In addition, as most older adults lived in small homes filled with clutter, physiotherapists were concerned about the safe implementation of clinical motor assessments, such as 3TUG and BBS. These challenges increase uncertainty about the quality and safety of physical exercise, especially when older adults are unable to receive timely feedback on changes in their motor abilities. If older adults do not receive clear and consistent information about changes in their motor health, such as improvement, stability, or deterioration, they may hesitate to continue exercising or struggle to adjust their physical exercise intensity appropriately. This disconnect reduces the feasibility of self-management strategies and increases the gap between support needs and system capabilities.

From a systemic perspective, the rich picture reveals three core disconnects in the current motor health self-management system: 1) High expectations are placed on older adults to manage themselves, but there is a lack of sufficient structural or informational support; 2) Limited availability of physiotherapists contrasts with the growing demand for individualized and continuous motor care among older adults; and 3) A mismatch between clinical assumptions and patient realities leads to fragmented and ineffective self-management pathways. According to systems thinking, identifying and addressing leverage points can lead to significant shifts in feedback loops or system behaviour with relatively small effort (D. Meadows, 2008). In the motor self-management system, three leverage points can be identified as 1) Access to timely support information on motor health management to empower older adults with self-management skills; 2) Extension of care delivery beyond clinical settings to address healthcare resource shortages; and 3) Improved feedback mechanisms to better align care strategies with real-world needs and behaviours. Digital self-management systems can offer promising solutions to these leverage points by providing adaptive education and guidance, continuous monitoring and real-time exercise feedback. They also help reduce reliance on limited healthcare resources and provide a more flexible and integrated healthcare experience.

6.3. Root Definition of Functionality Structure

Based on the rich picture analysis and discussion in Chapter 6.2, this section further applied the CATWOE analysis to define the functionality structure and purpose of the digital self-management system for motor health. CATWOE is a common method used in soft systems methodology to elaborate what the system should achieve, for whom, by whom, and under what constraints. (Checkland, 2000).

To benchmark the concept of the digital motor health self-management system and inform the root definition of the included functionality, numerous studies on digital health self-management systems were reviewed and cited. These reviewed studies all highlighted the importance of user-centric design strategies during system development. In detail, Doyle et al. proposed several suggestions for digital health self-management systems (Doyle et al., 2019). Personalised and adaptive care strategies were considered the primary design principles, followed by a holistic approach to self-management and scaffolding to support evolving user needs. Ekstedt et al. developed a digital self-management system for chronic diseases. The system included key components such as patient education, health feedback and remote monitoring, adherence support, psychological support, and lifestyle interventions, to help older adults self-manage their chronic diseases through adaptive feedback (Ekstedt et al., 2021). Moreover, Al-Saleh et al designed a (Al-Saleh et al., 2024) MEDSReM© System to improve older adults' medication adherence through medication education, decision support, reminding, and monitoring. Among the above three benchmarks, comprehensive functionalities, including education, health assessment, and health treatments, were suggested for developing digital health self-management systems. In addition, personalised and adaptive digital health self-management systems were also greatly valued.

However, few of these benchmarks have considered the systemic interplay between users, providers, and contextual barriers as revealed in the rich picture of motor health self-management in Chapter 6.2. Thus, the CATWOE was further used to conceptualise the functionality structure of a digital self-management system for motor health. The results of the CATWOE analysis are as follows:

Customers (C): Older adults were identified as the primary beneficiaries, to effectively and efficiently manage their motor health in home settings. They commonly face considerable challenges in sustaining physical exercise and motor management due to limited health literacy, limited access to timely clinical assessments, and insufficient feedback information on physical exercise. The secondary customers are stakeholders who assist older adults in their motor management, such as healthcare professionals, informal caregivers and family members.

Actors (A): System developers and caregivers are the leading actors in the motor health self-management process. Developers and technical teams are responsible for designing the digital self-management system and ensuring its accessibility, usability, and functionality. In addition, caregivers also play a supportive role in helping older adults use the system in the long term.

Transformation (T): The traditional fragmented in-person physiotherapy interventions are shifted to home-based motor management through a digital self-management system. This system included real-time data feedback, personalised management strategies, and user-centric interaction design. Based on motor assessment results and continuous activity tracking, older adults can self-monitor their fall risk and adjust their physical exercise and daily activities accordingly. Included functionalities also support patient education, motor health monitoring, and physical exercise, as emphasised in previous system benchmarks (Al-Saleh et al., 2024; Ekstedt et al., 2021).

Weltanschauung (W): This motor health self-management system is developed based on a worldview that emphasises empowerment, autonomy, and prevention. It believes that older people can self-manage their motor health if supported by the appropriate digital tools. The role of the digital self-management system is not to replace clinical care, but to complement it through more accessible, consistent and personalised digital solutions. This approach aligns with Doyle et al. (2019), who emphasise the importance of adaptive care strategies that can evolve as users' needs change.

Owners (O): The ownership of the digital self-management system belongs to healthcare institutions and academic research institutes. They are responsible for governance, funding, and system integration into health policy frameworks. However, in line with the user-centric design strategies, older adults are also considered partial owners of the digital system. Through participatory design, data ownership, and system customisation, older adults are allowed to actively participate in and shape the digital self-management system according to their needs.

Environmental Constraints (E): Several factors constrain the design and implementation of the digital self-management system. For example, the lack of reimbursement models for digital care and unequal access to technology limit the system’s scalability and inclusiveness.

According to the CATWOE analysis of the motor health self-management system, the root definition of the digital motor health self-management system was recognised as “A digitally supported motor health self-management system that enables older adults to monitor their motor health and perform physical exercise through accessible education materials, home-based evaluation, and adaptive exercise feedback”. Therefore, a comprehensive functionality design framework was initially proposed, as shown in Figure 26. In the framework, the education, evaluation, and exercise functionalities work together to help older adults understand motor health knowledge, assess their own motor health, such as fall risk, and engage in physical exercise. Through this integrated health self-management process, the system is expected to promote continuous health awareness, support active self-management, and encourage long-term adherence to healthy behaviours.

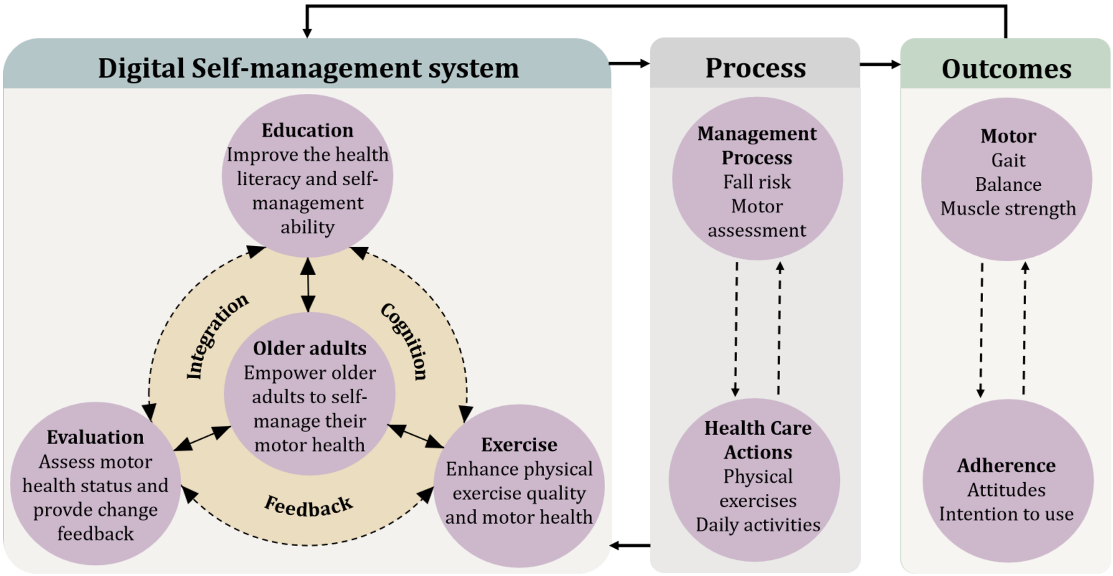


Figure 26. The initial functionality design framework construction

6.4. Development of the Functionality Design Framework

Based on the initial functionality design framework presented in the last section and the findings in Chapters 4 and 5, this section proposes detailed problem-solving paths for the education, evaluation, and exercise functionalities, as shown in Table 21. Based on the content of three functionalities and the nature of the digital self-management systems, a 3E ACTIVE-M Framework was further proposed in this chapter.

Health education and access to community healthcare resources are essential strategies for empowering older adults to develop health problem-solving skills and enhance their independence and quality of life (Choi & Seomun, 2024). Based on the protection motivation theory, Chapter 4 found that perceived vulnerability, perceived severity, rewards for maladaptive responses, and response costs had significant effects on older adults' behavioural intention to use digital self-management systems. Therefore, the education functionality included education materials related to thesis themes. In addition, content related to prevention actions and assistive aid use was also included in the education functionality to improve older adults' skills in performing physical exercises and using mobility aids, as shown in Table 21.

The perceived vulnerability referred to common risk factors for falls, such as balance decline, muscle weakness, medication side effects, and improper walking posture, aiming to raise awareness among older adults of their susceptibility to falls. The perceived severity described the potential consequences of falls and sarcopenia, such as hospitalisation, disability, fracture, or even death, to motivate older adults to act and engage in motor health–related behaviours. The prevention actions comprised a set of evidence-based practices, such as walking training, strength training, balance coordination and proper nutrition, aimed at empowering older adults with practical strategies for motor self-management. Maladaptive response rewards clarified common misconceptions about motor management and highlighted the long-term harms of inactivity, aiming to reduce psychological resistance to physical exercise. Response costs included simple, home-based exercises and real-life examples to demonstrate the minimal effort and convenience of fall prevention and motor management, lowering psychological resistance and encouraging user engagement. Assistive aid use was related to the proper selection and usage of mobility aids, such as canes and walkers, to reduce stigma and promote independent mobility.

Motor health evaluation can also increase older adults' perceived vulnerability through identifying motor health issues and tracking motor health changes (Maes & Karoly, 2005). Feedback on motor health performance is crucial for older adults to determine whether they should maintain or adjust their self-management strategies and healthy lifestyles (Swann et al., 2021). However, older adults often have limited access to regular motor evaluation within their communities. This lack of consistent health-related feedback hinders older adults' ability to identify motor health issues early and take action to prevent further deterioration. In this context, the digital motor health self-management system represents a promising home-based solution for the continuous monitoring of motor health in older adults. According to the findings in Chapter 5, the combination of multiple sensors with clinical assessments is recommended for collecting motion data and evaluating the motor health of older adults, as shown in Table 21.

Table 21. The construction of the 3E ACTIVE-M Framework

Functionality	**Content**	**Technology**	**Material**
Education	• Perceived vulnerability • Perceived severity • Prevention actions • Maladaptive response rewards • Response costs • Assistive aid use	• Tablet	• Guidelines for motor health management published by official healthcare institutions • Physiotherapists-led video demonstrations • Government-backed science communication videos
Evaluation	• Perceived vulnerability	• Tablet • Optical sensor • Inertial sensor	• Berg balance scale (BBS) • Three Meters Timed Up and Go test (3TUG) • Five Times Sit to Stand Test (5STS)
Exercise	• Prevention actions	• Tablet • Optical sensor	• Vivifrail program (warm-up exercise, muscular strength training, balance training and flexibility training)

Exercise functionality enables older adults to take preventive actions to enhance their motor health, including gait, balance, and muscle strength. Meta-analyses have shown that while mental or cognitive exercises can produce small but significant improvements in motor outcomes, physical exercise generally demonstrates larger effect sizes on key motor outcomes such as gait speed, balance, and muscle strength (Weng et al., 2025). Multimodal or cognitive–motor exercises are also suggested to be included in the exercise functionality if sufficient time is available. Given the limited intervention duration, physical exercise was prioritised to maximise measurable motor improvements within the available timeframe. According to physiotherapists' suggestions on home-based physical exercise training, stretching, strength training, aerobic exercises, balance training, and functional task training are important for older adults to maintain muscle strength and improve balance performance.

Given the potential safety concerns in home environments, exercise programs should be carefully designed to match the physical capacity of older adults. To address these concerns, the Vivifrail program was selected as the physical exercise material for this functionality. The Vivifrail program is an evidence-based and recognised multicomponent physical exercise program specifically designed for older adults (Izquierdo, 2019). It has been verified to be both safe and effective in improving balance performance, preventing falls, and enhancing motor ability in community-dwelling older adults (Casas-Herrero et al., 2022; Sánchez-Sánchez et al., 2022). Meanwhile, the adaptive structure of the Vivifrail program allows tailored exercise strategies according to individuals' fall risk and motor ability, ensuring personalised and safe exercise delivery at home. Additionally, an optical sensor was used in this functionality to collect data on the posture of older adults and provide feedback on their exercise performance.

Furthermore, according to the findings in Chapter 4, perceived ease of use and task-technology fit positively affect older adults' behavioural intention to use the digital self-management system. In addition, previous research has shown that older adults commonly experience perceptual decrease, motor coordination issues, and cognitive deterioration (Liu et al., 2021). Thus, easy-to-understand and intuitive data visualisation and interface design were considered as one design principle for the proposed digital self-management system in Chapter 7. In detail, the system should feature a large font size, high contrast, and a limited number of colours, along with simple interaction gestures such as swiping and tapping, multimedia presentations, and meaningful icons.

As the findings in Chapter 5 emphasise the importance of different body motion information and clinical tests in assessing the motor health of older adults, multidimensional motion tracking and analysis were recognised as another design principle for developing the designed digital self-management system. Given that optical sensors require an unobstructed environment for data collection and inertial sensors have limited ability to capture whole-body motion, they were applied together to collect multidimensional body motion data from older adults. In addition, various domain-specific motor health-related information, such as self-reported scales, gait parameters, and signal metrics, were integrated into the system to analyse older adults' fall risk and motor health.

In addition, based on the requirements of older adults for physical exercise feedback and activity reminders, multimodal motion performance feedback was determined as one design principle. Visual, audio, and vibration feedback are recommended for incorporation into the digital self-management system to support user engagement, enhance motivation, and improve the clarity of exercise performance cues. Moreover, personalised and attractive exercise management was identified as another design principle based on the user-centric design strategies. Personalised motor health management goals and physical exercise were developed for older adults in the digital self-management system. The four design principles and system design structure are shown in Figure 27.

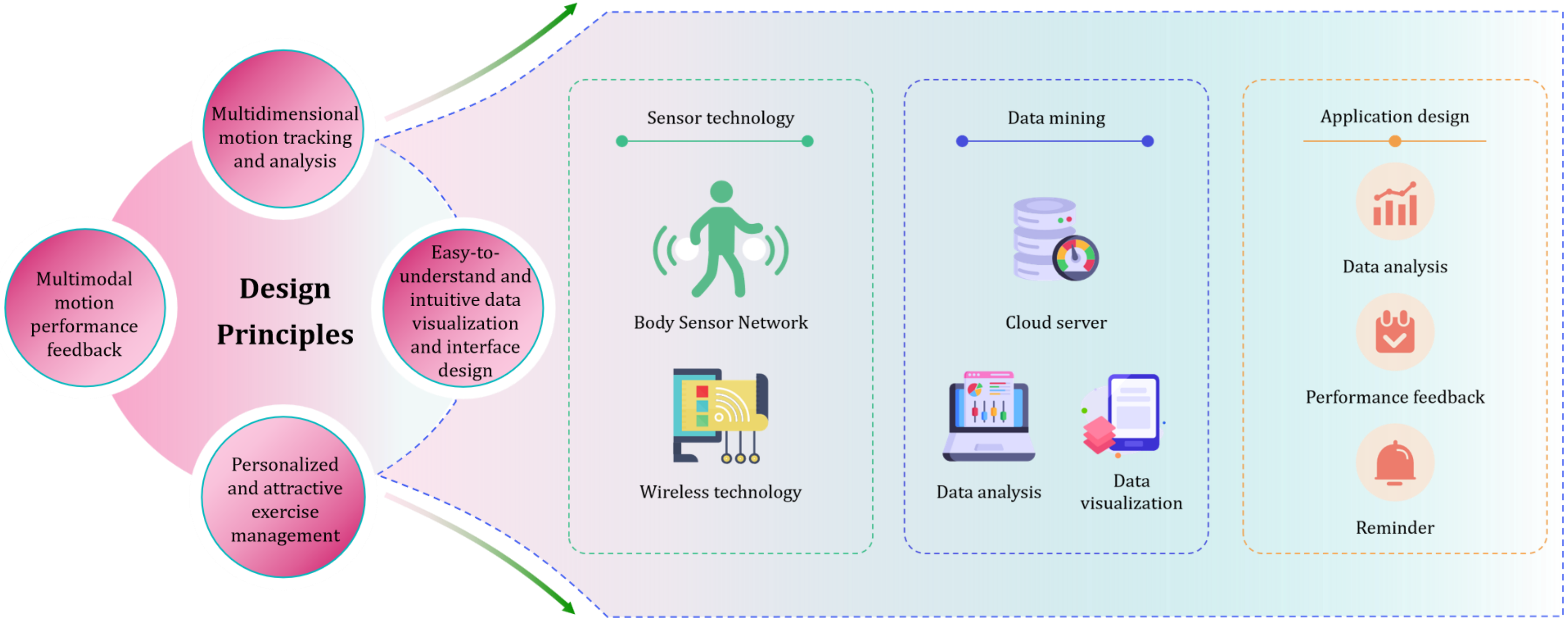


Figure 27. The proposed design principles for digital self-management systems

CHAPTER 7: DEVELOPMENT OF A DIGITAL SELF-MANAGEMENT SYSTEM FOR OLDER ADULTS' MOTOR HEALTH

7.1. Introduction

In this ageing era, the increased ageing population brings a growing burden on healthcare systems due to the prevalence of different diseases and geriatric syndromes among older adults. The World Health Organisation found that one sustainable solution to these socio-economic effects is to enable older adults to maintain functional independence and achieve "healthy ageing" (Ienca et al., 2021). Notably, motor health is a central pillar of maintaining functional independence. However, older adults commonly experience degraded motor abilities due to ageing and chronic diseases (Tang et al., 2022; G. Wang et al., 2024). The limited availability of physiotherapists also hinders older adults from receiving timely motor assessments and treatments in practice (Lanfear & Harding, 2023). Thus, digital self-management systems have emerged in recent years as an alternative approach to support motor health in older adults.

Existing digital self-management systems have primarily focused on a single functionality, such as evaluation or exercise. A few of them have integrated education, evaluation, and exercise into a single system to enable older adults to receive comprehensive interventions for motor health. Additionally, previous research on digital self-management systems often lacks user-centric design strategies, contributing to early abandonment among older adults (Ienca et al., 2021). Thus, this Chapter aimed to answer, “Question 3: What is the feasibility of the proposed functionality design framework for the elderly-centric digital self-management system, including usability and the effect of diverse functionalities on older adults' motor health self-management?” by designing and evaluating a digital self-management system for older adults’ motor health management. In detail, based on the proposed design elements and principles in Chapter 6, this study developed a digital self-management system and conducted a usability test to evaluate its usability and acceptance among end-users. The qualitative and quantitative results of the usability test were further analysed to update and supplement the design elements and principles in Chapter 6.

7.2. Functionality Design

Three functionalities, including education, evaluation and exercise, were integrated into the digital self-management system. In detail, the education functionality aimed to educate older adults on motor health, including gait, balance, and sarcopenia, as well as risk factors for falls, exercise tips, and self-care after experiencing a fall. This comprehensive information was available through text, picture and video resources, facilitating easy self-management of motor health for older adults. All content was sourced from public health media platforms and published by physical therapists (PTs) or government agencies. Based on the findings in Chapter 6, the educational materials in the system consisted of six themes: perceived vulnerability, perceived severity, prevention actions, maladaptive response rewards, response costs, and assistive aid use. In addition, according to the findings in Chapter 4, the function and system design for education functionality are shown in Table 22.

Table 22. The function and system design for education functionality

Functions	**Definition**	**System design**
Data collection	• Record the viewing themes and items by older adults • Record the viewing time of each theme and item	Backend management system design for researchers to manage content, users, settings, and monitor user activities
Data analysis	• Calculate the total viewing time of each theme • Compare the total viewing time of each theme within individual weeks and examine how the viewing time of each theme changes across different weeks	
Performance feedback	• Visualise viewing activities, including time and themes	Activity history interface design of the application (app) for users to review their historical education viewing activities
Data update	• Visualise trends in viewing time and theme distribution across daily, weekly, and monthly intervals	
Information search	• Search for relevant or targeted information based on user needs and preferences	Education functionality interface design of the app for users to choose preferred education materials
Goal management	• Set the education learning schedules	Goal setting interface design of the app for users to set schedules for motor self-management
Activity reminder	• Send notifications for newly published education updates and activity reminders to encourage users to engage in educational interventions at scheduled times	

The evaluation functionality used multiple sensors, including optical sensors and inertial sensors, to collect older adults' motion signals during clinical tasks. Artificial intelligence algorithms were further used to extract key features and predict older adults' motor health. The constructions of artificial intelligence algorithms were further elaborated in Chapter 7.4.

Although diverse clinical tests were suggested for integration into the digital self-management system in Chapter 5, the system designed in this chapter included only the 3TUG test (which involves walking, sit-to-stand transferring, and turning) as an example, as the core focus of this thesis is on functionality design. Moreover, due to limited time and resources, the development of additional algorithms was beyond the scope of this work. Future research can expand the system by incorporating additional clinical tests to improve its comprehensiveness and clinical utility. According to the findings in Chapter 4, the function and system design for the evaluation functionality are shown in Table 23.

Table 23. The function and system design for the evaluation functionality

Functions	**Definition**	**System design**
Data collection	• Three-axis acceleration, angular velocity, and angle (inertial sensor) • 3D skeleton coordinates (optical sensor)	Data cloud layer design for the system to collect, record and analyse user data to support digital motor health evaluation
Data analysis	• Data filtering and extraction • Artificial intelligence algorithms for motor evaluation	
Performance feedback	• Visualise the motor evaluation result and its change compared with the last time	Evaluation functionality interface design of the app for users to be aware of the motor evaluation results
Data update	• Visualise trends in assessed motor health across daily, weekly, and monthly intervals	Activity history interface design of the app for users to review their historical motor health evaluation within the app
Information search	• Search for targeted clinical tests based on user needs	Evaluation functionality interface design of the app for users to choose targeted

		clinical tests
Goal management	• Set the motor evaluation schedules	Goal setting interface design of the app for users to set schedules for motor evaluation
Activity reminder	• Send activity reminders to encourage users to engage in motor health evaluation at scheduled times	

Based on the guidelines of the Vivifrail program (Casas-Herrero et al., 2022), multi-component physical exercise was incorporated into the exercise functionality through video content. All videos were sourced from public health media platforms and were published by physiotherapists. In detail, warm-up exercises, muscular strength training, balance training, and flexibility training were included as the four themes of this functionality. The optical sensor was used to collect users' motion data and to analyse their posture accuracy based on the body angles. An accurate score ranging from 0% to 100% was then presented to users to provide feedback on their movement quality and encourage self-correction. Based on the findings in Chapter 4, the function and system design for the exercise functionality are shown in Table 24.

Table 24. The function and system design for exercise functionality

Functions	**Definition**	**System design**
Data collection	• 3D skeleton coordinates (optical sensor)	Data cloud layer design for the system to collect, record and analyse user posture accuracy
Data analysis	• Data filtering • Posture angles	
Performance feedback	• Posture accuracy (score)	Exercise functionality interface design of the app for users to be aware of their posture accuracy
Data update	• Visualise trends in physical exercise time and theme distribution across	Activity history interface design of the app for users to review their historical

	daily, weekly, and monthly intervals	physical exercise activities
Information search	• Search for targeted physical exercise based on user needs and preferences	Exercise functionality interface design of the app for users to choose targeted physical exercise
Goal management	• Set the exercise schedules	Goal setting interface design of the app for users to set schedules for physical exercises
Activity reminder	• Send activity reminders to encourage users to engage in physical exercise at scheduled times	

7.3. Hardware Development

The hardware system of the designed digital self-management system included an markerless optical sensor (Astra Pro Plus: Orbbec, Shenzhen, China) for capturing skeletal motion, inertial sensors (WT901WIFI: WitMotion Technology Co., Ltd., Shenzhen, China) for tracking body orientation and movement dynamics, and a tablet device for user interaction and system feedback display (Teclast M50 Android tablet: Teclast Technology Co., Ltd., Shenzhen, China). The illustration of the designed digital self-management system is shown in Figure 28.

The developed digital self-management system emphasised the integration of a markerless optical sensor (Orbbec Astra Pro Plus) and inertial sensors (WT901WIFI) to achieve complementary sensing performance. Notably, these two sensors were factory-calibrated before shipment, and no manual calibration was required throughout operations. The Orbbec sensor, suggested as a suitable replacement for the discontinued Kinect (Navarro et al., 2023; Venek et al., 2021), captures skeletal motion without the need for physical markers, maintaining user-friendliness for older adults. However, the Astra sensor has limitations in confined and obstructed environments. In this status, the inertial sensor compensates for occlusion and enhances motion accuracy. Compared with widely reported markerless Kinect or computer vision-based approaches, Orbbec and inertial sensor-based hardware components cost around USD 150, and their plug-and-play configuration with an iPad or smartphone minimises setup and maintenance efforts among older adults. This hybrid design offers better cost-effectiveness and robustness in variable living environments.

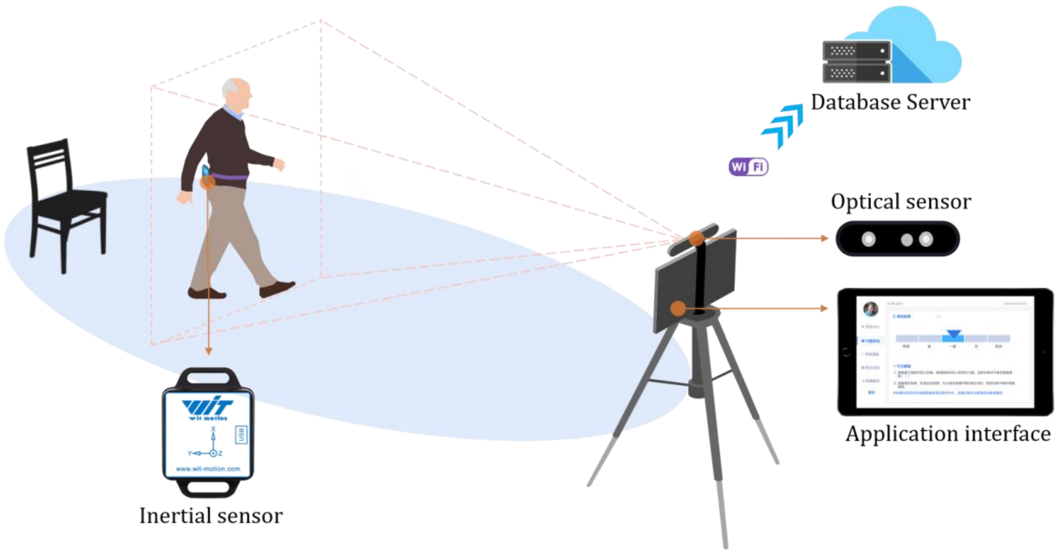


Figure 28. Illustration of the digital self-management system

The optical sensor was connected directly to the tablet using an adapter, while the inertial sensor was connected via Wi-Fi. As shown in Figure 29, the optical sensor and the tablet were placed 1.8 meters in front of the users, and the inertial sensor was worn on the users' lower back based on the findings in Chapter 5. The skeleton, acceleration, angular velocity, and angle data were initially collected and stored locally on the tablet. Upon connection to the internet, this data was automatically uploaded to a cloud database server (Tencent Cloud: Tencent Cloud Computing Co., Ltd., Beijing, China) for storage and further processing. After analysing the data and predicting motor ability and posture accuracy, the results were visualised through the application interface on the tablet. The tablet-based interface supported intuitive user interaction, allowing users to operate the system by tapping and swiping on the touchscreen. These interactions enabled older adults to independently access educational content, perform motor assessments, engage in physical exercise, review performance feedback, and manage system settings without professional assistance. A more detailed description of the interface design can be found in Chapter 7.5.

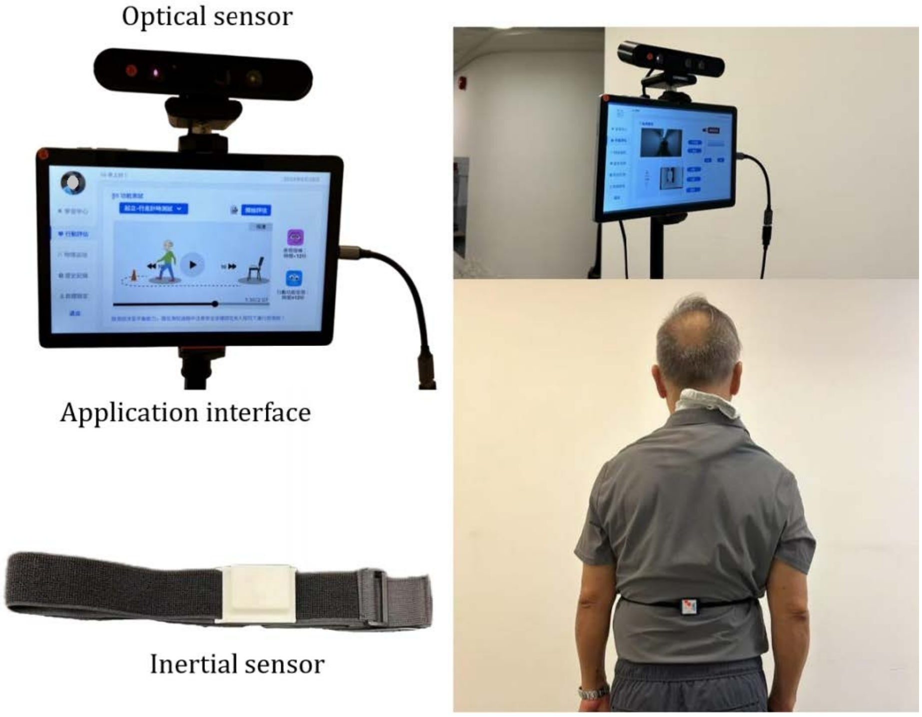


Figure 29. The physical setup of the digital self-management system

7.4. Motor Health Evaluation Algorithms

Since sensors, even the most accurate ones, produce noisy data, an optimisation algorithm that excludes sensor noise, such as the Kalman filter, is necessary to estimate stride length. The Kalman filter is a recursive algorithm that uses the state-space method to design the filter, making it suitable for the estimation of multidimensional stochastic processes. Moreover, wavelet denoising is used to reduce the noise interference in the measurement process. Based on wavelet decomposition, the signal and noise exhibit different properties at their respective scales. The wavelet coefficients of the actual signal and noise increase gradually with scale. The wavelet transform uses a finite-length decaying wavelet basis as follows:

$$WT(a,\tau) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} f(t) * \psi(\frac{t-\tau}{a}) dt \tag{1}$$

$$\psi_{a,\tau}(t) = \frac{1}{\sqrt{a}} \psi(\frac{t-\tau}{a}) dt \tag{2}$$

Where, $WT(a,\tau)$, represents the signal obtained after wavelet filtering, a and τ are scale and translation, respectively. τ specifies the particular region we are focusing on. a is the scaling parameter, which is required to be positive, as negative values do not result in a valid scaling operation. It allows us to pinpoint a certain frequency (represented by parameter a) at a specific moment in time (represented by parameter τ). $f(t)$ represents the original one-dimensional signal from an inertial sensor. The scale controls the scaling of the wavelet function, while the translation τ controls the translation of the wavelet function. $\psi_{a,\tau}(t)$ represents the wavelet base, which is constrained in the time domain.

To simplify the calculation process and achieve a better filtering effect, a cubic spline interpolation algorithm is adopted, using the polynomial least-squares method to approximate the sampling points, as shown in Eqs. (3)-(6).

$$i = 3, 4, \cdots, m-2 \tag{3}$$

$$y_i = \frac{1}{35}\left[-3(x_{i-2} + x_{i+2}) + 12(x_{i-2} + x_{i+2}) + 17x_i\right] \tag{4}$$

$$y_{m-1} = \frac{1}{35}\left[-8x_{m-3} + 12x_{m-2} + 27x_{m-1}\right] \tag{5}$$

$$y_m = \frac{1}{70}\left[-x_{m-4} + 4(x_{m-3} + x_{m-1}) - 6x_{m-3} + 69x_m\right] \tag{6}$$

The coefficients in Eqs. (3–6) are determined based on the Savitzky–Golay smoothing filter (Savitzky & Golay, 1964). Where y represents the input signal x processed after the cubic spline interpolation algorithm, i represents the current number of sampling points in the signal, while m denotes the total number of sampling points collected from the original signal by the sensor.

The equations to update the estimated values with the Kalman filter are shown in Eqs. (7)-(12).

$$\bar{x}_k^{-} = Ax_{k-1} + Bu_{k-1} \tag{7}$$

$$P_{\bar{k}} = AP_{k-1}A^{T} + Q \tag{8}$$

A is the system dynamics matrix, u_{k-1} is a known vector, which is called the control vector at time step $k-1$, and is the control matrix. x_{k-1} is a column vector representing the system's states at time step $k-1$. P_{k-1} refers to the value of the covariance matrix used in the filtering process. $P_{\bar{k}}$ represents the covariance matrix used to predict future system states. Q represents the matrix that accounts for noise within the system

The measurement update process is shown below:

$$x_k x_{k-1} < 0 \tag{9}$$

$$K_k = P_{\bar{k}}H^{T} \Big/ \left(HP_{\bar{k}}H^{T} + R\right) \tag{10}$$

$$\bar{x}_k = \bar{x}_{\bar{k}} + K_k(z_k - H\bar{x}_{\bar{k}}) \tag{11}$$

$$P_k = (I - K_k H)P_{\bar{k}} \tag{12}$$

Where x_k, and x_{k-1} are column vectors with the states of the system at time step k and $k-1$, A_k is the system dynamics matrix, u_k is a known vector that is called the control vector at time step k, B_k is the control matrix, K_k denotes the matrix of Kalman filter gains to update the system's estimates. Q_k is the process noise matrix at time step k, and R_k is the measurement noise.

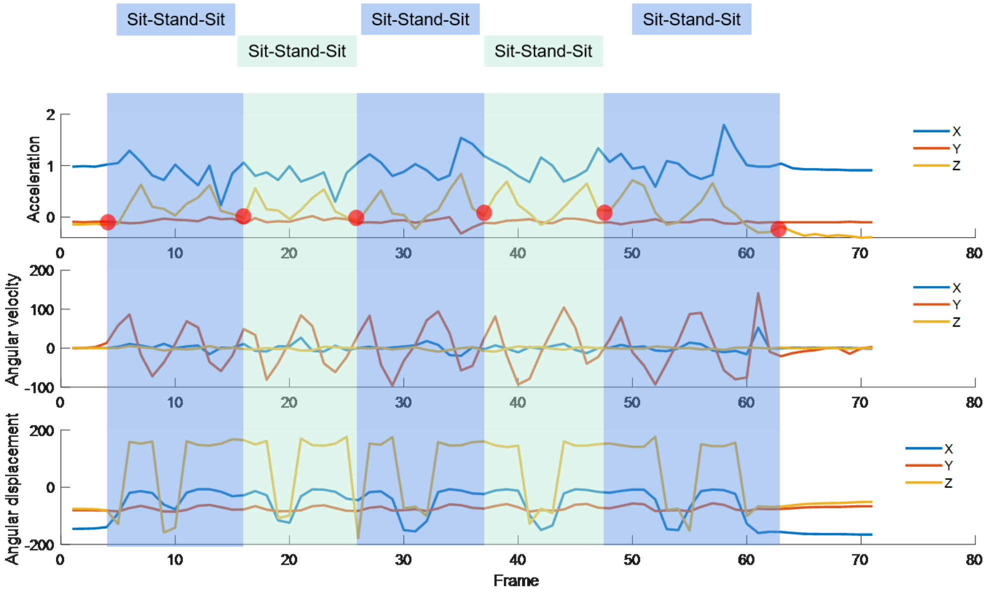


Figure 30. Extraction and collection of segmented sensor data

After data processing, the inertial sensor signal from the 3-meter timed up-and-go test was further segmented to extract gait features for motor assessment models (see Figure 30). To avoid potential bias introduced by single-algorithm approaches, a multi-algorithm fusion framework was employed to enhance the accuracy and robustness of motor health assessment, as shown in Figure 31.

As this thesis primarily focused on developing the functionality design framework for digital self-management systems, the AI algorithms used in the system were derived from previous validated research rather than newly developed within this work (X. Wang et al., 2024; Zhao et al., 2024). Specifically, one algorithm was developed to evaluate older adults' fall risk using inertial sensor data from 41 older adults (Low fall risk = 26) in Hong Kong (X. Wang et al., 2024). In the previous study, the Berg Balance Scale was used as the clinical gold standard to classify participants as high- or low-fall risk. Each participant wore an inertial sensor at the lower back and completed the 3-meter timed up-and-go test. Several key gait features, such as stride length, gait rhythm, and signals reflecting the motion of the lower back, knee, and foot, were extracted from the signals as input variables for Ensemble Elastic Net, which is consistent with the suggested gait parameters in Chapter 5 (X. Wang et al., 2024; Zhao et al., 2024; Zhou et al., 2024). The construction characteristics of the Ensemble Elastic Net are shown in Table 25. The model achieved an accuracy of 80%, a sensitivity of 90%, and a specificity of 71% in recognising fall risk among older adults (X. Wang et al., 2024).

Table 25. The construction of the Ensemble Elastic Net

Characteristics	**Setting**
Input	Demographic, descriptive, non-linear and spatiotemporal features
Output	The predicted score of motor health
Hyperparameter search	Grid search methodology
Ensemble method	Bootstrap sampling base classifiers + weighting aggregation
Training set	33 samples
Testing set	8 samples
Cross-validation method	Monte Carlo cross-validation with 50 repetitions

The other algorithm is a multiscale skeletal transformer using skeleton data from the Kinect sensor (Zhao et al., 2024). A total of 183 signal samples (Low fall risk =

117) obtained from older adults during the 3-meter timed up-and-go test were used to develop the algorithm. In this previous study, the Berg Balance Scale was also used to label older adults as high- or low-fall risk. A Kinect camera was used to collect a database of 25-point skeletal data from older adults during the 3-meter timed up-and-go test. The multiscale skeletal transformer included three key components. Firstly, an inter-joint skeletal topology framework was constructed to represent both physiological connections and functional dependencies among joints. Then, a ResNet-FPN backbone was used to enhance multiscale feature extraction. Finally, a multimodal output fusion transformer was used to combine dynamically and weight outputs from multiple model pathways. More information on the algorithms' construction characteristics is shown in Table 26. After validation, the model achieved 97.84% accuracy, 97.33% precision, 96.97% recall, and 96.92% F1 score. The detailed flowchart of the model is shown in Figure 31.

Table 26. The construction of the multiscale skeletal transformer

Characteristics	**Setting**
Input	25-joint skeleton sequences (3843 sequences)
Output	The predicted score of motor health
Data balancing	SMOTE method
Training set	80% (3,074 sequences)
Testing set	20% (769 sequences)
Validation set	10% of training (307 sequences)

Based on the predicted results from the two algorithms, a weighted voting strategy was used to determine the final decision. Motor health was then categorised into five levels: very poor, poor, normal, good, and very good.

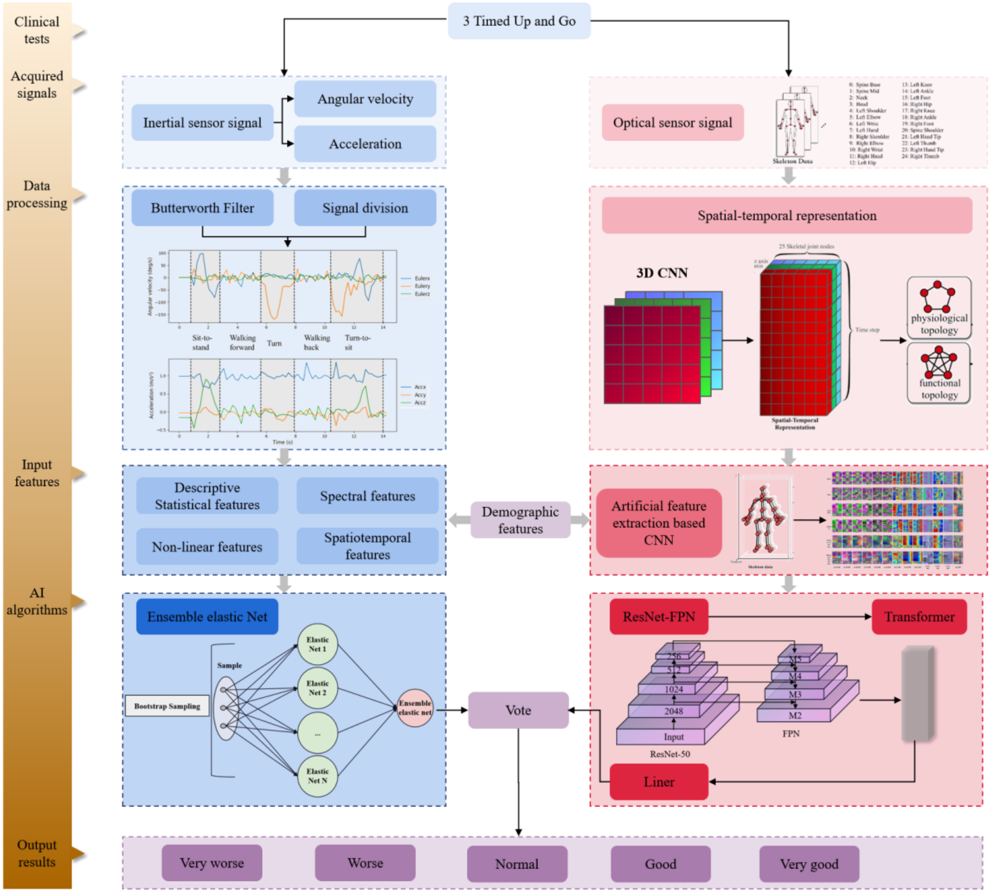


Figure 31. Constructions of artificial intelligence algorithms

7.5. Self-Management Application Design

The education functionality included six themes and used a drop-down menu for users to guide and search for the target education theme, as shown in Figure 32(a). Each theme further included multiple sub-items presented with brief textual summaries, offering a quick overview of key topics. This progressive interaction design approach was expected to reduce older adults' cognitive load and prevent information overload. When a sub-item was selected, the interface dynamically transitioned to a specific content page with multimodal educational materials, including instructional videos, images, and detailed texts, as shown in Figure 32(b).

…固身體的動態表現，不良的步態不只會造成足底筋膜炎、拇指外…響全身容易痠痛，甚至是骨刺、退化性關節炎等等。

隨著年齡增長，視覺、前庭覺、本體感覺的衰退導致60歲之後的平衡能力急劇下降。

平衡失調誘因

步態平衡失調可能由多種因素導致。首先,神經系統疾病、肌肉骨骼系統疾病和感覺系統問題,都會影響身體活動和平衡感,引發步態失調。

隨著年齡增長，人體維持平衡所依賴的多重感知和反應系統會逐漸衰退。首先，視覺系統中視網膜感光細胞減少、瞳孔對光線的調節能力下降，導致空間定位和環境感知不如年輕時敏銳；其次，內耳前庭器官中的毛細胞數量減少，使頭部運動和重力方向的感知變得遲緩；再者，本體感覺（肌腱、關節囊內的感受器）靈敏度下降，使得對肢體位置和關節角度的反饋變差；此外，肌肉力量和爆發力減弱，神經—肌肉反射速度也隨之減慢。多項研究表明，在60歲以後，上述各系統的衰退往往呈現加速趨勢，導致老年人對身體微小偏移的感知和及時糾正能力明顯下降，跌倒風險顯著增加。

本軟體所提供的所有醫療健康資訊僅供參考，具體診斷和治療請諮詢專業醫師。

Figure 32. The interface design of the education functionality

The evaluation functionality enabled older adults to perform three sensor-based clinical tests, including the 3TUG, 5STS, and BBS tests. However, only the 3TUG test was combined with artificial intelligence algorithms to predict the motor ability in the current system. In the future, more algorithms and models will be developed for other clinical tests. A drop-down menu was implemented to allow users to select the target clinical test and conduct the motor assessment. Multiple illustration materials, such as images, videos, and context, were presented in the interface to help older adults understand the processes and tasks of each clinical test, as shown in Figure 33(a).

After understanding the tasks of the selected clinical tests, older adults were allowed to perform a motor evaluation by connecting the sensors to the tablet. The result of motor evaluation was finally visualised in a separate interface, as illustrated in Figure 33(b). Additionally, personalised suggestions were provided to guide users in improving their motor health.

該測試主要評估跌倒风险、平衡能力、行動能力以及步态變化等，是臨床評估和康復計劃制定的重要依據。測試時間短（如≤10秒）表明行動能力良好，而時間較長（如≥12秒）則可能功能受限或跌倒風險增加。

測試流程：

1. 坐在一把標準高度（約45厘米）的椅子上，背靠椅背，雙腳自然放平。
2. 在聽到「開始」指令後，受試者站起、步行3米，轉身返回並坐回椅子。
3. 全程計時，記錄從站起到再次坐下所需的時間（以秒為單位）。

(a)

Hi 早上好！

2024年6月28日

測試结果

今日建議

1. 建議進行適度的阻力訓練，增強腿部和核心肌群的力量，這對於維持平衡至關重要哦！！！
2. 適量補充魚類、乳製品和蛋類，可以補充身體所需的維生素D，進而改善平衡和骨骼健康。

本軟體所提供的所有醫療健康資訊僅供參考，具體診斷和治療請諮詢專業醫師。

(b)

Figure 33. The interface design of evaluation functionality

The exercise functionality included four themes (warm-up exercise, muscular strength training, balance training and flexibility training). A drop-down menu was used to help users navigate and locate the target exercise theme, as shown in Figure 34(a). There were also multiple sub-items of physical exercises under each theme. To provide intuitive recognition and reduce cognitive demand in older adults, the sub-items were presented with a representative image and a brief title.

After selecting a specific sub-item for exercise, the application redirected the user to a dedicated interface including video and text. Older adults could follow the instructions and posture demonstrations provided in the video. Once individuals completed the physical exercise, an accurate score was provided to users for immediate feedback and self-assessment of their exercise performance, as shown in Figure 34(b).

進行該動作時雙腳與肩同寬，核心收緊，肩胛下沉，手臂微彎抬至與肩同高後控制下放。注意呼吸配合，以能完成10次的重量為宜，避免借力擺動或肩頭上聳，若感不適應減重或停止並諮詢專業人士。一共完成三組，組間休息一分鐘。

本軟體所提供的所有醫療健康資訊僅供參考，具體診斷和治療請諮詢專業醫師。

Figure 34. The interface design of the exercise functionality

A historical record interface was also integrated into the digital self-management system, allowing users to review their activities and performance in education, motor evaluation, and exercise functionalities, as shown in Figure 35. The historical records for education and physical exercise visualised viewing time and content on a daily, weekly, and monthly basis, as shown in Figure 35(a). In terms of the motor evaluation, the average motor ability was presented based on historical data within the user-selected time interval. In addition, the interface also allowed users to track performance trends over time and provided personalised suggestions to encourage consistent motor self-management.

Hi 早上好！ 2024年6月28日

近期建議

1. 建議阅读饮食管理相关内容，加强日常餐食的搭配比例。
2. 適量補充魚類、乳製品和蛋類，可以補充身體所需的維生素D，進而改善平衡和骨骼健康。

Hi 早上好！ 2024年6月28日

近期建議

1. 建議進行適度的阻力訓練 （比如平躺在床上，膝蓋彎曲，慢慢抬起來臀部），可以增強腿部和核心肌群的力量，這對於維持平衡至關重要哦！！！

本軟件所提供的所有醫療健康信息僅供參考，具體診斷和治療請咨詢專業醫生。

Figure 35. The interface design of the historical record

Furthermore, a goal-setting interface was designed to enable users to set schedules for watching educational materials, performing motor evaluation, or engaging in exercise, based on the digital self-management system, as shown in Figure 36. This interface provided activity reminders to encourage users to engage in scheduled activities and enable older adults to track their task completion rates.

行动健康目標設置

☐ 增强下肢肌力
☐ 增强下肢肌力
☐ 每日步行6000步数以上
☐ 每天运动半小时
☐ 增加平衡能力

目標完成度評估

增强下肢肌力	90%
增强上肢肌力	90%
每日步行6000步数以上	90%
每天运动半小时	90%
增加平衡能力	90%

Figure 36. The interface design of goal setting

7.6. Task-Based Usability Test

7.6.1. Methods

7.6.1.1. Semi-structured Interview Design

A semi-structured interview was conducted in this study to evaluate the usability of the developed digital self-management system. The procedure of the usability evaluation followed the three stages identified by Nielsen for end-user test

(Nielsen, 1994): preparation, test, and follow-up.

Two tasks were developed in this study to assess the usability of the digital self-management system. In the first part, a practical simulation scenario for motor health evaluation was presented, in which older adults wore the inertial sensor and performed 3TUG tests in front of the optical sensor and digital self-management system. After the motor evaluation, the motor health results were visualised to the participants. In the second part, participants' information search behaviour in education and physical exercise was evaluated. The participants were required to look for specific information in the application, and to identify the meaning of the visualized content.

The usability of the digital self-management system for motor health was evaluated using a two-part questionnaire. The first part assessed perceived usefulness, user attitudes, and behavioural intention to use the system, comprising ten items rated on a 5-point Likert scale ranging from 1 ('strongly disagree') to 5 ('strongly agree') (H. Wang et al., 2022). The second part was the system usability scale (SUS), a widely used standardised questionnaire that has been confirmed to be reproducible, reliable, and valid (Nielsen, 1994). It includes ten 5-point items (ranging from 1 = “strongly disagree” to 5 = “strongly agree”) for evaluating the overall usability of the proposed digital self-management system.

Six open-ended questions (“Which visualisation mode do you prefer for education functionality, evaluation and exercise?”; “Do you prefer animated videos, live-action videos or images?”; “Do you understand the meaning of data visualization in the system?”; “In addition to the functionalities of this digital self-management system, what other functionalities do you need to meet your self-management motor needs?"; "What benefits do you think this system can bring you?"; "What difficulties might you encounter while using this system?"), were designed to gather participants' attitudes and opinions regarding the design of the digital self-management system.

7.6.1.2. Participants

Older adults with the ability to move by themselves were recruited as participants in this study. The inclusion criteria for participants were as follows: 1) older than 60 years, 2) without serious diseases or dementia, 3) with the ability to move by themselves, and 4) with the ability to perform daily activities. The exclusion criteria were: 1) aged below 60 years, 2) with unstable mental conditions, 3) without mobility under the help of mobility aids, and 4) with severe hearing problems or other conditions affecting communication. All participants gave their informed consent. The Institutional Review Board of The Hong Kong Polytechnic University approved this study.

7.6.1.3. Data Collection

Participants were recruited using convenience sampling methods, with recruitment conducted through posters distributed at community centres and in the media. The study objectives and research protocol were first explained to the participants. All participants provided informed consent before proceeding. During the evaluation process, participants received a brief introduction to the designed digital self-management system. Then, they were asked to complete each experimental task, followed by a two-part questionnaire and a set of open questions. The evaluation process was recorded in audio format to ensure accurate documentation of the participants' responses.

7.6.1.4. Data Analysis

The data collected through usability evaluation were analysed with descriptive statistics and content analysis (Turner et al., 2006). Descriptive statistics, including the mean, standard deviation, and percentages, were used to assess the central tendency and distribution of the usability scores. The audio data captured during the open-ended questions were also transcribed to facilitate our content analysis, in which we aggregated and investigated the participants' opinions and feedback.

7.6.2. Results

Demographic information for the included participants is shown in Table 27. A total of 22 older adults (female=17; mean age = 67.18±4.22 years) were analysed in this usability test. The majority of participants were older adults, with women accounting for around 80%. Approximately half of the older adults had a junior high school education and lived with family members, accounting for 46% and 50% of participants, respectively. Based on the responses, the distribution of economic income among older adults demonstrated an overall balanced trend, with no uneven concentration in any specific income group. About three-fifths of the participants had chronic diseases (59%) and lower limb diseases (55%). In addition, around one-third of the older adults experienced at least one fall in the last year.

Table 27. The demographic information on included older adults (n=22)

Characteristics		**Number (percentage %)**
Gender	Female	17 (77.2%)
	Male	5 (22.8%)
Education	Primary or below	2 (9.1%)
	Junior secondary	10 (45.5%)
	Undergraduate	6 (27.3%)
	Postgraduate or above	4 (18.2%)
Living arrangement	Alone	8 (36.4%)
	With family members	11 (50.0%)
	With relatives	3 (13.6%)
Monthly income	Low	4 (18.2%)
	Moderate	7 (31.8%)
	High	5 (22.7%)
	Extremely high	6 (27.3%)
Health status	Chronic diseases	13 (59.1%)
	No diseases	9 (40.9%)
Lower limb diseases	Yes	12 (54.5%)
	No diseases	10 (45.5%)
Fall history in the last year	One time	3 (13.6%)
	2~3 times	3 (13.6%)
	4 times or more	1 (4.5%)
	None	15 (68.2%)

Figure 37 shows older adults' perceived usefulness of a digital self-management system in improving motor health-related outcomes. In detail, participants reported a high level of perceived usefulness of the system for increasing motor health knowledge, preventing motor impairments, improving motor health, and enhancing self-management ability, with all average scores above 4.00 (agree). Notably, older adults expressed greater confidence in the system's ability to enhance knowledge of motor health (4.18±0.39) and support the prevention of motor impairments (4.14±0.47).

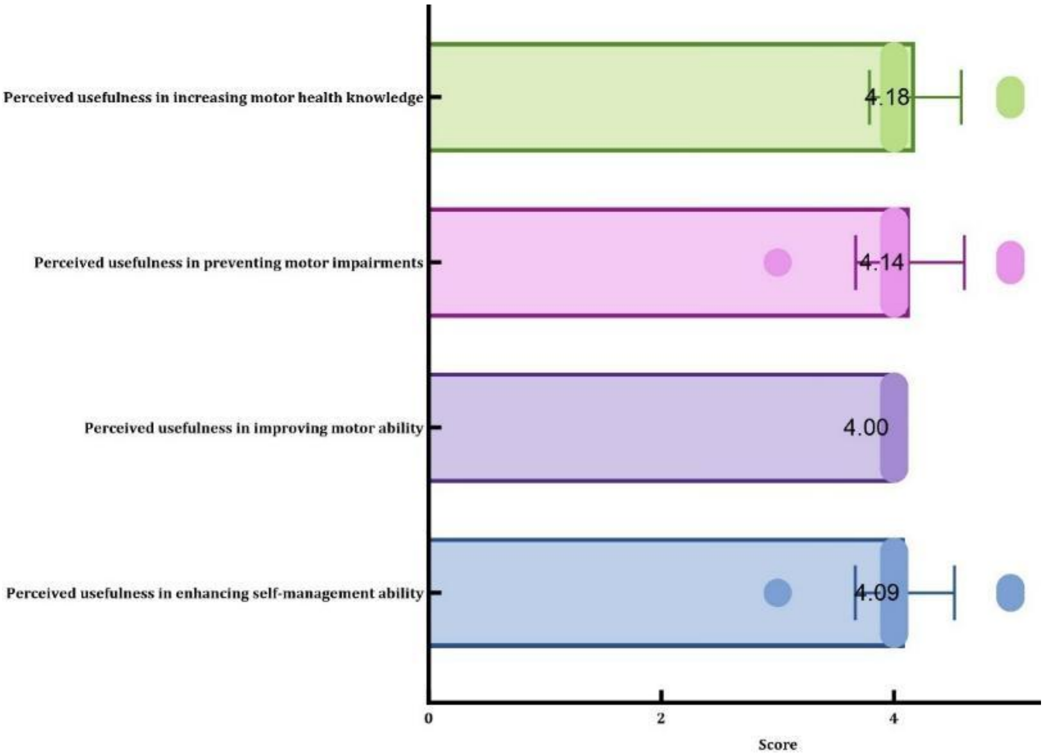


Figure 37. Perceived usefulness of the designed self-management system

As shown in Figure 38, older adults generally held positive attitudes towards the digital self-management system. The average overall acceptance score was 4.00 (SD = 0.44). Participants also considered the system helpful in meeting motor self-health management needs, with a mean score of 4.05 (SD = 0.72). Regarding specific functionalities, physical exercise received the highest score (mean = 4.32±0.65), followed by motor health evaluation (mean = 4.14±0.47) and education (mean = 4.00±0.62). The violin plots further illustrate that most responses clustered towards the higher end of the 5-point scale, confirming the system's perceived usefulness and acceptance across different developed functionalities.

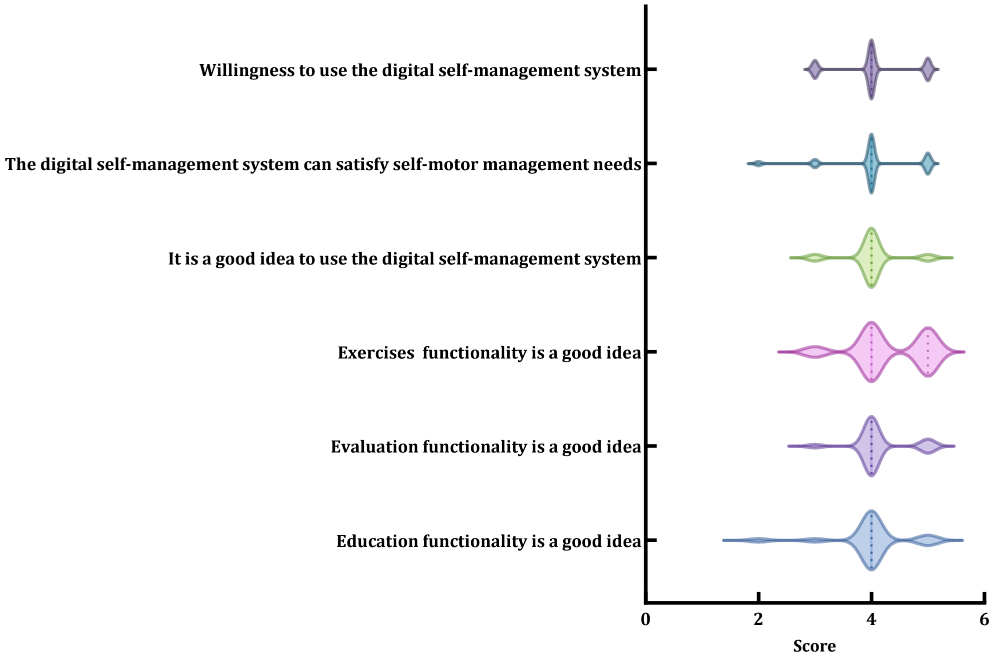


Figure 38.Attitudes to the design self-management system

Figure 39 displays responses to the 10 SUS items. The older adults provided high scores for the positive items and low scores for the negative items, indicating a positive overall impression of the perceived usability for digital self-management among these end-users. By calculating the SUS score according to guidelines outlined in previous research (Lewis, 2018), the average SUS score for the 22 participants was 68.50 ± 10.20, indicating a usability level in the “OK” to “good” range according to standard SUS interpretation.

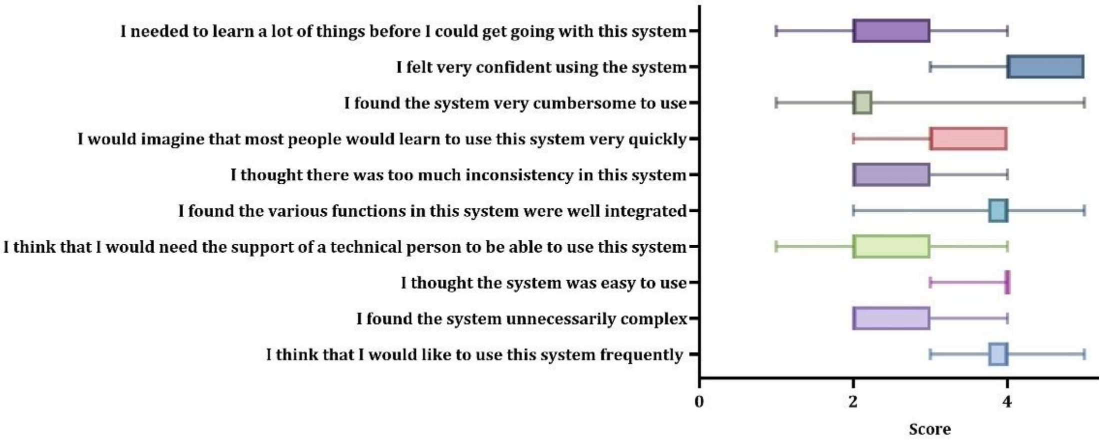


Figure 39. The SUS scores of the designed self-management system

Table 28 shows the qualitative results of the open-ended questions. Most participants preferred content presented through both video and text or pictures (95%), which helped them better understand the information. Older adults emphasised the importance of combining video with a small amount of key text. In addition, older adults show a strong preference for live-action characters in the videos or pictures (86%).

> *‘As we age, our eyesight gradually deteriorates, and we do not want to read too much text because it makes us feel tired and bored. I prefer watching videos and listening to lectures. If the videos could be combined with some keywords, I could quickly understand the main theme of the video, which would be even better.’* (PT4)

> *‘The real person looks more authentic, and some of their poses, including facial*

> *expressions and subtle hand movements, are more believable and coherent.'* (PT13)
>
> *'Real people make me feel more intimate, while animated characters make me feel distant.'* (PT19)

All participants reported that they can understand the data visualisations in the designed digital self-management system. However, some of them expressed a need for more specific feedback on their physical exercise performance. This highlights the need for guided information instead of assessment information. Additionally, older adults suggested that it is better for the digital self-management system to include several features, such as posture correction feedback, easier navigation with icons or images, categorisation of exercises by body parts, medical resource information and voice interaction. These opinions reflect the importance of intuitive design for older users.

> *'It is better to present physical exercise that targets different parts of the body, while describing the effects of these exercises, specifically applied to which muscles. This way I can be more specific in my physical exercise training.'* (PT11)
>
> *'I would like the system to be able to tell me how to do the exercise, to give me feedback on whether I'm doing it right, where I'm going wrong, and how I can improve it. Most importantly, the system can bring about behavioural changes, whether it's in posture or exercise habits.'* (PT6)

Participants identified several benefits of the developed digital self-management system. For example, they pointed out that the system could help manage physical exercise, assess motor health, increase knowledge of motor health, and prevent motor impairments, and that it was convenient for home use. However, some difficulties were also reported. Older adults were concerned about the accuracy and safety of their postures during physical exercise. They also reported that the declining vision may affect text readability. Due to the lack of motivation and inactive lifestyle, they were concerned that it would be difficult to use the designed digital self-management system in the long term.

> *'Ideally, it can check my motor health and let me know if I'm at risk of falling. That way, I'll be more motivated to exercise and avoid bigger problems later.'* (PT13)

> *'As I get older, I feel lazier and don't want to exercise. I get tired easily. The biggest barrier comes from me. I don't have enough motivation to keep using the system, even if I know it's helpful.'* (PT13)

Usability test also explored older adults' difficulties with the digital self-management system. The majority of participants expressed concerns about the accuracy of their exercise postures and their motivation to continue using the system. Additionally, in terms of the connection and operation of the sensors, the majority reported no challenges. Three older adults expressed concerns about the wear location of the inertial sensors, while the other three participants raised concerns about battery endurance. Thus, compared with sensors that require specific placement or calibration positions, markless sensors are more user-friendly for older adults.

Table 28. Older adults' opinions regarding the digital self-management system

Theme	**Code**
Content visualisation mode	+Video and text
	+Video and picture
Character format	+Live-action character
Data visualisation meaning	+Understand
	-Need more specific information on behaviour performance in the system
Needed functionalities or features	+Sufficient functionalities for requirements
	-Feedback information for exercise posture improvement
	-Simple navigation with icons or pictures
	-Physical exercise categories based on the body part
	-Need to be more interesting and add icons
	-Medical resource information
	-Voice interaction
Benefits	+Manage and enhance physical exercise
	+Assess motor health
	+Maintain and improve motor ability
	+Prompt regular and healthy behaviours
	+Increase motor health knowledge
	+Convenient for home use
Difficulties	-Exercise posture accuracy
	-Vision degradation to see the texts
	-Lack motivation and adherence to using the system in the long term

7.6.3. Discussions

Older adults hold greater positive attitudes toward the usefulness of the designed digital self-management system in improving self-management ability and motor health. They also tended to agree that they would use the digital self-management system in the future. Based on the SUS results, the system's usability was rated as good. Although the digital self-management system achieved high acceptance among older adults, some participants expressed concerns about its long-term use.

Compared with purely assessment-based feedback, such as motor health levels and physical exercise accuracy, older adults showed a stronger preference for guided strategies and clear instructions, including strategies to improve motor health and methods for adjusting physical exercise postures. Previous research also found that older adults desired to know “Why” and “How” when using digital healthcare systems, which made them feel more credible (Mansson et al., 2020). Step-by-step guidance, personal explanations, and practical strategies are highly valued by older adults, especially when learning new skills or using technology (Pappas et al., 2019).

Furthermore, older adults thought that it is difficult for them to continuously use the digital self-management system in the long term, which is consistent with previous findings (Amagai et al., 2022). Declining vision and the complexity of interface information were identified as potential influencing factors. Older adults reported preferring video interaction and special graphics, which were more intuitive and easier to understand (Pappas et al., 2019). Such multimodal content reduced older adults’ need for extensive reading and supported them with better comprehension, particularly for individuals with declining vision or cognitive load sensitivity.

Based on the findings of usability tests, the following section retained the valued design elements and incorporated additional suggestions to improve the digital self-management system.

7.7. Digital Self-Management System Iteration

According to the results in the task-based usability test, older adults preferred intuitive navigation for the system operation, video and keywords for material design, meaningful graphics for information presentation, and a voice module for system interaction. Thus, the designed digital self-management system was iterated to improve its usability using proposed age-friendly design strategies. The iterated content is shown in Table 29.

In detail, the drop-down menus for education and physical exercise functionality were replaced with horizontal, icon-based interfaces (see Figure 40), reducing the system's operational complexity. The education materials were presented using video, keywords and icons, as shown in Figure 41. The keywords and icon showed the main information extracted from the viewing video. This visualisation approach could help older adults quickly understand the video's topic and enhance their memory of relevant educational content.

Table 29. The iterated content of the digital self-management system

Functionality	**Original**	**Updated**
Education	Drop-down menu for theme selection	Horizontal icon-based interface for visual theme navigation
	Educational material: main text and images	Education material: video + keywords + icon
Evaluation	Illustration of clinical tests: image + video + main text	Illustration of clinical tests: video + keywords + icon
	Result: data visualisation + keywords	Result: data visualization + keywords + meaningful graphic
		Result: Add comparison with last time using meaningful graphic and key words
Physical exercise	Physical exercise type-based themes	Body part-based themes
	Drop-down menu for theme selection	Horizontal icon-based interface for visual theme navigation
	Feedback: Posture accuracy (score)	Feedback: Specific right and wrong information regarding joint angle, limb height, postural stability, exercise speed, and postural symmetry

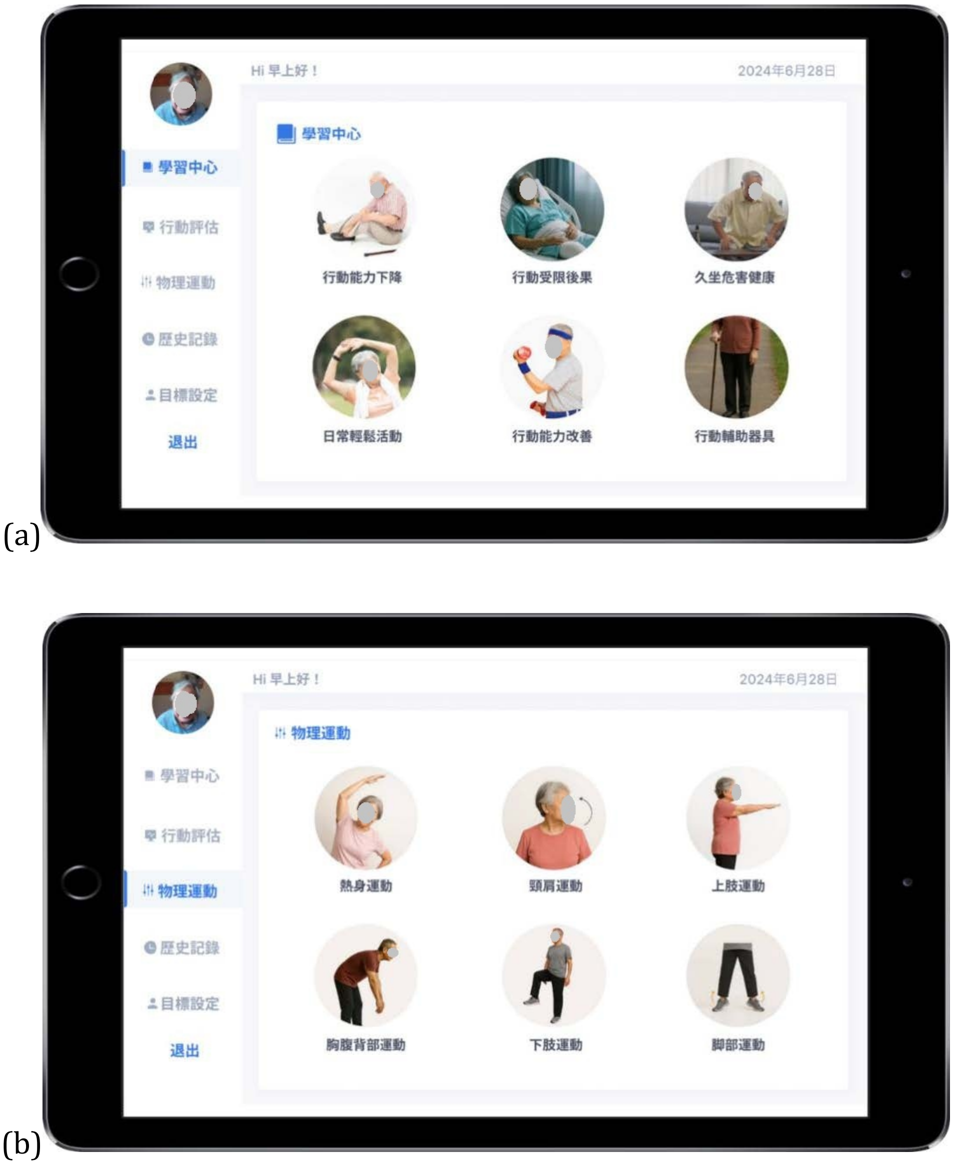
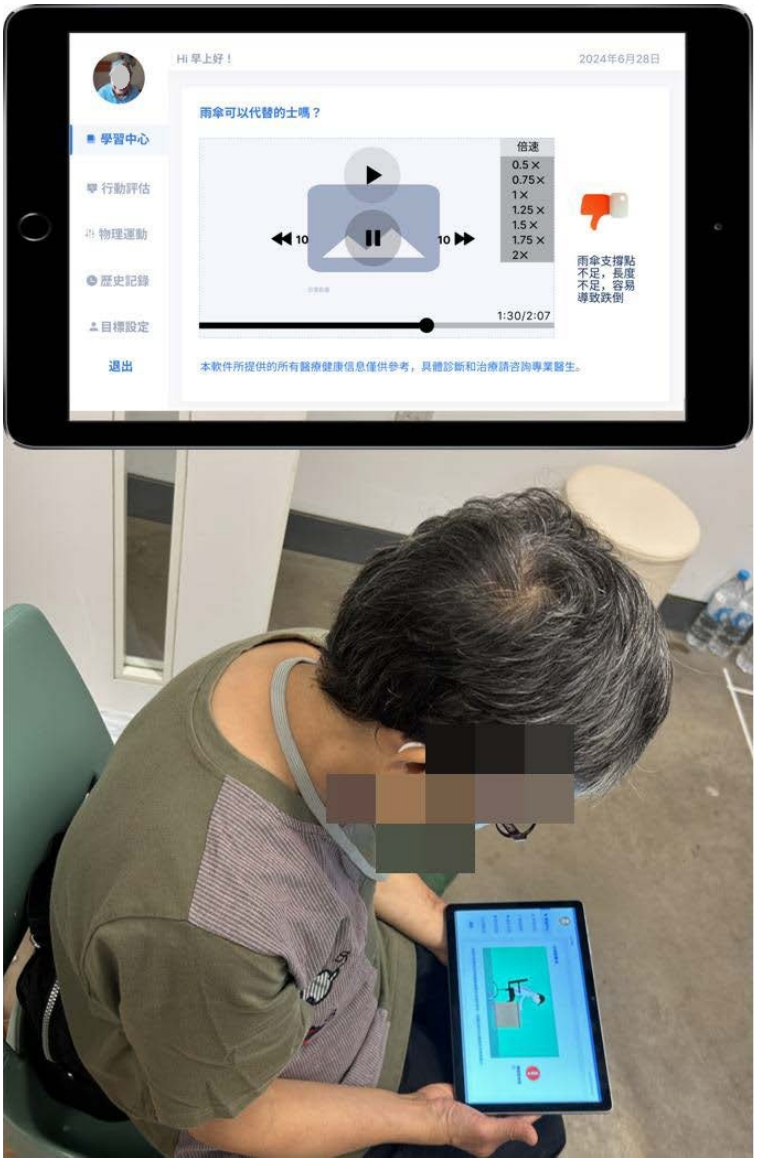


Figure 40. The iterated interfaces for theme selection: a) education functionality, b) physical exercise functionality

The illustration of clinical tests in evaluation functionality has been updated to incorporate videos, keywords, and icons. The keywords and icons explained the cutoff values for the clinical tests used in older adults' motor health assessments, helping them better understand their results. In addition, more meaningful graphics were added to the evaluation result interface to help older adults understand their motor ability and its changes, as shown in Figure 42.



Hi 早上好！

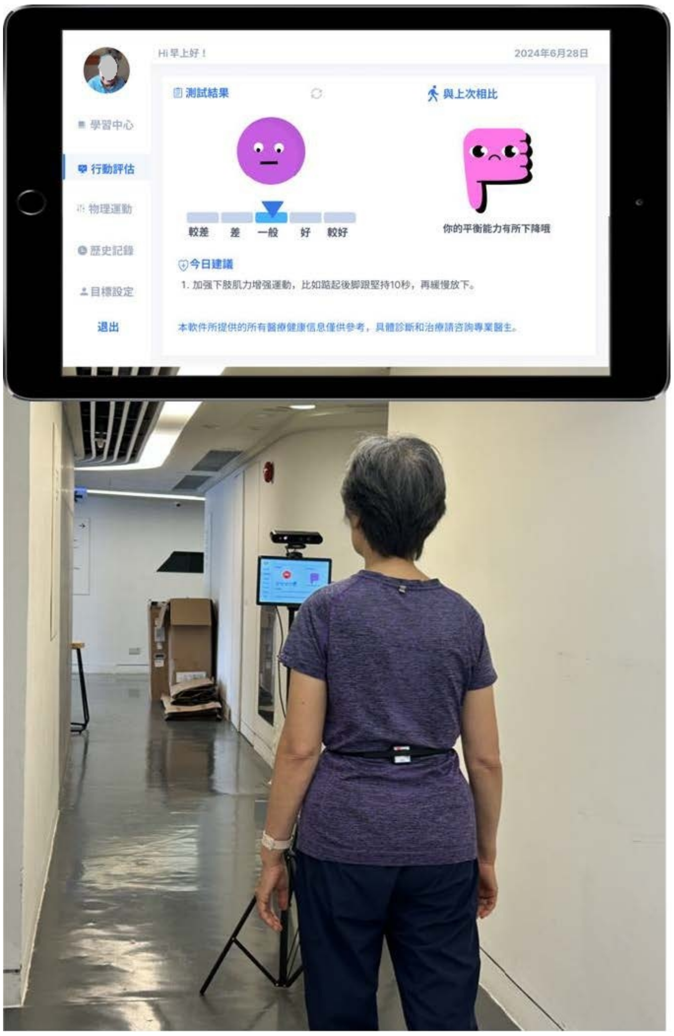
2024年6月28日

雨傘可以代替的士嗎？

雨傘支撐點不足，長度不足，容易導致跌倒

本軟件所提供的所有醫療健康信息僅供參考，具體診斷和治療請咨詢專業醫生。

Figure 41. The iterated interface for education materials



你的平衡能力有所下降哦

1. 加強下肢肌力增強運動，比如踮起後腳跟堅持10秒，再緩慢放下。

本軟件所提供的所有醫療健康信息僅供參考，具體診斷和治療請咨詢專業醫生。

Figure 42. The iterated interface for evaluation result visualisation

The main iteration for the physical exercise functionality was the exercise feedback information. To help older adults improve their exercise posture and prevent injuries, the feedback information shifted from posture accuracy to specific measures of joint angle, limb height, postural stability, exercise speed, and postural symmetry, as shown in Figure 43. For example, if an older adult's arm fails to reach shoulder height during physical exercise, the digital self-management system provides negative feedback such as "Arm height is too low (right/left)." Conversely, if the exercise is performed correctly, the system responds with positive feedback, such as “Good arm height.”

側平舉：增强中肩肌肉 （正向攝像頭）

注意事項

1. 右手臂：伸展不足，高度過低
2. 左右臂：做的很好
3. 上身：姿勢不穩定
4. 上身伸直，做得很好

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Figure 43. The iterated interface for physical exercise feedback

7.8. Summary

This chapter developed a digital self-management system for motor health and recruited older adults to conduct task-based usability test. The designed self-management system included education, evaluation and exercise functionalities to empower older adults to self-manage motor health. According to the usability test, older adults had positive attitudes toward the usefulness of the designed digital self-management system for motor health self-management and found it pleasurable to use in daily life. Additionally, the designed system achieved a “good” usability. Older adults also expressed several suggestions on the interface design. For example, the interface design should incorporate more graphics instead of text to enhance the system's intuitiveness. A combination of video and keywords was suggested as the material presentation module. In addition, older adults preferred clear, step-by-step guidance and practical strategies over assessment-only feedback. Based on the suggestions, an iterated digital self-management system was developed to conduct a pilot randomised controlled trial in Chapter 8.

CHAPTER 8: EFFECT OF FUNCTIONALITY-BASED INTERVENTIONS ON SELF-MANAGEMENT FOR MOTOR HEALTH: PILOT RANDOMIZED CONTROLLED TRIAL

8.1. Introduction

Previous studies suggested that digital health self-management systems mainly included education, evaluation and monitoring, and treatment functionalities (Moreno-Ligero et al., 2023). The digital education intervention has been verified to be effective in improving disease-related knowledge and health-related outcomes among older adults (Shah et al., 2022). Because older adults often lack regular screenings for fall risk in communities, the digital motor evaluation allows them to track their health and receive feedback on their performance, helping them assess whether they should maintain or adjust self-management strategies (Swann et al., 2021). In addition, compared with traditional physical exercise, digital physical exercise has been suggested to be more effective in improving older adults' motor health (Mao, Zhang, et al., 2024).

Although all three digital functionalities (education, evaluation and exercise) have potential benefits in improving older adults' motor health, it remains uncertain which functionality is more effective in enhancing older adults' motor self-management and health outcomes. Moreover, whether comprehensive interventions, including diverse digital functionalities, are more effective than a single functionality remains uncertain. Thus, it is important to conduct further research to investigate the effects of different functionalities and quantify their effect sizes on motor health outcomes.

In this context, this study aimed to address the following research question in Chapter 1: “Question 3: What is the feasibility of the proposed functionality design framework for the elderly-centric digital self-management system, including usability and the effect of diverse functionalities on older adults' motor health self-management?” Based on the designed digital self-management system in Chapter 7, this study conducted a single-centre interventional multi-arm randomised controlled trial (RCT) to investigate the effect of different functionalities in improving older adults’ motor health and their perception on this system.

8.2. Methods

8.2.1. Study Design

This study was a single-centre interventional multi-arm randomised controlled trial (RCT) with blinded assessors. The trial has been registered with the ISRCTN Registry platform and approved by the Institutional Review Board of The Hong Kong Polytechnic University. All procedures were conducted in accordance with the ethical standards of the institutional research committee and with the Helsinki Declaration. All participants provided written informed consent.

8.2.2. Participants

Participants were recruited using convenience sampling methods, with recruitment conducted through posters distributed at community centres and in the media. Interested individuals contacted the research team and were screened for eligibility before being randomly assigned to the intervention or control group.

Community-dwelling older adults were recruited for this study. The eligibility criteria of included older adults were: 1) Older than 60 years; 2) No serious diseases or dementia; 3) Have the ability to move by themselves; 4) Have the ability to perform daily activities; 5) Without communication difficulties Exclusion criteria included: 1) Below 60 years; 2) Unstable mental conditions; 3) Without movement ability; 4) With severe hearing problems or others affecting communication.

Based on the recommended sample size of 12 participants per group for pilot studies and a 20% attrition rate (Julious, 2005), this study included 15 participants in each group. This approach aligns with common practices in exploratory trials aimed at assessing feasibility and preliminary effects. Eligible participants were randomly assigned to digital system -based education group (CG), assessment group (AG), physical exercise group (PG), education + assessment group (EAG), education + physical exercise group (EPG), assessment + physical exercise group (APG), education + assessment + physical exercise group (EAPG) or the control group (CG) using a computer-based random number generator (1:1 ratio). A computer-based randomiser (https://www.randomizer.org/) was used to randomise participants. An independent researcher, not involved in participant recruitment or intervention delivery, was responsible for generating the allocation sequence and sealing it into anonymous envelopes to ensure allocation concealment. The assessors were blinded to the participant allocation. Considering the nature of the intervention, it was not possible to fully maintain blinding for participants and intervention researchers.

8.2.3. Data Collection

At baseline (pre-intervention), assessors collected the following baseline characteristics: 1) demographic information, including age, sex, educational level, marital status, living arrangement, smoking habits, drinking habits, chronic diseases, lower limb diseases, and assistant aid use experience; 2) Montreal Cognitive Assessment Scale (MocA) (Wong et al., 2009); 3) FRAIL scale (Morley et al., 2012); 4) dominant handgrip strength; 5) Short Physical Performance Battery (Pavasini et al., 2016) (SPPB) ; 6) Three Meters Timed Up and Go test (3TUG) (Podsiadlo & Richardson, 1991); 7) Short Falls Efficacy Scale International (short FES-I) (Kempen et al., 2008); 8) Physical Activity Scale for the Elderly (PASE) (Washburn et al., 1993); 9) General Self-Efficacy Scale (GSE) (Y. Wang et al., 2022); 10) perceptions (perceived usefulness in enhancing self-management abilities, improving motor health, increasing motor health knowledge) and attitudes (good idea to use the digital self-management system for motor health management, and behavior intention to use the digital self-management system) to the designed digital self-management system, all questions uses a 5-point Likert scale from 1 ("strongly disagree") to 5 ("strongly agree") (Meldrum et al., 2012). The outcomes ranging from 3) to 10) were also measured immediately after 4 weeks of intervention (post-intervention).

8.2.4. Interventions

Based on the responses of physiotherapists in Chapter 5, the average physical exercise intervention for older adults lasted around 40 minutes in the traditional clinical process (See Table 17). In terms of the motor assessment, the clinical duration is around 20 minutes(See Table 17). However, physiotherapists suggested that this duration can be reduced by half based on the digital assessment systems (See Figure 23). Thus, the intervention duration in the randomised controlled trial was identified as 40 minutes.

8.2.4.1. Education Group

Participants received a weekly digital self-management system-based education intervention in the education group, consisting of 4 sessions at a laboratory. At the first session, researchers introduced the content of education functionality in the digital self-management system and trained participants on how to use the system to search for and watch videos related to motor health self-management. Thus, the first session lasted approximately 60 minutes, including 20 minutes of training and 40 minutes of intervention. The subsequent sessions lasted around 40 minutes. During the 40 minutes, participants were allowed to watch video materials on topics that interest them.

8.2.4.2. Assessment Group

Participants in the assessment group received a weekly motor health evaluation based on the digital self-management system. All four sessions were conducted in a laboratory. At the first session, researchers introduced evaluation functionality and trained older adults on how to use the system to perform motor health evaluation. Thus, the first session lasted approximately 30 minutes, including 20 minutes of training and 10 minutes of motor assessment. The subsequent sessions lasted around 10 minutes.

8.2.4.3. Physical Exercise Group

Participants received a weekly digital self-management system-based physical exercise intervention in the physical exercise group, consisting of 4 sessions at a laboratory. At the first session, researchers introduced the content of physical exercise functionality in the digital self-management system and trained participants on how to use the system to perform physical exercise and understand feedback information. Thus, the first session lasted approximately 60 minutes, including 20 minutes of training and 40 minutes of intervention. The subsequent sessions lasted around 40 minutes. During the 40 minutes, participants were allowed to do 5 minutes of warm-up and 35 minutes of physical exercise based on the guidance and feedback of the system.

8.2.4.4. Education + Assessment Group

Participants in the education + assessment group received a weekly motor health education and evaluation based on the digital self-management system. All the 4 sessions were carried out at a laboratory. At the first session, researchers introduced education and evaluation functionalities and trained older adults on how to use the system to search for and watch videos related to motor health self-management and perform motor health evaluation. Thus, the first session lasted approximately 60 minutes, including 20 minutes of training, 30 minutes of education, and 10 minutes of evaluation. The subsequent sessions lasted around 40 minutes (30 minutes of education and 10 minutes of evaluation).

8.2.4.5. Education + Physical Exercise Group

Participants received a weekly digital self-management system-based education and physical exercise intervention in the education + physical exercise group, consisting of 4 sessions at a laboratory. At the first session, researchers introduced the content of education and physical exercise functionalities and trained participants on how to use the system to search for and watch videos related to motor health self-management, as well as perform physical exercise and understand feedback information. Thus, the first session lasted approximately 60 minutes, including 20 minutes of training, 20 minutes of education intervention, and 20 minutes of physical exercise intervention. The subsequent sessions lasted around 40 minutes, including 20 minutes of education intervention and 20 minutes of physical exercise intervention (5 minutes of warm-up and 15 minutes of physical exercise).

8.2.4.6. Assessment + Physical Exercise Group

Participants in the assessment + physical exercise group received a weekly motor health evaluation and physical exercise based on the digital self-management system. All four sessions were carried out in a laboratory. At the first session, researchers introduced evaluation and exercise functionalities and trained older adults on how to use the system to perform motor health evaluation and exercise. Thus, the first session lasted approximately 60 minutes, including 20 minutes of training, 10 minutes of evaluation , and 30 minutes of physical exercise. The subsequent sessions lasted around 40 minutes, including 10 minutes of evaluation and 30 minutes of physical exercise (5 minutes of warm-up and 25 minutes of physical exercise).

8.2.4.7. Education + Assessment + Physical Exercise Group

Participants received a weekly digital self-management system-based education, motor evaluation and physical exercise intervention in the education + assessment + physical exercise group, consisting of 4 sessions at a laboratory. At the first session, researchers introduced education, motor evaluation and physical exercise functionalities and trained participants on how to use the system to search for and watch videos related to motor health self-management, perform motor health evaluation, as well as perform physical exercise and understand feedback information. Thus, the first session lasted approximately 60 minutes, including 20 minutes of training, 15 minutes of education intervention, 10 minutes of evaluation and 15 minutes of physical exercise intervention. The subsequent sessions lasted around 40 minutes, including 15 minutes of education intervention, 10 minutes of evaluation and 15 minutes of physical exercise (5 minutes of warm-up and 10 minutes of physical exercise).

8.2.4.8. Control Group

The participants in the control group were suggested to continue their usual lifestyle and activities. No additional treatments or support were provided for the control group.

8.2.5. Data Analysis

Descriptive statistics, including mean, standard deviation (SD), or percentage, were used to summarize the included participants' demographic information and study outcomes. Based on the Shapiro-Wilk test for data normality, the difference in outcomes between baseline and post-intervention was further analysed using the Paired-samples T-test or the Wilcoxon signed-rank test (Ross et al., 2017). The One-way Analysis of Variance or Kruskal-Wallis H Test was also used to assess group differences in changes from baseline to post-intervention (MacFarland et al., 2016). Effect sizes of the interventions on outcomes were calculated using Cohen's d, with values of 0.2, 0.5, and 0.8 interpreted as small, medium, and large, respectively (Wan et al., 2024). These data analyses were conducted using IBM SPSS Statistics 29.0.2.0 (IBM Corp., Armonk, NY, USA). In addition, a partial least squares structural equation modelling was used to analyse the factors affecting motor health with SmartPLS 3.0 (SmartPLS GmbH, Boenningstedt, Germany). The statistical significance level was set at $p = 0.05$.

8.3. Results

8.3.1. Demographic Information of Participants

A total of 186 participants were recruited and screened in this study. Of these, 66 (35%) participants were excluded due to ineligibility for the inclusion criteria or decline to participate. Thus, this RCT study finally included 120 eligible community-dwelling older adults. They were randomly allocated to the education group (EG: n=15), assessment group (AG: n=15), physical exercise group (PG: n=15), education + assessment group (EA: n=15), education + physical exercise group (EP: n=15), assessment + physical exercise group (AP: n=15), education + assessment + physical exercise group (EAP: n=15), or the control group (CG: n=15).

Table 30 shows the demographic characteristics of the included participants. They had a mean age of 66.83 years (SD=4.28), with around 70% being female. Their average cognitive level (MocA) was 27.73 scores (SD=2.30). Approximately half of the participants were married (63%), had a secondary education level (50%), and had drinking experience (45%). Most of them lived with family members (75%), had no history of smoking (95%), and used mobility aids (96%). Hypertension and Hypercholesterolemia were the two most common chronic diseases among the included participants, affecting 24% and 27% of them, respectively. Around one in ten participants also had diabetes mellitus (12%) and Hyperlipidemia (12%). In addition, Osteoarthritis is the most common lower limb disease among older adults, accounting for 35% of the included participants.

Of the 120 included participants, 111 (92.5%) completed the outcome measure at T1 (immediately after 4 weeks of intervention). Based on the CONSORT flow diagram (Eldridge et al., 2016), the flowchart of the RCT study is shown in Figure 44.

Table 30. Demographic information of the included participants (n=120)

Demographic information		**Number (percentage)**	**Demographic information**		**Number (percentage)**
Gender	Female	85 (71%)	Hypertension	Yes	29 (24 %)
	Male	35 (29%)		No	91 (76%)
Education	Primary or below	1 (1%)	Hyperlipidemia	Yes	14 (12%)
	Junior secondary	15 (12%)		No	106 (88%)
	Secondary	60 (50%)	Hypercholesterolemia	Yes	33 (27%)
	Undergraduate or above	44 (37%)		No	87 (73%)
Material status	Married	75 (63%)	Heart Diseases	Yes	7 (6%)
	Widowed	10 (8%)		No	103 (94%)
	Separated/divorced	8 (7%)	Osteoarthritis	Yes	42 (35%)
	Single	27 (22%)		No	78 (65%)
Living arrangement	Alone	30 (25%)	Plantar fasciitis	Yes	15 (13%)
	Live with family members	90 (75%)		No	105 (88%)
Smoking	Current smoker	1 (1%)	Varicose veins	Yes	12 (10%)
	Former smoker	5 (4%)		No	108 (90%)
	Never smoker	114 (95%)	Achilles tendinitis	Yes	11 (9%)
Drinking	Current drinker	54 (45%)		No	109 (91%)
	Former drinker	2 (2%)	meniscus injury	Yes	10 (8%)
	Never drinker	64 (53%)		No	110 (92%)
Diabetes mellitus	Yes	15 (12%)	Canes	Yes	5 (4%)
	No	105 (88%)		No	115 (96%)

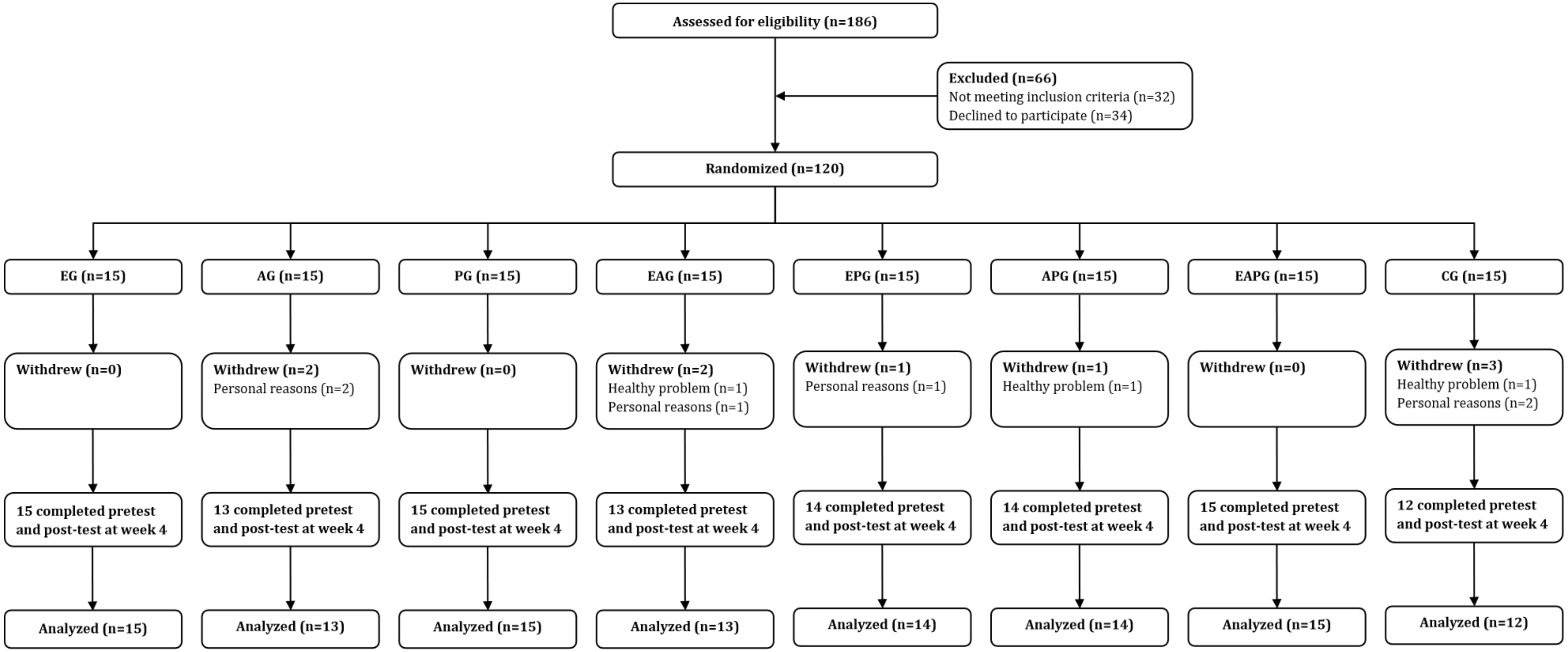

Figure 44. Flowchart of the RCT study with CONSORT flow diagram

8.3.2. Effects of Different Interventions

According to the results of the Paired-samples T-test or Wilcoxon signed-rank test (see Figure 45), participants in the education group (EG) showed a statistically significant improvement in the dominant handgrip strength from baseline (22.07±6.57) to post-intervention (26.77±8.80), with a mean difference of 4.70 (SD=5.10, p=0.003) relative to the value of baseline. Additionally, the assessment group (AG) demonstrated a significantly increased dominant handgrip strength at post-intervention (mean difference = 4.44 ± 7.21, p = 0.046). The physical exercise group (PG), education + assessment group (EAG), education + physical exercise group (EPG) and education + assessment + physical exercise group (EAPG) also presented a statistically significant increased dominant handgrip strength from baseline to post-intervention (PG: mean difference=3.38±15.00, p=0.012; EAG: mean difference=4.98±4.33, p=0.001; EPG: mean difference=3.84±4.86, p=0.003; EAPG: mean difference=2.88±4.20, p=0.014), respectively.

Among the groups with statistically significant differences in dominant handgrip strength, the Cohen's d values of EG and EAG ranged from 0.92 to 1.15 (see Table 31), indicating a large positive effect size. The PG had a small effect size of 0.23, while the other groups (AG: 0.62, EPG: 0.79, EAPG: 0.69) had medium effect sizes. However, no statistically significant improvement in the dominant handgrip strength was observed at assessment + physical exercise group (APG: mean difference=1.91±4.18) and control group (CG: mean difference=0.73±5.63), with p values of 0.111 and 0.448, respectively. According to the results of the Kruskal-Wallis H Test, no statistically significant group differences in this outcome change from baseline to post-intervention were observed (*p*=0.11, see Table 31).

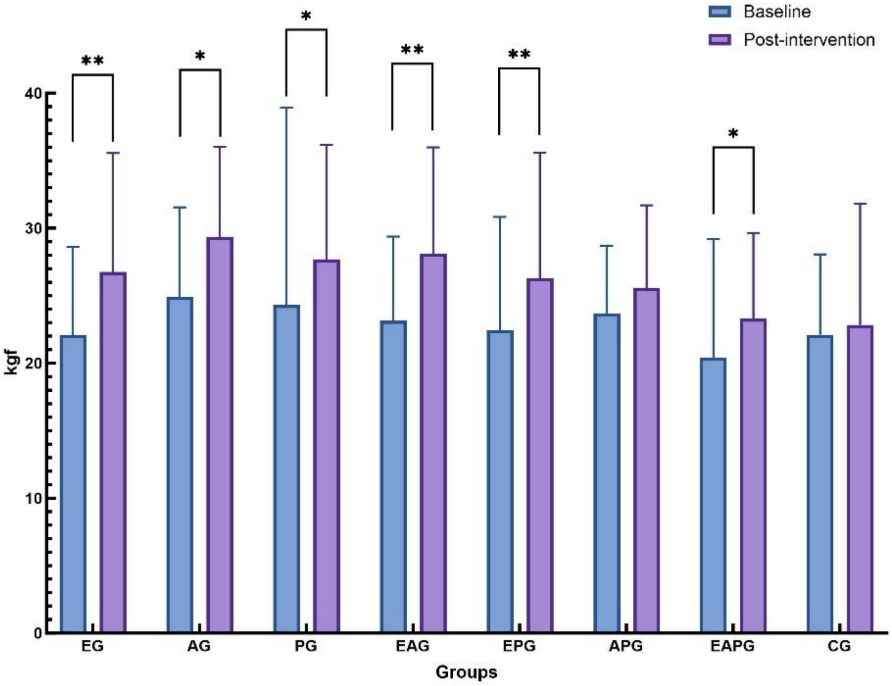

Figure 45. The difference in dominant handgrip strength between baseline and post-intervention (*: *p*<0.05; **: *p*<0.01)

Figure 46 shows the results of the Wilcoxon signed-rank test on Short Physical Performance Battery (SPPB). There was no statistically significant difference in SPPB value between the baseline and post intervention among all groups (EG: mean difference=-0.13±1.06, *p*=0.603; AG: mean difference=0.00±1.87, *p*=1.00; PG: mean difference=0.00±1.00, *p*=1.00; EAG: mean difference=0.23±0.93, *p*=0.366; EPG: mean difference=-0.57±1.22, *p*=0.068; APG: mean difference=0.00±1.75, *p*=0.891; EAPG: mean difference=-0.20±1.51, *p*=0.533; CG: mean difference=-0.33±1.37, *p*=0.046). In addition, as shown in Table 31, no statistically significant difference in SPPB score change from baseline to post-intervention was observed across the eight groups (*p*=0.90).

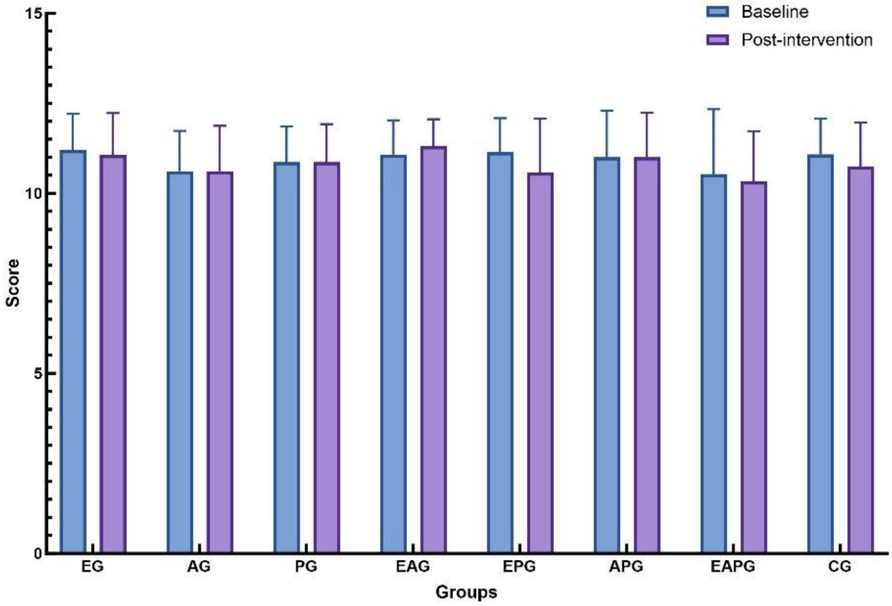

Figure 46. The difference in SPPB between baseline and post-intervention

Based on the results of the Paired-samples T-test on the Three Meters Timed Up and Go test (3TUG) in Figure 47, a statistically significant decrease in the 3TUG time was observed from baseline to post-intervention in AG (mean difference=-0.62±0.97; *p*=0.039) and PG (mean difference=-1.06±1.61, *p*=0.020), respectively. As shown in Table 31, the Cohen's *d* values for AG and PG were -0.64 and -0.66, respectively, indicating medium positive effect sizes in improving motor health.

However, there was no statistically significant difference in 3TUG value between the baseline and post-intervention among other groups (EG: mean difference=-0.35±1.08, *p*=0.230; EAG: mean difference=-0.15±1.14, *p*=0.635; EPG: mean difference=-0.25±1.20, *p*=0.440; APG: mean difference=-0.48±1.22, *p*=0.164;

EAPG: mean difference=-0.28±1.21, *p*=0.390; CG: mean difference=-0.25±1.89, *p*=0.660). In addition, according to the result of Kruskal-wallis H Test, no statistically significant difference existed in 3TUG value changes from baseline to post-intervention between eight groups (*p*=0.75).

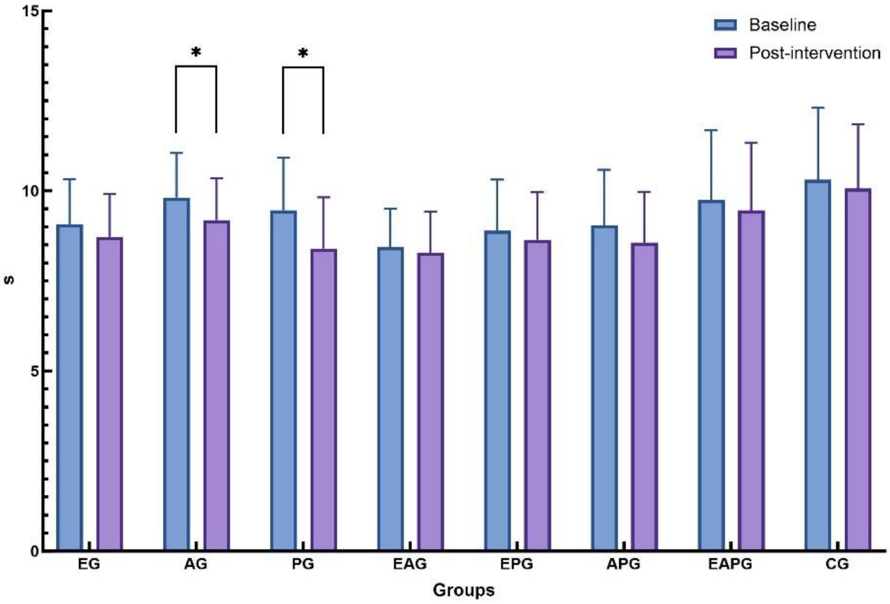

Figure 47. The difference in 3TUG between baseline and post-intervention (*: *p*<0.05)

Figure 48 shows the results of the Paired-samples T-test on Short Falls Efficacy Scale International (short FES-I). No statistically significant difference existed in short FES-I value between the baseline and post intervention among all groups (EG: mean difference= -1.13±2.85, *p*=0.146; AG: mean difference=-0.31±2.95, *p*=0.714; PG: mean difference=-1.60±4.36, *p*=0.177; EAG: mean difference=2.08±3.62, *p*=0.061; EPG: mean difference=1.07±2.95, *p*=0.197; APG: mean difference=-0.14±3.46, *p*=0.880; EAPG: mean difference=0.20±2.54, *p*=0.765;

CG: mean difference=1.42±6.24, *p*=0.449). Moreover, based on the result of the Kruskal-Wallis H Test in Table 31, no statistically significant difference existed in short FES-I value changes from baseline to post-intervention between eight groups (*p*=0.20).

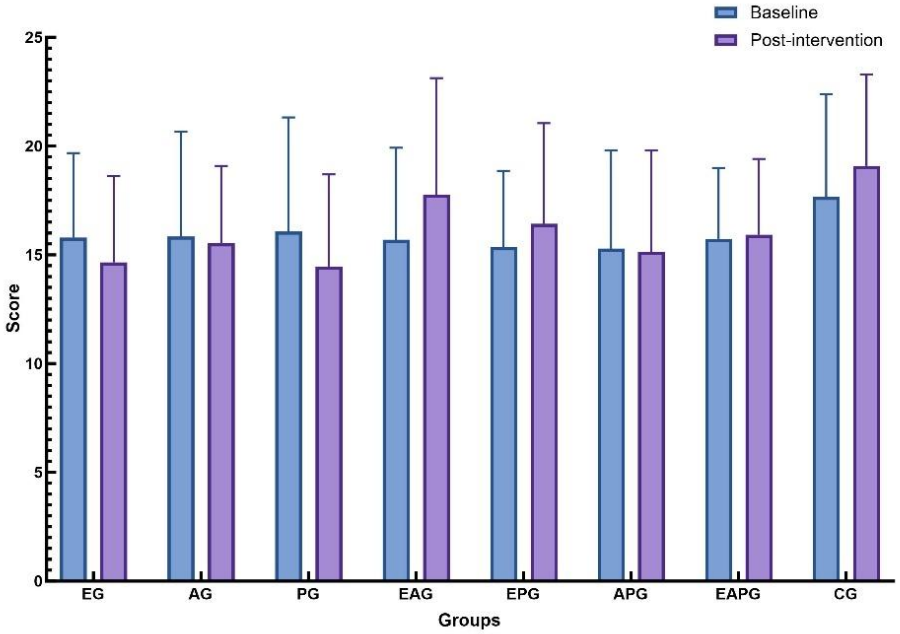

Figure 48. The difference in short FES-I between baseline and post-intervention

As shown in Figure 49, only the APG showed a statistically significant improvement in the Physical Activity Scale for the Elderly (PASE) from baseline to post-intervention (mean difference=38.63±55.20, *p*=0.022). Cohen's *d* value of APG was 0.70, indicating a medium positive effect size. The remaining groups presented no statistically significant differences in the PASE value between baseline and post-intervention (EG: mean difference=-11.10±82.95, *p*=0.612; AG: mean difference=18.56±50.71, *p*=0.212; PG: mean difference=2.82±61.07, *p*=0.496; EAG: mean difference=16.61±71.33, *p*=0.311; EPG: mean difference=-42.43±144.69, *p*=0.470; EAPG: mean difference=-7.39±73.25, *p*=0.691; CG: mean difference=2.77±61.18, *p*=0.878). According to the results of Kruskal-wallis H Test, no statistically significant difference existed in PASE value changes from baseline to post-intervention between eight groups (*p*=0.400).

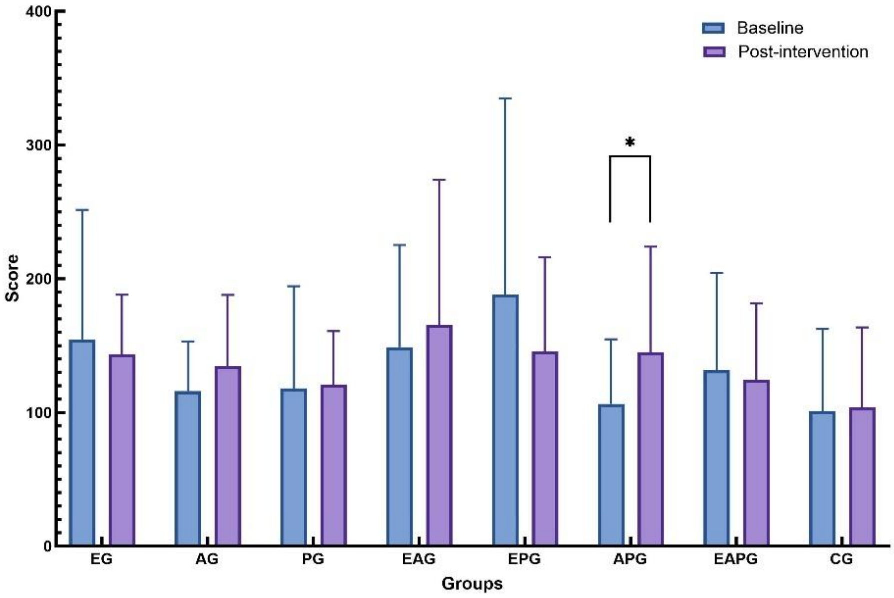

Figure 49. The difference in PASE between baseline and post-intervention (*: $p<0.05$)

Figure 50 shows the results of the Paired-samples T-test and Wilcoxon signed-rank test on General Self-Efficacy Scale (GSE). The EG presented a statistically significant improvement in GSE value from baseline (22.53±4.56) to post-intervention (26.13±5.68), with a mean difference of 3.60 (SD=5.32, *p*=0.033) relative to the value of baseline. The Cohen's *d* value of EG was 0.68, indicating a medium positive effect size.

However, there was no statistically significant difference in GSE value between the baseline and post intervention among other groups (AG: mean difference=-0.92±3.2, *p*=0.319; PG: mean difference=-0.93±5.11, *p*=0.491; EAG: mean difference=0.08±6.29, *p*=0.966; EPG: mean difference=0.57±5.11, *p*=0.682; APG: mean difference=1.86±4.42, *p*=0.140; EAPG: mean difference=-0.73±4.18, *p*=0.508; CG: mean difference=-2.92±5.79, *p*=0.109). Notably, as shown in Table 31, a statistically significant group difference existed in GSE value changes from baseline to post-intervention (*p*=0.04). In detail, the post-hoc pairwise comparisons revealed that EG significantly differed from CG (*p*=0.002).

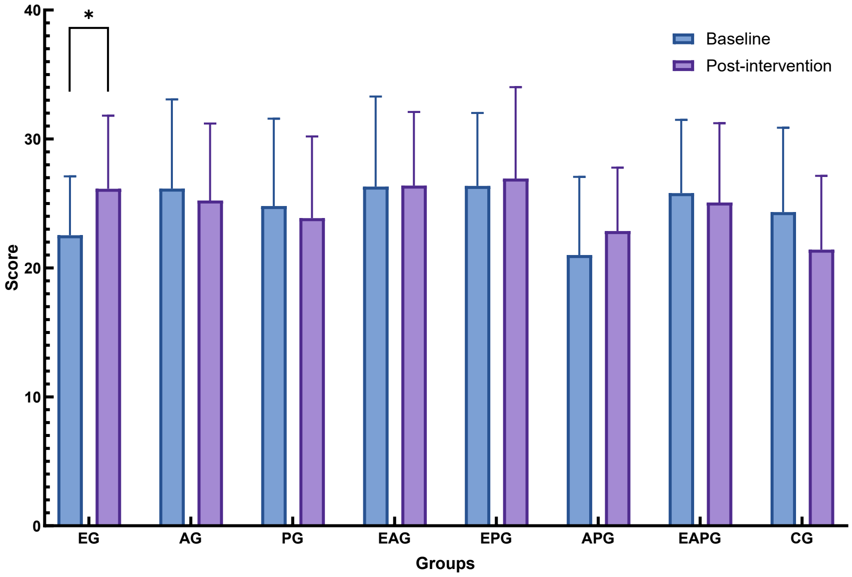

Figure 50. The difference in GSE between baseline and post-intervention (*: *p*<0.05)

Figure 51 presents the results of the Wilcoxon signed-rank test on older adults' perceived usefulness in enhancing self-management abilities. Within APG, a statistically significant difference existed in the perceived usefulness between baseline and post-intervention (mean difference=0.50±0.65, *p*=0.020). Cohen's *d* value of the APG was 0.77, indicating a medium positive effect size.

However, the other groups showed no statistically significant difference in older adults' perceived usefulness in enhancing self-management abilities between baseline and post-intervention (EG: mean difference=0.07±0.70, *p*=0.705; AG: mean difference=0.08±0.64, *p*=0.655; PG: mean difference=0.13±0.99, *p*=0.557; EAG: mean difference=0.38±0.77, *p*=0.096; EPG: mean difference=-0.21±0.08, *p*=0.317; EAPG: mean difference=0.13±0.99, *p*=0.660; CG: mean difference=-0.17±0.72, *p*=0.414). The result of Kruskal-wallis H Test revealed no statistically significant difference in perceived usefulness value changes from baseline to post-intervention between all groups (*p*=0.242).

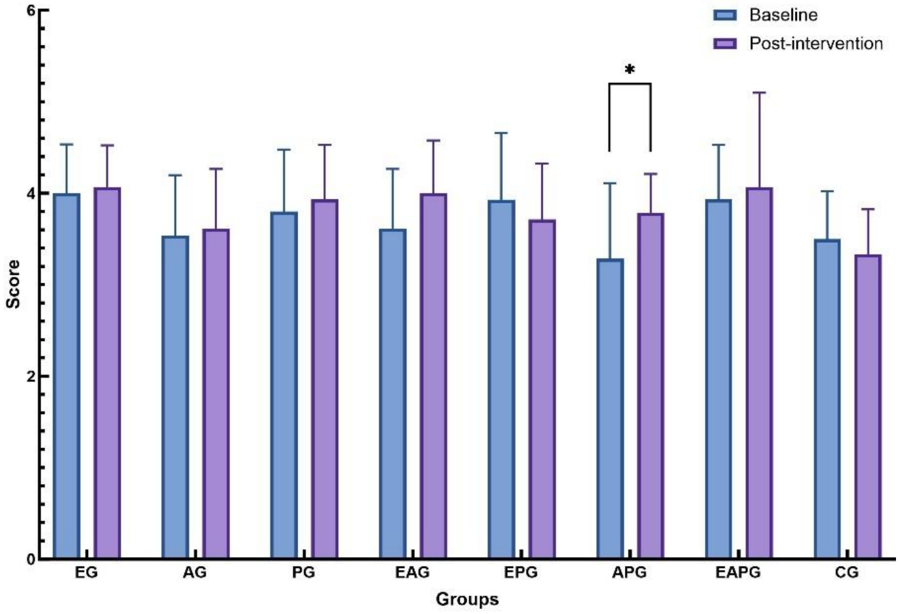

Figure 51. The difference in perceived usefulness in enhancing self-management abilities between baseline and post-intervention (*: $p<0.05$)

Figure 52 shows the results of the Wilcoxon signed-rank test on perceived usefulness in improving motor health. There was no statistically significant difference in this perceived usefulness value between the baseline and post intervention among all groups (EG: mean difference=0.00±0.65, *p*=1.000; AG: mean difference=-0.23±0.44, *p*=0.083; PG: mean difference=0.13±1.13, *p*=0.623; EAG: mean difference=0.23±0.73, *p*=0.257; EPG: mean difference=0.14±0.77, *p*=0.480; APG: mean difference=0.43±0.76, *p*=0.058; EAPG: mean difference=-0.07±1.16, *p*=0.660; CG: mean difference=-0.17±0.58, *p*=0.317). As shown in Table 31, no statistically significant difference existed in this perceived usefulness value changes from baseline to post-intervention between eight groups (*p*=0.304).

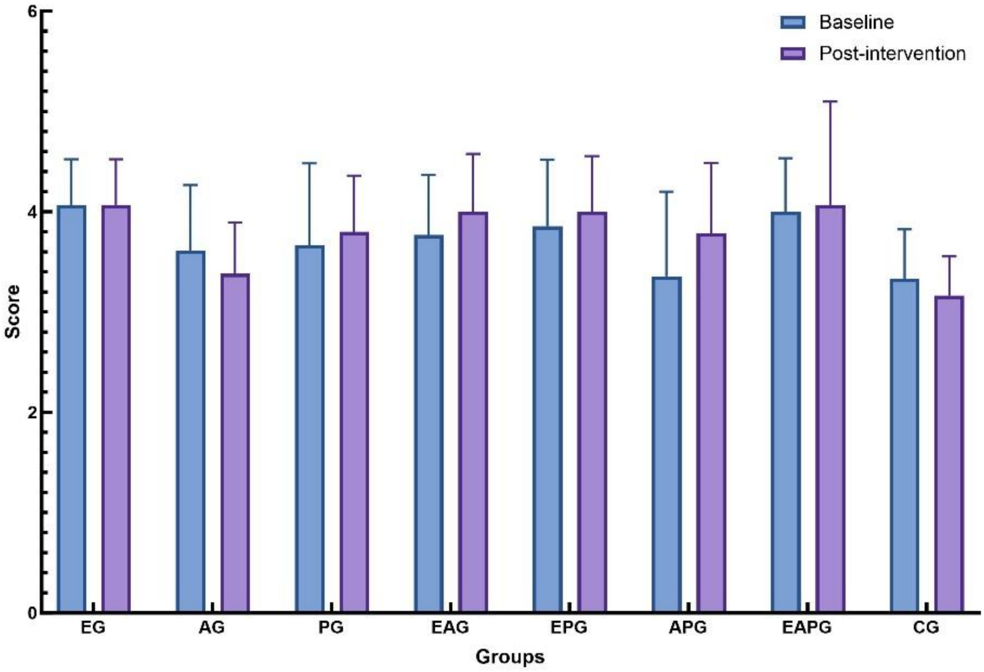

Figure 52. The difference in perceived usefulness in improving motor health between baseline and post-intervention

As shown in Figure 53, the results of Wilcoxon signed-rank test presented that no statistically significant difference existed in perceived usefulness in increasing motor health between the baseline and post intervention among all groups (EG: mean difference=0.07±0.59, *p*=0.655; AG: mean difference=-0.23±0.60, *p*=0.180; PG: mean difference=0.27±0.80, *p*=0.206; EAG: mean difference=0.08±0.64, *p*=0.655; EPG: mean difference=0.07±0.73, *p*=0.705; APG: mean difference=-0.36±0.74, *p*=0.096; EAPG: mean difference=0.07±0.70, *p*=0.705; CG: mean difference=-0.25±0.62, *p*=0.180). Moreover, based on the results of the Kruskal-Wallis H Test in Table 31, no statistically significant difference in perceived usefulness change from baseline to post-intervention was observed across the eight groups (*p*=0.302).

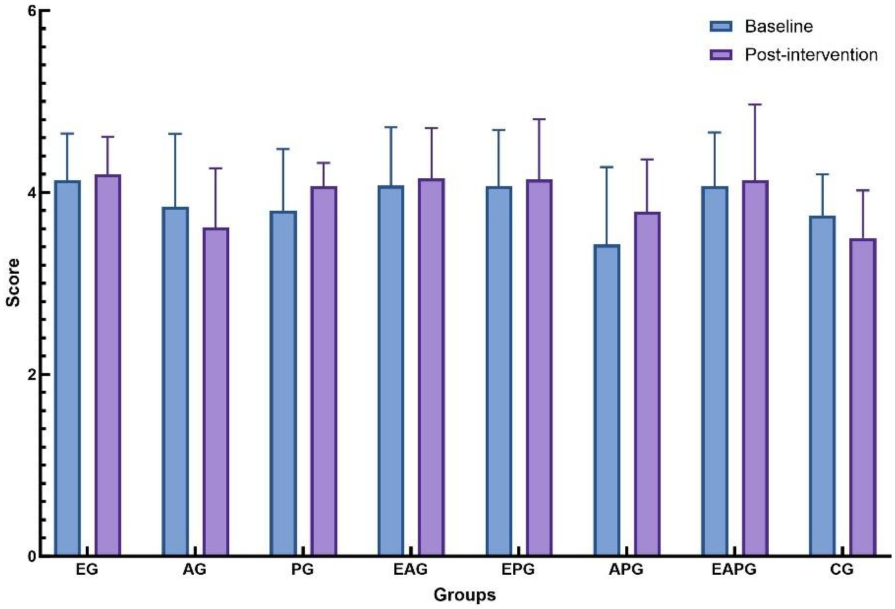

Figure 53. The difference in perceived usefulness in increasing motor health knowledge between baseline and post-intervention

Figure 54 shows the results of the Wilcoxon signed-rank test on older adults' attitudes towards the designed digital self-management system. There was no statistically significant difference in the attitude value between the baseline and post intervention among all groups (EG: mean difference=0.07±0.70, *p*=0.705; AG: mean difference=-0.15±0.80, *p*=0.480; PG: mean difference=0.33±0.90, *p*=0.160; EAG: mean difference=-0.08±0.49, *p*=0.564; EPG: mean difference=-0.07±0.47, *p*=0.564; APG: mean difference=0.210±0.80, *p*=0.317; EAPG: mean difference=-0.07±0.70, *p*=0.705; CG: mean difference=-0.17±0.72, *p*=0.414). In addition, Table 31 also revealed that no statistically significant difference existed in attitude value changes from baseline to post-intervention between eight groups (*p*=0.717).

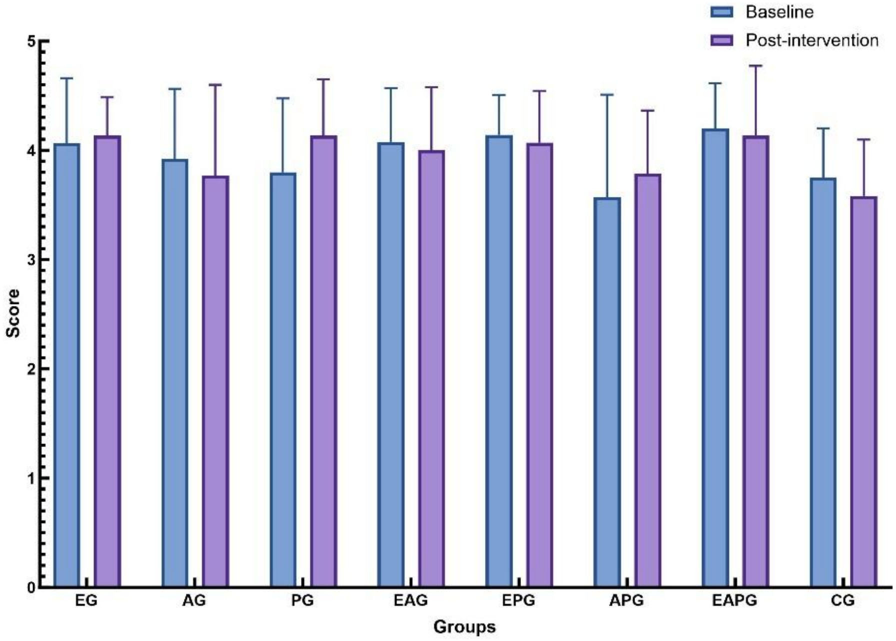

Figure 54. The difference in attitude (good idea) towards the digital self-management system between baseline and post-intervention

As shown in Figure 55, the results of Wilcoxon signed-rank test presented that no statistically significant difference existed in behavioral intention to use the designed digital self-management system between the baseline and post intervention among all groups (EG: mean difference=0.07±0.59, *p*=0.655; AG: mean difference=-0.23±0.93, *p*=0.366; PG: mean difference=0.00±0.76, *p*=1.000; EAG: mean difference=0.08±0.28, *p*=0.317; EPG: mean difference=0.14±0.53, *p*=0.317; APG: mean difference=0.00±0.78, *p*=1.000; EAPG: mean difference=0.00±0.76, *p*=1.000; CG: mean difference=0.17±0.58, *p*=0.317). Moreover, based on the results of the Kruskal-Wallis H Test in Table 31, no statistically significant difference existed in behavioural intention changes from baseline to post-intervention between the eight groups (*p = 0.909*).

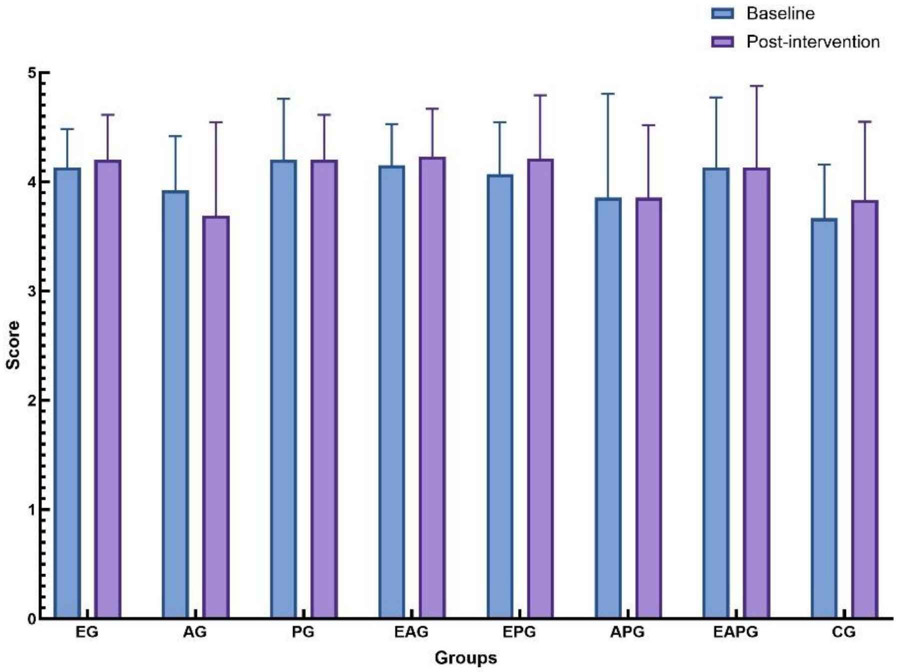

Figure 55. The difference in behavioural intention to use the digital self-management system between baseline and post-intervention

Table 31. Kruskal-wallis H Test for differences (Post-Pre) between the intervention and control groups (*: $p<0.05$; **: $p<0.01$)

Outcomes		**EG**	**AG**	**PG**	**EAG**	**EPG**	**APG**	**EAPG**	**CG**	***p***
Dominant handgrip strength	Δ(Post-pre)	4.70 (5.10)	4.44 (7.21)	3.38 (15.00)	4.98 (4.33)	3.84 (4.86)	1.91 (4.18)	2.88 (4.20)	0.73 (5.63)	0.11
	Cohen's d	0.92	0.62	0.23	1.15	0.790.46	0.46	0.69	0.13	
SPPB	Δ(post-pre)	-0.13 (1.06)	0.00 (1.87)	0.00 (0.23)	-0.57 (1.22)	0.00 (1.75)	-0.20 (1.52)	-0.33 (1.37)	-0.13 (1.35)	0.90
	Cohen's d	-0.13	0.00	0.00	0.25	-0.47	0.00	-0.13	-0.24	
3TUG	Δ(post-pre)	-0.35 (1.08)	-0.62 (0.97)	-1.06 (1.61)	-0.15 (1.14)	-0.25 (1.20)	-0.48 (1.22)	-0.28 (1.21)	-0.25 (1.89)	0.75
	Cohen's d	-0.32	-0.64	-0.66	-0.14	-0.21	-0.39	-0.23	-0.13	
FES	Δ(post-pre)	-1.13 (2.85)	-0.31 (2.95)	-1.60 (4.36)	2.08 (3.62)	1.07 (2.95)	-0.14 (3.46)	0.20 (2.54)	1.42 (6.24)	0.20
	Cohen's d	-0.40	-0.10	-0.37	0.57	0.36	-0.04	0.08	0.23	
PASE	Δ(post-pre)	-11.10(83.0)	18.56 (50.71)	2.82 (61.07)	16.61 (71.33)	-42.4 (144.7)	38.63 (55.20)	-7.39 (73.25)	2.77 (61.18)	0.40
	Cohen's d	-0.13	0.37	0.05	0.23	-0.29	0.70	-0.10	0.05	
GSE	Δ(post-pre)	3.60 (5.32) **	-0.92 (3.20)	-0.93 (5.11)	0.08 (6.29)	0.57 (5.11)	1.86 (4.42)	-0.73 (4.18)	-2.92(5.79)**	0.04*
	Cohen's d	0.68	-0.29	-0.18	0.01	0.11	0.42	-0.18	-0.50	
Enhancing self-management abilities	Δ(post-pre)	0.07 (0.70)	0.08 (0.64)	0.13 (0.99)	0.38 (0.77)	-0.21 (0.80)	0.50 (0.65)	0.13 (0.99)	-0.17 (0.72)	0.24
	Cohen's d	0.09	0.12	0.13	0.50	-0.27	0.77	0.13	-0.23	
Improving motor health	Δ(post-pre)	0.00 (0.65)	-0.23 (0.44)	0.13 (1.13)	0.23 (0.73)	0.14 (0.77)	0.43 (0.76)	0.07 (1.16)	-0.17 (0.58)	0.30
	Cohen's d	0.00	-0.53	0.12	0.32	0.19	0.57	0.06	-0.29	
Increasing motor health knowledge	Δ(post-pre)	0.07 (0.59)	-0.23 (0.60)	0.27 (0.80)	0.08 (0.64)	0.07 (0.73)	0.36 (0.74)	0.07 (0.70)	-0.25 (0.62)	0.30
	Cohen's d	0.11	-0.39	0.33	0.12	0.10	0.48	0.09	-0.40	
Good idea	Δ(post-pre)	0.07 (0.70)	-0.15 (0.80)	0.33 (0.90)	-0.08 (0.49)	-0.07 (0.47)	0.21 (0.80)	-0.07 (0.7)	-0.17 (0.72)	0.72
	Cohen's d	0.09	-0.19	0.37	-0.16	-0.15	0.27	-0.09	-0.23	
Behavioural intention	Δ(post-pre)	0.07 (0.59)	-0.23 (0.93)	0.00 (0.76)	0.08 (0.28)	0.14 (0.53)	0.00 (0.78)	0.00 (0.76)	0.17 (0.58)	0.10
	Cohen's d	0.11	-0.25	0.00	0.28	0.27	0.00	0.00	0.29	

8.3.3. Factors Affecting the Effects of Interventions in Improving Motor Health

In the proposed partial least squares structural equation model, SPPB was identified as the primary outcome variable, representing comprehensive motor health, as it includes walking, balance, and muscle strength assessment items (Pavasini et al., 2016). Dominant handgrip strength, the Physical Activity Scale for the Elderly (PASE), the Timed Up and Go test (TUG), and the Falls Efficacy Scale-International (FES-I) were also included as components of motor health evaluation. Previous studies suggested that the General Self-Efficacy Scale (GSE) influence older adults' health outcomes, such as PASE (Wu & Liao, 2024). In addition, the technology acceptance model has verified that perceived usefulness (PU) has an impact on users' attitudes and behavioural intention towards digital healthcare systems (H. Wang et al., 2022). Thus, this study proposed a research model, as shown in Figure 56, to analyse the factors influencing the comprehensive motor health of older adults.

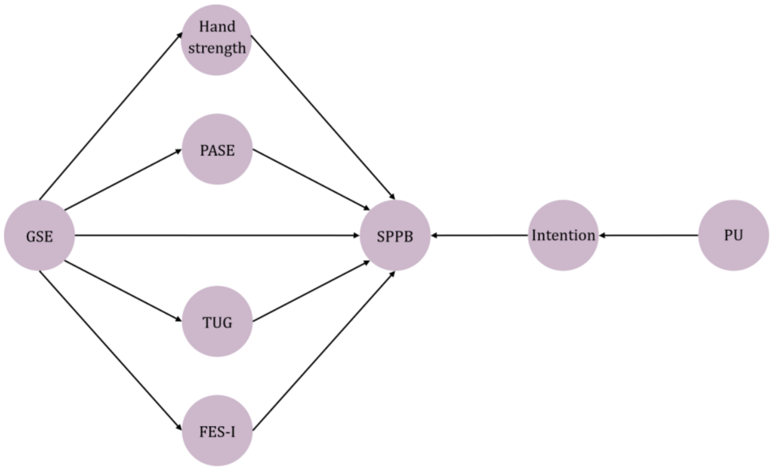

Figure 56. The proposed research model

In detail, the PU included the perceived usefulness of the designed digital self-management system in enhancing self-management abilities, improving motor health and increasing motor health knowledge. The intention consisted of attitude and behavioural intention to use the designed digital self-management system. The direct effect sizes for each path are shown in Table 32.

Table 32. The direct effects of constructs on motor health (SPPB)

Path	**Direct effects**	***p*-value**
Intention -> SPPB	0.023	0.812
FES-I -> SPPB	0.171	0.088
GSE -> FES-I	-0.284	0.013
GSE -> Dominant handgrip strength	0.385	<0.001
GSE -> PASE	-0.078	0.311
GSE -> SPPB	0.230	0.023
GSE -> 3TUG	-0.082	0.548
Dominant handgrip strength -> SPPB	0.034	0.798
PASE -> SPPB	0.021	0.842
PU -> Intention	0.620	<0.001
3TUG -> SPPB	-0.413	<0.001

Notes: SPPB: Short Physical Performance Battery; FES-I: Falls Efficacy Scale International; PASE: Physical Activity Scale for the Elderly; GSE: General Self-Efficacy Scale; 3TUG: Three Meters Timed Up and Go test; PU: Perceived usefulness

The GSE presented statistically significant positive effects on improving dominant handgrip strength ($p<0.001$), FES-I ($p=0.013$) and SPPB ($p=0.023$), with small effect sizes of 0.385, -0.284, and 0.230, respectively. The TUG also presented a significant influence on the SPPB, with a small effect size of -0.413 ($p<0.001$). Moreover, the PU significantly affected older adults' intention to use the designed digital self-management system ($p<0.001$, effect size=0.620), whereas the intention showed no statistically significant effect on the SPPB.

8.4. Discussions

The education group, with 40 minutes, showed a statistically significant positive effect on the General Self-Efficacy Scale (GSE) score compared to the control group in this study. Consistent with a previous study (Li et al., 2002), the GSE was also found to significantly improve participants' dominant handgrip strength and motor health (SPPB) and to reduce older adults' fear of falling (FES-I). Additionally, except for the assessment and physical exercise group, all other groups presented statistically significant positive effects in improving older adults' dominant handgrip strength. Notably, the education group achieved the largest effect size, while the physical exercise group had the smallest effect size. All groups including education presented at least a medium effect size in improving handgrip strength. Thus, based on the effect size, an education intervention of 30 minutes and above was suggested as the first-choice option for single interventions to improve handgrip strength, as shown in Figure 57. Meanwhile, the assessment group achieved a medium effect size in improving the handgrip strength, which is considered a secondary effective single intervention.

Previous studies also recognised the small effect size of physical exercise and suggested that the type of physical exercise influences its effect on improving handgrip strength (Labott et al., 2019; Wu et al., 2021). Thus, the duration of physical exercise should be longer than 40 minutes to allow older adults to engage in a variety of physical activities. Thus, the physical exercise of 40 minutes or more was recommended as the third choice for single interventions to improve handgrip strength. However, given that the test–retest reliability of handgrip strength can be influenced by time, repeated assessment, or the assessor (Nolan et al., 2020), the observed improvement may or may not be attributed to learning or observer effects rather than the intervention. Thus, further long-term interventions are recommended to distinguish genuine physiological benefits from procedural familiarity.

In terms of other motor outcomes, only the assessment group and physical exercise groups showed statistically significant decreases from baseline to post-intervention in the 3-meter timed up and go test, a clinical test that reflects the walking and balance performance in older adults (Podsiadlo & Richardson, 1991). Compared with the assessment group, the physical exercise group presented a higher effect size in reducing the total time of 3TUG. Therefore, the digital self-management system's exercise and evaluation functionality were recommended as first- and second-choice options for single interventions to improve walking and balance among older adults, respectively, as shown in Figure 57.

Notably, the intervention did not show significant effects across all outcome measures, such as SPPB and FES-I. Therefore, the recommended intervention duration in this study should be considered provisional and remains to be further verified through larger and longer-term trials. Further studies with larger sample sizes and extended follow-up periods are required to validate the robustness and generalizability of these findings.

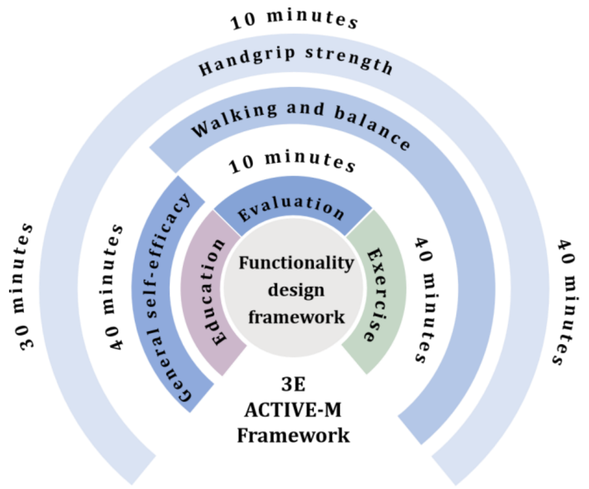

Figure 57. The proposed effective single intervention design based on the designed digital self-management system

8.5. Summary

Based on the digital self-management system designed in Chapter 7, this Chapter conducted a pilot randomised controlled trial to investigate the effects of different functionalities and to identify the factors affecting the effectiveness of interventions to improve motor health. The findings showed that education functionality has large and medium positive effect sizes in improving older adults' self-efficacy and handgrip strength, respectively. The evaluation functionality has medium effect sizes in improving older adults' handgrip strength and 3TUG performance. The physical exercise functionality has small and medium effect sizes in enhancing older adults' handgrip strength and 3TUG performance, respectively. In conclusion, all three functionalities have positive effects in improving specific motor health outcomes among older adults. However, their effectiveness and effect sizes are attributed to the intervention duration per session. For example, the education and physical exercise functionality should last more than 30 minutes and 40 minutes, respectively. Moreover, increased self-efficacy among older adults can improve their motor health outcomes. The findings were used to update the design framework for functionality design in Chapter 9.

CHAPTER 9: UPDATING OF THE DESIGN FRAMEWORK FOR FUNCTIONALITY DESIGN IN DIGITAL SELF-MANAGEMENT SYSTEMS FOR MOTOR HEALTH

9.1. Introduction

As the current global primary care resources are insufficient for the increased aging population, digital self-management systems have been developed as promising compensatory tools to empower older adults to manage health and maintain independence. For example, a game-centered health promotion was designed to reduce older adults' fall risk, increase their health knowledge and quality of life (Dispennette et al., 2019). Moreover, diverse sensors have been combined with traditional clinical tests to achieve fall risk prediction and motor health evaluation (Chen et al., 2022). Additionally, numerous sensor-based physical exercise have been developed to provide feedback and engage older adults into the exercise training (Mao, Zhang, et al., 2024).

Although these digital self-management systems were verified to have positive effects in improving older adults' positive affect, gait performance, balance and handgrip strengths, their design strategies were mostly focused on technology and ignored the participation of multi-stakeholders in the design process. Consequently, few systems considered clinical requirements and reflect real-world motor care workflows (Ienca et al., 2021). Older adults also tend to abandon digital self-management systems due to insufficient attention to their actual needs and experiences. Healthcare professionals suggested that existing digital care systems fail to provide effective and sustainable self-management among older adults (Wangmo et al., 2019). Furthermore, previous research commonly investigated the effect and usability of single functionality. Thus, it remains unclear which specific functionalities are most effective in improving particular motor health outcomes.

In this context, based on findings in previous Chapters, this study aimed to address the following research question: "Question 2: What design elements and principles for different functionalities should be included in the proposed functionality design framework for elderly-centric digital self-management systems to empower older adults during their daily motor health management?" The updated 3E ACTIVE-M framework for functionality design in digital self-management systems considered both older adults' requirements and preferences on functionality contents and application design elements, clinical motor health assessment and treatments, as well as effectiveness and intervention design of different digital functionalities. The framework is expected to guide human-computer interaction designers and health informatics system designers to develop acceptable, desirable, usable and effective digital motor health self-management systems, supporting older adults to improve their motor health and independence in the community.

9.2. Functionality Structure

According to the findings in Chapter 8, the randomised controlled trial demonstrated that three functionalities (education, evaluation, and exercise) had positive effects on specific motor health-related outcomes after 4 weeks of intervention (Education: handgrip strength, GSE; Evaluation: 3TUG; Exercise: 3TUG). However, the effectiveness and effect size of these functionalities varied across different motor health aspects. Specifically, education functionality had a medium effect size in increasing older adults' self-efficacy and enhancing their handgrip strength. The evaluation and exercise functionalities were effective in improving motor function, as assessed by the 3TUG. The findings verified the comprehensive functionality design principle in the proposed 3E ACTIVE-M Framework. Moreover, based on the findings of Chapter 8, the functionality design framework was updated to include a suggestion for the functionality intervention duration, as shown in Figure 58.

The development of the functionality framework was grounded in both empirical results and theoretical insights. Based on the behavioural science perspective (Baltes & Baltes, 1993), the functionality framework includes a motivation–action pathway. In detail, education functionality fosters self-efficacy and motivation to manage motor health among older adults. Based on the middle-range theory of health self-management, confidence is foundational to self-management behaviours and serves as a mediating variable between cognition and performance (Lawless et al., 2021). Older adults with higher self-efficacy are more proactive in seeking health information, engaging in self-management behaviours, and adhering to treatment plans (Whitehall et al., 2021). To support this motivational foundation, evaluation functionality provides timely information on individuals' motor performance, enabling older adults to develop situational awareness and make informed decisions about their self-management routines. According to goal-setting theory, feedback on health performance related to established goals is essential for individuals to assess whether they should maintain or adjust self-management strategies (Swann et al., 2021). Regular and personalised motor evaluation feedback ensures that self-management remains adaptive and sustainable. Moreover, as self-efficacy-oriented strategies emphasise providing mastery experiences (Kärner Köhler et al., 2018), exercise functionality further allows older adults to engage in structured and guided exercise training. This helps older adults translate their motivation and insights gained from assessments into practical, actionable steps. By facilitating continuous participation in physical exercise, this functionality plays a critical role in maintaining and improving motor health over time. The three functionalities are interlinked to form a closed-loop support system, addressing the motivational, diagnostic, and behavioural requirements of sustainable motor health self-management among older adults.

Each functionality is mapped to specific content and intervention time based on the findings from Chapters 4 to 8. For example, the education functionality addresses perceived vulnerability, perceived severity, prevention actions, maladaptive response rewards, response costs, and assistive aid use, based on protection motivation theory and the experiences of older adults. Evaluation functionality uses sensor technologies and clinical test tasks to inform older adults about their fall risk and motor health problems. Based on the results, guided and practical strategies should be further provided for older adults to prevent motor decline. The exercise functionality includes multicomponent interventions tailored to older adults' abilities, emphasising safety, adherence, and personalised step-by-step feedback to help older adults correct their exercise postures and prevent accidental injuries. Furthermore, the adequate intervention time for each functionality (30 minutes for education, 10 minutes for evaluation, and 40 minutes for exercise) was identified based on empirical evidence from the randomised controlled trial.

Additionally, the proposed functionality framework also highlights the usability and acceptability of digital self-management systems through four application design principles, including easy-to-understand and intuitive data visualisation and interface design, multidimensional motion tracking and analysis, multimodal motion performance feedback, and personalised and attractive exercise management. Based on the findings in Chapter 4, each functionality should include the seven functions of data collection, data analysis, data update, activity reminder, performance feedback, information search and goal management to help and encourage older adults to self-manage their motor health during daily life.

In summary, the framework was developed based on the synthesis of behavioural studies, trial-based evidence and systems thinking, generating a structured pathway from motivation to action. It ensures that the digital motor health self-management system is both elderly-centric and evidence-based. The detailed design of each functionality is elaborated in the following sections.

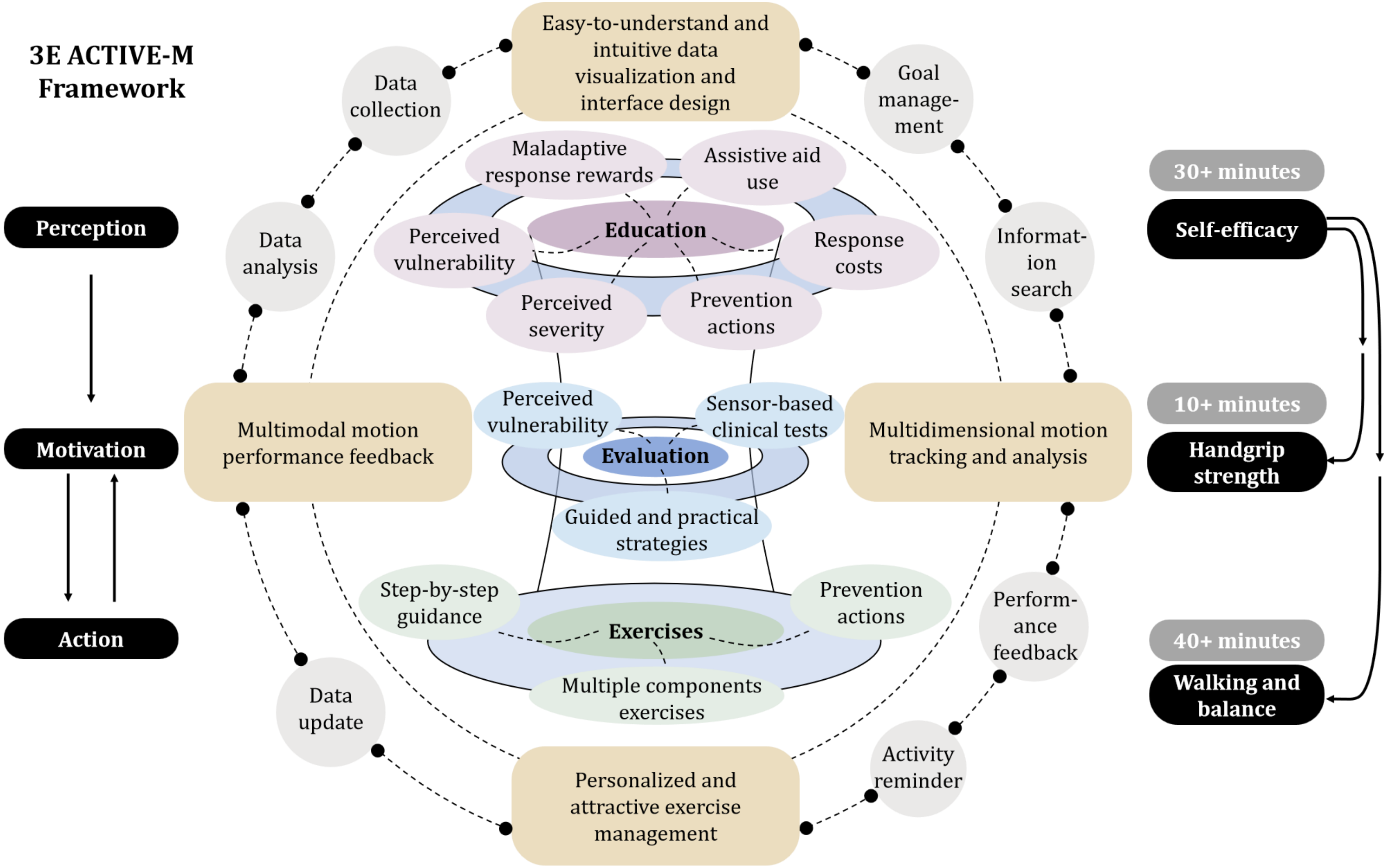

Figure 58. Updated functionality design framework for digital self-management systems for motor health

9.3. Education Functionality

9.3.1. Content materials

Based on the findings in Chapter 4 regarding the protection motivation theory, the education functionality provides educational materials, including physiotherapist-led videos, patient handbook, one-pager, medical resources, to improve older adults' perceived vulnerability and perceived severity, reduce their maladaptive response rewards and response costs related to motor management, and increase their skills in prevention actions and the use of assistive aids (see Figure 59).

Specifically, knowledge of the risk factors for falls, balance decline, muscle weakness, and wrong walking postures can help older adults realise their vulnerability to motor impairments and falls. Awareness of the potential consequences of motor degradation, such as gait abnormalities, falls, and sarcopenia, can help older adults recognise the severity of the issue and motivate them to engage in health behaviours like exercise and physical activity. As part of addressing maladaptive response rewards and response costs, the educational materials can rectify misconceptions about motor management methods, emphasise the adverse effects of inactivity, and introduce basic home-based exercise routines. Health literacy for prevention actions and assistive aid use primarily focuses on exercise training programs, medical resource information, and the proper selection and use of mobility aids.

Furthermore, older adults preferred live-action characteristics compared to avatar-based graphics or animations (Mao, Zhao, et al., 2024). To ensure the desirability of the digital self-management system, educational materials are suggested to be primarily delivered through videos featuring live-action characters, such as physiotherapists or official caregivers. Visual icons and keywords are recommended as complementary to the videos.

9.3.2. Interface design

As older adults' visual and cognitive abilities decline with age, simple and predictable interaction methods are recommended for the digital self-management system. Basic touch gestures (e.g., tapping and swiping) with generous targets and immediate feedback can reduce fine-motor demands, working memory load, and error rates in older adults. In addition, audio interaction (brief prompts and text-to-speech) can offload visual processing, support users with fluctuating vision, and provide step-by-step guidance.

Horizontal, theme-based navigation design can keep the menu shallow, allowing older adults to make fewer clicks and spend less effort planning their operation route. This helps older adults avoid getting lost and make decisions more quickly (Degen, 2024). An icon layout with short text labels also allows older adults to recognise options instead of having to remember them, which reduces confusion across screens. Large, consistent fonts make text easier to read when vision and processing speed slow with age, and high contrast between text and background helps when contrast sensitivity and glare tolerance are lower. Keeping a limited colour set also makes items easier to find and reduces mistakes in colour discrimination, improving readability and scan consistency (Liu et al., 2021). These designs can help develop an elderly-friendly, accessible, and user-friendly digital motor health self-management system, helping older adults build confidence and sustain their motor health self-management behaviours.

Individuals' interaction activities in education functionality are also suggested to be recorded and analysed. Older adults can thus check their viewing time and themes in the historical interface. As older adults commonly experience decreased memory (Liu et al., 2021), this feedback enables them to reflect on their learning engagement and identify themes that require further attention or reinforcement. Moreover, as individuals have different requirements and interests in the education content, the digital self-management system should be equipped with an information search function interface. This feature allows older adults to actively select relevant or personalised health education materials based on their preferences and conditions. In addition, to prompt older adults to engage in education programs, the system should include goal management and activity reminders.

9.3.3. Intervention design

The education functionality in a digital motor health self-management system acts as the foundational component, increasing older adults' motivation and health-related awareness, enhancing their self-efficacy and sustaining self-management behaviour. Based on the findings in Chapter 8, the education functionality has a positive effect on improving older adults' general self-efficacy and dominant handgrip strength.

Notably, only interventions exceeding 40 minutes of education showed a statistically significant positive effect on self-efficacy (GSE), while interventions exceeding 30 minutes significantly improved participants' dominant handgrip strength in the pilot study. Therefore, the minimum intervention time for the education functionality was specified in the detailed design structure, as shown in Figure 59.

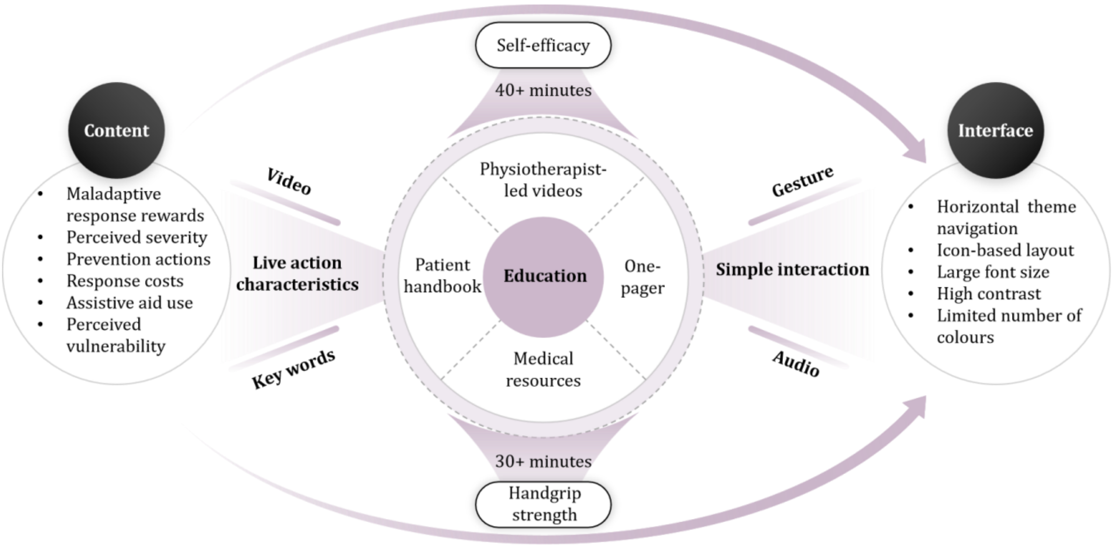

Figure 59. The detailed design structure of the education functionality

9.4. Evaluation Functionality

9.4.1. Sensor-based clinical tests and vital metrics

Based on the protection motivation theory and empirical evidence in Chapter 4, evaluation materials are designed to enhance older adults' perceived vulnerability and situational awareness. Through regular sensor-based clinical tests, older adults can gain insight into their fall risk, motor decline, or improvement, facilitating their goal setting and decision-making for motor management (Swann et al., 2021).

According to the findings in Chapter 5, since different clinical tests target specific domains of motor health, it is recommended to include multiple types of clinical tests, such as the Berg Balance Scale (BBS) for balance, the 3-Meter Timed Up and Go (3TUG) for functional mobility, and the Five Times Sit-to-Stand Test (5STS) for lower limb strength (See Figure 60). Meanwhile, the integration of multiple sensor modalities enhances data accuracy and compensates for the limitations of any single sensor (Chen et al., 2022). Consequently, multiple sensor technologies, such as optical and inertial sensors, are also recommended for collecting motion data from older adults during the clinical test process. Inertial and optical sensors enable whole-body motion capture in unrestricted settings, eliminating the requirement for a fixed capture space.

According to the clinical experience of physiotherapists in Chapter 5, they pay considerable attention to the vital metrics of the lower back, knee and foot. The motion of the lower back is associated with the control of the whole-body centre of mass and can serve as a proxy for stability (e.g., centre of mass sway) and mobility (Yu et al., 2025). Physiotherapists also carefully observe the knee flexion and extension, including range of motion, end-range pain, and functional performance during gait. However, the vital metrics of the foot, such as spatiotemporal gait parameters and foot declination, were considered as the most important indicators for gait and balance assessment (Zhou et al., 2024). Thus, after acquiring sensor signals during the clinical tests, the extraction of these key metrics is recommended for motor-health evaluation and interpretation.

9.4.2. Data visualisation

Instead of presenting bare numbers, the evaluation visualisation should combine graphics and keywords to deliver the motor health status that older adults can easily understand. Because contrast sensitivity and visual search often decline with age, each graphic should convey one core message and include a short keyword or text. Additionally, a clear motor health classification label and a brief explanation of its meaning are advised as a health result visualisation strategy for older adults. These data visualisation approaches, including simple visuals, limited text, and consistent labelling, reduce cognitive load and prevent confusion, supporting faster comprehension and safer decision-making among older adults.

Another recommended data visualisation strategy for evaluation functionality is to compare the current result alongside the previous result. A trend line or a spark line can be used to show the direction of change. Graphic and short explanation sentences are suggested to indicate the motor health change as “better”, “similar” or “worse.” This design supports quick judgment and safer follow-up decisions on self-management.

Moreover, after evaluating older adults’ motor health, guided and practical strategies should also be provided to encourage older adults to take appropriate actions, such as adjusting exercise intensity, seeking professional consultation, or modifying daily activities to reduce fall risk. Additionally, similar interaction design strategies in education functionality are also applied for evaluation functionality. Consequently, the proposed design structure of evaluation functionality can support self-awareness, risk prevention, and continuous self-monitoring among older adults.

9.4.3. Intervention design

The evaluation functionality plays a crucial role in providing objective, personalised insights into the motor health of older adults. It serves as a diagnostic bridge between awareness and action, prompting motivation through real-time performance feedback and meaningful self-reflection. Based on the findings in Chapter 8, the evaluation functionality has a positive effect on older adults' dominant handgrip strength and 3TUG performance (see Figure 60).

A single 10-minute intervention on evaluation functionality can statistically improve both handgrip strength and walking and balance performance (3TUG) during the pilot study in Chapter 8. Thus, for a digital self-management system for motor health among older adults, an evaluation functionality should be included to acquire, quantify, and visualise motor health status, enabling users to recognise their status and risks, and to tailor and adjust personalised interventions, thereby improving muscle strength, gait, and balance.

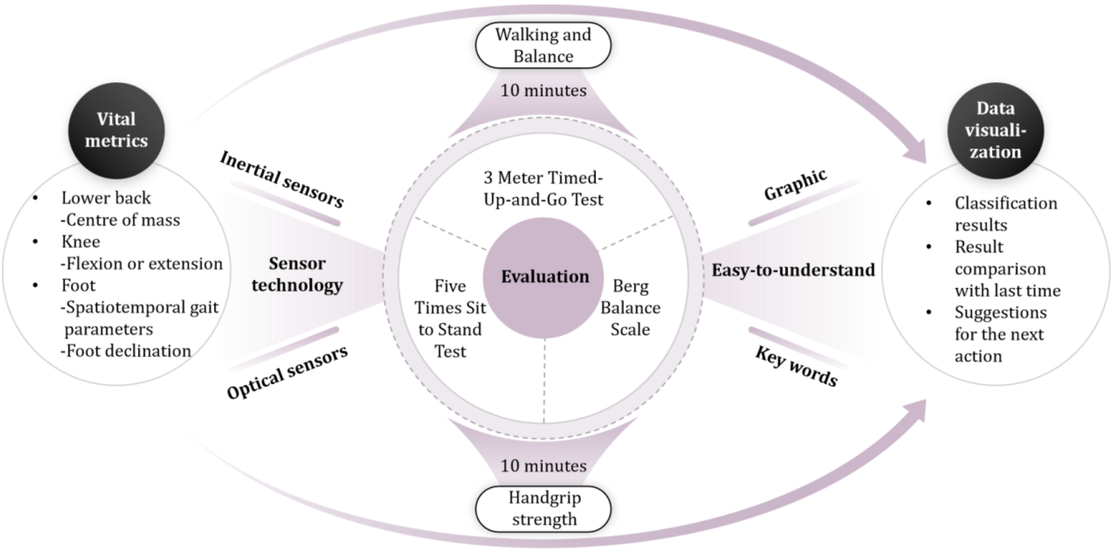

Figure 60. The detailed design structure of the evaluation functionality

9.5. Exercise Functionality

9.5.1. Exercise types

Previous studies and physiotherapists in Chapter 5 both highlighted the benefits of comprehensive physical exercise for older adults (Izquierdo, 2019; Izquierdo et al., 2025; Sánchez-Sánchez et al., 2022). Thus, the multiple components exercise, including warm-up exercises, muscular strength training, balance training, and flexibility training, is herein recommended as intervention content for digital exercise functionality, as shown in Figure 61. Warm-up exercises can increase muscle temperature and joint lubrication, reduce the risk of injury, and prime the body for movement. Muscular strength training enhances muscle strength, improving gait speed and daily functional tasks (Casas-Herrero et al., 2022). Balance training refines postural control and single-limb stability, thereby reducing the risk of falls. Flexibility training can enhance joint and soft-tissue extensibility, thereby supporting increased stride length and improved movement economy.

Compared with clinical exercise categories, such as strength, balance, and flexibility training, older people are more likely to understand and participate in exercise programs classified by body area, including the head, upper limb, trunk, lower limb, and feet. Additionally, exercise functionality is developed based on the theory of self-efficacy. As older adults often lack professional knowledge in motor rehabilitation (Kluft et al., 2018), the exercise functionality should clearly explain the purpose of each exercise and the specific body parts it benefits.

The same design strategies employed in the other two functionalities, such as exercise visualisation and interaction, are also suggested for the exercise functionality to enhance its usability and accessibility by reducing cognitive load and simplifying user engagement.

9.5.2. Feedback interaction

Based on the feedback from older adults in the task-based usability test, specific, personalised, and step-by-step exercise guidance and feedback are desired instead of overall performance score feedback. This design element can help older adults understand their exercise performance, correct improper postures in a timely manner, and prevent accidental injuries. Meanwhile, by tracking older adults' exercise progress and improvements over time, older adults are more likely to feel encouraged and motivated to participate in regular physical exercise (Gómez-

Redondo et al., 2024).

According to the findings in task-based usability test, to minimise cognitive load and support variable vision or hearing among older adults, exercise feedback is recommended to be delivered through short text and audio. Both knowledge of exercise performance should be provided to support older adults' immediate understanding and action. Feedback content should also be presented positively to reinforce correct form and safe effort. Specific, behaviour-linked praise, such as "knee alignment maintained" and "stance steady for 10 s", rather than generic approval, and small visual tokens (ticks or badges) are suggested to acknowledge goal attainment. This approach can strengthen self-efficacy, sustain motivation, and promote adherence.

When exercise posture is suboptimal, feedback shifts to concrete, single-step improvement cues that are easy to apply on the next action. Cues target joint angles (e.g., "extend the knee toward 0–5° in stance"), limb height ("lift the foot 3–4 cm higher"), postural stability ("reduce sway; hold 10 s without support"), exercise speed ("slow to a two-second eccentric"), and postural symmetry ("match left and right step length"). These specific step-by-step exercise feedback can improve older adults' exercise quality and prevent exercise injuries.

9.5.3. Intervention design

The exercise functionality is used to translate motivation and motor evaluation results into sustained physical exercise or daily activity among older adults. According to the findings in Chapter 8, exercise intervention had positive effects in improving handgrip strength, walking and balance performance (3TUG), indicating its essential role in maintaining motor health and reducing fall risk, as shown in Figure 61.

Notably, no effect was observed in exercise interventions of less than 40 minutes during the pilot study in Chapter 8. The intervention involving 40 minutes of physical exercise showed a statistically significant improvement in handgrip strength and 3TUG, as well as a tendency toward improvement in FES-I and SPPB. A previous systematic review on balance training programs suggested that the optimal duration for a single training session should be at least 45 minutes, which is consistent with this study (Brachman et al., 2017). Therefore, this framework suggests that the exercise intervention should last more than 40 minutes.

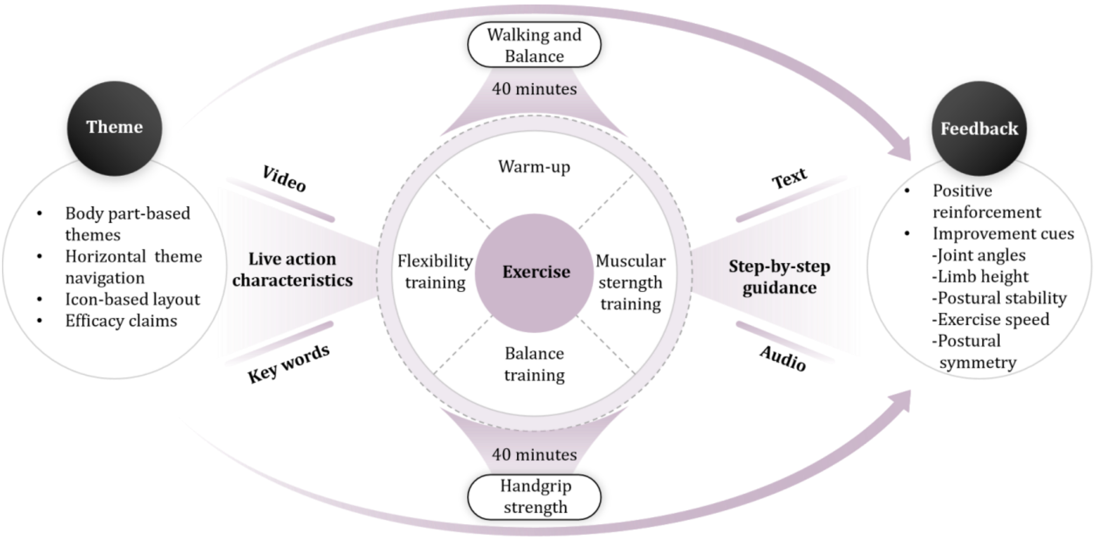

Figure 61. The detailed design structure of the exercise functionality

9.6. Summary

This chapter updated the elderly-centric design framework (3E ACTIVE-M Framework) for functionality design in digital self-management systems based on the findings in previous chapters. In detail, as each functionality contributes to different aspects of motor health, the framework includes education, evaluation, and exercise functionalities to support the development of a comprehensive digital self-management system. The framework identified the content design and the effectiveness and intervention duration for each functionality based on evidence-based findings. Moreover, four design principles, including easy-to-understand and intuitive data visualisation and interface design, multidimensional motion tracking and analysis, multimodal motion performance feedback and personalised and attractive exercise management, are determined for the application interface design. The updated functionality design framework is expected to translate evidence-based findings into practical digital solutions, guiding the further design of effective, accessible, and usable digital healthcare systems, and addressing the motivational, cognitive, and behavioural needs of older adults in self-managing their motor health.

CHAPTER 10: CONCLUSION AND FUTURE WORK

10.1. Major Findings

Based on the guidance of Macroergonomic Analysis and Design, cross-sectional surveys and semi-structured interviews were first conducted in Chapter 4 and Chapter 5 to explore older adults' perceptions and physiotherapists' perspectives on the functionality design of the digital motor self-management systems. According to their report, older adults held positive attitudes towards the usefulness of education, evaluation, and physical exercise functionalities in improving their motor health and self-management abilities. Consequently, older adults expressed great willingness to use the three functionalities and the digital motor self-management systems. Moreover, older adults reported that they sought the functions of data collection, data analysis, data update, performance feedback, information search and activity reminder for digital functionality. According to the protection motivation theory and task-technology fit, the functionalities of digital motor health self-management systems should include the contents of perceived severity, perceived vulnerability, maladaptive response rewards and response costs, and have the features of ease of use and task-technology fit. These functionality design features were identified as key factors in improving the acceptance of digital motor health self-management systems among older adults.

Given that motor health comprises diverse domains of physical function, such as strength, balance, and walking, physiotherapists suggested that multiple clinical tests and sensor modalities should be used in digital motor health self-management systems to provide whole-body motion analysis. In addition, considering the safety and feasibility of physical exercise in the home environment, comprehensive exercise programs including stretching, strength training, aerobic exercise, balance training and functional task training were recommended for older adults. As older adults tend to have limited exercise skills, feedback information should also be provided to older adults to help them maintain correct posture and prevent injuries.

By synthesising the data collected in Chapters 4 and 5, a rich picture was used in Chapter 6 to map the motor health self-management process and identify the situation challenges. The root definitions of education, evaluation, and physical exercise functionalities were further proposed to develop elderly-centric digital self-management problem-solving paths and a conceptual functionality design framework, aiming to increase older adults' acceptance of digital healthcare systems and improve their motor health and quality of life. To evaluate the feasibility of the proposed conceptual functionality design framework, a digital motor health self-management system was designed to conduct usability test and a pilot randomised controlled trial in Chapters 7 and 8, respectively.

Older adults reported high usability and strong acceptance of the designed motor health self-management system. Meanwhile, the education, evaluation, and physical exercises all presented benefits in improving older adults' motor health-related outcomes. Based on the findings, the final elderly-centric functionality design framework for the digital motor health self-management system was formed and verified to be feasible and practical. In detail, the framework provides design strategies on the effectiveness, content, intervention duration and application design of each functionality, supporting the transition from motivation to action in motor health self-management among older adults.

10.2. Framework Implications

By translating research findings into practical, elderly-centric solutions, the proposed 3E ACTIVE-M Framework for functionality design provides strategic guidance for developing accessible, desirable and effective digital motor health self-management systems, improving older adults' motor health and quality of life, helping human-computer interaction designers develop digital healthcare systems, reducing healthcare professionals and caregivers' care burden, and inspiring policymakers establish healthcare strategic directions.

The functionality framework emphasises the integration of motivational education, personalised assessment, and guided physical exercise functionalities in the digital self-management systems. By reducing barriers to engagement and facilitating self-awareness and behaviour change, this comprehensive digital health management strategy shifts older adults from traditional passive care recipients to more active and informed care managers of their motor health. Moreover, the 3E ACTIVE-M framework enhances users' long-term adherence to the digital self-management systems through four elderly-centric design principles.

First, easy-to-understand data visualisation and intuitive interface design reduce older adults' cognitive effort and make system interaction straightforward, thereby enhancing the accessibility of digital care systems for older adults with varying levels of digital literacy or physical limitations. Second, multimodal motion performance feedback used visual, auditory, and text cues to present educational knowledge, health management skills, motor evaluation results and exercise feedback in several forms. This multimodal approach helps older adults link physical performance with immediate and understandable feedback, reinforcing their awareness of body movement and health status. By offering diverse feedback formats, the system caters to older adults with varying sensory preferences or sensory impairments, making the learning and exercise experience more inclusive and engaging. Third, multidimensional motion tracking and analysis provide comprehensive insights into the user's movement quality from various perspectives, including gait, balance, and muscle strength. By visualising these aspects over time, older adults can detect subtle improvements that may go unnoticed in everyday activities. This longitudinal awareness boosts their confidence in physical progress and promotes ongoing participation. The system's ability to record and interpret minor variations also enables more precise evaluation of functional changes, supporting early intervention and personalised adjustments to exercise plans. Finally, personalised and attractive exercise management adapts exercise content, intensity, and frequency to each older adult's ability, motivation level, and health condition. Adaptive scheduling and gradual difficulty maintain challenge without causing fatigue, while goal-oriented routines enhance individuals' enjoyment. This personal relevance sustains engagement and supports long-term adherence by making each session meaningful and achievable. These four design principles create a cycle of awareness, feedback, and self-improvement, fostering a sense of autonomy among older adults, enabling them to feel more in control of their health management decisions and motivating them to sustain long-term self-management practices.

Notably, a multiple-sensor technology strategy was proposed in the framework to address diverse scenarios and user needs, as well as to improve the accuracy of motor health evaluation. Markless optical sensors, such as Orbbec or Kinect, enable comprehensive posture and symmetry assessment, making them ideal for gait analysis and exercise feedback within the evaluation and exercise functionalities. Although computer-vision-based technology has become more advanced, it depends on two-dimensional RGB images and model-based inference, which can be influenced by lighting, background, and occlusion. In contrast, the Orbbec sensor combines active infrared depth sensing, allowing direct capture of three-dimensional skeletal coordinates with high temporal resolution. This method offers greater accuracy and consistency for biomechanical parameters such as joint angles and balance sway, which are essential for motor health assessment. Moreover, inertial sensors offer a more portable, cost-effective, and privacy-preserving option suitable for compact living spaces, while they depend on proper placement and calibration to maintain accuracy. Guided by the framework, optical sensing is recommended when visual coaching and postural analysis are essential, while inertial sensing is preferable for scenarios emphasising accessibility, affordability, or privacy. Hybrid designs that fuse both modalities can further enhance robustness and data completeness. Moreover, the framework remains adaptable, allowing the future incorporation of emerging sensor technologies, such as radar, acoustic, vision-based skeletal estimation or textile-based sensors, to continuously improve and extend the digital self-management ecosystem.

The proposed functionality design framework also has several implications for both the development and implementation of digital care systems in human-computer interaction and health informatics fields. This framework considered older adults' requirements for digital care systems from the perspectives of personalised preferences and clinical needs, developing an elderly-centric, evidence-based approach to functionality design. For designers and researchers, the framework provides clear, structured guidance on digital functionality design by elaborating on the benefits for motor health-related outcomes and the design strategies for each functionality, including education, evaluation, and physical exercise. As the functionality design framework emphasises user-centric, personalised and adaptive features, including modular content delivery, real-time feedback, performance tracking, multimodal interaction methods and cognitive-friendly interfaces, designers can move beyond conventional technology development towards accessible and inclusive digital health management solutions. The functionality construction (education, evaluation, and exercise) can be adapted to other chronic conditions, such as cognitive decline, as shown in Figure 62. In such cases, education may focus on cognitive health literacy and caregiver guidance, evaluation may include digital cognitive assessments or daily activity monitoring, and exercise may involve memory or attention training. Only the specific outcomes and sensing modalities would require adjustment, while the overall interaction logic and feedback cycle remain applicable. This flexibility allows the framework to evolve into a broader digital self-management model supporting multiple health domains.

Furthermore, unlike conventional digital healthcare system design frameworks or strategies that emphasise interface features or technical functions, the proposed framework really stands out with three main characteristics that make it unique. First, it is evidence-based, with each design principle grounded in empirical findings from stakeholder interviews, contextual analysis, and early-phase surveys, ensuring practical relevance rather than speculative design. Second, it emphasises socio-technical alignment by integrating user needs with clinical workflows and home environments, supporting both desirability and usability. Third, it is centred on older adults, combining their personal preferences, digital capabilities, and autonomy with clinical requirements for motor assessment and intervention. Overall, the thesis contributes a structured, evidence-based, and elderly-centric framework for digital healthcare system design.

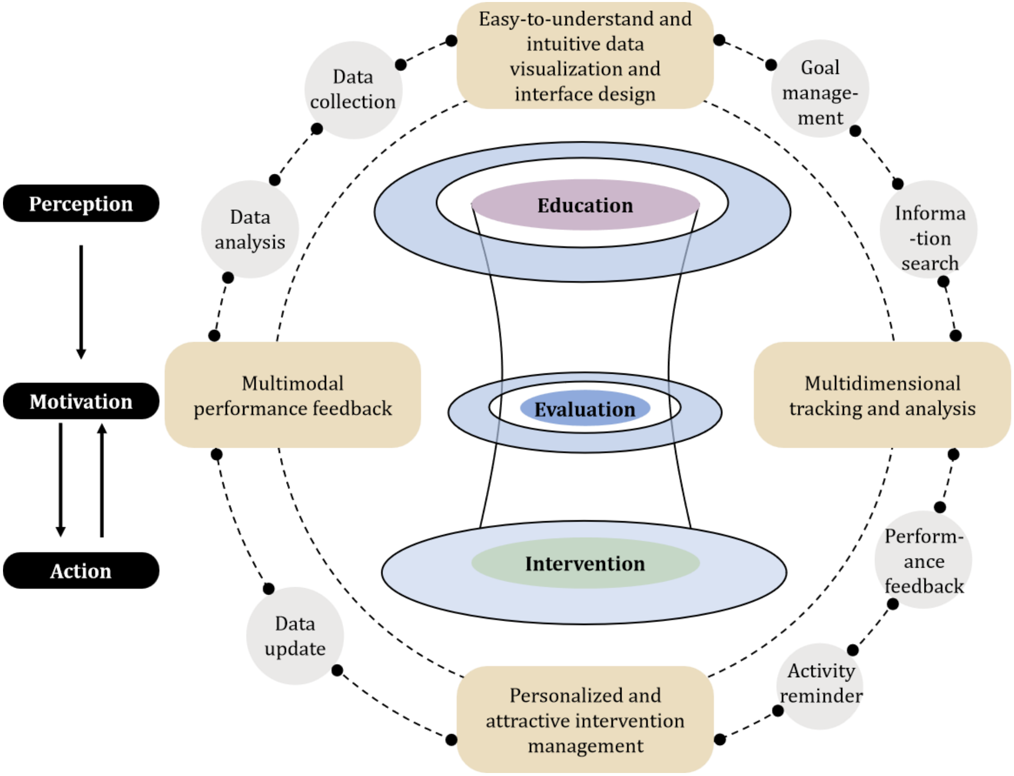

Figure 62. Transfer of the digital functional design framework for chronic diseases

The functionality design framework can also provide valuable insights for physiotherapists and caregivers in delivering digital motor health interventions and enhancing patient engagement in home settings. For example, the content design strategies for education functionality help physiotherapists identify education programs for older adults, encouraging sustained engagement in motor management and healthy activities. The framework also offers a potential solution for healthcare professionals to provide remote care among older adults. Based on sensor-based evaluation and exercise functionalities, physiotherapists can deliver motor care services beyond the traditional clinic scenario by tracking older adults' motor health and physical exercise performance, adjusting motor management strategies and supporting them in home-based rehabilitation. These digital functionality solutions for motor health management have also shown promise in reducing official care burden and improving the efficiency of remote healthcare for current healthcare services. Specifically, the functional design framework can be integrated into existing healthcare service systems through the combination of health data sharing and clinician-guided approaches. Interoperability with electronic health records can enable home-based digital assessment data, such as gait, balance, and muscle strength, as well as exercise adherence rates, to be transmitted to healthcare institutions in a standardised format. This data sharing enables healthcare professionals to monitor older adults' motor health changes remotely, interpret their health status, and make timely adjustments to intervention plans, thereby enabling large-scale health screening to be conducted quickly and cost-effectively. This framework also supports setting explicit clinical thresholds for alerts, such as automatically triggering follow-up assessments or professional consultations when decreased balance stability or increased fall risk is detected. Over time, digital self-management systems are expected to become bridges between home self-management and professional supervision, supporting early detection, timely intervention, and personalised rehabilitation in the community.

Policymakers and institutional administrators can also benefit from the proposed functionality design framework. As healthcare systems gradually emphasize community-based and technology-assisted aging, this functionality design framework provides a solid foundation for formulating future primary care strategies and service policies. Specifically, it offers structured guidance for policymakers to develop digital solutions, enhancing older adults' physical function and independence, delaying their institutionalization, and reducing healthcare burdens and costs. Policymakers can also use this framework to define evaluation criteria and implementation standards for digital motor health management systems used in community-dwelling older adults. Additionally, by integrating motivational and behavioural components, the framework aligns well with public health goals, particularly in promoting active ageing and ageing in place.

10.3. Contributions

Based on the exploratory findings on older adults and physiotherapists' perceptions and attitudes towards digital motor health self-management systems, this study provides insights into the motor self-management process in practice and its practical challenges. By identifying the barriers to health self-management among older adults, such as limited health literacy, little feedback on motor health management performance, and a lack of home-based motor management support, this thesis contributes to a deeper understanding of older adults' personal and clinical requirements for functionality features of digital motor health self-management systems. Additionally, the used research methods and flowchart can be generalised to other health management system investigations, particularly for complex, dynamic and long-term health problems like chronic diseases and geriatric syndromes.

A digital motor health self-management system was also developed in this study.

The designed system provides older adults with evidence-based education functionality, sensor-based evaluation functionality, and feedback-based physical exercise functionality. Unlike traditional digital healthcare systems that emphasise single functionalities and technologies, this system applied holistic and elderly-centric design strategies to address the multidimensional requirements of older adults in motor health self-management. Through sensor-based monitoring, personalized guidance, and user-friendly interaction, it allows older adults to engage in home-based self-care with greater confidence, safety, and consistency. Moreover, the pilot randomized controlled trial in this thesis verified the effectiveness of three digital functionalities in improving motor health-related outcomes. The findings suggest that digital motor health self-management systems can be identified as a promising alternative to traditional in-person motor health management services.

Furthermore, based on macroergonomic analysis and design method and systems thinking, this thesis proposed a functionality design framework for elderly centric digital motor health self-management systems. The framework consisted of effectiveness, content design, and intervention design for each functionality, as well as application design principles. This comprehensive structure provides clear and step-by-step guidance for designers or researchers to develop acceptable and effective digital motor health self-management solutions. Additionally, this framework also provides valuable insights into the development of digital functionalities for other health management systems. Its structure and design principles can be shifted to support digital solutions for older adults with different health problems, contributing to the development of effective and user-centric digital interventions beyond the scope of motor health.

10.4. Limitations and Future Work

Despite the diverse contributions of this thesis, it has several limitations that should be acknowledged. Among the framework, although handgrip strength and walking performance were selected as representative indicators of motor health, the study also included broader outcome measures to capture lower-limb strength, endurance, and functional ability. In particular, the Short Physical Performance Battery (SPPB) incorporated the five-time sit-to-stand test, balance assessments, and gait speed evaluation, which collectively reflect multidimensional aspects of lower-limb function. However, despite the inclusion of these measures, no statistically significant improvements were observed after the intervention. Additionally, the improvement in handgrip strength may or may not be caused by learning or observer effects. This may be attributed to the relatively short intervention duration and heterogeneity in participants' baseline characteristics. These factors may have reduced the statistical power to detect small to moderate improvements. Future studies with larger samples and longer interventions are expected to further examine the potential effects of the three functionalities on lower-limb motor outcomes and overall functional health in older adults.

Moreover, to benefit a broader older population, this thesis primarily focused on community-dwelling older adults as the target users of the digital motor health self-management systems. However, older adults with specific motor health problems such as high fall risk, frailty and sarcopenia, may or may not have different perceptions and requirements towards education, evaluation, and exercise functionalities. Therefore, the generalizability of the findings in this thesis may or may not be limited, especially considering the different functional abilities and health status of older adults. It is recommended that future studies stratify the older population and examine how specific needs, preferences, and barriers differ across subgroups. Based on the results, more detailed information can be integrated into the current functionality design framework, enhancing its practical implementation and adaptability to various user needs.

Additionally, the functionality design framework for the digital motor health self-management system was mainly developed from the perspectives of older adults and physiotherapists, emphasising the personal and clinical requirements. However, the opinions of other stakeholders, such as caregivers, family members, social workers, and healthcare policymakers, were not involved in the exploratory studies. This lack of consideration for broader social factors and structural support systems fails to provide insights into the sustainable implementation of motor health management among older adults. Therefore, future studies should involve more stakeholders to gain a more holistic understanding of the motor health management ecosystem among older adults, providing guidance in social support structures, care coordination mechanisms, and policy strategies.

Finally, as the main purpose of the pilot randomised controlled trial was to initially investigate the effects of three digital functionalities in motor health improvement, the intervention lasted only four weeks. Although the designed intervention duration is sufficient to identify short-term effects and initial feasibility, it fails to provide evidence-based insights into long-term behavioural change and adherence, the optimised intensity, duration, and frequency of each intervention, as well as the sustainable effects of the three digital functionalities. Therefore, longitudinal studies for more than 3 months are recommended to be conducted in the future to assess older adults’ adherence to system use, and the sustainability of motor health benefits. Such studies can also investigate potential obstacles of digital care system use and develop strategies to promote sustained engagement in older adults.

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