



Cost-Effectiveness of a Mobile Health Program for Pre-elderly Adults

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Abstract

In South Korea, over half the adults are insufficiently active. Mobile health (mHealth) interventions can increase physical activity. This study evaluated the cost-effectiveness of a smartwatch and smartphone application to promote moderate-intensity physical activity among South Korean adults aged 45–64 years. A Markov cohort model with seven health states was developed to compare intervention and non-intervention scenarios. Transition probabilities, utility values, and costs in the model were calculated using data from the National Health Insurance Service and the Korea National Health and Nutrition Examination Survey. The intervention effect was measured through changes in moderate-intensity physical activity (≥ 150 min/week) over a 12-week prospective study ($n=304$). The analyses used 10-year and lifetime horizons with comprehensive sensitivity. The intervention yielded an incremental gain of 0.0077 quality-adjusted life years (QALYs) at an additional cost of 6.3 USD/person, resulting in an incremental cost-effectiveness ratio (ICER) of 829 USD/QALY gained over 10 years. Benefits were greater in the 55–64 age group (455 USD/QALY) than in the 45–54 age group (1,595 USD/QALY). Probabilistic sensitivity analysis confirmed robust cost-effectiveness at a willingness-to-pay threshold of USD 20,000/QALY. The program using smartwatches and smartphones was cost-effective for middle-aged South Korean adults, particularly those aged 55–64 years. These findings support integrating mHealth solutions into national physical activity promotion strategies as an economically feasible approach to addressing physical inactivity and preventing chronic diseases in aging populations.

Keywords Physical activity · Mobile health · Cost-effectiveness · Chronic disease prevention · Markov model · Health economics

Introduction

Physical activity plays a crucial role in reducing the burden of noncommunicable diseases (NCDs) and improving overall health outcomes in modern healthcare systems. Specifically, moderate-intensity exercise can significantly reduce the risk of hypertension and type 2 diabetes, lower cardiovascular disease (CVD) mortality by up to 40% compared to sedentary individuals, and decrease overall CVD mortality [1].

These findings have led the WHO to recommend that adults participate in 150–300 min of moderate-intensity aerobic activity or 75–150 min of vigorous-intensity aerobic activity weekly [2]. Physical activity also enhances the quality of life of individuals with chronic conditions through effective disease management [3], emphasizing its vital role in the prevention and treatment of NCDs such as CVD, type 2 diabetes, and certain cancers [4].

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Physical activity can protect cognitive health [5] through demonstrated effectiveness of interventions, particularly when implemented in middle age or during the early stages of cognitive decline [6–8].

Despite these benefits, physical inactivity has emerged as a significant public health concern, contributing to 7.2% of all-cause mortality and increasing the risk of NCDs [9]. Global trends reveal a concerning increase in physical inactivity, rising from 26.4% in 2010 to 31.3% in 2022 [10], with particularly sharp declines in activity levels among adults aged 60 years or older.

The economic burden of physical inactivity significantly affects healthcare systems [11]. Studies attribute 1–4% of total direct healthcare costs to physical inactivity [12]. The situation in South Korea warrants particular attention, as insufficient physical activity among adults reached 52.2% by 2019 [13]. South Korean studies have demonstrated that physically inactive individuals incur 11.7% higher average medical costs than active individuals, particularly for expenses related to cardiovascular and metabolic diseases [14].

The middle-aged population (aged 45–64 years) represents a crucial target group for promoting physical activity. This age group faces an increased risk of chronic diseases and functional decline, with physical activity serving as a protective factor [4]. This period offers a critical window for preventive interventions before the typical decrease in activity among older adults. Interventions during this transitional phase are essential for establishing healthy aging patterns and preventing chronic conditions, including cognitive decline.

Smartphone applications offer significant advantages in addressing physical inactivity through their high accessibility and real-time monitoring, making them effective tools for promoting increased physical activity [15]. Although studies have demonstrated the effectiveness of mobile health (mHealth) interventions in promoting physical activity [16], evidence of their cost-effectiveness remains limited. Existing economic evaluations primarily focus on basic interventions, such as pedometers or text message-based approaches [17], leaving a knowledge gap regarding comprehensive smartphone app interventions [15, 16, 18, 19].

Globally, the role of mHealth in health promotion and disease prevention is gaining recognition. In South Korea, an increasing number of clinical trials are actively mobile health solutions. The integration of mobile technology into national health promotion strategies holds considerable promise for addressing the widespread challenges of physical inactivity. However, to justify large-scale implementation within publicly funded healthcare systems, evidence of the cost-effectiveness of such interventions is essential.

This study aimed to evaluate the cost-effectiveness of a smartphone app-based intervention for promoting physical activity among South Korean adults aged 45–64 years from a healthcare system perspective. The specific objectives are to:

1. Assess the impact of the intervention on the incidence of physical activity-related chronic diseases.
2. The incremental cost-effectiveness ratio (ICER) was calculated by measuring the costs and quality-adjusted life years (QALYs) associated with the intervention compared to a non-intervention state.

These findings inform evidence-based healthcare resource allocation to promote physical activity among middle-aged South Korean adults. This study specifically addresses the current evidence gap in the cost-effectiveness of mHealth interventions within the South Korean healthcare context, providing practical insights for implementing digital health solutions in chronic disease prevention.

Methods

Model Structure and Health States

A Markov cohort model was constructed to assess the intervention's impact on long-term health outcomes and costs (Fig. 1). This multistate transition model enables the analysis of disease progression pathways and mortality risk, accounting for both direct transitions between states and the simultaneous influence of multiple conditions on health outcomes. The model targets the general population aged 45–64 years, simulating outcomes over a 10-year period (base-case analysis), or until reaching a life expectancy of 85 years (scenario analysis).

The model comprises seven distinct health states, defined by the presence of chronic diseases and physical activity status: well-active, well-inactive, mild-active, mild-inactive, severe CVD, dementia, and death. The well and mild states are further subdivided by physical activity levels (active/inactive), creating the seven total states modeled. The hypothetical cohort began in either a well or mild chronic disease state, with potential annual changes in health status based on physical activity levels or natural disease progression.

The well state represents individuals who are free from chronic conditions and may either maintain their status or transition to any other state. Mild chronic diseases, specifically defined as hypertension and/or type 2 diabetes without severe cardiovascular complications. These conditions were selected based on their high prevalence in the target population and established associations with physical activity [20,

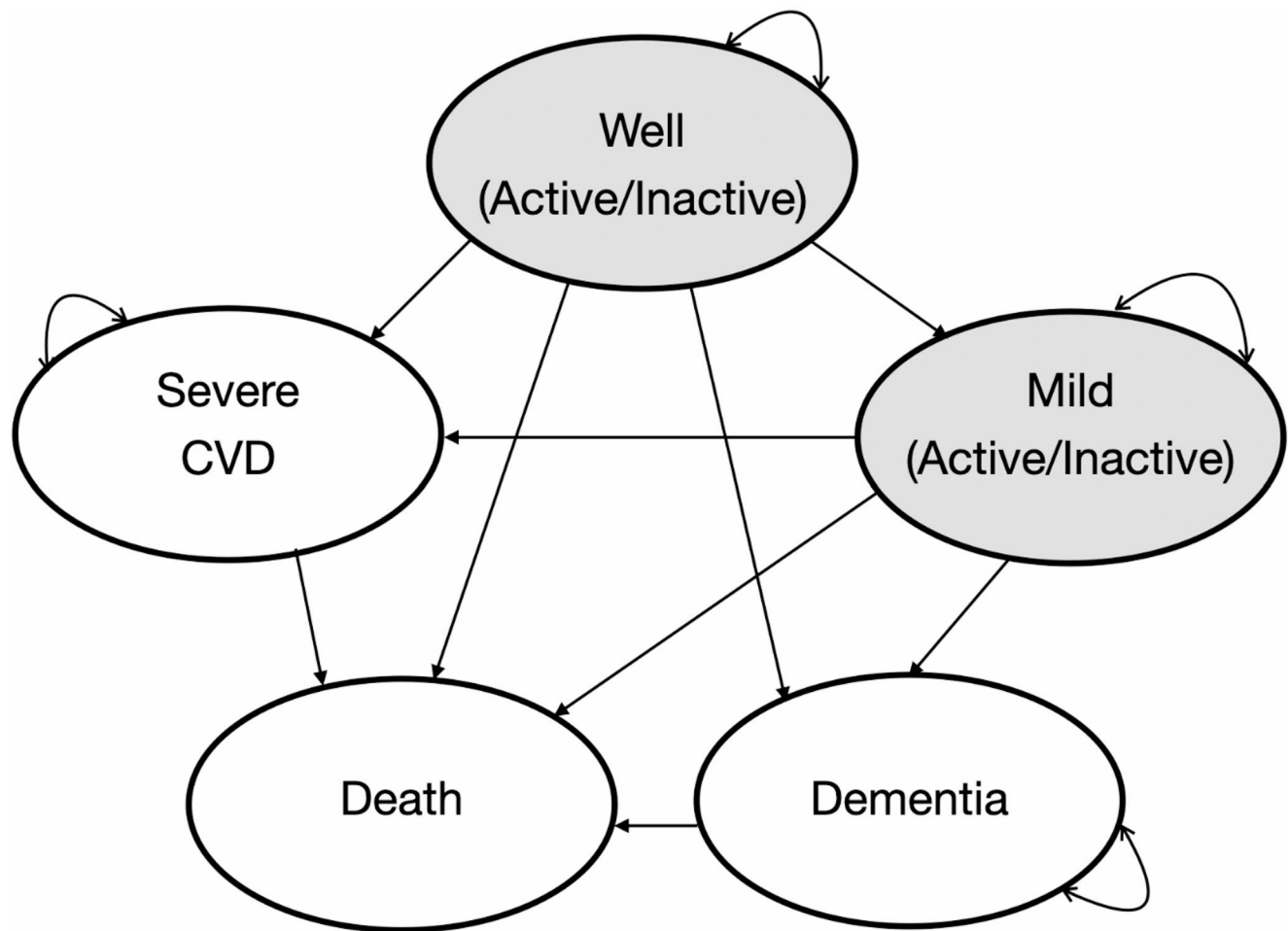


Fig. 1 Markov model

21]. Individuals with mild chronic diseases may maintain their current state, progress to either severe CVD or dementia, or die, but cannot revert to the well state. Individuals with severe CVD include those with serious cardiovascular and/or cerebrovascular conditions (ischemic heart disease, myocardial infarction, or stroke). Individuals in this state can either remain in this condition or transition to death, with no possibility of reverting to previous states [17, 21, 22]. Dementia is a condition in which individuals can only remain in their current state or transition to death [23]. To maintain model simplicity, transitions between the severe and dementia states were not incorporated. Both well and mild states include active and inactive substates that reflect physical activity levels, which influence transition probabilities. Death is an absorbing state that can occur during any other health state in the model.

The diseases selected for intervention included mild chronic conditions (hypertension and diabetes) and severe conditions (CVD, cerebrovascular disease, and dementia). These conditions were selected based on previous literature [17, 21–25].

Initial Cohort Population

The virtual cohort for the intervention program was designed to match the general population aged 45–64 years. The initial distributions of key characteristics—including age, health status (presence of mild chronic disease), and physical activity levels—were based on 2023 demographic statistics from Statistics Korea [26] and the KNHANES [27]. For modeling purposes, the target population was divided into two age groups: 45–54 years and 55–64 years, with representative ages of 50 and 60 years used as the starting ages for each group.

The Physical Activity Measurement Tool used in the KNHANES (2019–2020) was the Global Physical Activity Questionnaire (GPAQ) developed by the WHO [28–30]. To standardize the physical activity measurements in the survey data, vigorous-intensity exercise time was converted to moderate-intensity equivalent minutes by multiplying it by a factor of two, resulting in the total moderate-intensity physical activity time used in the analysis (Supplementary Document S3). To align the physical activity indicators with

those used in clinical trials assessing the intervention effect (Supplementary Document S1), walking-related items were excluded from the calculation of moderate-intensity physical activity time. Moderate- and vigorous-intensity activity times were calculated by summing the physical activities performed during both work and leisure.

According to survey results, 22% of individuals aged 45–54 and 18% of those aged 55–64 met or exceeded the recommended level of moderate-intensity physical activity (≥ 150 min per week) in the general population (Table 1).

Clinical Trial and the Intervention Effect

This study evaluated a comprehensive 12-week mobile application program paired with a smartwatch (Galaxy Watch series 6) specifically designed to promote physical activity. The program began with a one-week baseline data collection period, followed by continuous monitoring of participants' moderate-intensity physical activity. The app provides goal-achievement feedback and motivational messages to encourage participation, and it incorporates an incentive system in which participants can earn up to 6,000 points monthly, which are exchangeable for gift certificates.

This economic evaluation was based on a prospective, single-cohort clinical trial (IRB no.: 1041078–20240131-BR-020). A total of 304 participants aged 45–64 years were recruited from Seoul Dobong District between May and October 2024. Detailed trial methodology, recruitment procedures, inclusion/exclusion criteria, participant characteristics, and key trial results are provided in Supplementary Document S1.

The intervention effect was measured through changes in moderate-intensity physical activity time, a metric well supported by evidence demonstrating strong associations with health outcomes, including CVD, type 2 diabetes incidence, and all-cause mortality. Exercise intensity was determined using heart rate data from the smartwatches. Weekly moderate-intensity equivalent physical activity time was calculated based on the intensity level, with vigorous-intensity activity counted as twice that of moderate-intensity activity.

Participants were classified into two groups based on their weekly moderate-intensity physical activity time measured at week 0 (baseline) and week 12: those meeting or exceeding the physical activity guideline (≥ 150 min per week) and those not meeting the guideline [1, 31].

Among participants aged 45–54 years, the proportion meeting the recommended level of moderate-intensity physical activity increased by approximately 17% points (95% confidence interval (CI): 8.0%p, 25.6%p) after the intervention. For those aged 55–64 years, the increase was approximately 22% points (Table 1). Owing to the absence of a non-intervention control group, pre-intervention physical

activity levels were considered a reasonable approximation of the baseline non-intervention state [22].

The intervention effect was assumed to last for four years, with a 25% annual reduction, such that the effect would diminish completely by the fifth year [24]. Sensitivity analyses were conducted assuming alternative durations of intervention effects (two and six years).

Transition Probabilities

The National Health Insurance Service Health Screening Cohort (NHIS-Heals) database was used to analyze health outcomes among health-screening examinees [32]. Physical activity was assessed using the International Physical Activity Questionnaire-Short Form (IPAQ-SF) developed by the WHO [33, 34].

The IPAQ-SF (2009–2017) assessed weekly physical activity across three intensities: vigorous activities (≥ 20 min/day), moderate activities (≥ 30 min/day), and walking (≥ 30 min/day accumulated in ≥ 10 -minute bouts). The participants reported the number of days (0–7) they had engaged in each activity level during the past week, ensuring that there was no double counting across categories.

To standardize physical activity measurements, vigorous-intensity activity time was converted to moderate-intensity equivalents by applying a factor of two and combined with moderate-intensity activity time. Walking-related items were excluded from these calculations to maintain consistency with clinical trial metrics. The methods used for cohort construction and transition probability analysis have been documented in a separate study [35] (Supplementary Document S2).

Age-specific baseline disease incidence proportions were applied to the transition probabilities of physically inactive individuals in well and mild health states. These proportions were estimated by tracking the disease-specific incidence over a three-year period and converting it to annual incidence using the following formula:

$$\text{One-year incidence} = 1 - (1 - \text{Three-year incidence})^{(1/3)}$$

Although dementia cases were identified among individuals aged 45–54 years, the economic evaluation model assumed no incidence of dementia in this age group because of its extremely low prevalence in this demographic.

Disease incidence risk for the active group was calculated by multiplying the incidence rate of the inactive group in the corresponding health state by the hazard ratio (HR).

The baseline mortality applied to the well state was estimated using age-specific all-cause mortality rates from national statistics, excluding deaths due to CVD and dementia [36, 37].

Table 1 Model parameter estimates and sources

Parameters			
Cohort setting		Value	Source
Prevalence of mild chronic diseases by age group			
Aged 45–54 years		29.1%	KNHANES (2019–2020)
Aged 55–64 years		47.4%	
Initial distribution of physical activity by age group			
Aged 45–54 years		22.1%	KNHANES (2019–2020)
Aged 55–64 years		18.4%	
Aged 65–74 years		14.6%	
Aged ≥ 75 years		9.5%	
Treatment effect		Value	95% CI
Intervention-induced increase in active PA proportion by age group			
Aged 45–54 years		16.9%	(8.0%, 25.6%)
Aged 55–64 years		21.8%	(9.7%, 33.7%)
Treatment effect duration		4 years	Assumption
Transition probabilities: Baseline incidences for diseases		Mean	SD
Well to mild			
Aged 45–54 years		4.046%	0.045%
Aged 55–64 years		5.243%	0.069%
Aged 65–74 years		7.860%	0.157%
Aged ≥ 75 years		8.073%	0.329%
Well to dementia			
Aged 45–54 years		0%	0%
Aged 55–64 years		0.147%	0.012%
Aged 65–74 years		0.786%	0.050%
Aged ≥ 75 years		2.010%	0.164%
Well to severe			
Aged 45–54 years		0.493%	0.016%
Aged 55–64 years		0.989%	0.030%
Aged 65–74 years		1.692%	0.073%
Aged ≥ 75 years		2.558%	0.185%
Mild to dementia			
Aged 45–54 years		0%	0%
Aged 55–64 years		0.165%	0.012%
Aged 65–74 years		0.978%	0.037%
Aged ≥ 75 years		2.236%	0.094%
Mild to severe			
Aged 45–54 years		1.212%	0.036%
Aged 55–64 years		1.943%	0.042%
Aged 65–74 years		3.299%	0.068%
Aged ≥ 75 years		4.002%	0.126%
Transition probabilities: Relative risks		Adjusted HR	95% CI
Disease incidence relative risk for active compared to inactive group			
Well to mild		0.947	(0.916, 0.979)
Well and mild to dementia		0.784	(0.709, 0.868)
Well and mild to severe		0.953	(0.914, 0.992)
Relative risk for state-specific mortality			
Mild compared to well		1.381	(1.275, 1.495)
Dementia compared to well		4.669	(3.816, 5.712)
Severe compared to well		2.064	(1.831, 2.327)
Relative risk mortality for active compared to inactive group			
Well		0.774	(0.66, 0.907)
Mild		0.723	(0.648, 0.807)
Utilities		Mean	SD
Baseline utility by age group			

Table 1 (continued)

Parameters			
Aged 45–54 years	0.972	0.061	KNHANES (Supplementary Document S3)
Aged 55–64 years	0.955	0.085	
Aged 65–74 years	0.924	0.122	
Aged ≥ 75 years	0.915	0.136	
State-specific utility by health state			Literature [33, 34]
Dementia	0.6	0.34	
CVD for 1st year	0.57	0.276	
CVD for post year	0.78	0.209	
Dis (or plus) utility from baseline by health state			
Mild	−0.0095	0.0024	KNHANES (Supplementary Document S3)
Active	+0.0060	0.0025	
Costs	Mean(USD)	SD	Source
Intervention cost per person (Incentive + administration cost)	7.14	2.1	Clinical trial (Supplementary Document S1)
Average annual healthcare cost per person by health status			
Well			
Aged 45–54 years	239	239	NHIS Yearbook
Aged 55–64 years	303	303	
Aged 65–74 years	409	409	
Aged ≥ 75 years	559	559	
Mild			
Aged 45–54 years	540	540	
Aged 55–64 years	607	607	
Aged 65–74 years	668	668	
Aged ≥ 75 years	707	707	
Severe	2,657	2,657	
Dementia	3,115	3,115	

SD Standard deviation, SE Standard error, HR Hazard ratio, CI Confidence interval

State-specific mortality for mild, severe, and dementia states was calculated by multiplying the age-specific baseline mortality of the well state by the corresponding hazard ratio for each health state [35]. In the well and mild health states, the relative risk of mortality varied according to physical activity level. In other health states, the model did not distinguish between the physical activity groups as the statistical analysis found no significant differences in mortality among these groups. In the sensitivity analysis, the prior distribution of the hazard ratios was assumed to follow a lognormal distribution.

For transition probability estimation using the NHIS-HealS database, Cox proportional hazards models were applied with adjustment for key covariates including sex, age, and body mass index. This adjustment ensured that the association between physical activity and disease incidence or mortality was independent of these potential confounders.

Utility and Cost

Age-specific utility values were derived using data from the KNHANES (2019–2020). To estimate the utility values based on chronic conditions and physical activity levels,

a generalized regression model was constructed using the EuroQol five-dimension questionnaire (EQ-5D) index as the dependent variable. The EQ-5D is a standardized health-related quality of life instrument that comprises five dimensions (mobility, self-care, usual activities, pain/discomfort, and anxiety/depression). The EQ-5D index is a single preference-based utility value derived from the five-dimensional health state profile, ranging typically from 0 (death) to 1 (perfect health), and is commonly used in cost-utility analyses to calculate quality-adjusted life years (QALYs). The EQ-5D used in the KNHANES was the 3-level version (EQ-5D-3 L), and the value set applied was developed by Lee et al. (2009) [38]. This approach quantifies the impact of specific chronic conditions on the quality of life while controlling for other factors that affect health-related quality of life. Covariates included sex, age, body mass index, household income, education level, marital status, and the presence of depression [39] (Supplementary Document S3).

The utility values for severe chronic conditions and dementia were obtained from the literature [40, 41]. In the model, the utility values for dementia and CVD were applied uniformly across all ages within health states.

Cost data were obtained from the NHIS (2023) [42]. The cost of non-covered services was estimated by applying the

out-of-pocket payment rate for non-covered services, based on the 2023 NHIS survey on medical expenses for insured patients [43]. This analysis adopted a healthcare system perspective, excluding transportation, time, and caregiver costs.

The medical costs for a healthy state without chronic conditions (well) were assumed to be the average medical expenses for all diseases excluding the target conditions. This approach may overestimate costs for those in a well state, as these averages are typically calculated from individuals who use healthcare services, whereas some people in a well state may not access medical services at all during a given period. Including medical costs in the well state reflects the possibility of incurring healthcare expenses from other diseases in the absence of target conditions, accounting for the competing risks associated with longer survival. In the well and mild health states, medical costs were assumed to increase with age, whereas in the severe and dementia states, the same medical costs were applied across all age groups. For cost uncertainty modeling, a two-part model was applied to the well health state, while a gamma distribution was used for other health states where zero costs are rare [44, 45].

The intervention costs included incentives and administrative expenses. The incentive costs are based on the average incentive payments made during clinical trials. Administrative costs were calculated based on personnel expenses incurred during the three-month intervention period. In the no-intervention scenario, we assume that these costs will not occur. All costs were converted to 2024 USD.

Cost-effectiveness and Sensitivity Analysis

The base-case analysis estimated the quality-adjusted life expectancy (QALE) and costs for both the intervention and comparison groups over a 10-year time horizon, and calculated the ICER accordingly. In accordance with Korean health economic evaluation guidelines, both costs and health outcomes were discounted at an annual rate of 4.5%. An alternative analysis addressing structural uncertainty was conducted by varying the time horizon.

To assess the impact of the key parameters on the results, both one-way sensitivity analysis and probabilistic sensitivity analysis (PSA) were performed. The one-way sensitivity analysis included variations in the discount rate, magnitude, and duration of the treatment effect, utility values, and intervention costs. In PSA, 1,000 simulations were conducted based on the assumed prior distributions for each parameter. Our results of the PSA are presented as ICER scatterplot and cost-effectiveness acceptability curve. Credible intervals (CrI) were derived from the 2.5th and 97.5th percentiles of the PSA results distribution.

Results

Base-Case Analysis

During the 10-year analysis period, the group that received the mobile health intervention demonstrated a QALE of 8.207 (95% CrI: 6.97–8.64) years, with associated medical costs of approximately 5,000 (95% CrI: 1,656–10,197) USD. Compared to the group that did not receive the intervention, the intervention group experienced an incremental gain of 0.0077 (95% CrI: 0.0042–0.0103) QALYs at an additional cost of 6.3 (95% CrI: –10.8–16.3) USD. The resulting ICER for mobile health interventions was 829 (95% CrI: –1,559–2,746) USD per QALY gained. The mobile health intervention showed a lower ICER in the 55–64 year age group than in the 45–54 year age group. Extending the analysis to a lifetime horizon (assuming an expected lifespan of 85 years) reduced the ICER to 667 USD per QALY gained (Table 2).

Sensitivity Analysis

Assuming a 50% reduction in the effectiveness of the intervention on increasing moderate-intensity physical activity, the ICER increased to approximately 2,200 USD. By contrast, assuming a 50% enhancement in the intervention effect resulted in a decrease in the ICER to 370 USD. Assuming a shorter duration of effect from intervention-induced physical activity improvement (two years instead of four years in the base case), the ICER increased to approximately 1,600 USD. In contrast, extending the duration to 6 years resulted in a decrease in the ICER to approximately 370 USD (Table 2).

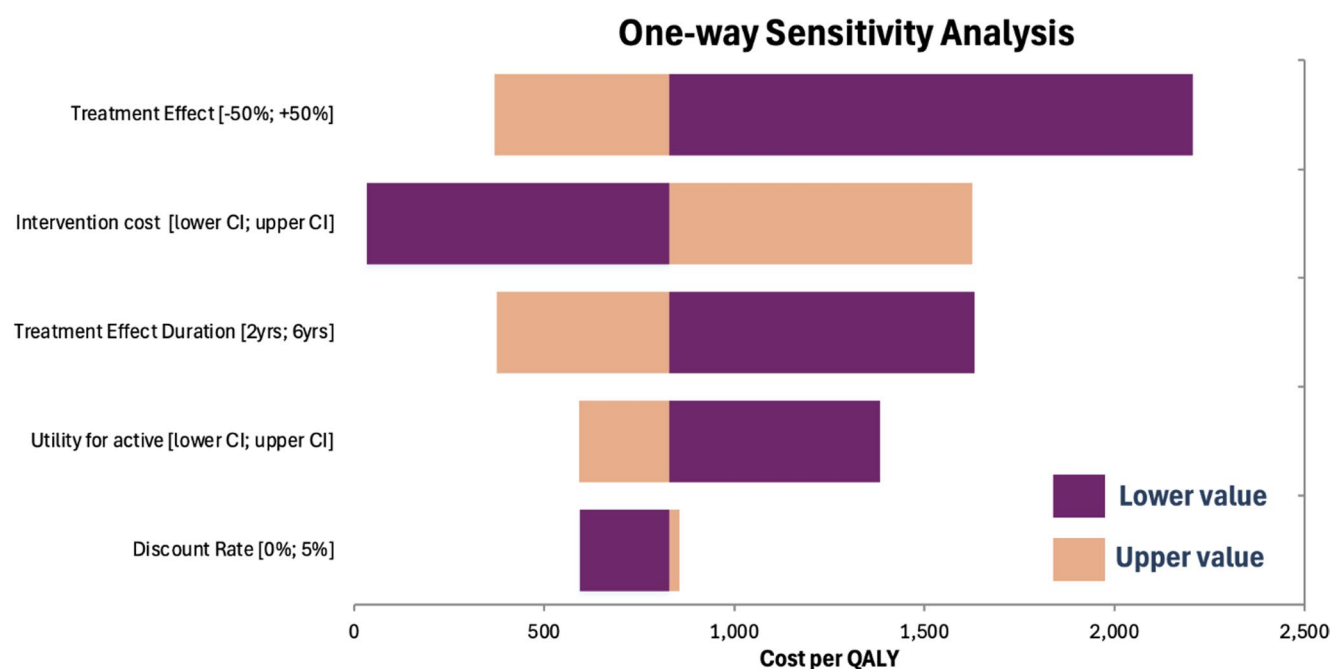
Further, one-way sensitivity analyses conducted on parameters including discount rate, intervention cost, and utility value revealed that the ICER remained below 2,500 USD across all scenarios (Fig. 2).

Figure 3 presents the results of 1,000 simulations conducted for the PSA. All the simulated outcomes fell below the willingness-to-pay threshold of both 20k and 30k USD per QALY. In several cases, mobile health interventions were more effective than comparators, offering greater effectiveness at a lower cost. The cost-effectiveness acceptability curve indicated that the probability of the intervention being accepted as cost-effective was nearly 100% at a willingness-to-pay threshold of approximately 3.5k USD. This suggests a highly robust finding that remains consistent even when accounting for uncertainty, particularly when adopting a willingness-to-pay threshold of 20,000 USD.

Table 2 Results of cost-effectiveness analysis

Analysis		No intervention (A)	Intervention (B)	Incremental Cost, QALYs (B) – (A)	ICER (Cost/QALYs)
Base-case analysis (95% CrI)					
Base case (10 years horizon)	Costs (USD)	4,994	5,000	6.3	829
		(1,648–10,192)	(1,656–10,197)	(–10.8–16.3)	(–1,559–2,746)
	QALYs (year)	8.199	8.207	0.0077	
		(6.96–8.63)	(6.97–8.64)	(0.0042–0.0103)	
Scenario analysis					
Subgroup aged 45–54 years	Costs (USD)	4,124	4,132	7.9	1,595
	QALYs (year)	8.405	8.410	0.0050	
Subgroup aged 55–64 years	Costs (USD)	5,877	5,882	4.7	455
	QALYs (year)	7.990	8.001	0.0104	
Lifetime horizon	Costs (USD)	13,505	13,513	7.5	667
	QALYs (year)	13.892	13.903	0.0113	
One-way sensitivity analysis					
Treatment effect –50%	Costs (USD)	4,994	5,002	8.4	2,207
	QALYs (year)	8.199	8.203	0.0038	
Treatment effect +50%	Costs (USD)	4,994	4,998	4.2	370
	QALYs (year)	8.199	8.211	0.0115	
Effect duration 2 years	Costs (USD)	4,994	5,001	7.8	1,631
	QALYs (year)	8.199	8.204	0.0048	
Effect duration 6 years	Costs (USD)	4,994	4,998	4.1	376
	QALYs (year)	8.199	8.210	0.0109	

Note) QALYs indicates quality adjusted life years; ICER indicates incremental cost-effectiveness ratio; CrI indicates credible intervals

**Fig. 2** Tornado graph of the one-way sensitivity analysis

Discussion

Principal Findings

This study demonstrates the cost-effectiveness of a mobile health (mHealth) intervention designed to increase

moderate-intensity physical activity among South Korean adults aged 45–64 years, a population transitioning into older adulthood. The benefits of moderate-intensity exercise for preventing chronic conditions and supporting cognitive health are well-established. This study further confirms the

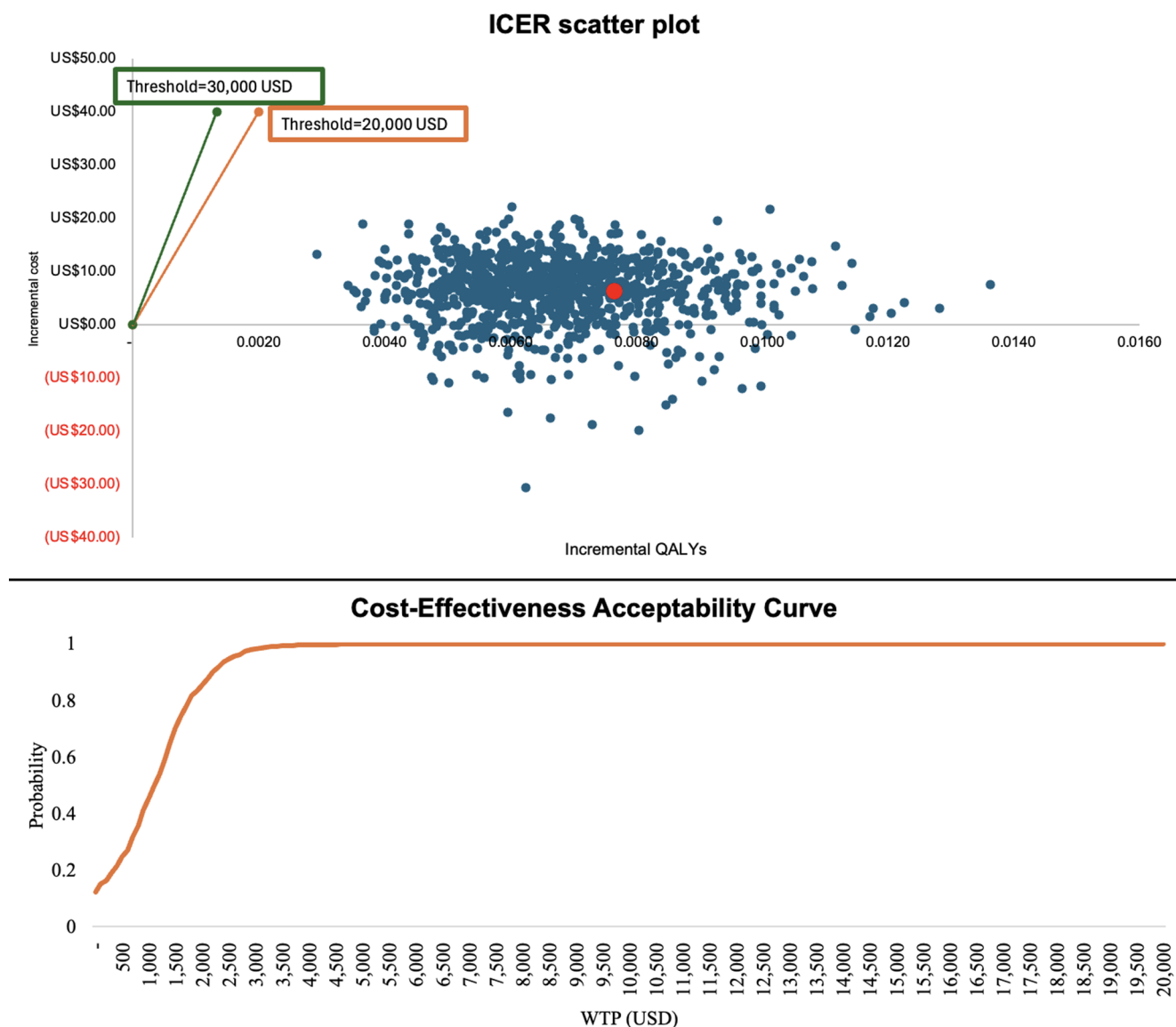


Fig. 3 Results of the probabilistic sensitivity analysis

value of timely interventions before significant age-related physical and cognitive functional deterioration occurs.

The intervention was especially cost-effective among adults aged 55–64 years, highlighting the importance of targeting this pre-elderly group. These findings are consistent with existing literature showing the preventive effects of physical activity on CVDs and dementia, both of which are major public health concerns. Additionally, this study reinforces the effectiveness of mHealth strategies in promoting behavioral change through accessible and scalable digital tools.

Our findings emphasize the importance of early intervention during the transitional period before adulthood. Promoting physical activity during this window can potentially delay or prevent the onset of severe chronic conditions such

as dementia and CVD, significantly impacting public health strategies. By highlighting dementia prevention through physical activity, our results underscore a priority for future healthcare policy development.

A key distinction of the present study lies in the definition and structuring of health states within the Markov model. Unlike most previous physical activity-related economic evaluations, which primarily model cardiovascular disease (CVD), diabetes, and certain cancers, our model explicitly incorporates dementia as a separate state. This reflects the growing body of evidence linking physical activity to reduced dementia risk, thereby allowing the model to capture both cardiovascular and cognitive benefits of the intervention. Furthermore, while prior studies often disaggregate ischemic heart disease, myocardial infarction, and stroke

into separate states, we consolidate these conditions into a single severe CVD state to streamline disease progression pathways without sacrificing policy relevance [17, 21–25].

Another distinguishing feature is the granular stratification of the “well” and “mild chronic disease” states by physical activity level (active/inactive). This enables the model to explicitly account for the differential risks of disease incidence and mortality associated with activity status. The model also introduces an intermediate mild chronic disease state—defined as hypertension and/or type 2 diabetes without severe cardiovascular complications—which more realistically represents the gradual progression from healthy status to severe disease. To maintain tractability, transitions between severe CVD and dementia were excluded, focusing the model on the most policy-relevant progression routes.

mHealth interventions can improve health through multiple mechanisms. Real-time feedback and goal setting enhance self-monitoring and motivation, while personalized reminders and incentives help sustain behavioral change over time. Continuous activity tracking via wearable devices enables the early detection of declining physical activity levels, allowing timely intervention to prevent deterioration. These features collectively contribute to improved cardiovascular, metabolic, and cognitive health outcomes, as supported by recent evidence linking mHealth adoption with sustained increases in moderate-to-vigorous physical activity and reduced risk of chronic diseases.

Strengths

A major strength of this study is its use of nationally representative data to directly estimate key model parameters, including transition probabilities and utility values, thereby enhancing the model’s validity and relevance to South Korean health policy. The model also incorporates locally sourced costs and disease incidence data to ensure context-specific applicability.

Moreover, using the Markov model allowed us to capture the long-term health and economic consequences of the intervention, providing more actionable insights for health policymakers. Probabilistic and one-way sensitivity analyses further confirmed the robustness of the intervention’s cost-effectiveness across a range of assumptions.

Limitations

This study has several limitations. First, the physical activity levels of the clinical trial participants at baseline were not reflective of those in the general population, potentially leading to an overestimation of the intervention effects. Second, although the clinical trial was conducted over 12 weeks, the model assumes a 4-year intervention effect

based on published evidence, which introduces uncertainty regarding the durability of the effect. Another limitation is that the study employs a cohort design rather than a randomized controlled trial, which may introduce selection bias and limit the ability to infer causality. In addition, the analysis adopted a limited healthcare system perspective and did not incorporate indirect costs such as productivity losses or caregiver expenses, leading to a conservative estimate of the economic impact.

A limitation of the survey instrument is that it only captures the number of days participants engage in physical activity above a certain threshold, without collecting detailed information on the duration of activity each day. Consequently, it is difficult to accurately estimate the total physical activity time, and the time spent on moderate-intensity activity may be somewhat underestimated.

Self-reported questionnaires are subject to recall and reporting biases because respondents rely on their memories to report physical activity levels. This often leads to the overreporting of physical activity. In particular, studies using the IPAQ-Short Form have shown a tendency to report higher levels of physical activity than objective measurements such as accelerometer data [46, 47].

Implications for Policy and Practice

Despite these limitations, our findings strongly suggest that mHealth interventions to increase moderate-intensity physical activity are an effective and economically sound strategy, especially when implemented in individuals with mild chronic conditions before the onset of more serious diseases. In addition to the health benefits, such programs may also reduce long-term healthcare expenditures and societal burdens.

Future Directions

Future research should consider long-term randomized controlled trials to validate the sustained effectiveness of mHealth interventions. Including a broader societal perspective in economic evaluations, encompassing productivity losses and informal caregiving costs, would provide a more comprehensive estimate of the economic impact. Finally, exploring user engagement and adherence over extended periods can guide the optimization of digital health programs.

In conclusion, integrating mHealth solutions into national physical activity promotion strategies for the pre-elderly population is timely and impactful. Strategic investments in such programs can lead to significant health and economic returns while addressing the pressing challenges of physical inactivity and population aging.

Conclusion

The smartphone app-based mHealth intervention evaluated in this study offers a cost-effective means of increasing moderate-intensity physical activity among South Korean adults aged 45–64 years with an ICER well below the commonly accepted willingness-to-pay thresholds, even under conservative sensitivity scenarios. Benefits are especially pronounced in the 55–64 age subgroup, suggesting that targeting the pre-elderly period can maximize health gains and economic returns. By delivering scalable real-time feedback and incentives, such digital interventions can alleviate the growing burden of chronic diseases and related healthcare costs in an aging population. These results support the incorporation of mHealth strategies into national physical activity promotion policies, highlighting the value of early technology-driven prevention efforts to improve long-term health outcomes and optimize resource allocation in healthcare systems.

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Author Contributions EB conceptualized and developed the economic evaluation model and conducted the cost-effectiveness analysis. AM performed the data analysis. SB conducted the analysis of clinical trial data. JK supervised the clinical research and provided expert input on its design and interpretation. SJ designed the overall framework for the economic evaluation. All authors contributed to drafting and revising the manuscript and approved the final version for submission.

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Data Availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Consent To Publish The authors consent to publish.

Informed Consent Not applicable.

Research involving Human Participants and/or Animals Not applicable.

Clinical trial number Not applicable.

Competing Interests The authors declare no competing interests.

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