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Research Article

Multicomponent interventions and technologies to reduce the burden of frailty, functional, and cognitive decline: insights from the Age-It Research Program

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Abstract

Objectives: Preventing age-related complications is a critical priority for health systems. Within the Age-It program, Spoke 8 aims to evaluate scalable, multicomponent, technology-assisted interventions to prevent frailty and mitigate functional and cognitive decline in older adults across different care settings.

Methods: Spoke 8 includes three clinical studies conducted in community, hospital, and long-term care settings, supported by cross-cutting work packages on digital infrastructure, technology development, and economic evaluation. The intervention model integrates physical, cognitive, nutritional, and psychosocial components, supported by digital tools, biomarkers of aging, and a centralized data platform.

Results: The project is expected to generate evidence on the effectiveness, feasibility, and cost-effectiveness of multidomain interventions implemented across diverse real-world settings, including community, hospital, and long-term care. Technology-assisted strategies—such as wearable sensors and digital cognitive tools—may enhance adherence and enable remote monitoring, while also supporting more personalized care delivery. The integration of artificial intelligence will facilitate the interpretation of complex clinical and biological data, improving risk stratification and the early identification of individuals most likely to benefit from targeted interventions. Together, these approaches may help reduce hospitalizations, delay functional decline, and promote aging in place.

Discussion: This initiative supports the transition toward more integrated and equitable care models for older adults. Through the implementation of scalable, person-centered interventions within routine services, the project offers policy-relevant strategies to address frailty and functional decline—contributing to the redesign of aging care in Italy and providing insights applicable across diverse health systems facing the challenges of population aging countries.

Keywords: Multidomain intervention, Prevention, Frailty, Dementia, Technology

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Frailty is a clinically identifiable condition marked by diminished biological reserves and reduced ability to maintain homeostasis, leading to increased vulnerability to adverse health outcomes, such as disability, hospitalizations, and mortality (Kim & Rockwood, 2024; Morley et al., 2013). Given its significant impact on individuals and healthcare costs (Dent et al., 2023), World Health Organization has recognized the prevention and management of frailty as a global health priority (World Health Organization, 2024).

Previous studies have demonstrated that multicomponent interventions targeting multiple health domains can effectively reverse frailty and prevent functional decline (Ferrara et al., 2023; Ngandu et al., 2015). However, questions remain regarding their feasibility in high-risk settings—such as acute hospital wards and long-term care (LTC) facilities—and the potential role of technology and the use of biomarkers associated with aging in supporting their implementation. These biomarkers, which include markers of inflammation, neurodegeneration, and metabolic dysregulation, are increasingly recognized as tools for early identification of vulnerability and trajectories of frailty (Salvioli et al., 2023). Additionally, evaluations of their socio-economic impact and long-term sustainability are lacking.

To address these gaps, Spoke 8 of the Age-It program (Age-It—Ageing well in an ageing society, 2023), funded by Italy's National Recovery and Resilience Plan (PNRR), has designed and launched the initiative "Multicomponent Interventions and Technologies to Reduce the Burden of Frailty, Functional, and Cognitive Decline." The project involves collaboration among clinicians, researchers, and technology developers from various Italian universities and institutions to design and assess pragmatic, scalable interventions for older adults with different levels of frailty (Figure 1). Further details on the overall Age-It Research Program are available on the official website: https://ageit.eu.

This article outlines the project's design, intervention settings and methodologies, and discusses the broader socio-economic and healthcare implications for Italy, with potential relevance for the United States and other Western countries.

Aims and objectives

The general aim of this multicenter, nationwide project is to assess the feasibility, efficacy, and cost-effectiveness of multicomponent, technology-supported interventions aimed at preventing or mitigating frailty, cognitive impairment, and functional decline among older adults in community, hospital, and LTC settings.

Specific objectives

1. To implement and evaluate tailored multicomponent interventions across three care settings, addressing physical, cognitive, nutritional, and psychosocial domains.
2. To assess the impact of these interventions on an individual's physical performance, cognitive function, nutritional status, and quality of life over time.
3. To evaluate the feasibility and acceptability of technology-supported interventions (e.g., tablets, cognitive platforms, wearable trackers).
4. To assess the changes in biomarkers associated with frailty in relation to multicomponent interventions.
5. To develop and implement a digital platform for data collection, monitoring, and visualization across trials.
6. To assess the cost-effectiveness of multicomponent interventions using micro-costing and health economic modeling from a societal perspective.
7. To provide policy-relevant insights for the design of scalable, integrated care pathways for aging populations.

Methods and analysis

Study design

This project is structured into six dedicated work packages (WP). The first three (Clinical WPs) focus on implementing intervention studies targeting older individuals across different settings: community, hospital, and LTC facilities. The remaining three WPs (Cross-cutting WPs) are dedicated to the development and integration of technological solutions and tools to support intervention delivery, data management, and cost-effective analyses (Figure 2).

Clinical WPs

The clinical activities of the Age-It program's Spoke 8 are organized across three interventional studies, all based on a shared common framework of digitally supported Multicomponent Interventions, each tailored to distinct care settings and target populations:

- WP1: The "ItaliaN study with Tailored Multicomponent interventions to Prevent functional and cognitive decline in community-dwelling Older adults" (IN-TeMPO) is a two-phase study on community-dwelling adults, including a feasibility phase followed by a parallel, 1:1 Randomized Controlled Trial (RCT) comparing Multicomponent versus self-guided intervention across nine Italian centers. The IN-TeMPO trial is inspired by the Finnish Geriatric Intervention Study to Prevent Cognitive Impairment and Disability (FINGER) (Ngandu et al., 2015) and is methodologically aligned with the principles of the World-Wide FINGERS network (Kivipelto et al., 2020), promoting international harmonization of multidomain prevention strategies for cognitive decline.
- WP2: The "Optimizing Prevention of Hospital-Acquired Disability Through Integrated Multidomain Intervention: The Age-IT program" (OPTIMAge-IT) is a pragmatic, cluster RCT across eight geriatric acute wards enrolling hospitalized patients to evaluate the effect of in-hospital multicomponent intervention at discharge and the feasibility of technological support at 6 months after discharge.
- WP3: The "Multi-domain Interventions to improve the COgnitive and fUNctional well-being of older individuals in residential sTructures" (I-COUNT) is a cluster RCT conducted in two LTC facilities, to evaluate the effect on microbiota composition of Multicomponent intervention plus enriched food versus usual care.

Study population and key inclusion criteria

- WP1: Adults aged ≥60, with mild frailty, lifestyle index score ≥2, Clinical Dementia Rating (CDR) ≤0.5, a Cardiovascular Risk Factors, Ageing and Dementia (CAIDE) score ≥6, and no major functional impairments.

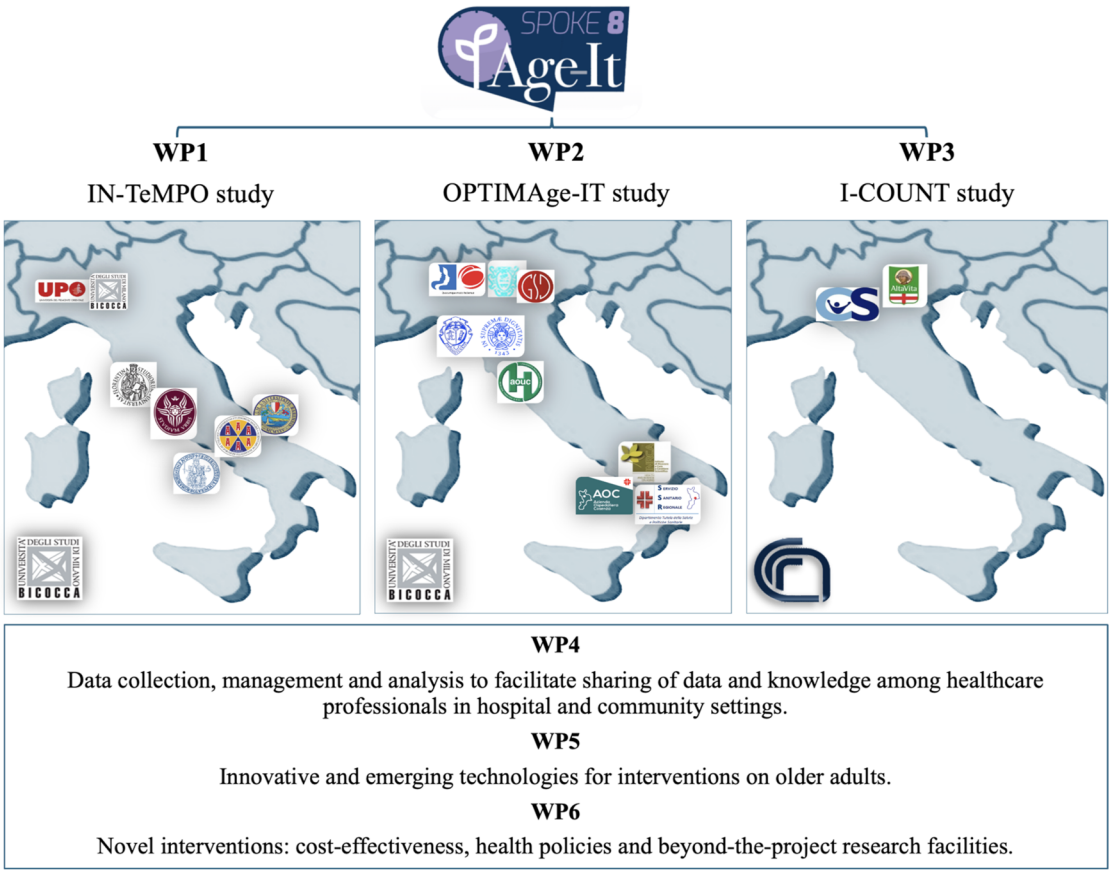

Figure 1. The Age-It Spoke 8 consortium institutions and partners.

- WP2: Adults aged ≥70, admitted to acute geriatric wards, with mild to moderate frailty, able to walk and communicate, and without severe cognitive deficits or delirium.
- WP3: Adults aged ≥70, institutionalized for at least 6 months, with a Mini-Mental State Examination (MMSE) ≥18/30, able to participate in cognitive and physical activities.

Recruitment strategies

- WP1 recruits community-dwelling adults through general practitioners, memory clinics, and public campaigns in collaboration with local health authorities.
- WP2 recruits eligible participants upon hospital admission in eight different secondary and tertiary care hospitals, following a standardized geriatric assessment.
- WP3 recruits residents of two long-term care facilities identified by local clinical staff, with eligibility confirmed by trained research personnel.

Multicomponent interventions

Multicomponent intervention includes at least three of the following evidence-based components, tailored to the individual needs, risk profiles, and care setting:

- Physical exercise, including balance, strength, and mobility training according to the Vivifrail protocol (Izquierdo et al., 2021), is adapted to functional capacity and frailty severity, with different implementation strategies across WPs. Participants in community programs engage in gym-based sessions aimed at promoting social interaction (WP1), while those hospitalized receive twice-daily supervised exercise, followed by weekly remote sessions post-discharge (WP2). In long-term care facilities, the intervention consists of twice-weekly group sessions for residents assigned to the exercise arm (WP3). Intervention intensity is defined according to Soldevila-Domenech et al. (2025) as the ratio between the total number of prescribed sessions and the duration in months. In WP1, the intervention includes three supervised sessions per week over 6 months (72 sessions, corresponding to an intensity of 12 sessions/month). In WP2, it is delivered three times per week for three months (36 sessions; 12 sessions/month). In WP3, participants receive two sessions per week for three months (24 sessions; 8 sessions/month).
- Digital cognitive training, delivered through validated platforms, is tailored to support key domains such as attention, memory, and executive function. In WP1 and WP2, training is provided via BrainHQ (Posit Science, San Francisco), an evidence-based platform featuring adaptive exercises across multiple cognitive domains. In WP3, cognitive training is implemented using REmote stimulation for COgnitive Decline (RECODE) (Rao et al., 2021), a computer-based platform designed to deliver remote cognitive stimulation.
- Nutritional counselling or supplementation is provided based on individual nutritional assessments and functional status. Dietary interventions are personalized, aligning with the principles of the Mediterranean diet,

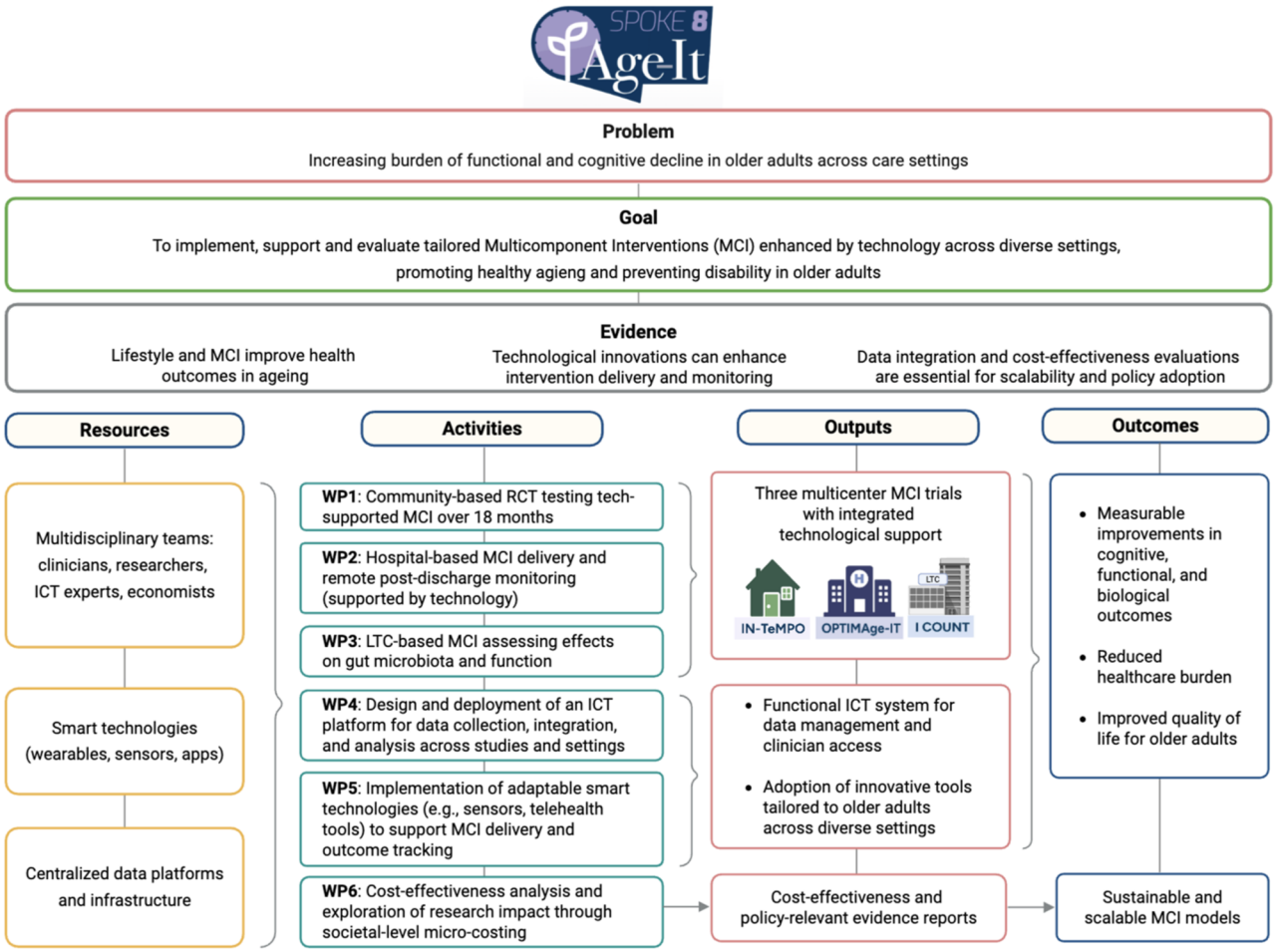

Figure 2. Logic model of Spoke 8 within the Age-It program. Abbreviations: MCI = multicomponent interventions; ICT = Information and Communication Technology; LTC = long-term care; RCT = randomized controlled trial.

emphasizing nutrient-rich, balanced meals. In WP3, nutritional support includes the use of enriched foods specifically adapted to the needs of institutionalized older adults.

- Vascular and metabolic risk factor monitoring includes medication review, blood pressure control, and lifestyle interventions. In WP3, participants are also offered vaccinations in accordance with the National Vaccination Plan. The CAIDE risk score is used only in WP1, reflecting its validation in community-dwelling older adults; in hospitalized or institutionalized populations, its predictive value is limited by feasibility constraints and the ceiling effect of age-dependent components (Fayosse et al., 2020).
- Psychosocial stimulation and group-based activities are implemented across all WPs to enhance social interaction, mood, and overall engagement.

Interventions are coordinated by a multidisciplinary team (MDT), which includes geriatricians/neurologists, physiotherapists, dietitians, neuropsychologists, nurses, and digital coaches. Digital coaches are highly skilled professionals tasked with aiding participants in the proficient use of digital tools and technologies that are essential to the intervention. This is particularly relevant for components such as cognitive training or remote monitoring. The composition of the MDT may vary according to the care setting and available resources, to ensure appropriate supervision, personalization, and monitoring of each intervention component. All team members receive specific training to standardize intervention delivery across sites and enhance participant adherence.

Biomarkers

A comprehensive panel of Blood-Based Markers (BBMs) is collected at baseline and follow-up for all participants across all WPs to assess associations with frailty, cognitive and functional trajectories, and intervention response (Sala et al., 2025). Gut microbiome–related biomarkers (GMBM) are exclusively collected in WP3. A complete list of biomarkers and the corresponding WPs in which they are collected is provided in Supplementary Table 1 (see online supplementary material).

Technology integration

The integration of digital technologies represents a core component of the intervention strategy across all WPs, supporting personalization, remote monitoring, and participant engagement (Figure 3).

- WP1: A selected subgroup of participants receives a tablet device equipped with the BrainHQ cognitive training platform, along with a smartwatch for continuous monitoring of physical activity and physiological parameters.

- WP2: All participants in the intervention arm receive a tablet preloaded with the BrainHQ cognitive training platform and a smartwatch for continuous activity monitoring. Remote follow-up is maintained for three months post-discharge to support adherence and monitor functional recovery trajectories.
- WP3: All participants in the intervention group are equipped with a smartwatch and have access to the RECODE cognitive training platform.

In all three WPs, socioeconomic status and digital literacy are systematically assessed at baseline and considered potential moderators of adherence to the technology-supported intervention and related outcomes. This is particularly relevant in WP1, where the intervention relies on remote digital engagement, but also informs feasibility analyses in WP2 and WP3, where in-person digital coaching is provided.

Outcomes

A structured overview of all study outcomes and their corresponding measurement tools is provided in Table 1.

In WP1, the primary outcome is the change in global cognitive performance at 18 months, assessed with a validated neuropsychological battery. Secondary outcomes include measures of physical performance, quality of life, psychological well-being, and nutritional status. In WP2, co-primary outcomes are functional performance at discharge and the feasibility of the home-based, technology-supported intervention. Secondary outcomes cover a broad range of clinical and functional variables, including cognitive and physical performance, frailty status, quality of life, hospital-related outcomes (e.g., complications, readmissions, length of stay), and healthcare costs. In WP3, the primary outcome is the change in gut microbiota composition at 3 months. Secondary outcomes include longer-term microbiota changes, cognitive and physical performance, nutritional and anthropometric parameters, psychological health, relevant blood-based biomarkers, and the feasibility of digital tools.

Cross-cutting WPs

WP4: data management and ICT platform

WP4 involves the creation of a centralized, secure data platform based on Microsoft Azure to collect, harmonize, and process clinical, functional, and sensor-derived data. The system allows:

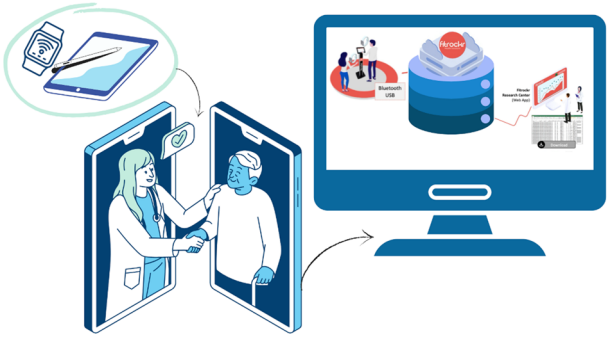

Figure 3. Information and Communication Technology (ICT) integration for remote intervention support in Spoke 8 activities.

- Integration of REDCap, wearable devices, cognitive platforms, and biospecimens.
- Pseudonymized storage, audit trails, metadata tagging, and visualization dashboards.
- Advanced analytics, including machine learning for trajectory clustering and outcome prediction.

WP5: technology development

WP5 focuses on the design, implementation, and evaluation of innovative, user-centered technologies that support and enhance multicomponent interventions. The development process is carried out in close collaboration among engineers, geriatricians, physiotherapists, cognitive scientists, and usability experts, ensuring that all technological solutions are tailored to the needs, preferences, and capabilities of older adults. User-centered technologies to be deployed and tested include:

- Smartwatches for continuous monitoring of physiological parameters and physical activity.
- Sensorized devices for use in both home and institutional environments, aimed at assessing movement, behavior, and safety.
- Advanced experimental tools, such as EEG-based brain-computer interfaces (BCI), digital twin models, and biosignal monitoring systems, are designed to explore future frontiers in aging care.

All devices comply with GDPR standards and are conceived to be scalable, interoperable, and user-friendly, with particular attention to accessibility for frail and cognitively impaired individuals.

WP6: economic evaluation

WP6 focuses on evaluating the economic sustainability and scalability of the multicomponent interventions tested across the different settings. The analysis is conducted by a multidisciplinary expert team including health economists, epidemiologists, biostatisticians, and clinical researchers, working in close collaboration with WP1, WP2, and WP3. Specifically, the WP6 health economists assess the following:

- A prospective cost-effectiveness analysis (CEA) is conducted from a societal perspective, accounting for both direct healthcare costs (e.g., clinical visits, diagnostic tests, use of devices) and indirect costs (e.g., caregiver time, loss of independence in activities of daily living).
- Clinical outcomes such as quality-adjusted life years (QALYs), functional status, and cognitive performance are tracked over time to estimate the value of the interventions.
- Incremental cost-effectiveness ratios (ICERs) for each intervention arm, and budget impact models are developed to assess the financial implications for the healthcare system.

Artificial intelligence integration

Artificial intelligence (AI) and machine learning models represent a further innovative component of this project. By leveraging longitudinal clinical, functional, and biomarker data, AI supports real-time monitoring, early risk detection, and

Table 1. Key outcome and measures across the three clinical WPs.

Outcome	WP1: IN-TeMPO	WP2: OPTIMAge-IT	WP3: I-COUNT
Physical/functional performance	Changes in SPPB, 4MWS, HGST, BADL at 12 months	Changes in SPPB at discharge, SPPB, ADL, and IADL at 6 months[a]	Changes in SPPB, dual-task walking tests, BIA, ADL, and IADL
Frailty	—	Changes in CFS in PC-FI at 6 months	—
Cognitive performance	Change in m-NTB at 12 months[a]	Changes in ACE-R and TMT A-B at 6 months	Changes in m-NTB, ACE-R, and TMT A-B at 6 and 9 months
Psychological status	Changes in GDS, Flourishing Scale at 12 months	Change in GDS at 6 months	Changes in PSS and DASS at 6 and 9 months
Nutritional status/ adherence to diet	Changes in MNA-SF, MDScale at 12 months	Changes in MNA-SF and MDScale at 6 months	Changes in MNA-SF and BMI at 6 and 9 months
Sleep	Change in PSQI at 12 months	Change in PSQI at 6 months	Change in PSQI at 6 and 9 months.
Quality of life	Change in WHOQOL-BREF at 12 months	Change in EQ-5D-5L at 6 months	WHOQOL-BREF at 6 and 9 months.
Biomarkers	Changes in blood-based inflammatory, metabolic biomarkers	Changes in blood-based inflammatory, metabolic biomarkers	Gut microbiome changes at 3 months; gut microbiome and inflammatory, metabolic BBMs at 6 and 9 months[a]
Technology	Adherence to the eHealth platform, wearable usage, and acceptability questionnaires	PREMs and drop-out rate.[a] Adherence to eHealth platform, wearable usage, System Usability Score	Adherence to the eHealth platform, wearable usage, and acceptability questionnaires
Healthcare use	—	Hospital readmissions, length of stay, mortality, cost-effectiveness analyses	Hospital admissions

Note. WPs = work packages; 4MWS = 4-meters walking speed; ACE-R = Addenbrooke's Cognitive Examination–Revised; ADL = activities of daily living; BADL = basic activities of daily living; BBMs = blood-based biomarkers; BIA = bioimpedance analysis; BMI = body mass index; CFS = Clinical Frailty Scale; DASS = Depression Anxiety Stress Scale; EQ-5D-5L = EuroQol 5 Dimensions, 5 Levels; GDS = Geriatric Depression Scale; HGST = Handgrip Strength Test; IADL = instrumental activities of daily living; MDScale = Mediterranean Diet Scale; m-NTB = Modified Neuropsychological Test Battery; MNA-SF = Mini Nutritional Assessment–Short Form; PC-FI = Primary Care–Frailty Index; PREMs = Patient Reported Experience Measures; PSQI = Pittsburgh Sleep Quality Index; PSS = Perceived Stress Scale; SPPB = Short Physical Performance Battery; TMT A-B = Trail Making Test, Parts A and B; WHOQOL-BREF = World Health Organization Quality of Life-Scale.
[a]Primary endpoints.

personalized care planning. Explainable machine learning approaches, such as feature importance analysis, enhance transparency and help identify which components of the intervention (e.g., physical, cognitive, nutritional, psychosocial) most influence outcomes. The study's multicenter design also allows for federated learning, enabling AI models development across sites without direct data sharing—thus ensuring data protection and compliance with GDPR regulations.

Implementation status of work packages

Study procedures are progressing steadily. Recruitment in WP2 and WP3 is nearing completion, while WP1 enrolment is ongoing. Early phases have revealed key implementation challenges. In WP1, recruitment has been slower than expected due to delayed participants' identification by general practitioners and low perceived need for prevention among community-dwelling older adults without overt clinical conditions. Digital illiteracy, particularly in lower-income groups, remains a barrier, and current eHealth tools are still poorly adapted to age-related cognitive and sensory limitations, underscoring the need for inclusive technological design and human support.

In WP2 and WP3, the high prevalence of frailty among hospitalized and institutionalized older adults confirms the clinical relevance of the intervention but limits inclusion of pre-frail individuals—the intended target group. Encouragingly, adherence to physical activity protocols has been high in both WPs, and social engagement has exceeded expectations, both during exercise and group-based educational sessions. Preliminary findings from WP3 also show good acceptance of digital tools and strong adherence to fortified food intake, reinforcing the feasibility and potential impact of the intervention across diverse care settings. Experiences WPs 1–3 will inform subsequent phases (WPs 4–6), to evaluate broader socio-economic outcomes, including equity, sustainability across regions, support for families, care-related costs, and strengthen community networks.

Discussion

This article outlines an innovative, multidimensional strategy to prevent frailty progression and disability in older adults across community, acute hospital, and LTC settings.

Frailty currently impacts a considerable portion of the older population and is projected to increase notably in the future (Kim & Rockwood, 2024). Recent population-level simulations conducted in the United Kingdom estimated that frailty prevalence among adults aged ≥50 increased from 26.5% in 2006 to 38.9% in 2017, with the highest economic burden attributable to individuals with mild and moderate frailty due to their large numbers. Projections indicate that frailty prevalence will reach 48.7% by 2027, corresponding to an estimated $7.25 billion USD increase in health and social care costs over 11 years (Walsh et al., 2024).

Despite the growing prevalence of frailty and its economic impact (Kim & Rockwood, 2024; Walsh et al., 2024), traditional care models remain insufficient. These models, often based on disease-specific pathways (Tinetti & Fried, 2004), tend to overlook the interplay of biological, functional, cognitive, and social factors that drive frailty and its progression toward loss of independence. To overcome these limitations, our model adopts a proactive, person-centered approach that integrates multicomponent interventions with digital health technologies, emphasizing prevention, continuity of care, and treatment adherence.

Italy is among the most aged societies worldwide, with over 23% of the population aged 65 or older—a proportion expected to exceed 30% by 2050 (Istat, 2023). This demographic trajectory, driven by exceptionally low fertility and high life expectancy, places Italy at the forefront of the global aging transition. The Italian context is further characterized by the coexistence of a universal public healthcare system, pronounced regional disparities, and a longstanding reliance on informal, family-based caregiving. These features make Italy a relevant case study for other high-income countries facing similar challenges—including healthcare fragmentation, workforce shortages, and rising long-term care needs (Bloom et al., 2015). At the same time, low- and middle-income countries are undergoing a rapid demographic shift due to increased life expectancy and declining fertility.

Therefore, strategic responses to this demographic shift must prioritize health systems redesign centered on a person's functional ability rather than disease, managing multimorbidity and frailty, and reducing inequalities in access to care (World Health Organization, n.d.). These efforts should also account for sociocultural and economic diversity by investing in integrated care, digital innovation, caregiver support, and community-based resilience.

In this context, the Age-It program provides a scalable blueprint to guide public health policy not only in Europe, but also in regions undergoing rapid demographic aging, such as East Asia and Latin America. Within this framework, Spoke 8 plays a central role by actively interfacing with other Age-It domains: it draws on insights from Spoke 2 (biology of aging) to guide biomarker selection and mechanistic hypotheses; aligns with Spoke 4 (life-course trajectories) to refine intervention timing and personalization; and collaborates with Spoke 5 (care systems) to promote continuity and integration across acute and long-term care. In addition, Spoke 8 contributes to evidence-informed policymaking in close synergy with Spoke 10 (governance and reform of aging-related policies).

The implementation of this approach has important implications for aging societies. It provides a scalable, sustainable framework to improve outcomes, delay institutionalization, and optimize healthcare resource use. From a policy and economic perspective, integrated, tech-enabled preventive care may reduce expenditures, support aging in place, and ease the burden on hospitals and informal caregivers—contributing to a more equitable system. Although previous studies have shown the benefits of multicomponent interventions in relatively healthy older adults, their adoption in hospital and LTC settings remains limited. This project seeks to bridge these gaps by embedding structured, person-centered interventions into routine care across community, hospital, and LTC settings, enhancing both ecological validity and scalability. Moreover, given the well-documented digital divide among older adults, particularly in low-SES populations, our study design explicitly considers socioeconomic status and digital literacy as key factors influencing intervention uptake. These variables will not only be analyzed as potential moderators of adherence and outcomes but also interpreted within a broader framework of health equity, access, and the need for inclusive digital health strategies.

A key innovation of this project lies in the integration of aging biomarkers to capture individual trajectories and identify high-risk subgroups, including those exhibiting accelerated biological aging or suboptimal recovery patterns. Combined with longitudinal clinical and functional measures, these data enable personalized intervention strategies and advanced predictive modeling.

In summary, the project offers a replicable, evidence-based model to address the challenges of aging across diverse health systems. While rooted in the Italian context—marked by rapid population aging, regional disparities, and a predominantly public care model—it provides insights with global relevance. The findings may guide future policy directions in Italy and beyond, especially regarding the integration of preventive care, digital tools, and multidisciplinary teams into routine services. The project responds to common challenges among high-income countries, including the United States, where demographic shifts, inequalities, and fragmented care threaten long-term sustainability. By testing scalable, tech-supported multicomponent interventions in real-world conditions, it contributes to the global transition toward more personalized, effective, and sustainable models of care for older adults.

Supplementary material

Supplementary data are available at *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences* online.

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Conflict of interest

None declared.

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