Cost Effectiveness of Community-Based Physical Activity Interventions

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Background: Physical inactivity is associated with the increased risk of many chronic diseases. Such risks decrease with increases in physical activity. This study assessed the cost-effectiveness of population-wide strategies to promote physical activity in adults and followed disease incidence over a lifetime.

Methods: A lifetime cost-effectiveness analysis from a societal perspective was conducted to estimate the costs, health gains, and cost-effectiveness (dollars per quality-adjusted life year [QALY] gained, relative to no intervention) of seven public health interventions to promote physical activity in a simulated cohort of healthy U.S. adults stratified by age, gender, and physical activity level. Interventions exemplifying each of four strategies strongly recommended by the Task Force on Community Preventive Services were evaluated: community-wide campaigns, individually adapted health behavior change, community social-support interventions, and the creation of or enhanced access to physical activity information and opportunities. Each intervention was compared to a no-intervention alternative. A systematic review of disease burden by physical activity status was used to assess the relative risk of five diseases (coronary heart disease, ischemic stroke, type 2 diabetes, breast cancer, and colorectal cancer) across a spectrum of physical activity levels. Other data were obtained from clinical trials, population-based surveys, and other published literature.

Results: Cost-effectiveness ratios ranged between $14,000 and $69,000 per QALY gained, relative to no intervention. Results were sensitive to intervention-related costs and effect size.

Conclusions: All of the evaluated physical activity interventions appeared to reduce disease incidence, to be cost-effective, and—compared with other well-accepted preventive strategies—to offer good value for money. The results support using any of the seven evaluated interventions as part of public health efforts to promote physical activity.
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Introduction

Physical inactivity is a global public health problem, and has been identified as a national public health priority.[1–3] There is clear evidence to link physical inactivity with an increased risk of many chronic diseases, including coronary heart disease (CHD), ischemic stroke, type 2 diabetes, breast cancer, and colorectal cancer.[1–3] The negative health effects of physical inactivity are paralleled by staggering economic consequences: the annual cost directly attributable to inactivity in the U.S. is an estimated $24 billion–$76 billion, or 2.4%–5.0% of national healthcare expenditures.[4–6]

Fortunately, modest increases in physical activity have the potential to produce substantial health benefits.[7] Further, systematic reviews of population-based interventions to promote health and prevent disease have provided strong evidence that public health efforts can successfully increase physical activity.[8,9] It

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appears that sustained physical activity initiatives could make substantial contributions to the control of chronic diseases. However, the potential benefits of physical activity promotion have not yet been fully realized, and the majority of adults in the U.S. (54.1%) do not engage in sufficient physical activity to meet public health recommendations.[10] This situation presents an important opportunity to evaluate the merits of competing physical activity promotion strategies and to develop effective public health policy. The need for decision making in an environment of uncertainty, scarcity, and competing priorities makes the use of cost-effectiveness analysis (CEA) attractive for public health planning.

These analyses attempt to answer the question *How much health improvement can be gained when an intervention is compared, dollar for dollar, with an alternative?* Rather than promoting cost savings, the goal of CEA is to determine how money can be spent with maximum public health benefit. Decision-analytic models have been used routinely to guide important public health policy decisions, from airbag regulation in motor vehicles and the widespread use of pneumococcal vaccine in older adults[11,12] to the improvement of cervical cancer screening practices globally.[13] Models have also been used to influence clinical practice guidelines for cardiovascular disease prevention[14,15] and to promote national anti-tobacco education efforts.[16] Markov models, which consider probabilistic events over time, are particularly well-suited to evaluate population-based health promotion efforts and to examine outcomes over an extended period of time.

The purpose of this study was to evaluate the cost-effectiveness (dollars per quality-adjusted life year [QALY] gained) of seven exemplar interventions to increase physical activity, relative to no intervention, as well as to follow disease incidence over a lifetime. This study is the first to integrate the best available epidemiologic and intervention data on physical activity into a CEA of the most promising public health interventions for physical activity promotion.

Methods

The CDC Measurement of the Value of Exercise (MOVE) Model

A comprehensive, flexible, state-transition Markov model was developed from a societal perspective to estimate the lifetime costs, health gains, and cost-effectiveness of population interventions that promote physical activity among U.S. adults. *Cost-effectiveness* is defined as the ratio of incremental costs (dollars) to incremental QALYs. The incremental cost is the difference between the total expected cost of the intervention and the total expected cost of no intervention. Incremental QALYs are the difference between the total expected QALYs associated with the intervention and the total expected QALYs with no intervention. The performance of interventions evaluated by this model was measured using the cost-effectiveness ratio (dollars per QALY gained). The *Guide to Community Preventive Services* (Community Guide), an evidence-based review of physical activity promotion, strongly recommends four strategies for adults: community-wide campaigns, individually adapted health behavior change, social-support interventions in community settings, and the creation of or enhanced access to places for physical activity combined with informational outreach activities.[8] Exemplar interventions representing each of these strategies were selected for the model (discussed below in Interventions).

Study Design

The simulation was started with a closed cohort the size of the U.S. adult population aged 25–64 years in 2004. The cohort was stratified by age, gender, and level of physical activity. At the beginning of the model, it was assumed that all cohort members were well, which was defined as the absence of five diseases: CHD, ischemic stroke, type 2 diabetes, breast cancer, and colorectal cancer. These are the diseases for which the strongest evidence exists associating regular physical activity with lower disease risk.[3,17] Because of the complex relationship between physical activity and obesity, the status of obesity as an intermediate variable along the pathways to disease, and the potential to double-count costs, obesity was not included as a disease outcome in this model. However, the model cohort is based on the 2003 Behavioral Risk Factor Surveillance Survey (BRFSS) and is representative of the population prevalence of overweight (37.9%) and obesity (25.2%).[18] The model then simulates the progression of the cohort as they change activity levels or develop illness over a lifetime. The likelihood of changing physical activity levels, developing disease, or dying is specified with probabilities.

Immediately following the 1-year physical activity promotion intervention, cohort members faced intervention-specific probabilities of improving their physical activity levels. Then, depending on the sustainability of the intervention effect, in subsequent years cohort members had an annual probability of either remaining in the new physical activity level or moving to a lower activity level. In the absence of the intervention, the change in physical activity levels from year to year was based on a natural history model, developed from age- and gender-specific physical activity data from the BRFSS.[18] Among the well, the risk of developing one of the five diseases depends on age, gender, and activity level. The risk of death depends on age, gender, and disease status. Thus, the ten states represented in the model constitute the four activity levels among the well, the five physical activity–related diseases, and death. Because there are insufficient published data describing differential mortality risk by both physical activity level among diseased adults and race/ethnicity, these factors were not included in this model. A schematic of the model is shown in Figure 1.

Data Sources

Population demographics. Data on age and gender distribution of the initial population[19] were obtained from the U.S. Census Bureau (Table 1[18–35]). Based on the public health physical activity recommendations of CDC and the American College of Sports Medicine,[7] the baseline population for this study's model was further divided into four levels of physical activity (inactive, irregularly active, sufficiently active to meet public health recommendations, and highly active) by age and gender, using data from the 2003 BRFSS[18] (Table 2[36,37]). The BRFSS does not include questions that allow further stratification of the starting population by the five diseases included in this model.

Interventions. Seven interventions studies were chosen; they are described in the Appendix.[38–44] Six strongly recommended exemplar interventions for the public health promotion of physical activity among adults were selected from those reviewed and categorized by the Task Force on Community Preventive Services (the Task Force). They dealt with the four strategies recommended for adults: community-wide campaigns, individually adapted health behavior change, social-support interventions in community settings, and the creation of or enhanced access to places for physical activity combined with informational outreach activities. A seventh, newer intervention study was added to better represent community-wide campaigns.[38–44] Criteria for inclusion were (1) a controlled study of adult subjects without established disease, (2) a detailed study protocol available for costing, (3) the availability of a physical activity outcome measure, and (4) a study duration of 3 months or longer. Excluded were interventions that did not provide baseline and post-intervention effect-size data or a reference group, did not report a measurable effect-size metric, or reported one that was not amenable to conversion to the metric used in this model.

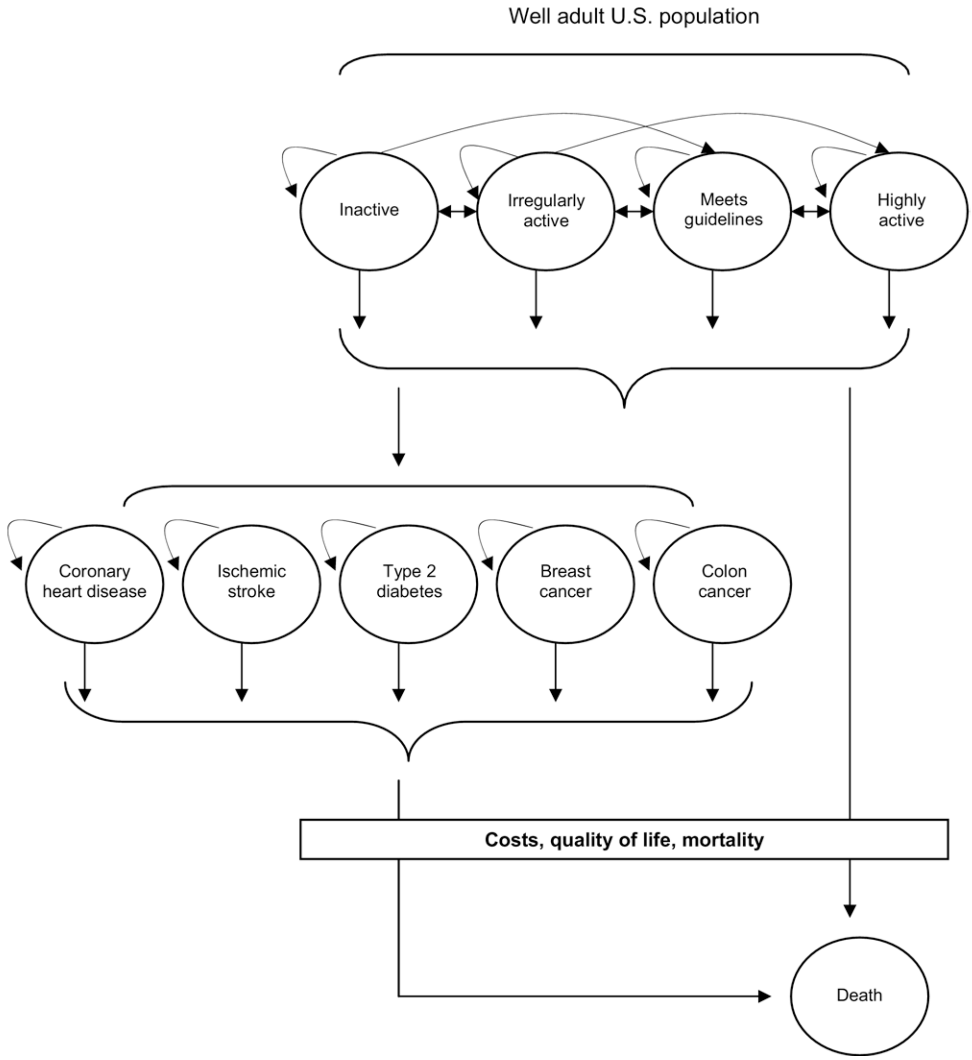

Figure 1. Conceptual overview of the CDC MOVE model. Illustration of the 10-state Markov process represented as a state-transition diagram. In this process, circles represent possible health states, and arrows represent allowed transitions among these discrete health states. In each cycle of the Markov model, transition probabilities denote the likelihood with which people within a particular health state will stay in that state (represented by the tight curvilinear arrows to and from a single circle); transition to a new health state; or die. Death is an absorbing state from which no future transitions are possible. The output from the Markov process is depicted by the box; a running tally of the total costs and quality-of-life benefits generated during each cycle as a result of being in a series of health states over time. MOVE, measurement of the value of exercise

Disease. To estimate the annual probability of developing each disease, population-based, disease-specific incidence data[22–27] were combined with relative risks derived from epidemiologic studies, specific for physical activity level and disease (Table 1).[6,28,29]

The median relative risk of each disease among people in the lowest activity level (inactive) compared with the highest level (highly active is approximately equivalent to ≥2000 kilocalories [kcal] per week), not controlling for medical conditions that are consequences of physical inactivity, including obesity, was obtained from a review of 120 studies.[6] The relative risk for ischemic stroke versus all stroke was adjusted based on data from a large cohort study.[29] To estimate the relative risk for the two intermediate physical activity levels, linear interpolation, assuming a dose–response relationship, was used.[17,45,46]

Mortality. A common method was used to estimate the annual probability of death, conditioned on having a particular disease, for each 5-year age group and gender. In addition to disease-specific prevalence data,[25,27,33–35] data from the 2002 *National Vital Statistics Reports* were used to estimate the annual probability of death in people with CHD, ischemic stroke, or type 2 diabetes, while the Surveillance Epidemiology and End Results database was used to estimate

Table 1. Sources of data used in the CDC MOVE physical activity policy model

Parameter	Source
U.S. population by age and gender[a]	19
U.S. population by physical activity level[a]	18
Physical activity	
Probabilities for moving among levels by age group and gender[b]	18
Maintenance of a particular physical activity level	20,21
Disease incidence	
Coronary heart disease	22
Ischemic stroke	23,24
Type 2 diabetes	25,26
Breast cancer	27
Colorectal cancer	27
RR of disease by physical activity level[c]	
Coronary heart disease (RR for inactive=1.5)	6,28
Ischemic stroke (RR for inactive=1.3)	29
Type 2 diabetes (RR for inactive=1.7)	6,28
Breast cancer (RR for inactive=1.3)	6,28
Colorectal cancer (RR for inactive=1.6)	6,28
Disease-specific mortality by physical activity level, age group, and gender	25,27,30–35

[a]Hypothetical cohort of 100,000 U.S. adults defined by gender and age distribution from U.S. Census Bureau and physical activity level distribution of 2003 BRFSS data, using predefined cut points
[b]These probabilities are conditional, and represent the probability of transitioning to another age, gender, and physical activity group given that an individual is already in a particular age, gender, and physical activity group.
[c]Relative risk values are non–gender-specific, do not control for BMI, and are a linear interpolation across physical activity levels, with the most active group set as the reference group with a RR of 1.0.
BRFSS, Behavioral Risk Factor Surveillance Survey; MOVE, measurement of the value of exercise; RR, relative risk

the annual probability of death from breast or colorectal cancer (Table 1).[30–32,45] To estimate the annual probability of death for well adults, available mortality data,[47] excluding disease-specific death rates for the five modeled diseases, were adjusted for age group and gender.

Quality of life. Quality-of-life (QOL) data were obtained for all disease and activity states from new analyses of the 2001 National Health Interview Survey, using previously validated scales for quality of well-being (QWB) widely accepted for assessing health-related QOL.[48–51] Multiple regressions to estimate QOL as a function of age, gender, disease, and physical activity level were performed (Table 3[52]).

Costs. Through direct communication with the authors of original investigations in combination with a review of manuscript protocols, each original intervention was itemized to determine all associated costs. In addition to the cost of materials and intervention delivery, out-of-pocket expenses paid by participants—such as required exercise clothing and equipment—were estimated. Participants' time was also valued as a cost, using age- and gender-specific wages.[53] For the enhanced-access intervention,[40] the costs associated with developing and maintaining the infrastructural components were included (e.g., physical activity facilities, trails; Table 3).

To derive medical cost estimates, a longitudinal medical claims database[52] was used to analyze claims for the five disease states by ICD-9 codes. From these costs, the effective annual cost was calculated for each of the diseases over a lifetime. An annual medical inflation factor of 8%[54] was applied, and the costs were discounted back to the present at 3% per year.[55] To improve national representativeness, medical-claims data were adjusted using Medical Expenditure Panel Survey data (Table 3).[56]

Modeling the Effect of Interventions

The four physical activity levels were characterized, using the MET-minutes per week, which captures the intensity, duration, and frequency of physical activity (Table 2). One MET represents the metabolic rate equivalent to consuming 3.5 milliliters of oxygen per kilogram of body weight per minute, and is equivalent to a resting metabolic rate.[37] One thousand MET-minutes per week of physical activity is roughly equal to 40 minutes per day of brisk walking at an intensity of 3.5 METs.[36]

To estimate the probability of moving to a higher physical activity level after intervention, intervention-specific MET-minutes were added to current levels, and the percentage of the cohort that moved from one level of physical activity to another as a result of an intervention was noted. This percentage was then used as a transition probability. For example, if adding a certain number of MET-minutes per week to all members of the inactive group caused 25% of them to move up to the irregularly active group, then the probability of moving from inactive to irregularly active was estimated as 0.25 in the first year following the intervention. Intervention effect-size estimates are shown in Table 3.

The impact of an intervention was assumed to decline after the intervention had ended, and the decline in maintenance of physical activity levels over time was modeled based on the limited data from the research literature on the long-term maintenance of increased physical activity resulting from interventions.[20,21] For all of the interventions, with the exception of the enhanced-access intervention,[40] a 50% decline in physical activity in Year 2 was modeled. For the enhanced-

Table 2. Distribution of original U.S. population cohort aged 25–64 years across physical activity levels

Physical activity level	MET-min/wk range[a]	Cohort frequency distribution (%)	
		Men	Women
Inactive[b]	0–150	18.3	21.7
Irregularly active[c]	151–855	29.1	38.1
Meets CDC recommendations[d]	856–2280	28.4	24.7
Highly active[e]	>2280	24.3	15.5

[a]1000 MET-minutes per week of physical activity is roughly equal to 40 minutes per day of brisk walking at an intensity of 3.5 METs.[36] One MET represents the metabolic rate equivalent to consuming 3.5 milliliters of oxygen per kilogram of body weight per minute and is equivalent to a resting metabolic rate.[37]
[b]<10 minutes of physical activity per week
[c]>10 minutes per week of physical activity, but ≤ recommended
[d]≥30 minutes (but <60 minutes) of moderate physical activity on 5 or more days a week, or ≥20 minutes vigorous physical activity on 3 or more days a week, or both
[e]≥60 minutes of moderate physical activity on 7 days a week, or ≥20 minutes of vigorous physical activity on 5 or more days a week, or both

Table 3. Select model parameters

INTERVENTION-SPECIFIC PARAMETERS		Value: Effect size at 1 year (MET-min/wk)		Value: 1-year per-person costs[a] (2003 $U.S.)		
Intervention	**Strategy**	**Men**	**Women**	**Men**	**Women**	**Source**
Stanford Five-City Project (see Appendix for description)	Community-wide campaign	50	32	1395	1239	44
Wheeling Walks (see Appendix for description)	Community-wide campaign	316	316	1837	1618	43
Use of organized walking groups, social gatherings, phone calls, cards, home visits, and a newsletter to enhance physical activity compliance and promote physical activity	Social support	228[b]	275	2554	2308	39
Initial training session involving walking maps and handouts on strategies and support (walking partner/walking group) for starting and maintaining a walking program; frequency and duration of phone calls varied to prompt participants to walk	Social support	210	210	1583	1504	41
Use of personal trainers, standard behavior therapy sessions, financial incentives, and phone calls to prompt participants to increase physical activity	Individually adapted behavior change	456	551	4070	3895	38
Intensive lifestyle modification program for adults at high risk of developing type 2 diabetes (see Appendix for description)	Individually adapted behavior change	435	435	4673	4673	42
Exposure to an environment that emphasized and supported a more active lifestyle (see Appendix for description)	Enhanced access	954.3	1151.7	5308	4646	40

DISEASE-SPECIFIC PARAMETERS	Value: Annual per-person medical costs[c] (2003 $US)		
Disease	**Men**	**Women**	**Source**
Coronary heart disease	10,800	12,500	52
Ischemic stroke	12,900	17,700	
Type 2 diabetes	8,900	10,900	
Breast cancer	N/A	11,000	
Colorectal cancer	15,300	16,600	
Well (absence of the five diseases)	2,500	3,100	
	Quality of well-being score[d] (age-specific)		
	Men (aged 40)	**Women (aged 40)**	**Source**
Coronary heart disease	0.647	0.623	48,49
Ischemic stroke	0.599	0.599	
Type 2 diabetes	0.663	0.650	
Breast cancer	0.734	0.686	
Colorectal cancer	0.672	0.691	
Well (absence of the five diseases): inactive	0.806	0.791	
Well (absence of the five diseases): irregularly active	0.810	0.796	
Well (absence of the five diseases): meeting public health physical activity guidelines	0.820	0.807	
Well (absence of the five diseases): highly active	0.829	0.818	

[a]Considered direct medical, direct nonmedical, and time costs as a function of age group for each exemplar intervention. Direct medical costs included staff labor wages, provider fees, and laboratory or monitoring test fees. Direct nonmedical costs captured costs associated with educational materials, physical activity monitoring devices, and participant out-of-pocket expenses. Time costs, where applicable, represented the monetary value of time spent participating in the intervention. The values shown are for the group aged 40–49 years.
[b]Estimated for men and adjusted for average body weight
[c]Longitudinal database from a major claims processor in the central U.S. The database contains 7 years of data and a stable population of approximately 350,000 members. Effective annual cost includes the entire stream of costs for each illness, including the lead-in costs in the years prior to diagnosis. To improve the generalizability of cost estimates, they were adjusted by nationally representative Medical Expenditure Panel Survey data.
[d]Quality-of-life (QOL) data by disease state, physical activity level, age, and gender were obtained from mean 2001 National Health Interview Survey–imputed quality of well-being (QWB) scores. Multiple regression equation for individuals with disease: $QOL = B_0 + B_1\,(Gender) + B_2\,(Age) + B_3\,(Age^2) + \sum_{i=1}^{5} B_{(i+3)}\,(Disease\ i)$. Multiple regression equation for well people: $QOL = B_0 + B_1\,(Gender) + B_2\,(Age) + B_3\,(Age^2) + B_4\,(MET\text{-}minutes)$.

access study, a 33% decline was modeled, because the environmental enhancements persisted long after the intervention had ended.

Following the substantial decline (33%–50%) in physical activity modeled post-intervention, in Year 2, cohort members were transitioned into a natural-history model, which models the general decline in physical activity that occurs with age.[3,10,57] Thus each year participants faced gender- and age-specific probabilities of moving to a lower level or remaining at the same physical activity level.

Estimating Cost Effectiveness

The cost effectiveness of each intervention was estimated, using methods consistent with the guidelines established by the Panel on Cost-Effectiveness in Health and Medicine.[55] The model was used to project lifetime costs as well as gains in both life-years (survival) and QALYs associated with the seven evaluated physical activity promotion interventions and with the no-intervention scenario. Consistent with the panel's recommendations, the societal perspective was adopted, and future costs and benefits were discounted to the present at an annual rate of 3%.[55] The average relative performance of each intervention was assessed compared to no intervention, using a ratio of the additional expected cost of each program divided by the additional expected QALYs gained relative to the no-intervention alternative. The number of cases of disease averted was also estimated. To determine the robustness of the final results, sensitivity analyses were conducted. These simulations included one-way, two-way, and probabilistic sensitivity analyses, with particular emphasis on intervention effect size and cost estimates. Last, as a form of model validation, a parallel model that substituted all-cause mortality for disease-specific mortality was developed.

Results

Average Cost Effectiveness

Estimates of the population health and economic outcomes associated with each intervention are shown in Table 4. Summarized are the average costs, effectiveness, and cost-effectiveness ratios associated with a one-time application of each physical activity promotion intervention relative to no intervention. Results are cumulative over a 40-year time-horizon for the whole U.S. population, aged 25–64 years, but average per-person values are reported here. Absent any new intervention to improve physical activity levels (by natural history), the average discounted quality-adjusted life expectancy was calculated to be 14.77 years, and lifetime costs were approximately $195,000. Intervention participation improved average QALYs by 0.7 to 5.3 weeks (i.e., equivalent to 0.014–0.102 QALYs in Table 4), with the Linenger[40] intervention yielding the greatest gain in QALYs compared to no intervention.

Cost-effectiveness ratios ranged between $14,000 and $69,000 per QALY gained. In one example, the Lombard intervention[41] (one of the social-support strategies) increased quality-adjusted life expectancy by 14.79 years and cost $27,370 per QALY gained relative to no intervention. In another case,[42] also in comparison with no intervention, the physical activity component of the diabetes prevention trial (an individually adapted health behavior–change strategy) had a cost-effectiveness ratio of $46,910 per QALY gained. All interventions appeared to reduce disease incidence: reductions ranged from 5–15 cases per 100,000 for colorectal cancer, to 15–58 cases per 100,000 for breast cancer, to 59–207 cases per 100,000 for type 2 diabetes, and to as many as 140–476 cases per 100,000 for CHD. The impact of interventions on the prevention of ischemic stroke (which often occurs later in life) did not follow the trend of disease-incidence reduction, probably because the model permitted the development of only one illness and because interventions increased longevity.

Sensitivity Analyses

Several assumptions were varied in a one-way sensitivity analysis. Repeating the intervention once after 20 years had a small effect on cost-effectiveness (results not

Table 4. Cost effectiveness of each intervention compared to no intervention

Study	Intervention strategy	Total cost (2003 $US)	Total LYs	Total QALY	Inc cost	Inc LYs	Inc QALY	Cost/LY ($/LY)	Cost/QALY ($/QALY)
	No intervention	195,013	19.370	14.767	—	—	—	—	—
Reger (2002)[43]	Community-wide campaign	195,713	19.401	14.816	$700	0.031	0.049	22,654	14,286
Lombard (1995)[41]	Social support	195,725	19.387	14.793	$712	0.016	0.026	43,663	27,373
Linenger (1991)[40]	Enhanced access	197,925	19.433	14.869	$2,912	0.063	0.102	46,442	28,548
Jeffery (1998)[38]	Individually adapted health behavior	196,918	19.410	14.831	$1,905	0.040	0.064	48,096	29,759
Kriska (1986)[39]	Social support	196,244	19.389	14.798	$1,230	0.019	0.031	65,447	39,690
Knowler (2002)[42] (DPP)	Individually adapted health behavior	197,734	19.406	14.825	$2,721	0.036	0.058	75,583	46,914
Young (1996)[44]	Community-wide campaign	195,973	19.379	14.781	$960	0.009	0.014	110,322	68,557

Note: Values are rounded to no more than three decimal places.
DPP, Diabetes Prevention Program; Inc, incremental; LY, life-year; QALY, quality-of-life year

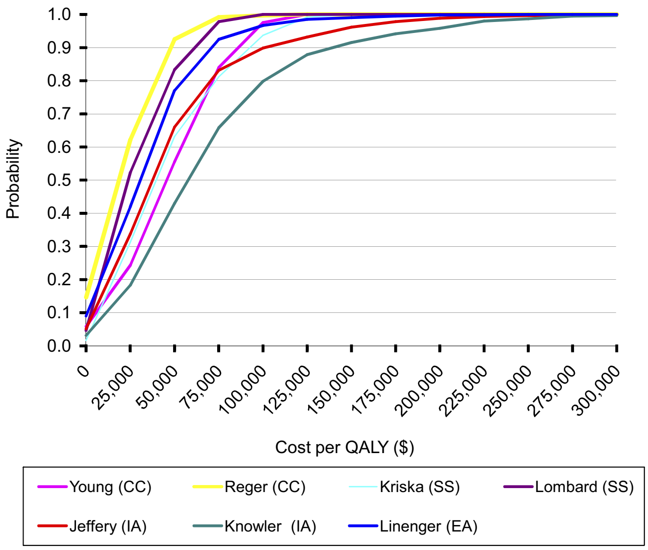

Figure 2. Results from probabilistic sensitivity analyses: acceptability curves representing variation of intervention costs and effect sizes

shown). Similarly, varying the dissipation of the effect sizes of the interventions had a marginal impact.

Shortening the analytic time-horizon from 40 to 30, 20, or 10 years influenced cost-effectiveness substantially. For example, while the Lombard intervention[41] had a cost per QALY of $27,000 over the original 40-year time-horizon, it had a cost per QALY of $147,000 over a 10-year horizon.

To assess the impact of uncertain intervention cost and effect-size parameter estimates on uncertainty in cost-effectiveness, a probabilistic sensitivity analysis (Monte Carlo analysis) was performed.[55] When running this analysis, a distribution of 600 ratios drawn from the underlying distributions of costs and effect sizes was obtained.

Using the distributions from this analysis, the probability was assessed that the cost-effectiveness of each intervention was below various thresholds that are commonly used to determine whether interventions provide good value for money. Results are shown by the acceptability curves in Figure 2. For example, there is a 55% chance that the cost per QALY of the Young intervention[44] is less than $50,000 per QALY, a commonly used benchmark of cost-effectiveness.[58] Likewise, using $200,000 per QALY as a more contemporary threshold, given that many widely accepted public health initiatives have cost-effectiveness ratios exceeding this value,[58] there is 100% chance (i.e., all 600 randomly selected pairs of costs and effect sizes produced cost-per-QALY estimates below $200,000) that the associated cost per QALY falls below it, suggesting that this intervention is cost effective, or acceptable. Thus, despite model parameter and resultant cost-per-QALY ratio uncertainties, it is likely that this intervention is an acceptable use of societal resources.

Conclusion

All of the evaluated physical activity interventions were found to be cost-effective and offered good value for money, with gains in both survival and health-related QOL, and with reasonable cost-per-QALY and cost-per-life-year ratios. These results support using any of the seven evaluated interventions as part of public health efforts to promote physical activity. Factors specific to implementing interventions within a given strategy and setting may introduce greater variability in cost-effectiveness than exists among strategies. The results do not suggest that any one of these recommended interventions is clearly more cost-effective than the others. Interestingly, even the most complex and expensive intervention (the physical activity component of the diabetes prevention program) proved to be cost-effective, suggesting that targeting high-risk populations with intensive interventions can be a good use of public health funds.

Although comparisons of public health strategies evaluated by separate economic analyses should be undertaken with caution, cost-effectiveness estimates of other well-known strategies provide context for these results. Risk-reduction counseling for CHD and targeted screening for type 2 diabetes cost $74,000 and $34,000 per QALY gained, respectively.[59,60] Further, both policymakers and the general public have reported being willing to pay more than $200,000 per QALY for gains in health.[58] The physical activity promotion strategies assessed in this analysis compare favorably with other well-accepted public health strategies that are deemed to be cost-effective.[59–62]

Although rigorous methodology was used to identify and incorporate data into the model, the sensitivity analyses were also revealing. Estimated cost-effectiveness was most influenced by intervention cost and effect size. However, probabilistic sensitivity analyses revealed that varying parameter estimates across a wide range of uncertainty still resulted in cost-effectiveness ratios below widely accepted thresholds for public health value.

Cost-effectiveness is also influenced by the time-horizon over which the analysis is evaluated. Shorter periods of evaluation are associated with less-favorable cost-effectiveness, suggesting that perspectives motivated by short-term gains may not see as much benefit from increasing physical activity, which prevents longer-term morbidity and premature mortality. Specifically, in the short term, upfront intervention costs that are less diluted by discounting outweigh the medical cost savings due to diseases that occur late in life.

Cost-effectiveness analyses are often susceptible to the design weaknesses and generalizability issues of their component studies, and analysts usually must make assumptions in model development. Incorporating additional detail into a model can help illustrate the complexity of reality, but a carefully validated parsimonious model is less susceptible to the inconsistencies, ambiguities, and redundancies of a more complex approach.[63] The strength of the current analysis lies in the systematic way in which these issues have been addressed. The study design has emphasized the use of the highest-quality data available from the fewest sources necessary to create a valid, streamlined model.

Given that it is conceivable that more than one of the evaluated interventions could be simultaneously implemented and that the intervention effect sizes of combining two or more of these interventions remain unknown in the literature, average cost-effectiveness ratios were reported. For completeness, incremental analyses (not reported) were performed. All of these issues are believed to be important foci for future analyses.

As with all models, several assumptions were necessary to carry out this analysis. In each instance, the most conservative and parsimonious approach was chosen. Key assumptions are noted here.

Because this model focuses on prevention and a long-term societal perspective and is based on the availability of data, the starting population was defined to be a cohort of well people aged 25–64 years. A separate analysis, not reported here, was conducted specifically for older adults. Due to limited data on race/ethnicity-specific disease outcomes and physical activity and intervention effects, it was not possible to extend the model to assess the cost-effectiveness of interventions in subpopulations by race or ethnicity.

People not falling into one of the five disease categories of interest were considered to be members of the well population, as done in other models of behavior change and primary prevention.[16] This assumption, while contributing to the model's parsimony, probably underestimates the potential impact of physical inactivity on other important diseases. The results of an alternate all-cause mortality model, which accounted for the direct effects of physical activity on mortality and QOL, yielded slightly more cost-effective results than the disease-specific model.

It was assumed that the lowest and highest physical activity categories from the BRFSS matched the lowest and highest physical activity categories of the epidemiologic studies from which the associations between physical activity and the relative risk of disease are derived. In general, the highest physical activity category in epidemiologic studies involving men is approximately 2000 kcals/week, slightly lower than this study's highest category of 2280 MET-minutes per week. Most epidemiologic studies involving women set lower thresholds for the highest physical activity category, so that the use of the 2280 MET-minutes per week level is conservative for men and extremely conservative for women.[6]

The BRFSS includes people with and without disease, while the entry cohort of this model is defined as *well.* It is possible that this biases the current sample toward a slightly larger percentage of the population's being sedentary than would be expected from an entirely healthy one. However, additional analyses of physical activity levels among self-reported diabetics and well people using 2003 BRFSS-weighted prevalences indicate that the increase in sedentary people is only 1.2%.

In the main analysis, it was assumed that each intervention was applied to the entire population, even though some of the interventions modeled (e.g., social-support or individually adapted health behavior–change strategies) are generally applied only to more-sedentary participants. Applying them to the whole population likely results in less-favorable cost-per-QALY estimates, given that people starting in the highest physical activity level accrue no further benefit in the model from increasing physical activity.

From the QWB analysis conducted, well people with higher levels of physical activity were found to report higher QOL levels than did well people who were less physically active. Given that these data are cross-sectional, causality cannot be inferred. Unfortunately, there are no longitudinal, population-based estimates for changes in QOL resulting from physical activity interventions.

Cost-effectiveness analyses have been criticized for using utility values for the entire population instead of those specific to the subpopulation likely to choose the treatment.[64] This paper shares that limitation. One opportunity for future research is to investigate how the inputs into the CEA model (conditional disease and mortality probabilities, and QWB) differ for likely intervention participants relative to the general population, and how use of the latter values affects the estimates of cost-effectiveness.

The results of these analyses have several important implications for research and public health practice:

- This study demonstrates that it is possible to carry out complex prevention modeling of community-based interventions using a decision-analytic approach previously focused on clinical analyses. The complexity and rigor of this method must be carefully balanced with parsimony to ensure the clarity and practicality of the results.
- The modeling approach that was employed is a useful adjunct to the rigorous evidence-based review carried out by the Task Force to identify recommended interventions for the Community Guide.
- Careful interpretation, translation, and communication of both the methods and results will be required if the potential of prevention modeling for guiding public health decision making is to be fully realized.
- Systematic reviews and CEA are important decision-making tools for public health practitioners and advocates.[65,66] Yet for a majority of public health interventions, reliable CEA data are lacking.[67] How-

ever, these results demonstrate that community-intervention strategies for physical activity are cost-effective, suggesting that the widespread implementation of these four intervention strategies is justified. CEA results such as these should be applied in context with information on program reach, effectiveness, feasibility, and community priorities and resources.[68]

This study applied high-quality data in a cost-effectiveness framework to extend the findings of the Community Guide to decision making regarding the allocation of societal resources. In taking a flexible, comprehensive, and rigorous approach with input from numerous health and economic sources, a new method has emerged to bring fundamental population-level research to life in setting health policy. The physical activity promotion interventions evaluated in this analysis provide good value for money. With few examples of prevention modeling in the literature to date, the results of this study provide compelling evidence to encourage similar evaluations for other public health prevention strategies and settings, and clearly demonstrate that these physical activity interventions should be implemented at the population level.

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Appendix. Strategy and intervention descriptions

Community-wide campaign

- Involves many community sectors in highly visible, broad-based, multiple-intervention approaches to increasing physical activity
- Communication techniques are a common element in all of the campaigns and are directed at large populations.
- Addresses sedentary behavior as well as cardiovascular disease risk factors (diet and smoking)
- Messages are in various media formats (e.g., radio, newspaper, mailings, billboards, paid advertisements, press releases), and can be a combination of two or more of these approaches.
- Interventions typically include some combination of social support, risk-factor screening, counseling, and education in a variety of settings (e.g., worksites, schools).

Author	Description
Young (1996)[44]	Stanford Five-City Project was a 6-year, integrated, community-wide multifactorial health education intervention for improving physical activity (print materials, radio, TV, seminars, community walking events, worksite- and school-based programs).
Reger (2002)[43]	Wheeling Walks was an 8-week intensive community-wide intervention that promoted walking among sedentary adults aged 50–65 years using paid media (TV, radio, newspapers, websites, billboards); public relations; and public health activities at worksites, churches, and local organizations.

Social support

- Interventions focus on changing physical activity behavior through building, strengthening, and maintaining social networks that provide supportive relationships for behavior change.
- Can be achieved either by creating new social networks or working within existing networks in a social setting outside the family
- Interventions typically involve setting up a buddy system, making a contract with others to achieve specified levels of physical activity, or setting up walking or other groups to provide companionship and support while being physically active.

Author	Description
Kriska (1986)[39]	Use of organized walking groups, social gatherings, phone calls, cards, home visits, and a newsletter to enhance exercise compliance and promote physical activity
Lombard (1995)[41]	After an initial training session involving walking maps and handouts on strategies and support (walking partner or walking group) for starting and maintaining a walking program, the frequency and duration of phone calls were varied to prompt participants' walking.

Individually adapted health behavior change programs

- Programs are tailored to the individual's readiness for change, specific interests, and preferences.
- Teaches participants specific behavioral skills that enable them to incorporate moderate-intensity physical activity into daily routines
- Behaviors may be planned (scheduled walk) or unplanned (taking stairs when the opportunity arises).
- Interventions use constructs from one or more established health behavior change models such as the social cognitive theory, the health belief model, or the transtheoretical model of change.
- All programs incorporate the following behavioral approaches: (1) setting goals for physical activity and self-monitoring progress toward goals, (2) building social support for new behavioral patterns, (3) behavioral reinforcement through self-reward and positive self-talk, (4) structured problem solving geared to maintenance of the behavior change, and (5) the prevention of relapse into sedentary behaviors. All of the interventions evaluated were delivered to people either in group settings or by mail, telephone, or directed media.

Author	Description
Jeffery (1998)[38]	Use of personal trainers, standard behavior-therapy sessions, financial incentives, and phone calls to participants to increase physical activity
Knowler (DPP) (2002)[42]	Intensive lifestyle-modification program for adults at high risk of developing type 2 diabetes, involving exercise testing, written information, and individual counseling sessions; a 16-lesson curriculum covering diet, exercise, and behavior modification; individual and group exercise sessions; and in-person visits and phone calls to participants

Enhanced access to places for physical activity combined with informational outreach activities

- Interventions involved the efforts of worksites, coalitions, agencies, and communities to create or provide access to places and facilities where people can be physically active (providing access to weight and aerobic fitness equipment in fitness centers or community centers, creating walking trains, and providing access to nearby fitness centers).
- Also incorporated components such as training on equipment, health behavior education and techniques, seminars, counseling, risk screening, health forums and workshops, referrals to physicians or additional services, health and fitness programs, and support or buddy systems

Author	Description
Linenger (1991)[40]	Exposure to an environment that emphasizes and supports a more active lifestyle (bike paths, extended fitness facility hours, opening of a new fitness center, cycling clubs, marked running courses, organized athletic events)

DPP, Diabetes Prevention Program