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■ *Research Paper*

Can the Target Set for Reducing Childhood Overweight and Obesity Be Met? A System Dynamics Modelling Study in New South Wales, Australia

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The persistent prevalence of childhood overweight and obesity raises significant concerns about the impact on health, society and the economy. Responding to a target announced in September 2015 by the New South Wales (Australia) Premier to reduce childhood overweight and obesity by five percentage points by 2025, a system dynamics model was developed to support Government and stakeholders responsible for meeting the target. A participatory model building process, drawing cross-sectorial expertise, was undertaken to estimate the individual and combined impact of interventions on meeting the target.

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The model demonstrated that it is theoretically possible to meet the target by implementing a comprehensive combination of policies and programmes. When limited to existing and enhanced population health interventions, the modelled result did not reach the target. The project provides an example of how participatory simulation modelling can combine a broad range of interventions together into likely scenarios and usefully inform government decision-making.

Keywords system dynamics modelling; evidence synthesis; public health policy; prevention policy; childhood obesity

BACKGROUND

Obesity is a complex global health challenge (Ng *et al*., 2014), with the prevalence of childhood overweight and obesity increasing over the past few decades in many countries (Wang and Lobstein, 2006; Ng *et al*., 2014; Ogden *et al*., 2015; Grant-Guimaraes *et al*., 2016). In Australia, overweight and obesity are significant contributors to the burden of disease (Australian Institute of Health and Welfare, 2016). Obesity is a major risk factor for a number of chronic diseases, including cardiovascular disease (Bastien *et al*., 2014), type 2 diabetes (Hu, 2008), musculoskeletal conditions (Grotle *et al*., 2008) and some cancers (Renehan *et al*., 2008). These conditions have significant social and economic impacts (Singh *et al*., 2008; Au, 2012) and have been estimated to cost the Australian health system over $21 billion annually (Colagiuri *et al*., 2010).

In the state of New South Wales (NSW), Australia, 22.9% of primary school children and 27.4% of secondary school students in 2015 were reported as being overweight or obese (NSW Health, 2017). Overweight and obesity in childhood is of concern, not only because of its impacts on child health but also because it is a strong predictor of long-term overweight and obesity, and associated chronic diseases in adulthood (Biro and Wien, 2010).

In an effort to address the individual, social and economic burden of childhood overweight and obesity, the World Health Organization recommended that member states adopt targets to halt the rise in obesity by 2025 (World Health Organization, 2013). Such targets have been adopted in countries including the United Kingdom (Abidin *et al*., 2014), New Zealand (Vandevijvere and Swinburn, 2014), the United States (US Department of Health and Human Services, 2010) and jurisdictions of Canada (Ontario Ministry of Health and Long Term Care, 2012). In 2015, the NSW Government unveiled a number of cross-portfolio priorities for the State, including a target to reduce the level of overweight and obesity in children (aged 5–16 years) by 5% over 10 years (NSW Government, 2015). The particular strategies by which this reduction would be achieved were not specified in this announcement. Based on current population projections, achieving the target would equate to a reduction in the number of children who are overweight or obese (than would otherwise have been the case) of 62 000 by 2025 (NSW Government, 2017).

There is evidence for the effectiveness of a number of public policy and programme interventions in reducing overweight and obesity and preventing unhealthy weight gain in children (Waters *et al*., 2011; World Health Organization, 2013; Bauman *et al*., 2016). While such interventions may demonstrate effectiveness in achieving weight reduction and preventing unhealthy weight gain for individuals at a point in time, these may not have the same impact on a population-based target centred on long-term reduction and maintenance. In addition, the impacts of implementing such interventions concurrently are unknown. Given that limited public resources are available to achieve government priorities and targets generally, understanding of the most efficient and effective combination of childhood overweight and obesity interventions and how they can be best implemented is essential if such targets are to be realized.

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In recognition of the complexity in public policy decision-making, modelling approaches based on systems thinking are increasingly being used to examine multifactorial population and public health issues, including overweight and obesity (Pauly *et al*., 2013; Carey *et al*., 2015). In particular, dynamic simulation modelling methods are known to lend themselves to supporting decision-making for complex problems and where the outcomes of interventions are unlikely to be realized in the short term. One modelling method, system dynamics, has been used successfully since the 1950s in the engineering, business and industry sectors (Forrester, 2007). More recently, system dynamics modelling has been used to support the design of efficient and effective responses to complex population health and health care problems (Djanatliev and German, 2013; Tejada *et al*., 2013; Flynn *et al*., 2014; Sadsad *et al*., 2014; Atkinson *et al*., 2015). Such a modelling approach has been suggested to be useful as a platform for drawing together disparate and diverse evidence sources (such as research evidence, expert and local knowledge and programme data) into a quantitative computer model. This model can then be used as a decision support tool to test the likely impacts of different policy scenarios and intervention combinations before they are implemented in the real world (O'Donnell *et al*., 2017). Further, the ability to account for population and behavioral dynamics (non-linear change over time) of childhood overweight and obesity, sources of real-world inertia and delay, and the potential non-additive effects of intervention combinations is suggested to make system dynamics modelling highly suited to addressing this complex health problem (Marshall *et al*., 2015; Liu *et al*., 2016).

Consequently, there has been a range of applications of system dynamics modelling to preventing childhood obesity (Brennan and Hovmand, n.d.; Homer *et al*., 2006; Madahian *et al*., 2012; Frerichs *et al*., 2013; Hall *et al*., 2013; Abidin *et al*., 2014). However, much of the existing work has focussed narrowly on body weight reduction and maintenance and was developed in countries (the USA and UK) that may differ to Australia in terms of behavioral, demographic, policy and infrastructure dynamics. The previous literature explores the development of models for varied purposes, including understanding obesity trends and the effect of combined interventions (e.g. all child obesity prevention or treatment interventions). Only one of these papers describes the creation of a model to examine how long it will take to achieve a government target (Abidin *et al*., 2014). However, this study from the UK was focussed on energy intake alone, not energy expenditure.

In this paper, we detail the application and initial outcomes of system dynamics modelling to address the question of what combination of high level strategies is likely to be needed to achieve a government target to reduce the population prevalence of childhood overweight and obesity by 5% over 10 years. This reduction is in comparison with the baseline 'business as usual' scenario of continuing existing NSW Health delivered programmes alone. The paper does not present a detailed examination of the likely impact of each programme, service or initiative within each strategy.

MODEL DEVELOPMENT

A core model building team (authors: N. R., V. L., J. A., S. N., M. H. and G. M.) was formed to oversee the technical development of the model and to facilitate input from the broader expert model building group. The team established that a model built through partnership between policy and multidisciplinary experts based on their deep tacit knowledge of the local context, issues and priorities, and developed using a broader systems lens (Lee *et al*., 2016) would be necessary to provide contextually appropriate decision support capability to inform how best to meet the NSW target.

A Participatory Model Building Approach

Given the diversity of evidence, opinions and interests associated with the determinants and possible solutions to childhood overweight and obesity (Vandenbroeck and Goossens, 2007; Allender *et al*., 2015), a diverse group of professional and community-based stakeholders were brought together to contribute to the building of

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the model. The participatory approach (Mikulskiene and Pitrenaite, 2012; Atkinson *et al*., 2015) was enabled by a partnership between The Australian Prevention Partnership Centre, the NSW Ministry of Health and the NSW Department of Premier and Cabinet. Participating stakeholders were experts whose primary fields included policy (*n* = 25), academia (*n* = 13), health economics (*n* = 3), public health (*n* = 2) and biostatistics (*n* = 1), as well as national and international leaders in dynamic simulation modelling (*n* = 4).

Input from the stakeholders was elicited through three participatory expert group workshops between July and November 2016. The workshops were co-facilitated by modelling (J. A.), content (J. W.) and project management (N. R.) experts. The workshops collaboratively mapped the key risk factors and pathways for childhood overweight and obesity, and the mechanisms by which selected interventions were hypothesized to have their effect (Figure 1). The conduct of the workshops was steered by guidelines and frameworks previously used to facilitate model conceptualization, formulation, quantification, calibration and validation, as well as conducting policy analysis/simulation experiments (Vennix *et al*., 1992; Andersen and Richardson, 1997; Bernard, 2010; Hovmand, 2014; Voinov *et al*., 2016; Voinov and Gaddis, 2017). The participatory simulation modelling process applied in this study has been more fully described elsewhere (Freebairn *et al*., 2016; Atkinson *et al*., 2017).

Modelling and Analysis Software and Simulation Process

The core model building team used iThink® v10 software (www.iseesystems.com/) to develop the model. The model was developed on a PC, with the operating system Windows, using a 64 bit i5 processor and 8 gigabytes of ram. The software used Euler's integration with a base time unit of years with a time step (dt) of 1/64. No preprocessing was required. The data tables were exported to Microsoft Excel for reporting purposes.

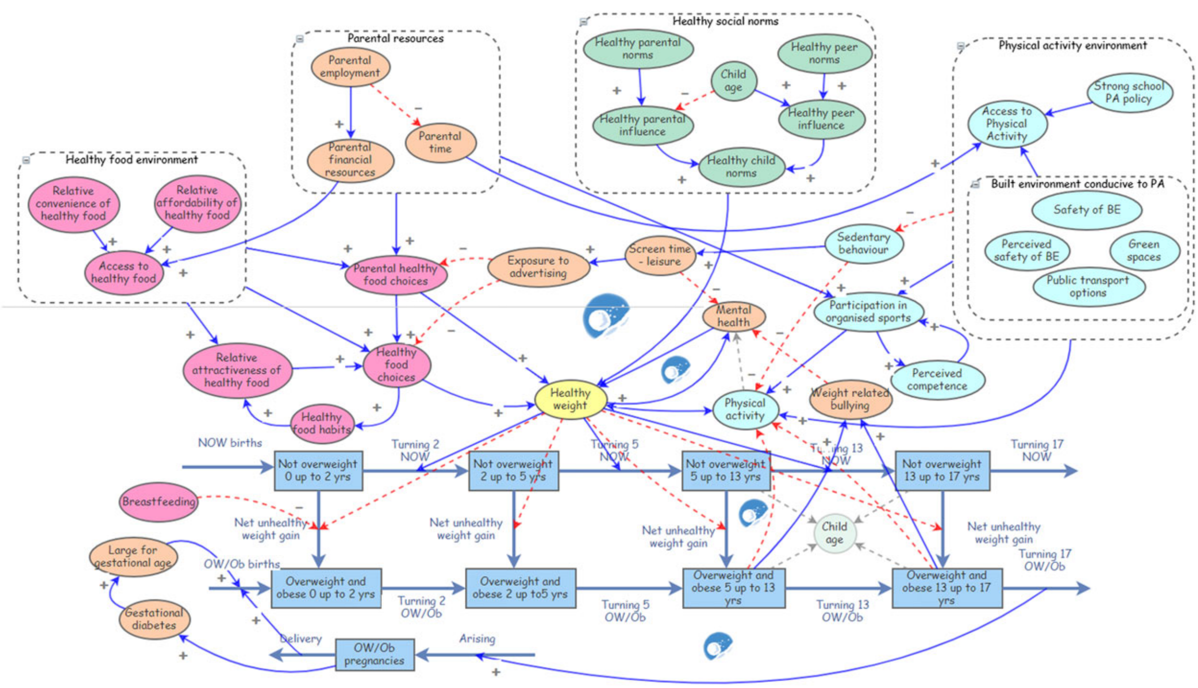

Figure 1 Conceptual model [Colour figure can be viewed at wileyonlinelibrary.com]

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Model Inputs

The structure and parameterization of the model drew on a range of data sources including census and population data, systematic reviews, meta-analyses, accepted formulas and conceptual models, survey data, policy/programme effectiveness data, economic data and the expert knowledge of the multidisciplinary stakeholders. Such data addressed demographic characteristics and trends, the prevalence of childhood overweight and obesity and the behavioral determinants thereof, and the effectiveness of policies and programmes for the prevention, treatment and management of childhood overweight and obesity. Census, population and health system data were sourced from the Australian Bureau of Statistics, NSW Health administrative datasets (HealthStats NSW) and NSW Department of Planning and Environment population projections. Data regarding the implementation and effectiveness of existing government childhood overweight and obesity policies and programmes were obtained from monitoring data held by NSW Health. Model input parameter values, their sources and the data used for model calibration are provided in Data S1, and model assumptions are in listed in Table 1. The model was

Table 1 Model assumptions

While these assumptions within the model are deemed to be plausible, future research and data collection in these areas will strengthen the model. The key assumptions and decisions are listed below:

(1) All migrant children entering the model are assumed to be not overweight/obese upon entry. At the start of the model run, there were 10 016 child migrants arriving in NSW (aged less than 17 years) per annum, compared with 96 448 births per annum. Hence, the ratio of child migrants:births was approximately 1:10. The total child population at the start/baseline was 1 546 286, therefore children entering the model as migrants only represent 0.65% of the total number of children in NSW each year. Although child migrants are only a small percentage of the total, the modellers have included these child migrants as part of a mass balance check against total population projections. The rates used to calibrate the 'business as usual' not overweight/obese and overweight/obese states and transition rates over the first 5 years of the model run are based on this assumption. The migration rates remain constant for the model run.

(2) The following age ranges were used for the subgroups in the model.

- Infants: 0–1.99 years (under 2 years of age)
- Preschool: 2–4.99 years (under 5 years of age)
- Primary school: 5–11.99 years (under 12 years of age)
- High school: 12–16.99 years (under 17 years of age).

(3) For our energy calculations, we have used the Schofield Equation (refer to Data S1).

- This is a method of estimating the energy required for normal growth based on basal metabolic rate (BMR) and base activity factor of males and females. A score is assigned to each of the physical activity interventions which specifies the effect by the end of each model run. Activating the 'sport and active transport' component produces the active transport 'score' of 1.105, meaning there is a 10.5% increase in physical activity by the end of the model run, whilst sporting activity promotion has a 'score' of 1.06, i.e. a 6% increase in physical activity.
- These scores are for the 12–17 age group and are reduced for the younger age groups. These scores are multiplied together to provide a factor for each age group referred to (in the model) as the Activity Index. The Base Activity Index is multiplied by the Activity Index to determine the Adjusted Activity Factor to be used in the Schofield Equation. With the current model settings, the Activity Index for the 12–17 age group computes to 1.38 at Year = 2025. The Base Activity Factor for this age group is 1.4. Therefore, the Adjusted Activity Factor becomes 1.4 × 1.38 = 1.93 which is the factor for the activity range between moderately active and very active. This is an optimistic outcome but well within the range of the Schofield parameters.

(4) Averages from population projections within each age group have been included, based on data from the Chief Demographer's Office (NSW Department of Planning and Environment, 2016)

(5) Cultural shifts in relation to either energy intake or expenditure and behavior change may be important in the long term. Due to the challenge in calibrating this general concept in the short term (i.e. for the duration of the Premier's Priority), the effect of cultural shifts has not been incorporated into the current version of the model.

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calibrated using population statistics from 2010 to 2016, to establish the validity and reliability of the model, and projected population estimates up to 2030 were also used.

The following nine interventions were prioritized by the stakeholder group for inclusion in the initial application of the model addressed by this paper:

(1) Increased healthy food choices in Government settings
(2) Settings-based, state-wide primary prevention programmes (e.g. conducted in early childcare centres, primary and high schools)
(3) Prenatal and post-natal interventions
(4) Advertising bans across all media types (restricting marketing of unhealthy food and beverages to children)
(5) Sugar-sweetened beverage tax
(6) Healthy food subsidies
(7) Social marketing campaigns
(8) Routine advice and clinical service delivery
(9) Environments to support physical activity (e.g. promotion of active transport, infrastructure and other sporting activity promotion).

Further information regarding these interventions is presented in Table 2.

Model Structure

The model structure is presented in both a detailed (Figure 2) and a simplified format (Figure 3). The model included age stratification aligned with the age-specific settings in which interventions were being delivered (e.g. infancy, preschool, primary and secondary/high school):

- Infants: 0–1.99 years (under 2 years of age)
- Preschool: 2–4.99 years (between 2 and 5 years of age)
- Primary school: 5–11.99 years (between 5 and 12 years of age)
- Secondary school: 12–16.99 years (between 12 and 17 years of age).

The model has an open population with births contributing infants to the model, who were allocated a status of overweight/obese or not overweight/obese based on a distribution drawn from NSW Health data (NSW Health, 2016), with overweight/obese classified as birthweight greater than 4.5 kg (Hadfield *et al.*, 2009). Infants and children also entered the model through net migration (interstate and overseas). For this group, a simplifying assumption was made that they were not overweight or obese at the outset but may become so over time. A representation of the ageing chain structure of childhood overweight and obesity in NSW is provided in Figure 2 and reflects the 'business as usual' scenario of current government programmes and initiatives to address childhood overweight and obesity. A representation of energy balance was included in the model, whereby energy intake less expenditure was considered to result in weight gain, loss or maintenance. The energy balance mechanism was informed by the Schofield equation (Schofield, 1985) and influenced by the impact of programmes on either energy intake or expenditure at each of the age ranges (Figure 2). The resultant net intake (Figure 3) influenced the net rate of children becoming overweight or obese. Further images of the model structure can be found in Supporting information, Figures S1, S2 & S3.

Model Outputs

Consistent with the NSW Government target of reducing the prevalence of childhood overweight and obesity by 5% over 10 years, the primary model output of interest was the proportion of overweight and obese children aged 5 to 16 (inclusive) living in NSW from 2016 to 2025, both overall and stratified by the age subcategories mentioned in the 'Model Structure' section of this paper. The model also produced a range of other outcome indicators including awareness of healthy food and behaviors, engagement with services, consumption of sugar-sweetened beverages and energy expenditure.

Scenario Testing

The following intervention scenarios were simulated (and compared against the business

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Table 2 Descriptions of interventions

Intervention name	Description	Effect
Healthy food availability in Government settings	Settings can include schools, hospitals and other services and involve the removal of unhealthy food products and increasing the availability of healthy alternatives. This may be through food provision, vending machines and shops within facilities.	Reduction of energy intake
Settings-based, state-wide primary prevention programmes (e.g. conducted in early childcare centres, primary and high schools)	These include State government-run programmes that are primarily delivered through settings, such as early childcare centres, primary and high schools and junior community sports clubs. These are often developed and implemented in partnership with external stakeholders including NSW Health, the NSW Department of Education and Transport NSW.	Reduction of energy intake and increase in energy expenditure
Prenatal and post-natal interventions	Interventions to support mothers with breastfeeding, according to current guidelines, are included.	Reduction of energy intake
Advertising bans across all media types (restricting marketing of unhealthy food and beverages to children)	A reduction in advertising, through various media, may result in effects on purchasing and consequent consumption of energy dense, nutrient poor products.	Reduction of energy intake
Sugar-sweetened beverage tax	The introduction of a 20% valoric tax on sugar-sweetened beverages (SSBs) may increase the sale price of these products, resulting in a reduction in purchase and consumption.	Reduction of energy intake
Healthy food subsidies	This intervention is to increase the affordability of healthy food through the application of subsidies. This subsidy may or may not be funded through the revenue of the sugar-sweetened beverage tax option.	Reduction of energy intake
Social marketing campaigns	Government social marketing campaigns could be delivered through TV, radio, outdoor advertising, social media or other novel PR 'activation' techniques and events. These may raise awareness of the risks of unhealthy food and an inactive lifestyle and of the benefits of healthy foods and an active lifestyle. They will also raise awareness of other interventions that could assist people and their families in weight loss. This may result in changes to both energy intake and expenditure	Reduction of energy intake and increase in energy expenditure
Routine advice and clinical service delivery	Increasing the identification and management of childhood overweight and obesity in clinical services, including the provision of information and advice for parents, development of new tools, and training for health and community professionals, may raise parents' awareness and knowledge of their children's weight status and promote	Reduction of energy intake and increase in energy expenditure

(*Continues*)

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Table 2 (Continued)

Intervention name	Description	Effect
	referrals to and uptake of appropriate programs when required.	
Environments to support physical activity (e.g. promotion of active transport, infrastructure and other sporting activity promotion).	Environments to support physical activity can include making physical activity (both planned and incidental) easier and more inviting for the population. This can include increasing walkability, providing exercise and active transport infrastructure (e.g. bike paths and improved pavements) and increasing the number, quality and accessibility of sporting infrastructure.	Increase in energy expenditure.

Scenario 1 (baseline) includes the existing settings-based, state-wide primary prevention programmes, social marketing campaigns and routine advice and clinical service delivery.

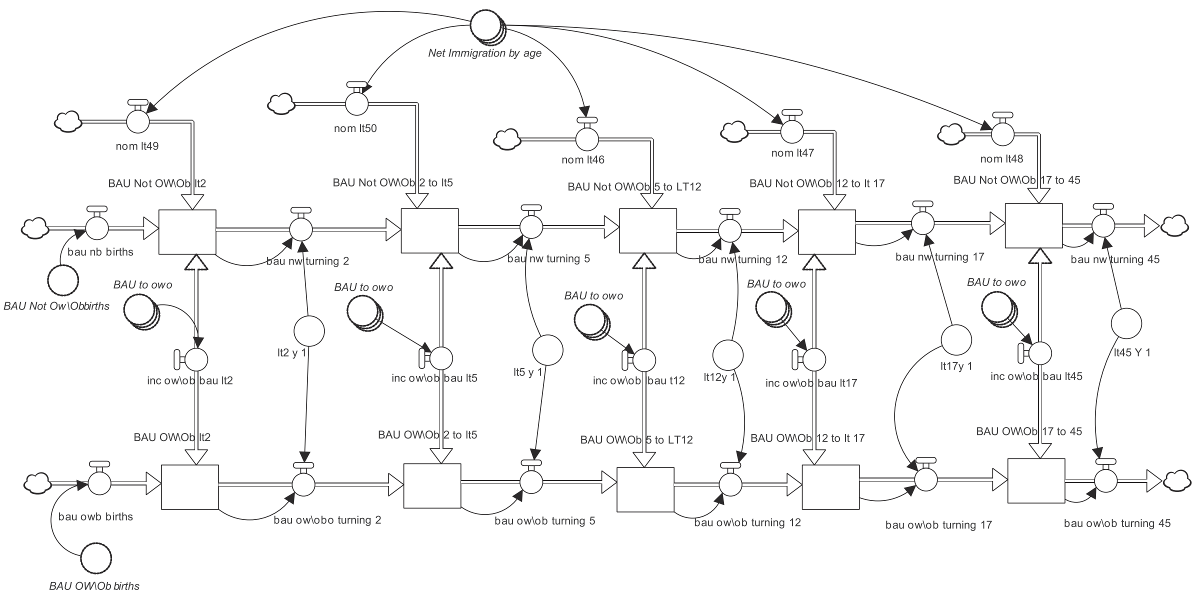

Figure 2 Detailed model structure

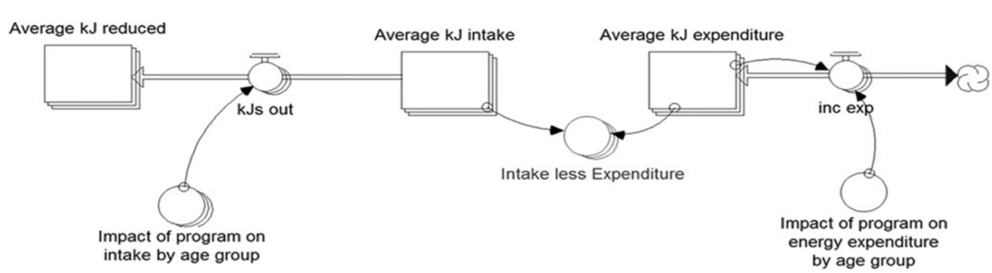

Figure 3 Simplified representation of programme impact on energy balance (kilojoules, kJ)

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as usual baseline, scenario 1) to determine what combination of interventions would achieve the target of a 5% reduction in childhood overweight and obesity by 2025, and how soon any impact would likely be seen:

Scenario 1: Business as usual baseline—continuation of existing NSW Health delivered programmes that are currently achieving 80% reach of the target population and 70% adoption.
Scenario 2: Enhancement of existing programmes currently delivered by NSW Health (reach of programmes increased to 85%; adoption of programmes increased to 80%).
Scenario 3: Enhancement of existing programmes (as per scenario 2), plus expansion of built environment infrastructure, plus expansion of sport and active transport. This involves an increase of the relative 'units' of infrastructure and sporting promotion by eight units per year, where the baseline level is 100 units.
Scenario 4: Full suite of modelled interventions, that is, enhancement of existing programmes (as per scenario 2) plus expansion of built environment infrastructure, plus expansion of sport and active transport, plus adverting restrictions, sugar-sweetened tax and healthy food subsidies.

Sensitivity Analyses

The model was progressively refined over multiple iterations with input and advice from domain and policy experts. Due to the large number of parameters in the model, exhaustive sensitivity analysis for each combination of variables was not feasible due to combinatorial explosion. Given the possibility of measurement error in data used for calibration, targeted parameter variation experiments were conducted by varying the key parameters governing the primary outcome (prevalence of childhood overweight and obesity), namely:

(1) Net overseas migration—drawn randomly from a lognormal distribution with mean set according to projected annual migration statistics (2015–2025) (NSW Department of Planning and Environment, 2016) and standard deviation set at 5000.
(2) Prevalence of infants who are considered to be large for gestational age (a risk factor for subsequent childhood overweight and obesity) (Qiao *et al.*, 2015). The minimum (1%) and maximum (4%) prevalence values were used.

Two sensitivity analysis scenarios were considered: varying the projected migration alone and varying the projected migration plus the prevalence of infants who are considered to be large for gestational age.

The baseline simulation and intervention scenarios were each run 100 times. Comparison of simulation results between baseline and intervention scenarios were expressed as the absolute per cent difference in the mean of two independent samples for the same population. Results are presented in Table 3.

The sensitivity of the model was tested by introducing parameter variation for the most uncertain two specific parameters, the rate of net overseas migration and the percentage of infants born who are large for gestational age. The very low standard error rate, when compared with the mean (column 4) in Table 3, confirms that the model is robust. It is important to note the significant increase in standard deviation (sixfold to 12-fold) when the combined parameter variation is applied (i.e. when the prevalence of infants who are considered to be large for gestational age parameter is varied from 1% to 4%, together with variation in the projected migration parameter).

MODEL RESULTS

The model was calibrated using population statistics from 2010 to 2016. Simulation of the prevalence of childhood overweight and obesity for that period broadly replicated retrospective data from population health surveys (Figure 4). The results of scenarios tested are presented in Figure 5 and Table 4 and summarized in the following text.

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Table 3 Results of sensitivity analysis: summary of estimated difference in childhood overweight and obesity in the NSW population for simulated scenarios against the baseline using the two approaches to sensitivity analysis

	Varying the projected overseas migration parameter alone				Varying the projected overseas migration and the prevalence of infants who are considered to be large for gestational age parameters (combination).			
	1.	2.	3.	4.	1.	2.	3.	4.
Scenario 1: Baseline ('Business as usual')—NSW Health interventions only, intervention reach at 80%, adoption at 70%	2.95	0.08	–	–	2.66	0.50	–	–
Scenario 2: Enhanced NSW Health interventions only, intervention reach at 85%, adoption at 80%	3.12	0.08	5.89	±0.01	2.85	0.47	7.18	±0.05
Scenario 3: Enhanced NSW Health interventions, plus built environment, sport and recreation interventions	4.55	0.04	54.38	±0.01	2.86	0.49	7.23	±0.05
Scenario 4: Full suite of modelled interventions	4.88	0.05	65.73	±0.01	4.63	0.45	73.98	±0.05

1. Mean reduction across 100 runs for the baseline scenario (by year 2025)
2. Standard deviation for the mean reduction across 100 runs for the baseline scenario (by year 2025)
3. Increase in the reduction expressed as a percentage of the difference of population means for the baseline and the specified scenario
4. Margin of error for the difference of the population means of the baseline and the specified scenario.

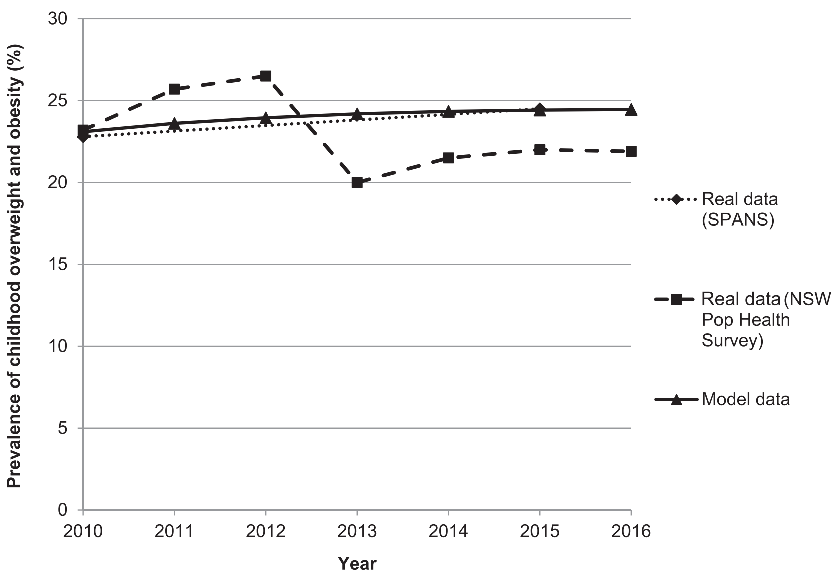

Figure 4 Comparison of real world data (NSW Schools Physical Activity and Nutrition Survey—SPANS (NSW Health, 2017) and NSW Population Health Survey (NSW Health, 2018)) with model outputs, for the purposes of validation

Scenario 1: NSW Health existing programmes alone. The model simulation of the 'business as usual' scenario in which the impact of current Government initiatives was examined indicated that the prevalence of childhood overweight and obesity would be reduced by 2.9% by mid-2025.

Scenario 2: Enhancement of current NSW Health programmes. Under the enhanced programme conditions, the forecast reduction in

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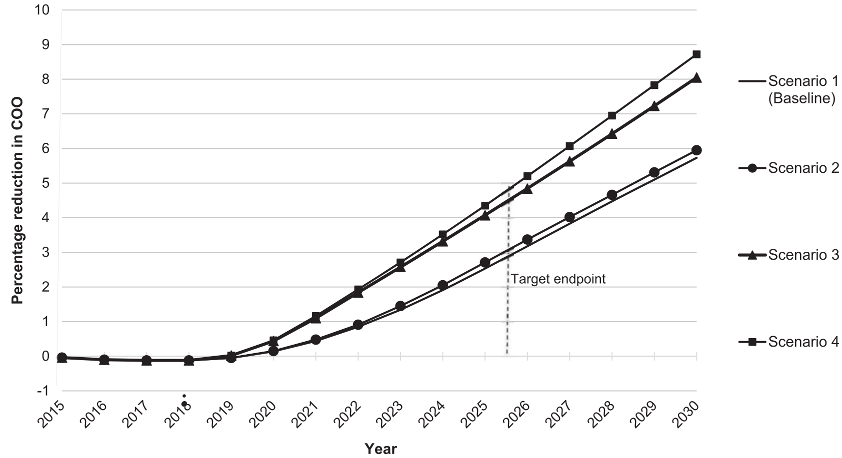

Figure 5 Forecast percentage reduction in childhood overweight and obesity (COO) prevalence among 5- to 16-year olds in New South Wales, Australia

Table 4 Summary of estimated reductions in childhood overweight and obesity in 2025, following combinations of selected interventions

	No. of overweight and obese children by mid-2025	% reduction in childhood overweight and obesity by mid-2025
Scenario 1 (business as usual baseline): current NSW Health programmes at 80% reach and 70% adoption	273,116	2.9
Scenario 2: Expansion of current NSW Health programmes to achieve 85% reach and 80% adoption	270,629	3.1
Scenario 3: Expansion of current NSW Health programmes plus expansion of built environment infrastructure plus expansion of sport and active transport	251,620	4.5
Scenario 4: Full suite of modelled interventions	246,941	4.9

childhood overweight and obesity was 3.1% by mid-2025.

Scenario 3: Enhancement of existing NSW Health programmes plus expansion of built environment infrastructure and expansion of sporting facilities and promotion and active transport opportunities. The forecast reduction in childhood overweight and obesity under this scenario was 4.5% by mid-2025.

Scenario 4: Full suite of nine interventions. The model forecast a 4.9% reduction in childhood overweight and obesity by mid-2025 and a 5% reduction at the end of 2025/early 2026.

The time series for each scenario presented in Figure 5 highlights the delay in impact of interventions on the prevalence of overweight and obesity for children aged 5 to 16 years. The earliest that a small (1%) reduction in the prevalence of childhood overweight and obesity might be seen is 2020/2021.

DISCUSSION

This paper describes for the first time, the results of a participatory approach to the building of a

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system dynamics model that forecasts the impact of a range of interventions on the prevalence of childhood overweight and obesity in NSW, Australia. The locally valid model was developed to identify the combination of interventions needed to achieve the state Government target of reducing childhood overweight and obesity by 5% over 10 years. The model replicated a historical time series of births, deaths, population growth and overweight and obesity rates in children. Model scenarios identified that the target could be achieved if a comprehensive range of policies and programmes were implemented.

While the model demonstrates that it is theoretically possible to achieve the target of a 5% reduction in childhood overweight and obesity in NSW by the end of 2025, substantial cross-portfolio policy actions will be required. The collective impact of 'business as usual' interventions (i.e. continuing NSW Health programmes to address childhood overweight and obesity at their current levels of reach and adoption) was found to be insufficient to achieve the target. By supplementing these 'business as usual' interventions through enhanced reach and adoption rates (targets of 85% reach and 80% adoption), overweight and obesity projections remained short of the NSW Government's priority target (3.1% reduction). Such findings suggest that implementation of additional strategies would be required to achieve the target, a finding confirmed by the results of modelling the full range of interventions considered in this study. Such interventions included improvements to built environment infrastructure (e.g. improving the walkability in communities; Leslie *et al.*, 2006), increasing opportunities for children to engage in sport and recreation (e.g. organized sports and increasing the amount of active transport by children), as well as fiscal policies to dis-incentivize unhealthy beverages and make healthy food more affordable (i.e. a tax on sugar-sweetened beverages and subsidies for healthy food), advertising restrictions on the marketing of unhealthy food and beverages to children and increasing the availability of healthy food.

These interventions fall under the jurisdiction of health, urban planning and education portfolios and therefore require cross-sectoral collaborative government action. The findings of this modelling exercise confirm the conclusions of evidence reviews (UK Government Office for Science, 2007; Waters *et al.*, 2011; Bauman *et al.*, 2016) and international policy directions (World Health Organization, 2013), namely, that childhood overweight and obesity is influenced by multiple determinants. As a consequence, a socioecological, multi-agency approach is necessary. The need for a cross-sectoral government response to childhood overweight and obesity is reflected in the NSW Health delivery plan for this priority (NSW Government, 2016).

The model outcomes also provided guidance regarding the timing of intervention effects, with model outputs forecasting that there will be little discernible impact until 2020. This delay in impact is a result of the length of time needed for interventions to be implemented and scaled up, sustained weight loss or prevention of unhealthy weight gain at an individual level being realized only after a length of time, and the further deferral for sustained population level reductions to be realized.

Similarly, the model outputs suggested that all interventions need to be implemented in order to reach the target approximately 6 months after the proposed end date of mid-2025. If any of the target estimates of intervention reach and adoption are not realized, the suite of interventions would not achieve the target by the 2025 target date. This suggests that if a greater level of certainty around reaching the target on time is required, additional strategies to increase the impact of interventions are likely to be required.

Reflections on the Participatory Model Building Process

Based on the policy context around reaching the NSW target, system dynamics offered an opportunity to supplement existing but incomplete evidence with a level of mathematical rigour to support decisions around how best to achieve

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population health objectives within a given time period.

Strategic implementation decisions needed to reduce the overall level of childhood overweight and obesity can be informed by the insights of this model. The participatory approach used to develop the model brought together researchers, policymakers, programme planners, practitioners, health economists and modellers. This helped to ensure that the model applied the full range of evidence and perspectives available to draw conclusions around reaching the NSW Government's priority. The process proved valuable in facilitating knowledge sharing between diverse stakeholder groups and enhancing the estimation capacity of the model (Freebairn *et al*., 2017). The strengthening of partnerships established through this process should provide a sound basis for ongoing cross-sectoral and cross-agency engagement and action to address childhood obesity and attempts to meet the NSW Government target.

Limitations

There are a number of methodological characteristics that require consideration when interpreting the findings of this paper. While the model accounts for behavioral and population dynamics that impact childhood overweight and obesity, aggregate systems models cannot consider the complex mechanisms and trajectories that affect dietary decision-making and physical activity for individuals. Agent-based models may be more appropriate for capturing these mechanisms in the future, as more supporting evidence and data become available (Marshall and Galea, 2014; Giabbanelli and Crutzen, 2017).

Data on the outputs of interest at a programme level were sometimes limited. Consequently, programme data were supplemented by relevant literature and the input of expert opinions through the model building workshops and meetings. The model building process has emphasized the need to strengthen ongoing data collection to measure intervention impact and evaluate policy and programme implementation against this target (Hanson, 2012).

Geographical variation in social disadvantage that contributes to differential overweight and obesity trends across NSW as well as differential effects of interventions by gender, socio-economic status and cultural groups were not considered in the current model due to a lack of data. Further development of the model is required to address the impact of these important factors on the achievement of the target. Additionally, the model was limited to the analysis of groups of interventions (e.g. environments to support physical activity) and therefore does not demonstrate the incremental benefit of individual interventions, for example, the expansion of bike paths. Enhancement of the model, subject to available data, would allow for such more fine-grained analyses.

An investigation of intergenerational impacts was beyond the model timescale and boundary for the current work; however, these may play a role in childhood overweight and obesity and will be the subject of further modelling efforts. Additional work is being undertaken to integrate an economic component to the model and add new interventions; however, the model provides a robust basis from which to estimate the quantitative trade-offs of not implementing particular interventions and to manage expectations around how soon impacts will be evident when monitoring the progress towards the target.

CONCLUSION

Significant cross-sectoral government action will be required to achieve the NSW Government's priority target of reducing childhood overweight and obesity by 5% by 2025. A comprehensive suite of interventions including enhancement of existing population health programmes, expansion of built environment infrastructure, sport and recreation programmes, advertising and fiscal interventions are all necessary to achieve the target. For greater certainty, additional strategies to increase the impact of interventions are likely to be required.

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DEDICATION

We dedicate this work to our colleague, mentor and above-all friend, Associate Professor Sonia Wutzke (1970–2017). The public health community is richer for having had you as one of its most passionate advocates.

CONFLICT OF INTEREST

One of the co-authors (M. H.) is a distributor of iThink, the modelling software used for this project, and mentioned in this paper.

AUTHORS' CONTRIBUTIONS

All authors contributed to the conception of the paper. N. R., J. A., V. L., M. H. and G. M. created the initial draft manuscript. All authors provided important intellectual contributions to the model development, revisions of the draft manuscript and approval of the final manuscript.

THE EXPERT STAKEHOLDER GROUP

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SUPPORTING INFORMATION

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

Data S1 - Parameter estimates and data sources

Figure S1 - structure representing the mechanism for program engagement and behaviour change

Figure S2 - structure representing the mechanism of healthy food choices

Figure S3 - structure representing the mechanism relating to physical activity infrastructure

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