Developing an agent-based model exploring collective patterns and income inequalities in adult's leisure-time physical activity

Sophie Jones[1'[0000-0001-5757-7343]'], Ruth Hunter[1'[0000-0001-7315-0382]'] and Leandro Garcia[1'[0000-0001-5947-2617]']

[1] **Queen's University Belfast**, Centre for Public Health, Institute of Clinical Sciences Block A, Royal Victoria Hospital, Belfast, UK, BT12 6BJ

sjones31@qub.ac.uk

Abstract. Acknowledging that physical activity is a complex behaviour and that macro patterns emerge due to dynamic interactions between system parts can help us understand physical activity inequalities across the population. Using this perspective, an agent-based model was designed and developed to explore collective patterns and income inequalities of leisure-time physical activity. The agent-based model was developed in two main processes: conceptual model development and operationalization. The model represents two abstract cities, including people and spaces to practice leisure-time physical activity. At each time step (equivalent to one week in the real world), individuals decide to practice leisure-time physical activity, considering economic, psychosocial, social, and physical environment factors. It is hoped that through simulating this decision process over time, we can understand how physical activity inequalities are formed and sustained, which will be beneficial for considering how to intervene in these systems to reduce these inequalities and improve overall population health.

Keywords: Physical activity inequalities, Agent-based modelling, Complex systems, Emergence, Computer simulation

1 Introduction

There is currently little understanding of what shapes physical activity inequalities, specifically for different income groups across various contexts [1]. To try and address this, research and policy have often adopted downstream and often reductionist approaches, which overlook the complexity of how physical activity inequalities come to exist in the first place [2]. Therefore, instead of using traditional approaches to identify what could be driving these inequalities, we need to reorient our thinking about physical activity inequalities from a static perspective and instead realize they emerge due to interactions between parts of a complex system.

With this more dynamic approach in mind, we developed an agent-based model (ABM) to explore collective patterns and income inequalities of adult's leisure-time physical activity (LTPA), acknowledging that income inequalities in LTPA exist due to the dynamic interactions between individual, psychosocial, economic, social, and physical environment factors. Specifically, we use a bottom-up approach to understand how individual-level decisions aggregate to form the population patterns of LTPA we observe over time.

2 Methods

The ABM was designed and developed through two main processes: (1) conceptual model development and (2) operationalization of the ABM. The primary function of the ABM was to simulate how an individual's decision to practice LTPA may be influenced by psychosocial, economic, social, and environmental factors. Therefore, before operationalizing the ABM, it was necessary to develop a conceptual model to provide insight into how this decision-making process occurs in real life [3].

2.1 Conceptual model development

The purpose of the conceptual model was to outline the process of an individual deciding to practice LTPA each week, highlighting the relevant mechanisms and factors that may influence this decision and how these relationships may occur. The conceptual model development included four main stages: (1) a preliminary version was drafted using the knowledge of the research team; (2) an intermediary version was drafted as a result of two realist-informed reviews aimed to substantiate assumptions about what specific mechanisms and factors may be influencing LTPA, and how these may have different influences for different income groups, across contexts; (3) an expert consultation with academics in relevant areas, aimed to assess the conceptual model; and (4) finalization of the conceptual model, based on expert assessment.

2.2 Model operationalization

Following the conceptual model's completion, the ABM's operationalization began using NetLogo version 6.3.0 [4]. To inform model development, the Overview, Design Concepts, and Details + Decision (ODD + D) protocol [5] was used to guide model structure and content.

Operationalization of the model involved translating our understanding of how individuals make their decisions to practice LTPA from our conceptual model to a suitable algorithm in the ABM. This process was done progressively by initialising the world, and agents, then using the conceptual model to inform the relevant agent and environmental attributes and parameters for the model. Throughout the operationalization, the ABM was continuously reviewed by two members of the research team to check syntax, spelling, and monitoring of all procedures (i.e., using diagnostic plots, visualization, and stress test with parameter values outside the expected ranges).

3 Results

The finalized conceptual model can be found in Figure 1 below. The conceptual model is based on four major theories: the Social-ecological theory [6], the Integrated behaviour change model for physical activity [7], Opinion dynamics [8], and the Sociological theory [9]. Eleven reviews and 38 empirical studies further supported the model's development through two separate realist-informed reviews, along with expert assessment. Two tables accompany the conceptual model, explaining our underlying assumptions about the relationships (not included in this abstract).

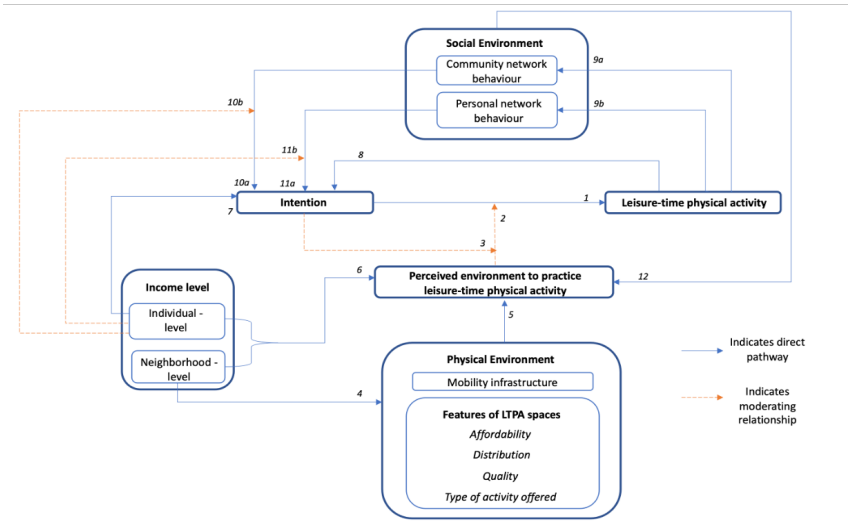

Fig. 1. Finalised conceptual model.

If people perceive >0 spaces in their perception radius
set 'potentially active'
ask 'potentially active' people to calculate the utility of each LTPA space in their perception radius
{utility = quality, distance, LTPA activity offered, and area level of income}
select the space with the highest utility 'x'
set 'x' as 'best space'

If people perceive 0 spaces in their perception radius
set LTPA-behaviour -1 (do not practice LTPA)

For people who are 'potentially active'
update intention for LTPA
{updated intention for LTPA = individual's past behaviour + behaviour of their personal network + behaviour of their observed community + the utility of 'best space'}

If random-generated number <= updated intention
set ltpa-behaviour 1 (practice LTPA)
If random-generated number > updated intention
set ltpa-behaviour -1 (do not practice LTPA)

Fig. 2. Pseudo-code for the decision-making process in the model.

Using the conceptual model, the ABM's algorithm was developed (see fraction of pseudo-code in Figure 2). The model contains two abstract cities, different by level of socio-economic segregation, to explore the dynamics between area and individual levels of income and LTPA practice. Central to the model is individuals making their decision to practice LTPA. This decision is based on their intention, influenced by economic, psychosocial, social, and physical environment factors, which are conditioned by the individual's socioeconomic status (specifically their level of income).

4 Conclusion

This agent-based model is the first to adopt a dynamic perspective to consider income inequalities in LTPA, acknowledging them to be an emergent feature of interactions within complex adaptive systems. It is hoped that through simulating individual-level decisions, over time, we can begin to understand how inequalities in physical activity are aggregated and sustained, catalyzing a different perspective for thinking about physical activity inequalities in the future.

References

1. Van Cauwenberg, J., De Clercq, B., Deforche, B., Cardon, G. and Chastin, S.F., Accuracy and inequalities in physical activity research. The Lancet Global Health, 7(2), 183-184. (2019).
2. Buchan, D.S., Ollis, S., Thomas, N.E. and Baker, J.S., Physical activity behaviour: an overview of current and emergent theoretical practices. *Journal of obesity*, *2012*.
3. Railsback, Steven F., and Volker Grimm. Agent-based and individual-based modelling: a practical introduction. Edition? Princeton university press, location? Pages? (2019).
4. Wilensky U. NetLogo, https://ccl.northwestern.edu/netlogo/, last accessed 19/04/2023.
5. Müller B, Bohn F, Dreßler G, Groeneveld J, Klassert C, Martin R, et al. Describing human decisions in agent-based models–ODD+ D, an extension of the ODD protocol. Environ Model Softw 48, 37–48. (2013)
6. Sallis, J.F., Cervero, R.B., Ascher, W., Henderson, K.A., Kraft, M.K. and Kerr, J., An ecological approach to creating active living communities. Annu. Rev. Public Health 27, 297-322. (2006.)
7. Hagger, M.S. and Chatzisarantis, N.L., An integrated behaviour change model for physical activity. Exercise and sport sciences reviews, 42(2), 62-69. (2014).
8. Acemoglu, D. and Ozdaglar, A., Opinion dynamics and learning in social networks. *Dynamic Games and Applications*, *1*,3-4 9. (2011).
9. Bourdieu, P., La Distinction. Critique sociale du jugement. Paris : Les éditions de minuit (dt. (1979)