

Understanding the system dynamics of obesity-related behaviours in 10- to 14-year-old adolescents in Amsterdam from a multi-actor perspective

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Submitted to Journal:
Frontiers in Public Health

Specialty Section:
Public Health and Nutrition

Article type:
Original Research Article

Manuscript ID:
1128316

Received on:
20 Dec 2022

Journal website link:
www.frontiersin.org

Conflict of interest statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest

Author contribution statement

Conception and design of the work: ALP, KS, WW. Supervision: KS, WW. Funding acquisition: KS, CD, CR, TA, MC, SPJK. Writing original draft: ALP, KS, WW. Interpretation and critically reviewing manuscript: ALP, KS, HE, EvdE, TA, CD, CR, RH, VB, MC, SPJK, WW. All authors read and approved the final manuscript.

Keywords

Overweight and obesity, adolescents, complex systems, Causal Loop Diagram, System dynamics

Abstract

Word count: 207

To develop an understanding of the dynamics driving obesity-related behaviours in adolescents, we conducted systems-based analysis on a causal loop diagram (CLD) created from a multi-actor perspective, including academic researchers, adolescents and local stakeholders. The CLD contained 121 factors and 31 feedback loops. We identified six subsystems with their goals: 1) interaction between adolescents and the food environment, with profit maximisation as goal; 2) interaction between adolescents and the physical activity environment, with utility maximisation of outdoor spaces as goal; 3) interaction between adolescents and the online environment, with profit maximisation from technology use as goal; 4) interaction between adolescents, parenting and the wider socioeconomic environment, with a goal focused on individual parental responsibility; 5) interaction between healthcare professionals and families, with the goal resulting in treating obesity as an isolated problem; and 6) transition from childhood to adolescence, with the goal centring around adolescents' susceptibility to an environment that stimulates obesity-related behaviours. Analysis showed that inclusion of the researchers' and stakeholders' perspectives contributed to an understanding of how the system structure of an environment works. Integration of the adolescents' perspective enriched insights on how adolescents interact with that environment. The analysis further showed that the dynamics driving obesity-related behaviours are geared towards further reinforcing such behaviours.

Contribution to the field

Childhood overweight and obesity are considered complex problems as they result from the interaction of multiple, dynamic factors. Factors range from individual behaviours such as screen time to more upstream factors such as urban design. Understanding the system dynamics of those factors is a key step towards developing interventions that can enable systems change. Most studies that focus on gaining system understanding of childhood overweight and obesity to date use a single perspective, for example stakeholders, the target group or academic literature. Integrating multiple perspectives is however important because each actor has a different perception of the problem, which ultimately influences the way in which the system can be changed. Furthermore, gaining a deeper understanding of how the system behaves (i.e., the system dynamics) is necessary to be able to change a system. This paper reports the results of an integrated system map containing the perspective of academic researchers, adolescents and stakeholders. The system map contains 121 factors, 31 feedback loops and 6 sub-systems. Analysis revealed that the system dynamics around obesity-related behaviours in 10-14 year old adolescents in Amsterdam, the Netherlands, are geared towards further reinforcing obesity-related behaviours over time.

Funding statement

This work was supported by a grant from the Netherlands Cardiovascular Research Initiative: An initiative with support of the Dutch Heart Foundation, ZonMw, CVON2016-07 LIKE.

Ethics statements

Studies involving animal subjects

Generated Statement: No animal studies are presented in this manuscript.

Studies involving human subjects

Generated Statement: No human studies are presented in this manuscript.

Inclusion of identifiable human data

Generated Statement: No potentially identifiable human images or data is presented in this study.

In review

Data availability statement

Generated Statement: The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

In review

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2 **10- to 14-year-old adolescents in Amsterdam from a multi-actor**
3 **perspective**

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32
33 **Keywords: overweight and obesity, adolescents, complex systems, causal loop diagram,**
34 **system dynamics**

35
36 **Running title: System dynamics of obesity-related behaviours**

37
38 Word count: 7755 words

39
40 Number of figures: 10 figures (including 3 Appendix figures)

41
42 Number of tables: 0

47 **Abstract**

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To develop an understanding of the dynamics driving obesity-related behaviours in adolescents, we conducted systems-based analysis on a causal loop diagram (CLD) created from a multi-actor perspective, including academic researchers, adolescents and local stakeholders. The CLD contained 121 factors and 31 feedback loops. We identified six subsystems with their goals: 1) interaction between adolescents and the food environment, with profit maximisation as goal; 2) interaction between adolescents and the physical activity environment, with utility maximisation of outdoor spaces as goal; 3) interaction between adolescents and the online environment, with profit maximisation from technology use as goal; 4) interaction between adolescents, parenting and the wider socioeconomic environment, with a goal focused on individual parental responsibility; 5) interaction between healthcare professionals and families, with the goal resulting in treating obesity as an isolated problem; and 6) transition from childhood to adolescence, with the goal centring around adolescents' susceptibility to an environment that stimulates obesity-related behaviours. Analysis showed that inclusion of the researchers' and stakeholders' perspectives contributed to an understanding of how the system structure of an environment works. Integration of the adolescents' perspective enriched insights on how adolescents interact with that environment. The analysis further showed that the dynamics driving obesity-related behaviours are geared towards further reinforcing such behaviours.

In review

72 1. Introduction

73
74 Public health problems such as childhood overweight and obesity result from the interaction
75 of multiple factors within a complex adaptive system. A complex adaptive system can be
76 defined as a collection of interconnected factors that is more than the sum of its parts (1).
77 Such factors operate at multiple levels – ranging from individual behaviours like the amount
78 of sedentary time to more upstream factors related to the economic, sociocultural, physical
79 and political environments (2). Identifying such factors and interconnections is considered an
80 important step in gaining an understanding of a complex adaptive system. This understanding
81 can enable action to bring about systems change, and it can serve as a basis to assess changes
82 over time (3).

83 One way of developing a system understanding is through *system mapping*. A
84 frequently used mapping tool is the *causal loop diagram* (CLD) (4). Such diagrams provide
85 visual representations of the complexity of a problem, depicted in the form of factors, causal
86 relationships, polarity and feedback loops (5). A well-known example of a CLD system map
87 is the Foresight map. It identifies a broad range of factors that influence childhood overweight
88 and obesity, thus providing a ‘whole’ picture of the system (6). At the core of the Foresight
89 map is ‘energy balance’ around which are over 100 interconnected factors clustered in seven
90 major sub-systems directly or indirectly affecting energy balance. For the first time, this map
91 showed that obesity results from many interconnected policy, environmental, social,
92 economic, cultural, behavioural, and biological causes. While succeeding in effectively
93 illustrating the wide range of causes of obesity, the Foresight map was developed by experts
94 based on empirical research literature, and it thus creates an *academic perspective* on the
95 system in question.

96 Another potential important perspective to take into account is that of *stakeholders*.
97 Friel et al., (7) for example conducted collaborative conceptual modelling workshops with
98 stakeholders from different sectors in Australia including academia, non-governmental health
99 organizations and government to create a system map that illustrated the multiple factors
100 associated with inequities in healthy eating. This system map resulted in the identification of
101 seven sub-systems including 1) food supply and environment; 2) transport; 3) housing and the
102 built environment; 4) employment; 5) social protection; 6) health literacy; and 7) food
103 preferences. One more potential important perspective to consider is that of the *targeted*
104 *group* itself, often identified through methods such as group model building (GMB) (8-11).
105 Savona et al., (11) conducted for example GMB with adolescents in five European countries
106 in order to map the factors that they considered to be important obesity drivers. In the overall
107 systems map that represented the perspective of more than 200 adolescents, three sub-systems
108 stood out: 1) commercial drivers of adolescents’ unhealthy diet; 2) mental health and
109 unhealthy diet; and 3) social media use, body image and motivation to exercise.

110 A common characteristic of such CLDs is that they provide a single perspective on the
111 system – a perspective of experts based on research literature or a perspective of stakeholders
112 or of the target group. What is still missing, to our knowledge, is a system map or CLD that
113 *integrates* multiple perspectives, including those from experts, various stakeholder groups and
114 the target group itself. Such a *multi-actor perspective* is important because different actors
115 have different perceptions of the causes of a problem, and these influence the ways in which
116 the system can be changed (12-14). Hence, when mapping a system, one should ideally
117 consider the perspectives of the various actors in order to obtain a more complete system
118 understanding (12, 13). Indeed, in their framework for transformative systems change, Foster-
119 Fishman and colleagues have described such a system understanding from a multi-actor
120 perspective as a key step in the process towards effecting systems change, as this accentuates
121 the subjective nature of understanding systems (13).

122 Another common characteristic of most CLD papers in the literature, including the
123 abovementioned examples, is that these mostly focus on developing and understanding of the
124 system in terms of *system structure*, describing the included factors, connections and feedback
125 loops of a particular problem (4). Foster-Fishman and colleagues further emphasise in their
126 framework that one not only needs an understanding of the *system structure* when trying to
127 understand the targeted system, but an understanding of the *system function* is also required in
128 order to change the status quo of a system. Such a system function understanding includes a
129 more in-depth analysis of the system as a whole, which identifies and understands the deeper
130 system dynamics in terms of structure, goals and paradigm (13, 15).

131 In this paper, we aim to identify and understand the underlying system dynamics that
132 drive obesity-related behaviours in 10- to 14-year old adolescents in Amsterdam, by
133 conducting systems-based analysis from a multi-actor perspective. We report on how we
134 applied systems dynamics methods to assess the extent to which these methods led to new
135 understandings of the targeted problem in the local context.
136
137

138 2. Methods

139 140 2.1 The LIKE programme

141 The results presented in this study are part of the larger Lifestyle Innovations Based on Youth
142 Knowledge and Experience (LIKE) programme (16), which is part of the Amsterdam Healthy
143 Weight Programme, a local-government-led whole-systems approach (17). The LIKE
144 programme is designed to tackle childhood overweight and obesity in 10- to 14-year-old
145 adolescents in three neighbourhoods with a low socioeconomic status in the Amsterdam East
146 city district in the Netherlands. It combines a system dynamics and participatory action
147 research approach in order to develop, implement and evaluate a dynamic action programme.
148 To arrive at such dynamic action programme, the first part of LIKE focuses on developing an
149 understanding of the targeted system. In LIKE, we refer to this system understanding as the
150 pre-existing system of obesity-related behaviours in 10- to 14- year-old adolescents in
151 Amsterdam. We allude to ‘pre-existing system’ because in systems evaluations, there is no
152 control or baseline system, rather, the system continuously changes over time either with or
153 without intentional intervention (3).
154

155 2.1.1 Procedures

156 In LIKE, we combine three different perspectives to achieve a system understanding. The
157 academic researchers’ perspective provides an external view of the system and was published
158 here (18). In this paper we enriched our system understanding by adding the adolescents’ and
159 stakeholders’ perspectives to provide an additional internal view of the system. On top of that,
160 we conducted system-based analysis to understand the underlying system dynamics. This was
161 operationalized by following a three-step process. First, data were collected separately from
162 the different perspectives. The data were then integrated to arrive at an overarching map, or
163 CLD, of the pre-existing system. Finally, the resulting CLD was analysed using system-based
164 methods to understand the underlying system dynamics. The exact procedures are detailed
165 below. Ethical approval for the data collections was obtained from the institutional medical
166 ethics committee of Amsterdam UMC, Location VUMC (2018.234).
167

168 **2.2 Step 1. Data collection from a multi-actor perspective**

169 To operationalize the central aim of identifying and understanding the underlying system
170 dynamics that drive obesity-related behaviours we focused on four behaviours that are
171 particularly significant to childhood overweight and obesity and which are also the focus of
172 the Amsterdam Healthy Weight Programme. These include dietary behaviour, physical
173 activity, sedentary behaviour and sleep. We conducted an in-depth needs assessment in LIKE
174 between 2018 and 2021 to gain insights of the system dynamics that related to these four
175 behaviours. Of note, as our focus was in uncovering the system dynamics, we collected data
176 that accounted for the change over time of factors influencing the four targeted behaviours,
177 rather than a static situation. A central question for the collection of data was therefore: “What
178 factors explain the dynamics in dietary behaviour, physical activity, sleep, and sedentary
179 behaviour, in 10- to 14- year-old adolescents Amsterdam in the past three decades?”. During
180 the needs assessment period, various methods were employed, including the construction of
181 CLDs by academic researchers based on research literature (18); construction of CLDs by
182 adolescents (Helga Emke et al., unpublished data, 2022); GMB with stakeholders, including
183 parents and other actors in the direct environment of adolescents (schoolteachers, sport
184 coaches etc.) (Wilma Waterlander et al., unpublished data, 2022); and interviews with
185 healthcare professionals (HCPs) (19), (Emma van den Eynde et al., unpublished data, 2022).

187 **2.2.1 Researchers’ perspective**

188 As mentioned above, the academic researchers’ perspective on the pre-existing system had
189 previously been captured in LIKE during 2019–2020 (18). Based on a selection of factors
190 retrieved from systematic reviews, four CLDs were created around physical activity, dietary
191 behaviour, sedentary behaviour and sleep. These CLDs revealed the presence of dynamics
192 including feedback loops, mechanisms and subsystems. Highlighted subsystems included for
193 example home and school environments but also newly identified subsystems such as urban
194 systems, social welfare and macroeconomics. For more details on the construction of these
195 four CLDs and results hereof, we refer to the work of Waterlander and colleagues (18).

197 **2.2.2 Adolescents’ perspective**

198 Participatory action groups were conducted between 2018 to 2020 at two primary and two
199 secondary schools located in the LIKE target areas in Amsterdam East. Participatory action
200 groups consisted of four to eight adolescents aged 10 to 14 and an academic facilitator. In
201 these participatory groups, adolescents were first trained in research skills, and they
202 subsequently investigated, among their peers, the factors that influenced their dietary
203 behaviour, physical activity, sedentary behaviour and sleep. Adolescents then analysed the
204 collected data separately for primary and secondary schools and summarised the major factors
205 associated with the four targeted behaviours into six CLDs (three constructed by primary
206 school children and three CLDs by secondary school adolescents). From these CLDs, three
207 overarching subsystems were identified: 1) Adolescents live in a physical activity
208 environment with easy access to unhealthy food products; 2) Social norm around unhealthy
209 behaviours are formed by peers, friends and family; and 3) Unhealthy behaviours are
210 interrelated and reinforce each other. Details of the participatory action group process will be
211 published elsewhere (Helga Emke et al., unpublished data, 2022).

213 **2.2.3 Stakeholders’ perspective**

214 The stakeholders’ perspective was captured through two different methods. First, four GMB
215 workshops were held in 2020–2021 in Amsterdam East. 29 to 31 stakeholders participated in
216 the different rounds and represented the sectors schools, healthcare, local government, the

217 Amsterdam Healthy Weight Programme, sports clubs, and community and youth
218 organisations (including volunteers and parents). During the GMB workshops, participants
219 constructed a CLD around dietary behaviour, physical activity, sedentary behaviour and sleep,
220 in adolescents from their perspective as local stakeholders. This CLD revealed the presence of
221 five subsystems: 1) the food environment; 2) the home environment; 3) sleep; 4) physical
222 activity; and 5) transition from 10 to 14 years. The details of the GMB process will be part of
223 a separate paper (Wilma Waterlander et al., unpublished data, 2022).
224 Lastly, interviews with 18 HCPs were conducted in 2019–2020 to gather data about barriers
225 and facilitators that bear upon obesity-related behaviours in adolescents with obesity and their
226 parents. These barriers and facilitators were summarized into seven themes including 1)
227 individual child factors; 2) role of the parents; 3) physical environment; 4) socioeconomic
228 environment; 5) cultural environment; 6) family’s experience with healthcare; and 7) family’s
229 motivation. For more details on these results we refer to (19). Moreover, the HCPs interviews
230 data were also used to identify barriers and facilitators that influence the professional support
231 and care for adolescents with obesity and their parents. Identified themes included for
232 example conducting a biomedical, psychosocial and lifestyle assessment, tailoring the
233 approach to the adolescent and parents’ needs, and investing in building a relationship. Details
234 will be provided elsewhere (Emma van den Eynde et al., unpublished data, 2022).

235 236 **2.3 Step 2. Developing the map of the pre-existing system**

237 On the basis of the data sources outlined above, the next step involved the integration of the
238 data to arrive at a multi-actor perspective CLD of the pre-existing system. The process is
239 outlined below. Maps were first created using STICK-E software (STICK-E version 3,
240 Deakin University) and then imported in KUMU (Relationship mapping software, 2022) for
241 editing purposes. The final representation of the pre-existing map was edited in Adobe
242 Illustrator CS5.

243 244 **2.3.1 Step 2.1 Merging the researchers’ literature-based CLDs**

245 The first step consisted of constructing a ‘baseline’ CLD system map. As input for this
246 baseline CLD, the four separate CLDs – relating to adolescents’ dietary behaviour, physical
247 activity, sedentary behaviour and sleep, representing the academic perspective (18) – were
248 merged into an overarching baseline CLD covering all four behaviours. System map
249 development started with the researchers’ perspective because those CLDs were already
250 published while the CLDs from the other perspectives were still being developed. Integration
251 of the four separate CLDs was performed by merging the CLDs on the basis of common
252 factors. For example, the sedentary behaviour CLD was linked with the sleep CLD by the
253 factor ‘screen use’, which was present in both CLDs. Next, the resulting baseline CLD was
254 iteratively refined by removing duplicate variables and by making sure each factor was at the
255 same level of detail and specificity (20). For example, the factors ‘screen use for school or
256 work’ and ‘use of screen-based social media by adults’ were incorporated into the ‘screen use
257 as social norm’ factor. This process resulted in a baseline system map that reflected the
258 researchers’ perspective.

259 260 **2.3.2 Step 2.2 Adding the adolescents’ perspective**

261 The next step involved integrating the perspective of adolescents into the baseline map.
262 Factors associated with dietary behaviour, physical activity, sedentary behaviour and sleep
263 that were present in the six CLDs constructed by adolescents (Helga Emke et al., unpublished
264 data, 2022), but still absent in our evolving map, were extracted. Examples include ‘gaming’,
265 ‘nightmares’, ‘biking’, and ‘supermarket proximity’. As well single factors as connections
266 between the factors were added to the map. These connections were based upon the causal

267 connections and polarity identified by adolescents in the original six CLDs. A positive
268 polarity marked positive causation meaning that as a cause increases, the effect also increases;
269 or that as a cause decreases, the effect also decreases (more chicken leads to more eggs). A
270 negative polarity marked inverse causation meaning that as a cause increases, the effect
271 decreases; or that as a cause decreases, the effect increases (more foxes leads to less chicken)
272 (18).

273

274 **2.3.3 Step 2.3. Adding the stakeholders' perspective**

275 Integration of the stakeholders' perspective into the system map followed a two-step process.
276 First, factors present in the stakeholders' CLD (produced in the GMB workshops) but still
277 absent in our system map were added. Those factors related to issues such as health (e.g.
278 'listening to your own body', 'health as a priority') and the home environment (e.g. 'parents
279 as role models', 'parents in survival mode'). Connections between the newly added factors
280 were drawn by the present authors reflecting the direction of causality between factors as
281 observed in the original stakeholders' CLD. Second, the interview data from HCPs were
282 incorporated. As previously mentioned, these data were used to identify themes around
283 barriers and facilitators influencing both obesity-related behaviours in adolescents with
284 obesity and their parents (19) as well as around the professional support and care that those
285 adolescents and parents receive (Emma van den Eynde et al., unpublished data, 2022).
286 Because those data were not in the form of CLDs, we reviewed the identified themes and sub-
287 themes and treated these as factors in order to add these to our system map. Examples of
288 newly added factors include 'parents being supportive and involved' and 'vagueness of the
289 healthcare system'(19). Some factors from the original data were not added, because their
290 level of detail and specificity did not equate with that of the factors already included (overly
291 broad formulations such as 'obesogenic environment' or 'the healthy choice should be the
292 easy choice'). Because the original HCPs data merely noted factors and made no connections
293 between them, we iteratively drew connections and identified directions of causality, based on
294 our interpretations of the data. The researcher that collected the original data (EvdE) closely
295 monitored this process.

296

297 **2.3.4 Step 2.4. Identification of feedback loops**

298 Lastly, the connections and directions of causality between all factors in the evolving system
299 map were re-assessed to facilitate identification of feedback loops. A feedback loop refers to a
300 sequence of factors and interconnections that creates a closed loop of causal influences (3).
301 Feedback loops can either be reinforcing, which indicates exponential growth or decay, or
302 balancing, indicating stabilization or tending to equilibrium (21). The identification of
303 reinforcing and balancing feedback loops was performed by ALP and WW, and reviewed by
304 the rest of authors of the present study. Altogether, this process resulted in the creation of a
305 multi-actor map of the pre-existing system of obesity-related behaviours in adolescents.

306

307

308 **2.4 Step 3. System-based analysis of the map of the pre-existing system**

309 In the final step, a system-based analysis (17) of the CLD of the pre-existing system was
310 performed to gain an understanding of the dynamics of obesity-related behaviours. This
311 analysis was performed using the Intervention Level Framework developed by Johnston and
312 colleagues and is based on five levels: system paradigm, goals, structure, feedback loops and
313 elements (22). We used the Intervention Level Framework to distinguish the structure and
314 function of the pre-existing system.

315 To understand the system structure, we analysed the CLD to assess the identified
316 factors (ILF level *elements*) and feedback loops (ILF level *feedback loops*). The clustering of
317 feedback loops revealed the presence of specific themes that helped us identify subsystems
318 and the overall system structure (ILF level *structure*). The identification of the system
319 structure as well as the subsystems was carried out iteratively through group discussions by the
320 authors until consensus was reached. To understand the system function, we subsequently
321 tried to identify subsystem goals (ILF level *goals*) and the overarching system paradigm (ILF
322 level *system paradigm*). This was done by building on existing expert knowledge on system
323 function, for example as detailed in the report of the Lancet Commission on Obesity (23).
324 Finally, both the map of the pre-existing system and the system-based analysis were reviewed
325 by all authors to make sure all collected data were accurately presented in the CLD and
326 correctly interpreted.
327

328 3. Results

329 In total, we identified 121 unique factors in the final systems map; 50 of these derived from
330 the researchers' perspective, 74 from the adolescents' perspective and 54 from the
331 stakeholders' perspective (Figure 1). Due to overlap between the perspectives, the sum of the
332 factors from all perspectives is greater than the total number of factors in the integrated
333 system map. We also identified a total of 31 reinforcing feedback loops. Six different
334 subsystems emerged (Figure 1). The total numbers of factors within each subsystem from the
335 three perspectives, as well as the numbers of factors that were unique to a single perspective
336 in each subsystem, are shown in Figure 2. Subsystem 6 is not shown in that figure, as the
337 factors in that subsystem were embedded in the other five, as explained below. Identified
338 factors, feedback loops, system structures and system goals will be discussed below
339 separately for each of the six identified subsystems.

340

341 Figure 1. Pre-existing system of obesity-related behaviours in an integrated multi-actor
342 perspective with identified subsystems

343

344 Figure 2. Total numbers of factors and unique factors from the perspectives of researchers,
345 adolescents and stakeholders in subsystems 1–5

346

347 Figure 3. Subsystem 1: Interaction between adolescents and the food environment

348

349 3.1 Subsystem 1: Interaction between adolescents and the food environment

350 Figure 3 illustrates the interaction between adolescents and the food environment. Out of a
351 total of 23 factors, 12 were derived from the researchers' perspective, 17 from the
352 adolescents' perspective and 12 from the stakeholders' perspective. A total of 11 factors were
353 unique to a single perspective. Six reinforcing feedback loops were identified as we integrated
354 all perspectives (Figure 3, R1–R6).

355 The first two reinforcing feedback loops (R1, R2) relate to the relatively low price of
356 unhealthy food, which makes unhealthy food more attractive and easily accessible. This
357 boosts the demand for unhealthy food, which in turn allows food providers to maintain lower
358 prices. The high demand for unhealthy food, in turn, reinforces the availability and
359 accessibility of unhealthy food. The second two reinforcing feedback loops (R3, R4) reveal
360 how this demand and supply chain of unhealthy food leads to high revenues, which can then
361 be used for the marketing of such foods, thereby further reinforcing the availability and
362 accessibility of unhealthy food.

363 Another feedback loop relates to the social norm that eating unhealthy food is cool and
364 normal. In most larger Dutch towns and cities, a supermarket is found on almost every street
365 corner. Visiting the supermarket with friends during school hours and buying unhealthy food
366 together is seen by many adolescents as normal behaviour and as a fun and attractive social
367 activity. This reinforces the social norm that eating unhealthy food is cool and normal (R6).

368 In addition to physical exposure, we found a feedback loop involving online exposure
369 to unhealthy food. Adolescents typically spend a large amount of their time in online
370 environments. Especially on social media platforms, peer pressure to buy and eat unhealthy
371 food is commonly prevalent (for example when influencers advertise unhealthy foods) (R5).
372 This further sustains the social norm that eating unhealthy food is cool and normal.

373 Taking together all 23 factors, their interconnections, and the six reinforcing feedback
374 loops, we see a system structure revolving around the comparatively high availability,
375 accessibility and affordability of unhealthy food. Such food may be preferred by adolescents
376 not only because of the easy access, but also through the prevailing social norm that eating
377 unhealthy food is cool and normal. This is further reinforced by marketing, social media and
378 peer-group influence surrounding unhealthy foods. In terms of system goals, we observe that
379 these factors belong to a larger system that focuses on profit maximisation, which can be
380 achieved by selling as much food as possible – whereby unhealthy foods (heavily processed
381 and with high energy density or high sugar, salt and fat content) are the more profitable
382 option. For example, the stakeholders in our GMB workshops explained that local business
383 owners prefer unhealthy over healthy foods, because the revenues are larger and the losses (as
384 from food waste, logistics and cooling) are much lower.

385

386 Figure 4. Subsystem 2: Interaction between adolescents and the physical activity environment

387

388 **3.2 Subsystem 2: Interaction between adolescents and the physical activity environment**

389 Figure 4 illustrates the interaction between adolescents and the physical activity environment.
390 A total of 31 factors emerged, of which 17 derived from the researchers' perspective, 26 from
391 the adolescents' perspective and 8 from the stakeholders' perspective. In total 17 of the
392 factors were unique to a single perspective. Seven reinforcing feedback loops were identified
393 in integrating the perspectives (Figure 4, R7–R13).

394 Reinforcing feedback loop R7 illustrates how urbanisation generally increases traffic
395 density and neighbourhood deprivation, resulting in limited outdoor space for active play. The
396 high demand for housing and businesses in cities like Amsterdam has prompted the building
397 of sport facilities on the outskirts of neighbourhoods, thereby increasing the distance to the
398 facilities; as a consequence, adolescents make less use of the facilities. A related factor is
399 greater traffic density, which generally reduces the perceived safety of the physical activity
400 environment. Adolescents then cycle less and make more use of public transport. This
401 hampers sustainment of a healthy social norm of active outdoor play and active transportation
402 (R8). The more the physical activity environment is perceived as unsafe, the more its
403 attractiveness to adolescents declines, leading to lower participation by adolescents and their
404 peers in active play and transport (R9). Also due to the perceived unsafety, parents will be
405 less motivated to encourage habits of active play and transport, further weakening the healthy
406 social norm (R10). In turn, once a social norm of active outdoor play and transport does not
407 prevail, adolescents will be less encouraged to create free time for such activities, thus further
408 reducing their motivation (R11). That may make alternative, more sedentary behaviours, such
409 as screen use, more attractive (R11, R12) (thus linking with subsystem 3 below) and thereby
410 make the physical activity environment all the less enjoyable (R12, R13).

411 Taking all 31 factors, their interconnections and their seven reinforcing feedback loops
412 together, we see a system structure with dwindling availability of attractive, safe outdoor

413 spaces for physical activity by adolescents. This undermines a healthy social norm of outdoor
414 active play and active transportation. We note that this structure is part of a larger system goal
415 that revolves around maximising utility for limited urban space by prioritising housing,
416 business and motorised transport above outdoor space for active play.

417
418 Figure 5. Subsystem 3: Interaction between adolescents and the online environment
419

420 **3.3 Subsystem 3: Interaction between adolescents and the online environment**

421 Figure 5 illustrates the interaction between adolescents and the online environment. From a
422 total of 38 factors, 19 derived from the researchers' perspective, 32 from the adolescents'
423 perspective and 7 from the stakeholders' perspective. A total 24 of the factors were unique to
424 a single perspective. Twelve reinforcing feedback loops were identified in integrating the
425 perspectives (Figure 5, R14–R25).

426 The first feedback loop (R14) relates to screen use as part of everyday life. Virtually
427 all ordinary tasks of adolescents, including schoolwork, require using screens. This results in
428 a society that is highly dependent on technology, and where the high demand and supply of
429 new technologies further reinforce that dependency and help sustain the social norm of screen
430 use as part of everyday life. The screen use norm is reinforced yet further by a fear among
431 adolescents of missing out (FOMO) on what happens online; this induces an addictive effect
432 of constantly wanting to be online (R15, R16). Social media use by adolescents plays herein
433 an important role. The countless notifications received from WhatsApp, Instagram and
434 TikTok further fuels adolescents' curiosity to stay up to date, not to miss out, and hence to be
435 perpetually online (R17). Adolescents' high levels of screen use are not only common during
436 the daytime; they also use screen devices before bedtime, adversely affecting sleep and
437 reducing restful moments (R18). Social media use, watching Netflix, YouTube and movies,
438 and gaming are activities frequently performed by adolescents in evening and nighttime hours
439 (R19–R21). These reinforce a social norm that it is cool to stay awake (R19–R24). Screen use
440 at night is often accompanied by snacking and caffeine use, giving adolescents an even
441 greater sensation of energy, causing pre-sleep alertness and adversely affecting sleep and
442 dietary behaviour (R21–R22). Furthermore, they often experience nightmares after gaming or
443 watching horror movies, and this also affects sleep (R23–R25).

444 Taking together all 38 factors, their interconnections and twelve reinforcing feedback
445 loops, we see a system structure revolving around 24/7 availability and accessibility of
446 screens, whereby everyday life tasks are increasingly performed on screens. We observe that
447 this screen use maximisation is part of a larger system whose goal is to maximise the profits
448 obtained from technology use. For example, adolescents who like videogames generally
449 follow their favourite gaming influencers on streaming channels. The more followers those
450 influencers have, the more profits these can make through lucrative deals offered by private
451 sector companies – such as for advertising unhealthy food in their videos – and the more
452 profits those companies eventually make.

453
454 Figure 6. Subsystem 4: Interaction between adolescents, parenting and the wider
455 socioeconomic environment
456

457 **3.4 Subsystem 4: Interaction between adolescents, parenting and the wider 458 socioeconomic environment**

459 Figure 6 illustrates the interaction between adolescents, parenting and the wider
460 socioeconomic environment. In a total of 31 factors, 14 derived from the researchers'
461 perspective, 14 from the adolescents' perspective and 18 from the stakeholders' perspective.

462 A total of 19 of the factors were unique to a single perspective. Three reinforcing feedback
463 loops were identified in integrating the perspectives (Figure 6, R26–R28).

464 The first feedback loop (R26) relates to a large number of households in our research
465 community living in relative poverty, where parents typically have long, inflexible working
466 hours and hence limited free time and higher stress levels. This, in turn, may put parents in a
467 ‘survival mode’, leaving limited headspace for matters such as preparing healthy meals.
468 Parents find themselves in a vicious circle as financial problems accumulate; that triggers
469 even more stress, as they often need to solve such multiple problems in a short time span
470 (R27).

471 With such financial problems occupying parents’ headspace, they often pay less
472 attention to their children’s health behaviours. As parents have less time for their children,
473 grandparents may play a greater role in the upbringing of adolescents (R28). In our research
474 community, a large percentage of such grandparents come from cultures where unhealthy
475 eating may be seen as tradition and culture, for example when guests are welcomed with an
476 abundance of food, usually unhealthy.

477 In combination with the parents’ limited headspace, their transition to their new role as
478 coaches or mentors of young adolescents, rather than childrearsers of younger children,
479 commonly makes it difficult for them to set, monitor and enforce rules regarding sleep,
480 dietary behaviour, screen behaviour and physical activity.

481 Taking together all 31 factors, their interconnections and three reinforcing feedback
482 loops, we see a system structure that revolves around parents’ limited capabilities to stimulate
483 healthy behaviours, in particular in ethnically diverse groups of lower socioeconomic status.
484 Parents are subject to competing demands and stressors, possibly relating to financial worries,
485 long working hours, general uncertainty, and traditional cultural roles and patterns. We note
486 that this is part of a larger system whose goals prescribe individual responsibility while
487 compelling parents to prioritise household livelihood security at the expense of stimulating
488 healthy behaviours.

489

490 Figure 7. Subsystem 5: Interaction between families and healthcare

491

492 **3.5 Subsystem 5: Interaction between healthcare professionals and adolescents with** 493 **obesity and their parents**

494 Figure 7 illustrates the interaction between healthcare professionals (HCPs) and adolescents
495 with obesity and their parents. From a total of 27 factors, 2 factors derived from the
496 researchers’ perspective, 1 from the adolescents’ perspective and 27 from the stakeholders’
497 perspective. A total of 25 of these factors were unique to a single perspective, that of the
498 stakeholders. The reason for the comparatively large number of factors in the stakeholder
499 perspective is that ‘healthcare’ was not included nor discussed as a potential subsystem in the
500 researchers’ and adolescents’ original data, but only in the stakeholder data. Moreover, in
501 contrast to the other identified subsystems, the healthcare subsystem data relates specifically
502 to adolescents *with obesity* in a healthcare setting or context, rather than to the general
503 population. Three reinforcing feedback loops were identified (R29–R31).

504 All three of the reinforcing feedback loops were linked to a single feedback loop
505 outlined in subsystem 4 involving the interaction between adolescents, parenting and the
506 wider socioeconomic environment (Figure 6, R26). It showed that poorer families in our
507 research community were often in survival mode, with limited headspace to think about
508 health-related behaviours. This feedback loop feeds into the factors of ‘low general priority
509 for health’ and ‘limited awareness of a health problem’ (in this case, overweight) (R29, R30).
510 From the perspective of HCPs, this results in families showing little motivation to change

511 unhealthy behaviours; this could lead to normalisation of overweight and obesity and to
512 misperceptions of what constitutes a healthy weight (R30).

513 The three reinforcing feedback loops further show that a number of factors are
514 important to ensure that families have a positive healthcare experience. These include
515 investing in a family–professional relationship, offering a treatment approach tailored to a
516 family’s needs, and managing treatment expectations between families and HCPs (R31). The
517 interviews with HCPs revealed that achieving these aims is not automatically assured. One
518 challenging situation may arise when HCPs regard a healthy lifestyle from a Western
519 European perspective, hence not sufficiently taking the cultural diversity of families into
520 account. Culture serves here as an example of underlying factors related to obesity that may
521 not be readily observable to HCPs but may nevertheless contribute to the problem.

522 Taking together all the 27 factors, their interconnections and the three feedback loops,
523 we see a subsystem where many conditions, such as a family–professional relationship and a
524 tailored approach to a family’s needs, must be met if adolescents with obesity and their
525 parents are to modify and sustain health behaviours. The interviews with HCPs revealed that
526 these conditions have not yet been fully achieved in the healthcare system, for reasons such as
527 insufficient time for appropriate care and support and insufficient consideration of families’
528 cultural aspects by HCPs. This results in a system that treats obesity mainly as an isolated
529 medical problem, with little attention for the social and cultural contexts that affect problem
530 management by adolescents and parents.

531

532 **3.6 Subsystem 6: Transition from childhood to adolescence**

533 In analysing the sixth subsystem, we took a slightly different approach as compared to
534 previous subsystems. The reason is that the factors relating to the child-to-adolescent
535 transition are embedded within the various other subsystems (Figure 1), rather than forming
536 feedback loops that are unique to this subsystem itself. Subsystem 6 therefore tightly interacts
537 with the five subsystems previously discussed.

538 We noted that, during this transition period, adolescents are extra susceptible to the
539 influence of the system they are a part of. Such susceptibility may manifest itself in a display
540 of obesity-related behaviours. During the transition, adolescents generally increase their
541 consumption of unhealthy foods (subsystem 1), decrease their levels of physical activity
542 (subsystem 2) and increase their sleep-affecting screen time (subsystem 3). We identified
543 three principal factors that foster susceptibility to systemic influence. The first relates to the
544 adolescent urge for freedom. Greater autonomy and independence enables them, for example,
545 to purchase unhealthy food from easy accessible environments (such as supermarkets). The
546 second factor reflects the adolescent desire to be part of and accepted by a group, making
547 them particularly vulnerable to peer pressure and to influences from social media. The third
548 factor involves seeking instant gratification. It is more gratifying for adolescents to spend long
549 hours gaming with their friends and ‘enjoying the moment’ (subsystem 3) than to force
550 themselves to be physically active because that would be good for their health (subsystem 2).
551 Long-term health benefits are not typically prioritised by adolescents during this transition
552 period; and parents, who could help curb unhealthy habits, may experience diminished
553 influence on their children (subsystems 4 and 5). During the transition from childhood to
554 adolescence, parents shift from a childrearing role to more of a coaching or mentoring role.
555 The new role can make it difficult for parents to set, monitor and enforce rules about healthy
556 behaviours (subsystem 4).

557 We conclude that the wider system goal here is linked to biological and psychosocial
558 mechanisms, which include increased autonomy and independence, susceptibility to peer
559 pressure and social media exposure, and gratification-seeking – factors that make adolescents
560 specifically susceptible to an environment that fosters obesity-related behaviours. Adolescents

561 report, for instance, that they are continuously exposed to a multitude of unhealthy food
562 advertisements and providers in their close surroundings. This may not only trigger a craving
563 for unhealthy food, but it may also constrain them from escaping that environment to seek
564 healthier foods and activities.
565

566 **4. Discussion**

567 This study sought to identify and understand the underlying system dynamics that drive
568 obesity-related behaviours in adolescents. We developed a CLD with a multi-actor
569 perspective and subsequently performed systems-based analysis to understand the pre-existing
570 system in terms of both system structure and function. The focus was on adolescents aged 10
571 to 14 in an urban setting. The resulting CLD contains 121 unique factors, 31 feedback loops
572 and 6 subsystems (revealing system structure) with their corresponding system goals
573 (revealing system function).

574 The first subsystem reveals the interaction between adolescents and the food
575 environment. The system goal is *profit maximisation*, which can be achieved by selling as
576 much food as possible, with the more profitable option being unhealthy foods (heavily
577 processed, high energy density, high in sugar, salt or fat). Subsystem 2 shows the interaction
578 between adolescents and the physical activity environment, whereby the system goal is *utility*
579 *maximisation* for limited urban space, with housing, business and motorised transport
580 prioritised above outdoor space for active play. Subsystem 3 focuses on the interaction
581 between adolescents and the online environment, with a system goal of *profit maximisation*
582 *from technology use*. Subsystem 4 shows the interaction between adolescents, parenting and
583 the wider socioeconomic environment; system goals prescribe *individual responsibility*,
584 which may compel parents to prioritise household livelihood security at the expense of
585 stimulating healthy behaviours. Subsystem 5 highlights interaction between healthcare
586 professionals and families, with a system goal under which obesity is *treated as an isolated*
587 *medical problem*, with insufficient attention to social and cultural contexts that may hinder
588 adolescents and their parents in managing the problem. Subsystem 6 relates to the dynamics
589 of the child-to-adolescent transition, which can also be seen as an element in each of the other
590 five subsystems; here the system goal relates to *biological and psychosocial mechanisms* –
591 increased autonomy and independence, susceptibility to peer pressure and social media
592 exposure, seeking instant gratification – which make adolescents particularly vulnerable to an
593 environment that fosters obesity-related behaviours.
594

595 **4.1 Findings relating to system structure**

596 The CLD presented in this study shows the combined perspectives of academic researchers,
597 adolescents and stakeholders. Overall, adolescents contributed the most factors to the CLD
598 (74/121), followed by stakeholders (54/121) and researchers (50/121). That finding applied
599 both to unique factors and to factors deriving from multiple perspectives, and it underlines the
600 importance of including multiple perspectives. For example, in subsystem 3 (interaction
601 between adolescents and the online environment), the researcher and stakeholder perspectives
602 highlighted the social norm around screen use as a key mechanism in this subsystem.
603 However, only after we included the adolescents' perspective did it become apparent what
604 this mechanism actually meant to adolescents – that screen use in the form of social media,
605 gaming and movie-watching serves to sustain a social norm that it is cool to stay awake at
606 night.

607 We further explored that finding by highlighting the factors in the CLD separately for
608 each perspective (Figure S1, S2, S3); this reveals that important information on the system
609 structure is lost in each separate CLD. For example, looking at the feedback loops for each

610 single perspective, we found 7 loops for the academic researchers, 12 loops for the
611 adolescents and 5 loops for the stakeholders, whereas integrating the perspectives resulted in
612 31 reinforcing feedback loops. Generally speaking, the researchers' and stakeholders'
613 perspectives contributed to the exposure of the system structure, of *how a specific*
614 *environment works*, whereas integration of the adolescents' perspective revealed *the ways in*
615 *which adolescents interact* with this environment. For example, from the researcher
616 perspective we learned that screen use as a social norm is sustained by an environment that
617 reinforces supply and demand for technological devices. The adolescent perspective then
618 showed how that social norm is *further* sustained in activities like purchasing the latest video
619 gaming devices in the market and using them as instruments of peer interaction in the online
620 world. Previous studies have likewise underlined the importance of including multiple
621 perspectives to obtain a fuller understanding of a system (13). In a study by McGlashan and
622 colleagues (24), factors present in a Foresight map (6) were compared with factors present in
623 a map developed by community stakeholders (8). This showed that the largest proportion of
624 factors in the Foresight map focused on the physiology cluster (23%), whereas social
625 psychology was the largest cluster in the community stakeholders' map (38%), with a mere
626 2% of factors focused on physiology.

627

628 **4.2 Findings relating to system function**

629 Whilst analysis of system structure in terms of system factors and feedback loops provides
630 important information about a system, it does not yet provide insights into the deeper system
631 dynamics (system goals). The latter can be referred to as *system function*, and it is crucial for
632 understanding, and subsequently changing, the system as a whole.

633 First, our analysis of the system as a whole revealed that the system primarily contains
634 reinforcing feedback loops encouraging obesity-related behaviours, without balancing
635 feedback loops discouraging the behaviours. While this finding can partly be explained by the
636 methods we used (with a focus on obesity-related behaviours), it does show a system geared
637 to reinforcing obesity-related behaviours. One subsystem that could potentially serve as a
638 balancing loop is the healthcare system (subsystem 5). In practice, however, the conditions for
639 good obesity care – where social and cultural contexts would form an integral part of the
640 treatment of adolescents with obesity – are not yet being fully satisfied. Moreover, even if
641 such conditions were to be met, healthcare can, at best, provide an answer to only part of the
642 system – by helping those who are already overweight. It cannot prevent obesity-related
643 behaviours from occurring in the first place.

644 Second, when we examine the functioning of this system in terms of emergent
645 properties at the individual level, we observe a system that gears people towards instant
646 gratification in terms of social media likes, tasty food, belonging to a group and other
647 pleasures. Such gratification is specifically important for young adolescents in the transition
648 from primary to secondary school, in that they are suddenly exposed to greater autonomy,
649 with growing peer-group influence and diminishing parental supervision (25-28). At the same
650 time, parents themselves struggle with this new phase, in particular with regard to a lack of
651 parenting skills surrounding mobile phone and social media use (29-32).

652 Third, when looking at the emergent properties of the system at a macro level, we see
653 that the system function for multiple, but not all, subsystems revolves around the goal of
654 maximising short- or longer-term economic growth in the paradigm of a market-driven
655 economy. Private-sector companies are known to use strategies that promote specific products
656 and choices that are detrimental to health (33). Specific examples of the conflicting system
657 goals from public health and commercial perspectives can also be found in the growing
658 commercial determinants of health literature. This points up the fundamental conflict between
659 imperative shareholder value maximisation and population health (33). In agreement with

660 previous research, our analysis has shown that young people in the child-to-adolescent
661 transition period are particularly susceptible to the marketing and production strategies of
662 commercial companies. That derives from adolescents' peer influences, their immature
663 cognitive and emotional development, and their high exposure to unhealthy foods in their
664 physical and online environments (34-36).

665 While it is obviously highly challenging to influence macro system functions, it is
666 important to understand the system in which we are operating, and to be aware that any public
667 health intervention aiming to change the system will have to work within (or probably
668 against) that system. Having such system knowledge will likely result in the development of
669 different types of interventions and programmes (15, 23). For example, the social marketing
670 literature shows us how instruments from traditional marketing (product, price, promotion,
671 place) can be used to 'sell' healthier alternatives. However, even though such a social
672 marketing approach may benefit individuals, groups or societies as a whole (37-39), it still
673 does not address the system goals. Placing cartoon characters on fruit, for example, will not
674 address the marketing mechanisms that make unhealthy food attractive and profitable. The
675 emerging field of systems social marketing indeed emphasises the need to adopt a more
676 holistic or systems mode of operandi (40). A more systemic alternative would include a full
677 understanding and consideration of the adolescents' perspective in efforts to promote a
678 particular health outcome. For example, adolescents indicated to us that they find their
679 physical environment unattractive and boring, as it is designed mainly for young children. If
680 adolescents were to have a voice in the design of outdoor spaces, they might make more use
681 of such spaces and increase their levels of physical activity.

682

683 **4.3 Strengths and limitations**

684 To the best of our knowledge, this is the first study that combines a multi-actor perspective
685 with a system-based analysis in order to understand the dynamics of obesity-related
686 behaviours. A limitation of our study is that, while we combined different perspectives from
687 the original data sources in our aggregated CLD, the system-based analysis and interpretation
688 was performed only from the academic perspective. Ideally, one would feed the final results
689 back to the adolescents and the stakeholders to make sure our interpretation agrees with their
690 perceptions of the system; or one might even involve adolescents and stakeholders in the
691 analytic process. However, such system analysis without proper guidance might have been
692 challenging for the groups involved here, in particular because not all subsystems identified in
693 our study (such as subsystem 5) were discussed in the original single-perspective data.
694 Nevertheless, authors that were involved in the original data collection on the various
695 perspectives were also involved in the system analysis, and we checked our interpretations
696 against their original data.

697 Another limitation may be that, although systems are dynamic, the figurations of the
698 system as presented in our study may seem static. Our results should therefore be interpreted
699 as the understanding we developed from snapshots of the pre-existing system, while still
700 bearing in mind that system understanding is a progressive process. The identified subsystems
701 and the concurrent system goals highlighted in our study can serve as a basis for locating
702 points to intervene in the system, also known as leverage points (1). Foster-Fishman and
703 colleagues refer to this step as the final information needed to successfully develop and
704 implement interventions that can alter the status quo of targeted systems (13). In the LIKE
705 programme, we indeed seek to use the insights obtained from the present study as a basis to
706 find leverage points and develop actions to help change the system into a healthier system for
707 adolescents.

708 Finally, it is important to point out that the uncovered underlying system dynamics described
709 in this study refer to those dynamics found to be relevant to our target group (10- to 14- year-

710 old adolescents) in the context of a Western urban setting. The observed dynamics are a result
711 of our methods which relied on academic experts' perspective and interpretation, and
712 adolescents' and stakeholders' perspectives. For that reason, the resulting pre-existing system
713 CLD of obesity-related behaviours does not present evidence for the exact working of the
714 system dynamics but should rather be interpreted as one piece of a bigger puzzle. Indeed, we
715 did not intend to develop a full conceptual model of childhood overweight and obesity, but
716 one that focused on our target group and setting. However, the types of dynamics (feedback
717 loops, subsystems, and goals) identified in this study are also relevant in other contexts. For
718 example, subsystems that have as goal economic profit.
719

720 **5. Conclusions**

721 Our paper has confirmed the relevance of combining multiple perspectives in gaining system
722 understanding of obesity-related behaviours. The researchers' and stakeholders' perspectives
723 contributed in particular to an understanding of how the system structure of the obesogenic
724 environment works. Integrating the adolescents' perspective enriched the insights on how
725 adolescents interact with that environment. The system analysis revealed that the system in
726 which adolescents live is composed of multiple subsystems that interact with one another and
727 whose goals serve to reinforce obesity-related behaviours over time. Multiple subsystems
728 operate within a paradigm which, on the individual level, maximises short-term gratification;
729 this is intensified by factors such as the urge for freedom that characterise the transition from
730 childhood to adolescence. On the macro level, the paradigm maximises economic growth.
731 Understanding such types of system drivers is crucial for the development of future
732 interventions.

733
734

735 **6. Conflict of Interest**

736 The authors declare that the research was conducted in the absence of any commercial or
737 financial relationships that could be construed as a potential conflict of interest.

738

739 **7. Author Contributions**

740 Conception and design of the work: ALP, KS, WW. Supervision: KS, WW. Funding
741 acquisition: KS, CD, CR, TA, MC, SPJK. Writing original draft: ALP, KS, WW.

742 Interpretation and critically reviewing manuscript: ALP, KS, HE, EvdE, TA, CD, CR, RH,
743 VB, MC, SPJK, WW. All authors read and approved the final manuscript.

744

745 **8. Funding**

746 This work was supported by a grant from the Netherlands Cardiovascular Research Initiative:
747 An initiative with support of the Dutch Heart Foundation, ZonMw, CVON2016-07 LIKE.

748

749 **9. List of abbreviations**

750 CLD – Causal loop diagram

751 GMB - Group model building

752 LIKE – Lifestyle Innovations Based on Youth Knowledge and Experience programme

753 HCPs - Healthcare professionals

754

755 **10. Acknowledgements**

756 We would like to thank all the members of the LIKE consortium for their contribution in the
757 Needs Assessment data interpretation. We are also grateful to Loes Crielaard for providing
758 feedback on this paper. We also thank Elida Movilla Pinzon for her help editing the final map.
759 Lastly, we thank Douglas Creighton, Josh Hayward and Prof. Steven Allender for their
760 feedback and help on how to use the STICK-E software.

761

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763

764 11. References

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In review

882 **Figure captions and legends**

883

884 Figure 1. Pre-existing system of obesity-related behaviours in an integrated multi-actor
885 perspective with identified subsystems

886

887 Factors derived from the researchers' perspective are shown in yellow, those from the
888 adolescents' perspective in purple, and those from the stakeholders' perspective in blue.
889 Factors present in at least two of the three perspectives are shown in green. Black arrows
890 indicate positive polarity and red arrows indicate negative polarity in the causal relationship
891 between factors.

892

893 Figure 2. Total numbers of factors and unique factors from the perspectives of researchers,
894 adolescents and stakeholders in subsystems 1–5

895

896 Figure 3. Subsystem 1: Interaction between adolescents and the food environment

897 Factors derived from the researchers' perspective are shown in yellow, those from the
898 adolescents' perspective in purple, and those from the stakeholders' perspective in blue.
899 Factors present in at least two of the three perspectives are shown in green. Black arrows
900 indicate positive polarity and red arrows indicate negative polarity in the causal relationship
901 between factors.

902

903 Figure 4. Subsystem 2: Interaction between adolescents and the physical activity environment

904 Factors derived from the researchers' perspective are shown in yellow, and those from the
905 adolescents' perspective in purple. Factors present in at least two of the three perspectives are
906 shown in green. Black arrows indicate positive polarity and red arrows indicate negative
907 polarity in the causal relationship between factors.

908

909 Figure 5. Subsystem 3: Interaction between adolescents and the online environment

910 Factors derived from the researchers' perspective are shown in yellow, those from the
911 adolescents' perspective in purple, and those from the stakeholders' perspective in blue.
912 Factors present in at least two of the three perspectives are shown in green. Black arrows
913 indicate positive polarity and red arrows indicate negative polarity in the causal relationship
914 between factors.

915

916 Figure 6. Subsystem 4: Interaction between adolescents, parenting and the wider
917 socioeconomic environment

918

919 Factors derived from the researchers' perspective are shown in yellow, those from the
920 adolescents' perspective in purple, and those from the stakeholders' perspective in blue.
921 Factors present in at least two of the three perspectives are shown in green. Black arrows
922 indicate positive polarity and red arrows indicate negative polarity in the causal relationship
923 between factors.

924

925 Figure 7. Subsystem 5: Interaction between families and healthcare

926 Factors derived from the stakeholders' perspective are shown in blue. Factors present in at
927 least two of the three perspectives are shown in green. Black arrows indicate positive polarity
928 and red arrows indicate negative polarity in the causal relationship between factors.

929

930 Figure S1. Map of the pre-existing system of obesity-related behaviours from the perspective
931 of researchers

932

933 Factors shown in yellow were unique to the researchers' perspective. Factors shown in green
934 were present in the researchers' perspective but also in the adolescents' and/or stakeholders'
935 perspectives. Black arrows indicate positive polarity and red arrows indicate negative polarity
936 in the causal relationship between factors.

937

938 Figure S2. Map of the pre-existing system of obesity-related behaviours from the perspective
939 of adolescents

940

941 Factors shown in purple were unique to the adolescents' perspective. Factors shown in green
942 were present in the adolescents' perspective but also in the researchers' and/or stakeholders'
943 perspectives. Black arrows indicate positive polarity and red arrows indicate negative polarity
944 in the causal relationship between factors.

945

946 Figure S3. Map of the pre-existing system of obesity-related behaviours
947 from the perspective of stakeholders

948

949 Factors shown in blue were unique to the stakeholders' perspective. Factors shown in green
950 were present in the stakeholders' perspective but also in the researchers' and/or adolescents'
951 perspectives. Black arrows indicate positive polarity and red arrows indicate negative polarity
952 in the causal relationship between factors.

953

954

955

Figure 2.JPEG

Researchers' perspective Adolescents' perspective Stakeholders' perspective

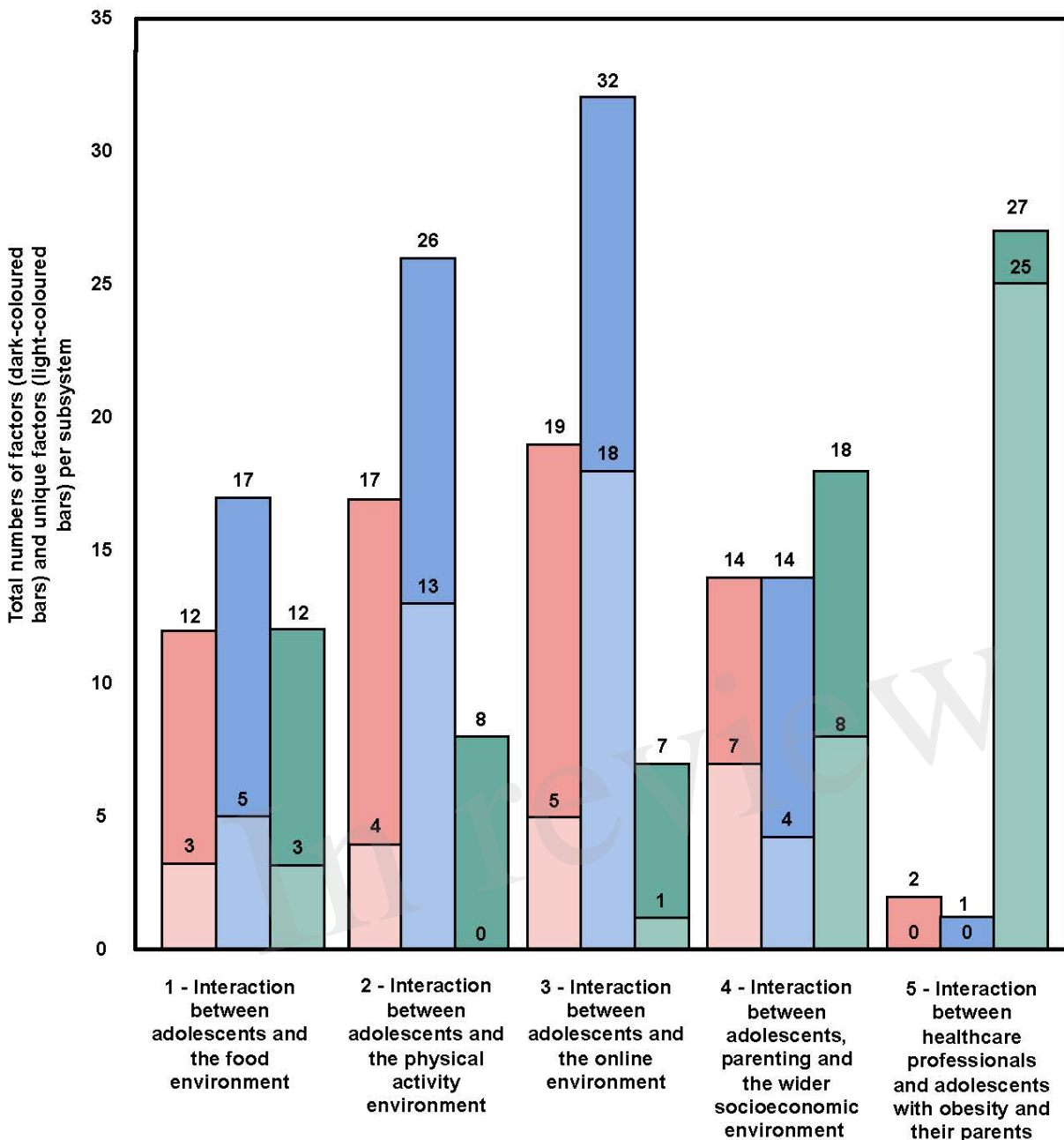


Figure 3.JPEG

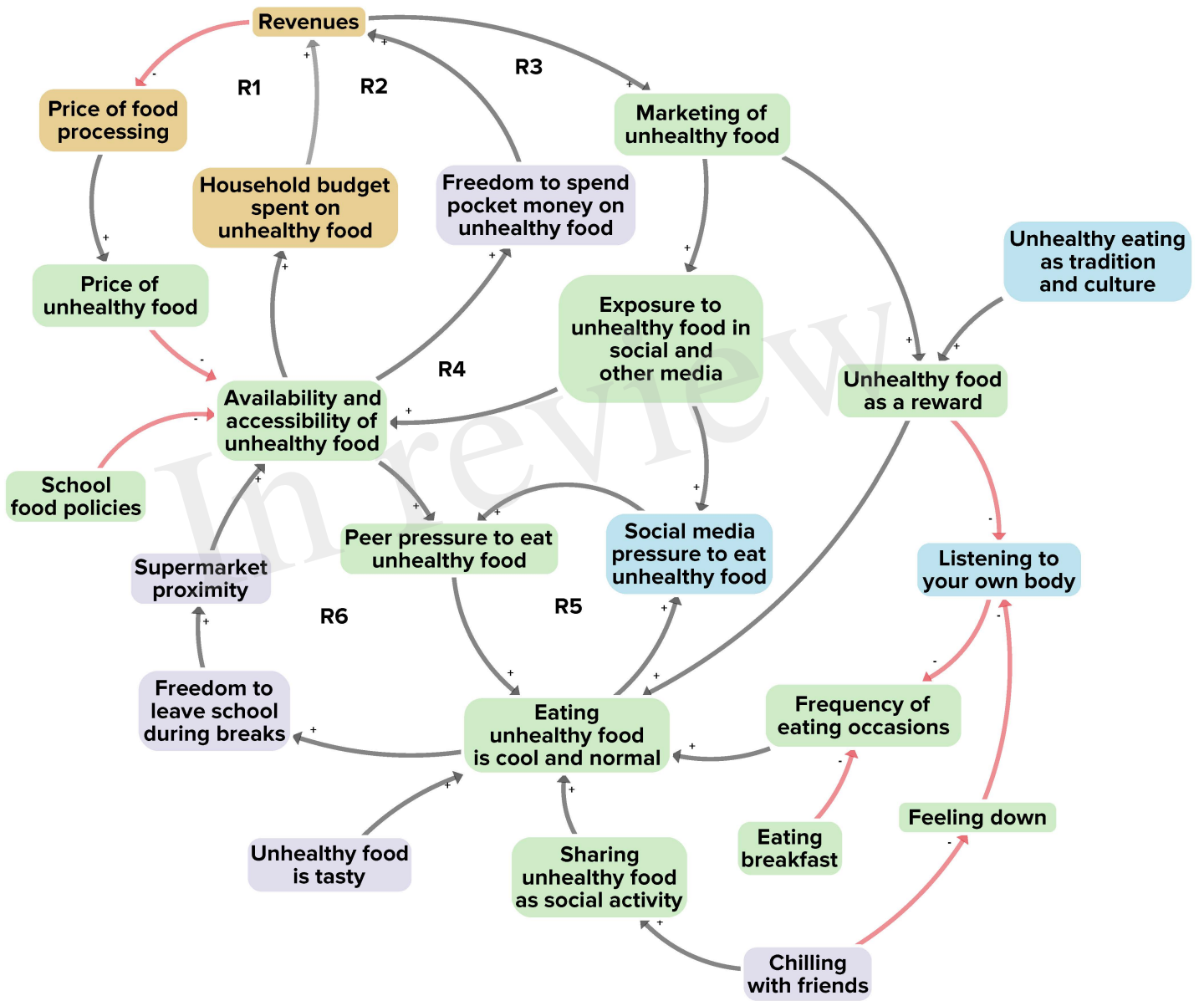


Figure 4.JPEG

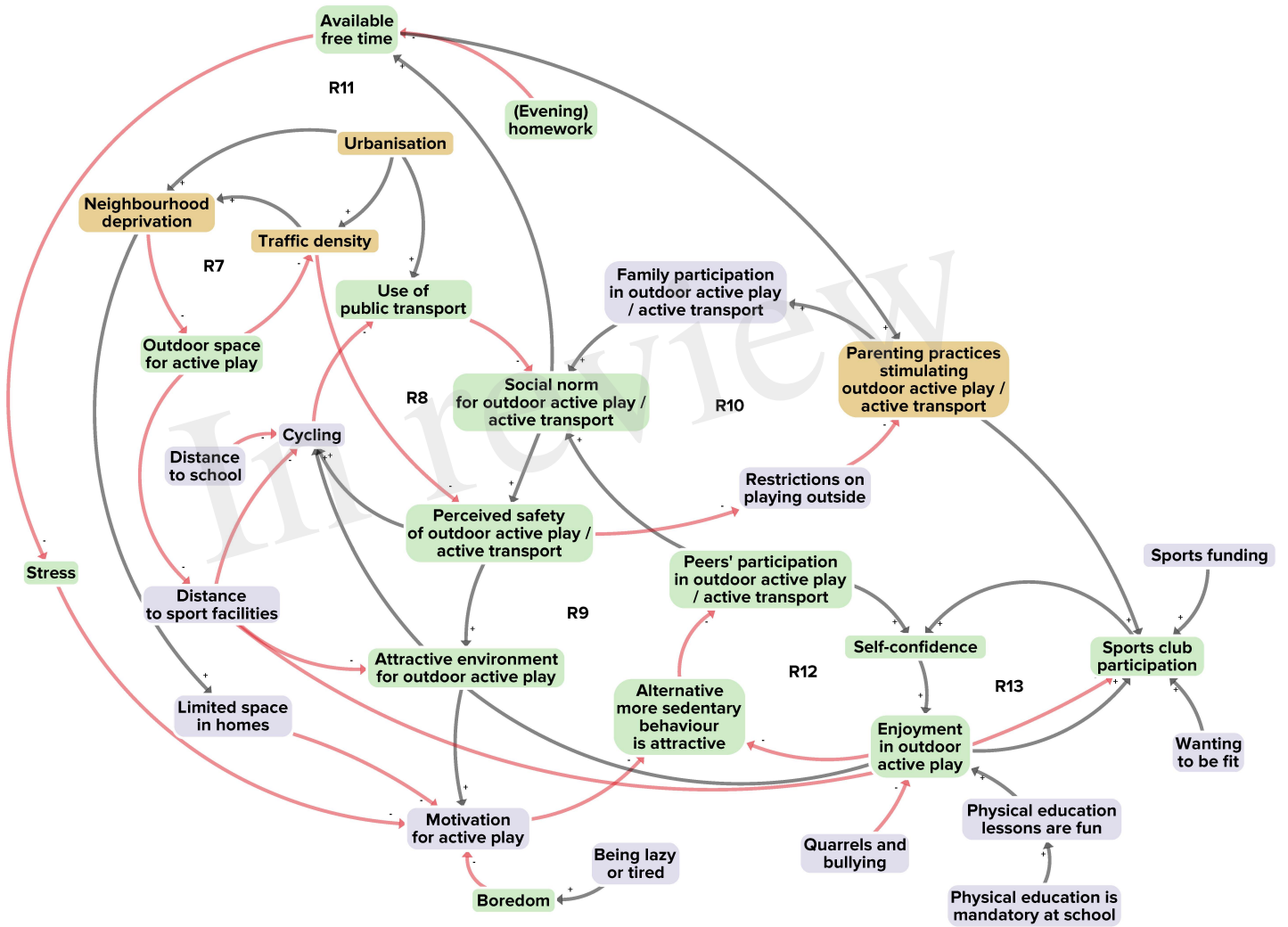


Figure 7.JPEG

