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Potential cost-effectiveness of e-health interventions for treating overweight and obesity in Australian adolescents

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Summary

Background: E-health, defined as the use of information and communication technologies to improve healthcare delivery and health outcomes, has been promoted as a cost-effective strategy to treat adolescent overweight and obesity. However, evidence supporting this claim is lacking.

Objectives: Assess the potential cost-effectiveness of a hypothetical e-health intervention for adolescents with overweight and obesity.

Methods: The costs and effect size (BMI reduction) of the hypothetical intervention were sourced from recent systematic reviews. Using a micro-simulation model with a lifetime time horizon, we conducted a modelled cost-utility analysis of the intervention compared to a 'do-nothing' approach. To explore uncertainty, we conducted bootstrapping on individual-level costs and quality-adjusted life years (QALYs) and performed multiple one-way sensitivity analyses.

Results: The incremental cost-effectiveness ratio (ICER) for the e-health intervention was dominant (cheaper and more effective), with a 96% probability of being cost-effective at a willingness-to-pay (WTP) of $50 000/QALY. The ICER remained dominant in all sensitivity analyses except when using the lower bounds of the hypothetical intervention effect size, which reduced the probability of cost-effectiveness at a WTP of $50 000/QALY to 51%.

Conclusion: E-health interventions for treatment of adolescent overweight and obesity demonstrate very good cost-effectiveness potential and should be considered by healthcare decision makers. However, further research on the efficacy of such interventions is warranted to strengthen the case for investment.

KEYWORDS
adolescence, cost-effectiveness, e-health, obesity

1 | INTRODUCTION

Adolescent overweight and obesity are major public health issues, particularly in developed nations like Australia, where 1 in 4 young people are above a healthy weight.[1] They are associated with a range of serious health conditions, including hypertension,[2] type 2 diabetes,[3] obstructive sleep apnoea[4] and musculoskeletal disorders,[5] while weight-related stigma and bullying can lead to psychological disorders such as depression and anxiety.[2,6,7] This has significant economic consequences, both directly through greater healthcare costs[8] and indirectly through excess school absenteeism,[9] poorer academic performance[10–12] and reduced future economic prosperity.[13] Further, adolescent overweight and obesity tend to persist and progress over the life-course,[14,15] increasing the magnitude of obesity-related morbidities and premature mortality in adulthood, the costs of which were estimated to be $8.6 billion in Australia in 2015.[16]

Adolescence, defined by the World Health Organization (WHO) as the phase of life between 10 and 19 years,[17] is a particularly vulnerable time for the development of overweight and obesity.[18] Physiological changes associated with the pubertal growth spurt,[19] hypersensitive pleasure-seeking centres in the developing brain,[20] emerging autonomy and the influence of social media, advertising and peer groups are just some of the factors that lead many adolescents to develop poor diets and not achieve the recommended levels of physical activity.[18] This is reflected in findings from the 2011–12 Australian National Nutrition and Physical Activity survey, which revealed adolescents aged 14–18 years were the highest consumers of sugar-sweetened beverages and discretionary foods.[21] Additionally, the 2017–18 Australian National Health Survey found only 11% of Australian adolescents aged 15–17 years were sufficiently active for their age.[22]

To date, most interventions for adolescent overweight and obesity have focussed on individual behaviour change, aiming to improve physical activity levels and dietary quality. A Cochrane review of 44 studies found such interventions may be beneficial in achieving small reductions in weight in adolescents aged 12–17 years.[23] In Australia, interventions are usually delivered face-to-face through multi-disciplinary weight-management services at hospital clinics or community health centres.[24] However, the availability and accessibility of these services have been described as inadequate, particularly for adolescents with severe obesity and those from rural and remote communities.[24] A potential solution for these issues is to deliver such interventions through e-health (for example, telehealth, messaging and apps), which promise low-cost, accessible, individualized and destigmatised obesity treatment to adolescents.[25] The use of e-health, defined by WHO as the use of information and communication technologies to improve health care delivery and health outcomes,[26] has accelerated in recent years due to the COVID-19 pandemic[27] and is already being used for behaviour change self-management interventions for several chronic health conditions in adolescence, including asthma and diabetes.[28,29]

A 2021 systematic review of e-health interventions for the treatment of overweight and obesity in children and adolescents found they can be effective in reducing body mass index (BMI) and should be considered by practitioners and policymakers.[30] However, treating adolescent overweight and obesity is just one of many health issues that must be considered within the constraints of a finite budget. For decision makers, evidence that these interventions are also cost-effective, or provide 'value-for-money', is required to help inform resource allocation. Although e-health interventions are often promoted as cost-effective, evidence supporting this claim is currently lacking.[31] As such, our aim was to estimate the potential cost-effectiveness of a hypothetical e-health intervention for treatment of overweight and obesity among Australian adolescents.

2 | METHODS

We conducted a modelled cost-utility analysis of a hypothetical e-heath intervention applied to a cohort of 14-/15-year olds with overweight and obesity, compared to no intervention, using a lifetime time horizon and a healthcare perspective. Our choice of perspective and time horizon is based on recommendations from National Institute for Health and Care Excellence evidence standard frameworks for digital health technologies (UK)[32] and guidelines for preparing assessments for the Medical Services Advisory committee (MSAC) (Australia).[33]

2.1 | Hypothetical e-health intervention

To create our hypothetical e-health intervention, we sourced an intervention effect size (reduction in BMI) and an intervention cost from recent systematic reviews. The intervention effect size was from a subgroup meta-analysis of 5 studies evaluating e-health interventions for treatment of overweight and obesity in adolescents aged between 12 and 17 years.[30] The interventions in the included studies were all behaviour change in nature (with goals to improve physical activity levels and dietary quality) but delivered via a range of e-health modalities (including websites, text-messaging, telehealth, wearable devices and active video games). The synthesized effect size was a difference in BMI of −0.633 kg/m2 (95% confidence interval: −0.072, −1.193 kg/m^2).

For the hypothetical intervention cost, we used the mean cost per person from 25 studies evaluating web-based or telephone-delivered interventions for preventing overweight and obesity and/or improving obesity-related behaviours.[31] The target population for all but one of these studies was adults, with the remaining study evaluating an intervention on a population of grade 9 children (age 13–14 years). Costs per person from each trial were reported, with 19 from sources within trial and the remainder sourced from similar interventions in the literature. Cost components included personnel time and equipment costs (reported in all studies), with broader costs associated with productivity also included in six studies.[31] Using recommended methods,[34] we inflated all reported costs to 2019 values using health consumer price indexes[35] then, for non-Australian studies, converted to Australian dollars (AUD) using the mean exchange rates for each currency for that year.[36] From this, we estimated the mean cost per person ($509) and 95% confidence intervals ($211, $808).

2.2 | Model input populations

Our input population consisted of 3270 adolescents aged 14/15 years with individual-level data (including direct measurements of weight

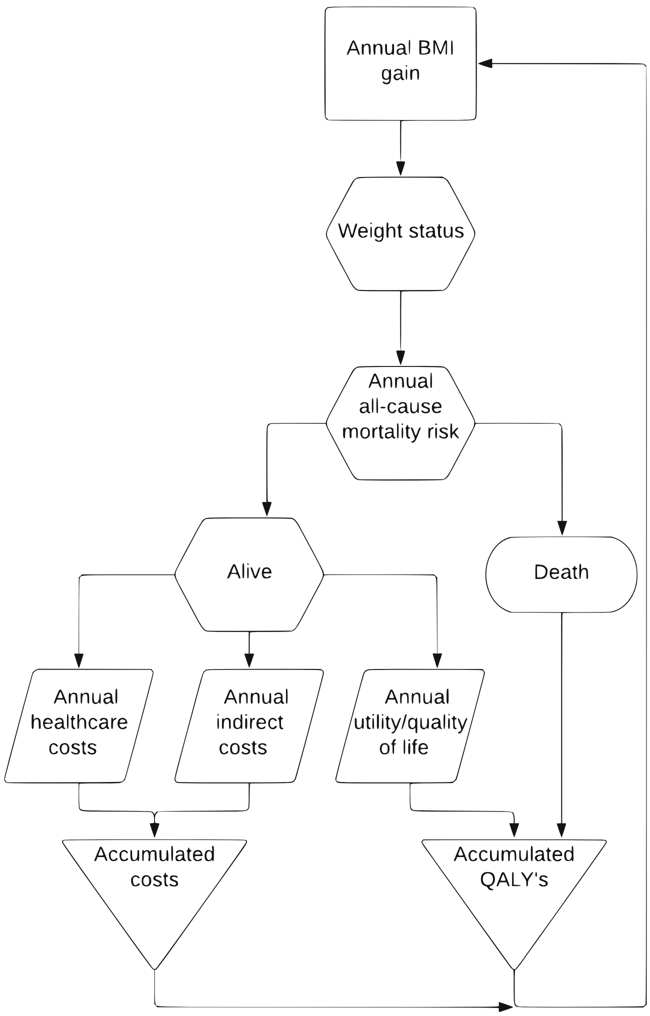

FIGURE 1 Schematic illustration of the EPOCH life-course model

and height), collected in 2014 from the Longitudinal Study of Australian Children (LSAC).[37] Participants were randomly selected into LSAC using a two-stage clustered design to obtain a nationally representative sample of children.[38] Survey weighting methods used by the LSAC allow for valid inferences to be made about the entire national population of adolescents.[39] In our case, the cohort chosen as the baseline population for modelling represented a national population of 232 399 14-/15-year-olds in 2014. With this input population, we created a 'control' cohort, with no changes applied, and an 'intervention' cohort, with the reduction in BMI and costs from our hypothetical e-health intervention applied once at baseline to all individuals with overweight and obesity.

2.3 | Micro-simulation model

To estimate the long-term costs and health outcomes of our two cohorts, we used the Early Prevention of Obesity in Childhood (EPOCH) life-course model, a micro-simulation model with annual discrete time steps. This model includes newly derived BMI growth equations for adolescent boys and girls aged between 14 and 18 years to link two existing validated models, the EPOCH model[40] and an Australian adult obesity[41] model. A schematic illustration of one annual cycle of the EPOCH life-course model is seen in Figure 1.

The control and intervention cohorts entered the model and were simulated for 86 annual cycles (until individuals reach 100 years of age or die). In each annual cycle, individuals became 1 year older, experienced a change in BMI, and incurred weight-status-dependent healthcare costs, indirect costs (from lost productivity), and utility (quality of life). A 5% discount rate was applied for future costs and quality adjusted life-years (QALYs), in accordance with recommendations in Australia.[33]

Further details of each component of the model are described below, with a summary of the model assumptions provided in Appendix 1.

2.3.1 | BMI trajectories

Annual BMI growth was calculated from multi-variable equations based on the individuals' age, sex and current BMI status (see Appendix 2 for internal validation of the model with LSAC data for adolescents from 10/11 to 18/19 years). Weight status was categorized based on WHO BMI age- and sex-specific cut points for adolescents 14–19 years,[35] and WHO BMI cut-points for adults 20 years and older (normal weight [BMI ≤24.9 kg/m^2], overweight [BMI ≥25 kg/m^2 and ≤29.9 kg/m^2], obesity class 1 [BMI ≥30 kg/m^2 and ≤34.4 kg/m^2], obesity class 2 [BMI ≥35 kg/m^2 and ≤39.9 kg/m^2], and obesity class 3 [BMI ≥40 kg/m^2]).[42]

2.3.2 | Mortality

Annual mortality risk was calculated as a function of age, sex and, from age 35 years, weight status. This is based on methods previously described[41] using the hazard of mortality for weight status above a healthy weight[43] and Australian lifetable data from 2018 to 2020.[44]

2.3.3 | Healthcare costs

Annual healthcare costs were calculated based on age, sex and weight status using a 'top-down approach', as previously described.[45] These methods incorporate national administrative records of health expenditure in Australia 2018–19[46] and apply percentage excess costs for those with overweight and obesity classes relative to healthy weight, derived from an Australian population-based study[47] (for children and adolescents up to 14 years) and a systematic review (for individuals aged 15 years and above).[48] Costs were valued in 2019 AUD and are presented in Appendix 3.

2.3.4 | Indirect costs

Indirect costs from productivity losses through weight status-associated absenteeism from school and work were accrued annually using a human capital approach. This approach measures lost productivity as the amount of time that working life is reduced due to illness.[49] Data on annual excess absenteeism from school for adolescents with obesity aged 10–14 years[9] and paid work for individuals with overweight and obesity aged 15–64 years[50] were sourced from Australian studies. Valuation of school absenteeism for adolescents with obesity aged 10–14 years was calculated by the following equation:

$$\text{Annual indirect cost} = \text{excess school days absent compared to healthy weight} \times \text{average daily wage}(2019\ \text{AUD})$$

where average daily wage was used to represent missed work from the child/adolescent's parent or caregiver.[9]

For valuation of paid work absenteeism for individuals aged 15–64 years, we used the following, previously described, equation[51]:

$$\text{Annual indirect cost} = \text{excess paid work days absent compared to healthy weight} \times \text{average daily wage}(2019\ \text{AUD}) \times \text{participation rate} \times \text{employment rate}$$

where age- and sex-adjusted participation and employment rates were sourced from Australian administrative data.[52] No indirect costs were accrued by individuals beyond 64 years in the model, as we did not have data informing weight-associated lost productivity. Annual indirect costs can be viewed in Appendix 4.

2.3.5 | Utility/quality of life

Health state utility values based on weight status were multiplied by the appropriate duration of the health state to generate QALYs. Weight-associated utility values were sourced from systematic reviews and meta-analyses for children and adolescents up to 17 years (healthy weight, overweight, obesity)[53] and for adults 18 years and over (healthy weight, overweight and obesity classes 1–3)[54] (Appendix 5). From the studies included in these systematic reviews, health state utility values were measured using a range of multi-attribute utility instruments.

2.4 | Modelled cost-utility analysis of hypothetical e-health intervention

To determine the cost-effectiveness of the hypothetical e-health intervention, we calculated an incremental cost-effectiveness ratio (ICER), which compares the differences in simulated lifetime costs and QALYs of the two cohorts through the following equation:

$$\text{ICER} = (\text{mean costs of intervention cohort} - \text{mean costs of control cohort})/(\text{mean QALYs of intervention cohort} - \text{mean QALYs of control cohort})$$

TABLE 1 Characteristics of input population of 14/15 year olds used in modelled cost-utility analysis

	Girls ($n = 1579$, population size = 110 830)	Boys ($n = 1691$, population size = 121 568)
Mean age (years) (SD)	14.92 (0.39)	14.93 (0.44)
	Control	**Intervention**
Mean BMI (kg/m^2) (SD)	22.48 (4.23)	22.28 (4.01)
Weight status (%) (95% CI)		
Healthy	69 (66, 71)	71 (69, 74)
Overweight	21 (20, 24)	20 (18, 22)
Obesity	10 (8, 12)	9 (7, 11)

As we chose a healthcare perspective, for our base-case analysis, only healthcare and intervention costs for each individual were included in our mean cost estimates.

2.5 | Uncertainty and sensitivity analyses

Multiple deterministic one-way sensitivity analyses were conducted, using the upper and lower 95% confidence intervals of the following parameters: hypothetical intervention effect size (−1.193 kg/m^2 and −0.072 kg/m^2); intervention cost ($808 and $211), and weight status-associated utility values (see Appendix 5). We also investigated the effects of using the 1st and 3rd quartiles of weight associated percentage excess annual healthcare costs (see Appendix 3). Additionally, we conducted sensitivity analyses using discount rates of 3% and 7% and adopting a limited societal perspective by including indirect costs in our mean cost estimates, as recommended by the MSAC.[33] Lastly, we investigated the effect of reducing the time-horizon to 65 years of age.

To explore joint uncertainty in costs and health outcomes we conducted non-parametric bootstrapping (5000 samples) of costs and QALYs for the base case and sensitivity analysis scenarios. We then plotted cost-effectiveness acceptability curves for each scenario to assess the probability the intervention would be cost-effective at a 'willingness-to-pay' (WTP) threshold of $50 000/QALY, an unofficial threshold for 'value-for-money' in healthcare decision-making in Australia.[55]

3 | RESULTS

Characteristics of the model input population can be seen in Table 1, with the hypothetical e-health intervention estimated to reduce population prevalence of overweight and obesity by 2% in both males and females.

Over a lifetime, the intervention cohort was estimated to accumulate net cost savings of $150 and gain an extra 0.024 QALYs per person compared to the control cohort. This translated to the mean

TABLE 2 Cost-effectiveness results for base case scenario and sensitivity analyses

Scenario	Incremental costs (95% CI)	Incremental QALYs (95% CI)	Mean ICER ($/QALY)	Probability cost effective at WTP $50 000/QALY
Base case (Intervention cost $509, effect size = −0.633 kg/m2)	$-150 ($-146, −$154)	0.024 (0.023, 0.025)	Dominant[a]	96%
Intervention cost, lower 95% CI ($211)	$-232 ($-226, $-237)	0.024 (0.023, 0.025)	Dominant	97%
Intervention cost, upper 95% CI ($808)	$-68 ($-65, $-70)	0.024 (0.023, 0.025)	Dominant	95%
Intervention effect size, lower 95% CI (−0.072 kg/m^2)	$128 ($126, $130)	0.0023 (0.0022, 0.0024)	$55 751/QALY	51%
Intervention effect size, upper 95% CI (−1.193 kg/m^2)	$-451 ($-441, $-461)	0.046 (0.044, 0.048)	Dominant	100%
3% discount rate	$-250 ($-243, $-257)	0.040 (0.038, 0.042)	Dominant	96%
7% discount rate	$-75 ($-73, $-78)	0.016 (0.015, 0.017)	Dominant	96%
Weight-associated % excess healthcare costs, lower IQR[b]	$-104 ($-100, $-107)	0.024 (0.023, 0.025)	Dominant	96%
Weight-associated % excess healthcare costs, upper IQR[b]	$-220 ($-213, $-226)	0.024 (0.023, 0.025)	Dominant	96%
Utility decrements compared to healthy weight, lower 95%CI[c]	$-150 ($-146, −$154)	0.014 (0.013, 0.014)	Dominant	94%
Utility decrements compared to healthy weight, upper 95%CI[c]	$-150 ($-146, −$154)	0.036 (0.034, 0.037)	Dominant	97%
Societal perspective	$-209 ($-204, $-214)	0.024 (0.023, 0.025)	Dominant	96%
Time Horizon of 65 years of age	$-172 ($-167, $-176)	0.021 (0.020, 0.022)	Dominant	96%

[a]'Dominant' indicates the intervention is estimated to be both less costly and result in better health outcomes compared to no intervention.
[b]See Appendix 3 for interquartile ranges (IQR) of weight status associated % excess costs used in sensitivity analysis.
[c]See Appendix 5 for 95% CI's of weight status associated utility decrements used in sensitivity analysis.

ICER of the hypothetical e-health intervention being dominant (cheaper and more effective) (Table 2).

3.1 | Sensitivity analyses

Table 2 demonstrates the change in results compared to the base case scenario from the various sensitivity analyses. In all cases, the mean ICER remained dominant, with the exception of using the lower 95% CI value for intervention effect size, which increased the mean ICER to $55 751/QALY.

Figure 2 demonstrates bootstrapped incremental cost/QALY pairs to reflect the uncertainty around the ICER point estimate, while Figure 3 shows the cost-effectiveness acceptability curve, both for the base case scenario. At a WTP of $50 000/QALY, the base case intervention had a 96% probability of being cost-effective. However, if using the lower 95% CI of intervention effect size, the probability could drop to 51% (see Table 2).

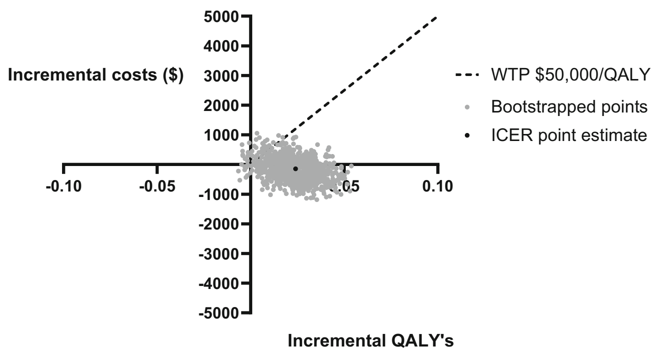

FIGURE 2 Cost-effectiveness plane for base case scenario

4 | DISCUSSION

In this study, we have conducted a modelled cost-utility analysis of a hypothetical e-health intervention for treatment of overweight and obesity, compared to a 'do-nothing' approach, in a cohort of 14- and 15-year-old Australian adolescents. The intervention was both effective and cost saving, with a 96% probability of being cost-effective at $50 000/QALY. This indicates that e-health interventions for adolescent overweight and obesity have very good potential as cost-effective strategies to address this major public health issue.

To the best of our knowledge, this is the first study to evaluate the cost-effectiveness of e-health interventions specifically targeting treatment of overweight and obesity in an adolescent population. A 2020 UK study evaluated the cost-effectiveness of an e-health intervention to increase physical activity in a cohort of high-school students,[56] while a 2021 Australian study conducted a cost-effectiveness analysis of a mobile health (m-health) intervention for high school students and their parents to improve dietary intake.[57]

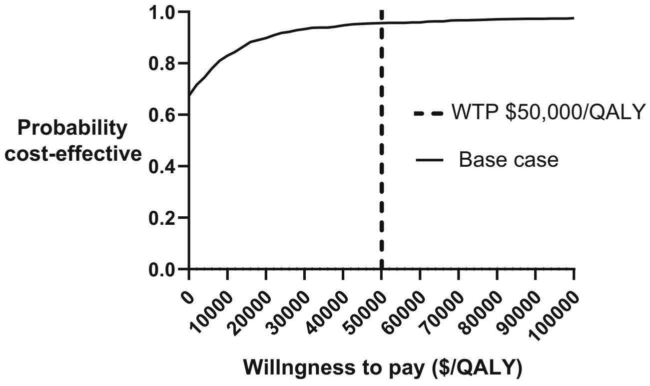

FIGURE 3 Cost-effectiveness acceptability curve for base case scenario

Although these studies were both behaviour-change interventions, neither were specifically targeting those with overweight or obesity, but rather were broad-based interventions applied to all students in the study cohort regardless of weight status. The cost-utility analysis of the intervention designed to increase physical activity did not explicitly report an ICER but stated it was 'not cost-effective'.[56] The economic evaluation of the intervention designed to increase the nutritional quality of school lunchboxes was reported in natural units (cost per reduction in lunchbox energy), which makes direct comparison to our results not possible.[57]

Although our results are promising, the sensitivity of our results to the intervention effect size is reason for caution. This is not surprising given the wide confidence intervals and considerable heterogeneity of the five studies in the sub-group meta-analysis that informed this estimate. Although the interventions in all five studies focussed on behaviour change, they differed in mode of e-health delivery, parental involvement, duration of between-group effects (ranging between 6 and 12 months) and whether the e-health intervention was delivered alone or as an adjunct to usual care.[30] Interestingly, a systematic review and meta-analysis of eight studies evaluating digital health interventions for weight management in children and adolescents was published shortly after the systematic review we referenced for intervention effect size and found very similar results (mean BMI change $-0.61\ \text{kg/m}^2$, 95% CI $-0.13\ \text{kg/m}^2$, $-1.10\ \text{kg/m}^2$).[58] High levels of heterogeneity between studies have also been an issue in summarizing the effectiveness of e-health interventions for treatment of obesity in adults.[59–61]

The unit cost for the e-health intervention used in our base case analysis ($509 per person) may be more expensive than expected. In general, e-health technologies are associated with much larger fixed costs (invested up front in technology development) compared to variable costs (e.g., technology maintenance).[62] This results in the marginal cost for e-health technologies tending towards zero with each additional user,[62] an advantage over traditional face-to-face and time-intensive interventions. However, this may not be the case for all e-health modalities. For example, telehealth interventions likely require greater time investments from clinician/healthcare providers as opposed to web-based or mobile-based interventions. Although there is some conjecture as to whether telehealth interventions should fall under e-health,[63] they were included in both systematic reviews that informed our hypothetical e-health intervention effect and cost. Indeed, the inclusion of telehealth interventions likely contributed to the high hypothetical intervention cost, as the intervention costs sourced from the systematic review ranged from as little as 94 cents per person (web-based intervention) to over $3200 per person (telephone counselling). Despite this, intervention cost did not significantly influence our overall results, as even using the upper bounds of intervention cost ($808 per person) resulted in the estimated ICER remaining dominant.

Strengths of our study include the use of a large nationally representative cohort of adolescents, conducting our economic evaluation with a lifetime time horizon to capture all important differences in costs and health outcomes, valuing costs and health outcomes across obesity classes rather than obesity as a whole, and the extensive sensitivity analyses. A limitation of our study is assuming that weight loss would be achieved uniformly in all individuals exposed to the intervention. Engagement and adherence are recognized as being critical to the success of e-health interventions for weight loss; however, compliance may be particularly challenging with adolescents.[25] Additionally, although smartphone ownership among adolescents in developed nations like Australia is estimated to be as high as 94%,[64] a 'digital divide' can occur with young people of low socio-economic backgrounds,[65] including those from rural and remote communities, who are at greater risk of developing overweight and obesity.[66,67] Another limitation was that, although not part of our base case analysis, our consideration of a societal perspective was limited to including only indirect costs related to weight-associated short-term absenteeism during individuals' school and working lives. There can be arguments made that all time lost due to illness should be valued equally no matter the age or employment status,[68] as well as a consideration for valuing lost leisure time.[69]

In conclusion, e-health interventions for adolescent obesity offer very good potential as cost-effective strategies to address this serious public health issue and should be considered by decision makers to support and expand current weight-management services in Australia. However, further research on the efficacy of such interventions, particularly in rural/remote and among disadvantaged populations, is warranted to further strengthen the case for investment.

AUTHOR CONTRIBUTIONS

Joseph Carrello, Alison Hayes and Thomas Lung conceived and designed the analysis. Joseph Carrello performed the analysis, which was reviewed by Alison Hayes and Thomas Lung. All authors contributed to the writing of the manuscript.

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CONFLICT OF INTEREST

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the Department of Social Services, Australian Government, but restrictions apply to the availability of these data, which were used under licence for the current study, and are therefore not publicly available. Data are however available from the authors upon reasonable request and with permission of Department of Social Services, Australian Government.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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