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Framework for understanding health inequalities over the life course: the embodiment dynamic and biological mechanisms of exogenous and endogenous origin

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ABSTRACT

Understanding how structural, social and psychosocial factors come to affect our health resulting in health inequalities is more relevant now than ever as trends in mortality gaps between rich and poor appear to have widened over the past decades. To move beyond description, we need to hypothesise about how structural and social factors may cause health outcomes. In this paper, we examine the construction of health over the life course through the lens of influential theoretical work. Based on concepts developed by scholars from different disciplines, we propose a novel framework for research on social-to-biological processes which may be important contributors to health inequalities. We define two broad sets of mechanisms that may help understand how socially structured exposures become embodied: mechanisms of exogenous and endogenous origin. We describe the embodiment dynamic framework, its uses and how it may be combined with an intersectional approach to examine how intermeshed oppressions affect social exposures which may be expressed biologically. We explain the usefulness of this framework as a tool for carrying out research and providing scientific evidence to challenge genetic essentialism, often used to dismiss social inequalities in health.

BACKGROUND

The relationships between the social structures of human societies and our health have been studied for decades, with a large literature stemming from social epidemiology, sociology, geography, psychology and beyond. Yet understanding how structural, social and psychosocial factors come to affect our health resulting in health inequalities is more relevant now than ever as trends in mortality gaps between rich and poor have appeared to widen in the past decades.¹ Describing health inequalities is the first step, but remains insufficient to help redress them. To move beyond description, we need to hypothesise about how structural and social factors may cause health outcomes. This involves dipping into a wide interdisciplinary literature, embracing diverse research methodologies thinking about what health actually is, understanding human developmental processes and societies as well as how we constructed our medical systems. In this paper, we propose a theoretical synthesis on the construction of health inequalities over the life course through the lens of influential theoretical

work, and a new conceptual framework for understanding social-to-biological processes dynamically. Our framework offers a pragmatic way of breaking down and operationalising theories when confronted with designing research, selecting variables and interpreting findings as applied to both fundamental research and action-oriented research interested in social-biological questions.

SOCIAL-TO-BIOLOGICAL PROCESSES AND HEALTH INEQUALITIES: KEY THEORETICAL FOUNDATIONS

Perhaps one of the most important ideas which has contributed to understanding why health inequalities are so ubiquitous over space and time was developed in social epidemiology by Krieger, referred to as embodiment. Krieger explicitly defined the term as a core construct of her previously outlined ecosocial theoretical framework.² The term embodiment ‘expresses an abstract idea, a process, and concrete reality. Whether used literally or figuratively, it insists on bodies as active and engaged entities’.³ She went on to explain the central tenet of what embodiment means: ‘at the most general level, embodiment, as an idea, refers to how we, like any living organism, literally incorporate, biologically, the world in which we live, including our societal and ecological circumstances’.³ The everyday lives of humans occur within social structures which inequitably distribute resources, trauma, access to healthcare and education (etc), hazards, thus differentiating our exposure to socially patterned biological mechanisms affecting health.

The process of embodiment is a dynamic adaptive response occurring continually across the life course. The human body’s plasticity in response to environmental challenges changes throughout life, marked by periods of sensitivity in early life and during later senescence.⁴ Research on the *Developmental Origins of Health and Disease* (Dohad) highlighted the major role that environmental exposures (nutritional, chemical, chronic stress) during intrauterine life, play on health outcomes.⁵ The hypothesis-driven Dohad approach has remained strongly influenced by the biological sciences and relatively impervious to the structural, social, cultural and psychosocial nature of human interactions. However, a similar concept to embodiment was developed by Hertzman in 1999 which he referred to as biological embedding, alluding to its



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roots in the biological sciences and intricately linked to what he called the ‘ubiquitous’ socioeconomic gradient in health.⁶

The socioeconomic gradient in health is the pattern often taken by social inequalities in health. For example, the most socially advantaged have the longest healthy life expectancy, those slightly less advantaged than them have a shorter healthy life expectancy, but theirs is longer than the people slightly less advantaged than them. And so, a stepwise pattern occurs along the social gradient, arriving at the most social disadvantage who spend the largest proportion of their lives in poor health, and die the earliest.⁷ It is because of the socially stratified reality within which most humans exist that Hertzman described the social gradient in health as a ‘social fact’.⁸ His focus was on human developmental processes: ‘early life provides a roughly ordered sequence of developmental windows of opportunity that, in turn, allow both mundane and extraordinary experiences to get under the skin at strategic time points to alter specific biological functions, which, in turn, have the capacity to alter life course trajectories’.⁸ In 2012, Hertzman provided an overview of how biological embedding may operate, starting with brain development and its sensitivities to early life experiences. Hertzman and Boyce described that the health consequences of internal physiological responses to the external environment occurring as children develop, varies across social contexts. They concluded that, over time, differences in developmental trajectories of people who are biologically sensitive to context will drive the expression of social gradients in health.⁹ The specificity of Hertzman’s approach was to focus on early human development and child well-being considering the social, cultural and educational environments that affect children in their present and future lives. This was exemplified in the fundamental and interventional research conducted by the Human Early Learning Partnership (<http://earlylearning.ubc.ca/>) which he founded.

Within the social sciences, one of the founding fathers of life course research, Elder, analysed the life courses of children and adolescents during a time of socioeconomic turmoil in his work *Children of the Great Depression*¹⁰ which helped define the principles of life course theory. According to Elder and colleagues,¹¹ (i) life-span development refers to human development and ageing as being dynamic, continuous and lifelong processes; (ii) human agency is about how individuals construct their own lives through the choices and actions they take regarding the opportunities

and constraints of their circumstances; (iii) historical time and place is a principle outlining how individuals’ life courses are embedded and shaped by the historical times and places they experience in their lives; (iv) timing refers to the antecedents and consequences of life transitions, events and so on being variable according to the moment they occur in a person’s life; (v) linked lives is a reference to the way our lives are lived in an interdependent way and socio-historical influences are expressed through a network of shared relationships. Elder and the developmental psychologist Bronfenbrenner mutually influenced each other’s work, Bronfenbrenner’s ‘bioecological’ model of child development remains influential today¹² and resonates with the ecosocial theory of social epidemiology. As such, these influences from diverse disciplines led to the emergence of a life course approach in social epidemiology in the late 1990s.^{13 14} The life course theory has become an interdisciplinary conceptual framework stemming from different disciplines of the social sciences¹⁵ that seeks to understand the multiple factors that shape people’s lives from birth to death, placing individual and family development in cultural and historical contexts.

EMBODIMENT DYNAMIC: A MODEL TO FACILITATE RESEARCH ON HEALTH INEQUALITIES

Evidence has accumulated to show that many social and psychosocial exposures over the life course are likely to influence subsequent health.¹⁶ Krieger herself underlined that embodiment is a process where bodies are transformed over time as ‘a consequence of animate beings’ terms of engagement in their world’.³ As such, combining the life course approach, Hertzman’s work on embedding with Krieger’s core concept within the ecosocial theory, we developed a novel approach to studying social-to-biological processes. We used the theoretical works of Krieger, Hertzman and Elder to formulate a conceptual framework to operationally guide our research on social to biological processes of embodiment. We suggest that social to biological processes can be classified into two broad categories of socially patterned biological mechanisms. Both are subject to the socio-historical structures and stratifications in place in that environment which underlie the lived experiences of populations

The embodiment dynamic is described in [figure 1](#). It relies on understanding the socially structured environment in which

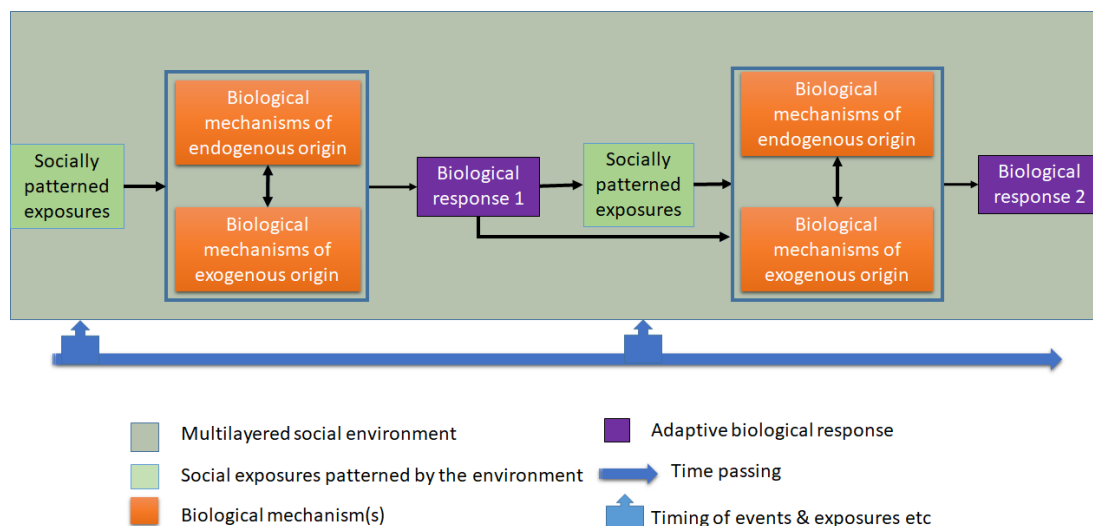


Figure 1 The embodiment dynamic: socially stratified exposures elicit biological mechanisms of endogenous or exogenous origin leading to a biological response, this dynamic repeats itself over time and is sensitive to the timing of exposures.

humans live as being multi-layered. Such a model allows us to consider the biological complexities internal to human bodies, and the layers of environmental factors external to the body, starting with the most intimate home environment, moving outward to the neighbourhood, community and finally, to the socio-political country-level context. Social exposures (green boxes), exist in all of these layers (green background) and refer to all exposures and conditions that are patterned by our social structures, namely the geopolitical and economic systems, the welfare state but also white supremacy, legacies of colonialism and so on. Such systems affect the quality of one's housing and one's relationships, the school one attends and its funding, the cleanliness of the air or water, access to public transport, the quality and accessibility of healthcare, behavioural factors, and are at the root of racism and poverty and so on. Social exposures may lead to biological responses (purple box) induced by biological mechanisms of exogenous or endogenous origin (orange boxes). The passing of time (horizontal blue arrow) renders the process of embodiment dynamic and subject to constant change. Considering the timing of exposures (vertical blue arrows) is key to understanding why events and experiences may not have the same impact depending on when they occur in relation to the life course and the environmental context. The biological response at any one instant affects the new biological baseline which may have a knock-on impact on the next sets of exposures, how the biological mechanisms operate, and subsequent biological responses.

EMBODIMENT DYNAMIC: SOCIAL EXPOSURES AND BIOLOGICAL MECHANISMS

Mechanisms of exogenous origin

Processes through which socially patterned entities or conditions external to the body, either (i) enter the body and elicit a physiological response from it (inert or living entities like foodstuffs, asbestos, viruses, bacteria, pollutants, etc) or (ii) lead to physical harm (injuries, accidents) or exertion (movements, actions). Should external entities enter the body by being ingested, breathed-in, through the skin barrier and so on, they can affect our biological systems and cause them to respond.¹⁷ The same applies to environmental conditions that require physical exertion, which may lead to wear-and-tear on bodies or cause injury. Responses may be positive, negative or neutral.

Exposure to these types of entities depends on the structural factors such as political and economic systems that produce inequalities in terms of occupation, place of residence, housing, school inequitable transit access, air and water quality. They depend also on behaviours which expose people to smoking, alcohol and the nutrients in our food and so on which are socially patterned and introduce into our bodies entities that induce biological responses. Social structures affect both the likelihood of coming into contact with exogenous factors and the way we embody them.

The SARS-CoV-2 virus which causes the COVID-19 disease is a clear example of an exogenous entity, contact with which may be dependent on structural factors which are the backdrop to our social lives, activities and behaviours. Depending on one's occupation, use of public transport and housing, for example, exposure to viral pathogens is likely to be different. An analysis of the UK Biobank participants showed that during the spring of 2020 SARS-CoV-2 infection rates were higher among essential workers, and among non-white non-essential workers.¹⁸ Another example, in our previous work on the Epstein-Barr virus (EBV) we showed that by the age of three, children from overcrowded

and social deprived housing, were more likely to be carriers of the virus.¹⁹ This may have an impact on the priming and development of children's immune systems, affecting (positively or negatively) their immune response across the life course. The health consequences of early EBV exposure are not usually negative. Moreover, mechanisms of exogenous origin may also include more functional factors such as movements, gestures and physical efforts which develop and wear the body in different ways.

Mechanisms of endogenous origin

Processes through which sensory interpretations of socially patterned interactions with the environment elicit responses from the central nervous system, as well as cognitive and psychological functions. Our perception of situations, experience of relationships and other daily psychosocial experiences induce biological mechanisms of endogenous origin. The specificity of these mechanisms of endogenous origin is that these refer internal biological processes that occur as a consequence of sensory and neurobiological signals. Our perceptions and emotions lead to a cascade of responses by the neuroendocrine system and also psychological responses, among others. Given the importance of early life development in the formation of neurological architecture and peripheral physiological systems,⁴ interactions, relationships and experiences from conception may have an effect on subsequent biological responses across the life course.²⁰ As such mechanisms of endogenous origin are affected by the timing of their occurrence over the life course, as well as the other life course principles, such as historical context and linked-lives, referring to salient and intermeshed relationships such as those with family members.²¹ We observed in previous work that early life social disadvantage²² stressful psychosocial experiences during childhood²³ may have long-term physiological consequences, resulting in the wear-and-tear of multiple systems. In turn, such biological wear-and-tear is associated with premature mortality.²⁴

For example, immune/inflammatory, cardiovascular or metabolic biomarkers have been shown to vary according to socioeconomic variables, especially education.^{25 26} This relationship persists after adjustment for conventional health behaviours, suggesting that socioeconomic position may be associated with biological function, possibly through endogenous mechanisms solicited in response to environmental challenges and that need to be further investigated. Socioeconomic position and race may lead to mechanisms of endogenous origin through chronic solicitation of the stress response systems when disadvantaged and racialised groups of the population find themselves systematically discriminated against. Disadvantaged populations are more likely to be exposed to insecure neighbourhoods, insecure and low-paid jobs, poor access to green spaces and transport, confronted with barriers to access care or education, all of which increase the constant solicitation on the stress-response system affecting physiological systems over time, making them more susceptible to developing chronic disease.

Links between mechanisms of exogenous and endogenous origin

These two sets of mechanisms may also interact over the life course and affect each other. For example, once a mechanism of exogenous origin has been embodied, it may affect the nature and type of biological response elicited by a mechanism of endogenous origin positively, negatively or neutrally. Conversely, the biological response elicited by a mechanism of exogenous

origin may be modified according to biological changes caused by mechanisms of endogenous origin.

These two major sets of biological mechanisms may involve transformations at different biological levels including the molecular level, such as epigenetic changes, which are likely to influence and modify gene expression.²⁷ They may have a different impact depending on the developmental maturity of individuals,²⁸ and their socially determined activities.¹⁴ Modifications to gene expression may be exposure-specific: some epigenetic changes have been shown to be specifically associated with tobacco use,²⁹ changes that are different to those associated with psychosocial stress such as maternal separation.³⁰ Some of these changes may disappear or be observed several years after the exposure suggesting both reversibility and lasting effects. Some of these changes may be transmitted across generations.³¹

EMBODIMENT DYNAMIC FRAMEWORK: INTERSECTING INEQUALITIES AND CHALLENGING ESSENTIALISM

By combining the embodiment dynamic with an intersectional approach, we can begin to understand how intermeshed structural oppressions, including sexism, racism, class exploitation, ableism (etc), affect health partly through social-to-biological pathways, leading to socially patterned embodied differences. In 2016 Krieger wrote about the importance of a theoretical framework with embodiment at its centre, to challenge the embodied reality of racial discrimination. Such theoretical framing, she argued 'is what fosters research on associations between implicit and explicit measures of exposure to racial discrimination, racialized economic segregation, and adverse health status—and makes clear there is nothing “distal” about structural discrimination because it is intimately encountered and embodied, day in and day out'.³²

Such an approach enhances our understanding of how oppressed/discriminated social groups face structural challenges on a historical and intergenerational scale, as well as during their own life courses. The overlapping and interacting forms of oppression at the heart of intersectional theories, lead to members of minoritised groups being unnecessarily faced with exposures leading to biological mechanisms of exogenous and endogenous origin.³³ On top of this, they are systematically discriminated against in our health systems.³⁴ An intersectional approach combined with the embodiment dynamic framework may facilitate understanding within the health sector about why minoritised populations have been disproportionately affected by the COVID-19 pandemic both in terms of their differential exposures to mechanisms of exogenous origin, but also their differential biological susceptibilities through intergenerational and life course exposures to mechanisms of endogenous origin, namely chronic exposure to physiological stress leading to physiological wear-and-tear.³⁵ However, the lack of an intersectional approach reinforces the recurrent narrative based on false assumptions that higher mortality rates among ethnic minorities are due to genetic characteristics rendering these populations more vulnerable to disease.

Bringing together an intersectional conceptual framework with the embodiment dynamic also allows us to challenge genetic essentialism, referring to the idea that characteristics observed at the group level are attributable to innate characteristics of human nature. More specifically, genetic essentialism refers to a worldview in which 'genes come to define the essence of humans and other living creatures, the distinctions and commonalities among them',³⁶ erasing the incredible complexity of the relationships between genotype and phenotype. While the role of

genetics in human development and health is important, genetic essentialism, especially regarding purported differential racial distributions of genes related to biology or disease in science and the media, leads to racial attitudes and a resurgence of ideas that racial groups are essentially different.³⁶ Unfortunately, it also has a place in medical practice, where clinical differences between men and women or between white and non-white people are primarily attributed to genetics.³⁷ As such, our approach allows for a clearer understanding of how biological and health differences observed between social groups (eg, income, occupation, race/ethnicity) are driven by a dynamic interaction between humans and their socially stratified environments across the life course. By demonstrating the social nature of biology, the embodiment dynamic framework underlines that layers of complexity lie on top of the genome. Our flexible biologies have allowed us to adapt to our changing environments. These environments being socially structured is therefore expressed in our bodies. Our framework allows for the social pattern of biological and health outcomes to be examined in such a way as to unpick any existing social-to-biological dynamics over the life course, via exogenous or endogenous mechanisms, which may underly the observed differences.

Socially patterned biological differences have been observed at different biological scales, from epigenetic to protein level²⁷ meaning that we can talk about a socially driven biology of inequality.¹⁶ Understanding this dynamic could benefit health promotion and prevention approaches as well as clinical interventions. For example, in the roll-out of vaccination in the community to prevent the transmission of SARS-CoV-2 and the disease it causes, a social dimension to the vaccination strategy beyond age stratification may account for biological risk which increases with age more rapidly among those who are poor.³⁸ Since biology differs depending on people's social environment,³⁹ it is likely that medical treatments for certain health conditions may perform differently or cause different side effects.⁴⁰

EMBODIMENT DYNAMIC FRAMEWORK: FACILITATING OPERATIONALISING SOCIAL-TO-BIOLOGICAL RESEARCH QUESTIONS

This framework provides a pragmatic way to apply ecosocial and life course theories to social-biological questions when confronted with research design, analysis and interpretation. For fundamental research, this framework can help specify hypothesis testing and model-building. It requires being explicit about the social variables (green boxes) you wish to examine as your epidemiological 'exposures' and asks you to specify the socially patterned biological mechanisms of exogenous and endogenous origin (orange boxes) over the life course (blue arrows) through which they may relate to health outcomes. Identifying these mechanisms may help select the variables of interest in a dataset and think about when those variables occur over the life course and relate to socially ascribed life stages as well as human developmental processes. This approach may also help to identify mechanisms that cannot be tested with the data. Interpretation of analyses can then be related back to these hypothesised mechanisms. Regarding interventional research considerations, the framework may facilitate the identification of factors on which policy action is possible within the time-frames of interventions. See [box 1](#) for an applied example.

As with all frameworks, its schematic and simplified nature has its limits. For example, we have not included interactions with the healthcare system and trajectories of care in this model. These are important, and may also be socially patterned, namely

Box 1 Operational example of how the embodiment dynamic framework might be applied to fundamental and policy-related research

Let us examine how social class in childhood may relate to coronary heart disease at the age of 50 in terms of social–biological processes. Structurally patterned variables (green boxes) such as social class, may relate to mechanisms of exogenous origin (orange boxes), for example through: nutrition, tobacco use, air pollution, linked with biological mechanisms of vasoconstriction and atherosclerosis (purple box). Structurally patterned variables (green boxes) such as social class, may relate to mechanisms of endogenous origin (orange boxes), for example through: financial hardship, stressful neighbourhood conditions, experience of racism, lack of job security or control, linked through the stress-response system to chronic exposure to cortisol which leads to atherosclerosis and high blood pressure (purple box). The nature and effect size of these variables is likely to vary over the life course (blue arrows) in relation to age and socially ascribed life stages. Breaking down neighbourhood factors to identify the effects of air pollution, built environment, availability of food and green spaces, the nature of public transport on mechanisms of exogenous and endogenous origin, may help to identify policy-actionable factors that could be empirically tested with the aim of redressing health inequalities.

institutional bias and discrimination within healthcare systems. While they may exacerbate social-to-biological phenomena, they are a separate set of processes that deserve to be modelled as such.

CONCLUSION

The dynamic model of embodiment and its definition may be useful to researchers because it allows us to conceptualise the highly complex relationship between variables involved in producing health states and health inequalities while also making pragmatic analytical decisions to focus on segments of the dynamic. We can choose to specify exposures and hypothesise about social-to-biological mechanisms of different types. We can define a biological response and/or health outcome of interest. The dynamic framework forces us to consider how time and timing affect the relationships within it. We can use this framework as a conceptual model with which to select appropriate methods, statistical approaches, datasets and variables. It is useful as a tool for teaching about social-to-biological processes, and communicating to clinical practitioners and policymakers. The integration of this phenomenon in the field of prevention could make it easier to develop interventions based on proportionate universalism approaches,⁴¹ where resources and policies are allocated in proportion to the needs of population groups.

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