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Biological embedding vs. embodiment of social experiences: How these two concepts form distinct thought styles around the social production of health inequalities

Séverine Louvel ^{a,*}, Alexandra Soulier ^b

^a PACTE – Sciences Po Grenoble, 1030 Avenue Centrale, Domaine Universitaire, 38040 Grenoble Cedex 09, France ^b IHPST - Institut D'histoire et de Philosophie des Sciences et des Techniques (UMR 8590), Maison de La Philosophie - Marin Mersenne, 13, Rue Du Four, 75006 Paris, France

ABSTRACT

Objectives: This article compares research on biological embedding and the embodiment of social experiences, two concepts proposed in the 1990s to introduce a new perspective on the social production of health inequalities. We draw on Ludwig Fleck's concept of 'thought style' (1935/2008) to question the possible emergence of a common research program around the processes by which the social becomes biological.

Methods: We compiled a corpus of 322 articles referring to either biological embedding or to the embodiment of social experiences, identified in the Web of Science core collection and published from 1990 to 2021. We analyzed the articles' use of these concepts using scientometric indicators and qualitative content analysis. **Results:** Initial differences between the research agendas associated with biological embedding and embodiment are strengthened as both concepts circulate around scientific communities studying the social production of health inequalities. Thought styles formed around embedding and embodiment differ significantly in terms of shared references, sets of methods and research questions, and policy recommendations. Research on biological embedding forms a thought style shared by researchers in the biomedical and public health sciences. Conversely, the concept of embodiment of social experiences connects perspectives from biomedical, public health, human and social sciences, and gathers three thought styles, one identical to that of biological embedding and two formed in social epidemiology and in medical anthropology.

Conclusions: Acknowledging the differences between the concepts and divergences in their evolution provides an opportunity for identification of topics where thought styles are either complementary or in tension.

1. Introduction

In the 1990s, the concepts of biological embedding (Hertzman and Wiens, 1996; Shonkoff et al., 2009) and the embodiment of social experiences (Krieger, 1999, 2005) were independently proposed to designate the processes by which social environments produce health inequalities. To these authors, the concepts are not simply metaphors for how social environments “get under the skin”; they also imply conceptual claims and methodological propositions. Recently, the two concepts have been used interchangeably (Shonkoff, 2012; Evans et al., 2021; Barboza Solís et al., 2016). Does this indicate the formation of a unified research perspective? If so, on the basis of which methods or objects of study has this rapprochement taken place? What are the implications for

research practices and their potential applications to policy? In this article, we argue that it does matter whether one chooses the term “embedding” or the term “embodiment”. Following previous studies in the philosophy and the sociology of science (Bailer Jones, 2002; Keller, 1995; Louvel, 2020), we suggest that studying which concept is used, and in which papers, is an integral part of the study of scientific practices. We draw on the notion of thought style (Fleck, 1935/2008) to relate the uses of the concepts of embedding and embodiment to ways of doing research. We analyze thought styles that have formed around both concepts as well as their evolution, convergence and divergence. Thought styles can be defined,

following Fleck (1935/2008), as sets of references, methods and objects of study shared by members of a research community. They shape the definition of research questions as well as the range of possible answers to them. This concept is heuristic in several ways for describing research using the concepts of biological embedding/embodiment. First, thought styles form around collectives located in a specific socio-historical context. This concept grasps modes of scientific inquiry in a more precise way than Crombie's "styles of scientific thinking" (1994) or Hacking's "styles of reasoning" (1992), which are characteristic of broad historical periods. In addition, the concept of thought styles emphasizes that the sciences continuously evolve through the circulation of ideas and flows of exchange between and within collectives. Whereas different paradigms (Kuhn, 1962/2018) may exist in sharp contrast with each other and develop within bounded temporal sequences, thought styles follow ad-hoc lines of development, which depend on collaborative work and scientific communication. In particular, scientific literature is essential to the formation, connection or distancing of styles of thought (Blümel and Schniedermann, 2020).

Our purpose is not to review evidence gained from studies using the concepts of biological embedding or embodiment of social experiences. Rather, we describe the formation of thought styles associated with each of these two concepts by analyzing their circulation in the scientific literature. To this end, we use scientometric and qualitative analysis of articles. First, we compare the initial research agendas put forward with both concepts. Then, we argue that their differences have been reinforced with their uptake by several scientific communities. Research on biological embedding forms a thought style shared by researchers in the biomedical and public health sciences. Conversely, the concept of embodiment of social experiences connects perspectives from biomedical, public health, human and social sciences, and gathers three thought styles, one identical to that of biological embedding and two formed in social epidemiology and in medical anthropology (see Fig. 1).

To acknowledge the differences between the two concepts under study provides an opportunity for critical discussion and for identification of areas and topics where thought styles are either complementary or in tension. These differences pertain to the scientific practices through which social inequalities in health are studied, as well as in the foreseen intervention modalities and broader impacts of research on policy. We argue that to seriously consider the conceptual distinction between embedding and embodiment may help forward debates around the study of social inequalities in health and their translation to public health recommendations.

2. The initial research agendas

2.1. 1. Towards new perspectives on health inequalities: two concepts for thinking about how social environments 'get under the skin'

The concept of biological embedding appeared in the fields of epidemiology and neuroendocrinology within the span of a few years. Hertzman (1999) defined biological embedding as "the process whereby differential human experiences systematically affect the healthfulness of life across the life cycle" (p. 89) and elaborated on it in further publications (Hertzman, 2012). In neuroendocrinology, Shonkoff et al. (2009) introduced the notion of "biological embedding of adversities during sensitive developmental periods" (p. 2252). In epidemiology, Krieger (1999) proposed the concept of embodiment of social experiences: "How we literally incorporate biologically—from conception to death—our social experiences" (p. 296). While earlier work by Krieger (1999) did not refer to previous uses of the concept, in later work Krieger (2005) mentioned its philosophical origins in phenomenology (Husserl, 1950), where the lived body constitutes the fundamental structure of all knowing; as well as its theorization by sociologist Bourdieu (1980), for whom socialization can be achieved through the body; and its definition by anthropologist Csordas (1990), for whom embodied experiences transcend the dualism of subject vs. object; nature vs. culture; and body vs. mind.

The concepts of embedding and embodiment have several points in common. First, both concepts aim to criticize the epidemiology of individual risk factors in the study of chronic diseases (Susser and Susser, 1996). In contrast, the authors defining these concepts proposed an ecological approach to the social environments likely to generate health inequalities. Hertzman (1999) distinguished three levels of social environment (macro: the amount of wealth and its distribution; meso: voluntarism; social affiliation, trust, and cohesion; discrimination and social exclusion; and micro: the nature and quality of personal social support, i.e., intimate relationships, friendship, and the availability of personal help when needed). Hertzman (2012) drew from ecological systems theory (Bronfenbrenner, 1979) to outline the intertwining of social environments and the unique combination of experiences for each individual. Krieger and Davey Smith (2004) listed several ways of existing in society (as a member of a societal context, as holder of a social position, by contributing to activities of social production, and through social consumption, social position and social reproduction). Second, both concepts emphasize the combination of biological and social pathways in the formation, maintenance and transmission of health inequalities throughout the life course (Power and Hertzman, 1997). Krieger (1999) considers embodiment a central element of ecosocial theory which: “posits that how we develop, grow, age, ail, and die necessarily reflects a constant interplay, within our bodies, of our intertwined and inseparable social and biological history” (p. 296). For instance, she identifies four pathways through which racial discrimination against African Americans causes hypertension: residential and occupational segregation leading to malnutrition and lead exposure; perceived or anticipated discrimination generating high psychosocial stress; targeted marketing of high-alcohol beverages to African American communities; and insufficient or inappropriate medical care (op. cit.). Lastly, concepts of biological embedding and embodiment aim to challenge some of the established thinking in public health. Biological embedding should explain why interventions designed as “magic bullet type social, emotional, and/or educational interventions” (Hertzman and Wiens, 1996, p. 1092) are likely to fail to reduce social inequalities in health in the long term. It should also explain the limited effects of prevention efforts focused on adults and help shift the dominant public health paradigm toward developmental health (Shonkoff et al., 2009). Both concepts should also guide public health prevention programs based on evidence of the bodily and biological damage inflicted on disadvantaged populations, regardless of individual behaviors (Krieger, 2001; Hertzman and Wiens, 1996).

The concepts of biological embedding and embodiment also define quite distinct research agendas, in particular with regards to periods of life taken into account, or to the attention paid to biological mechanisms in the production of health inequalities.

2.2. 2. Two distinct research agendas

First, the concept of biological embedding suggests that physical, cognitive and behavioral development are decisive factors for health outcomes in adulthood. The prenatal period, childhood and adolescence, are described as a sensitive period during which the biological embedding of social environments is likely to have long-term effects on health (Hertzman, 2012). This view is in line with the Developmental Origins of Health and Disease (DOHaD) perspective, according to which prenatal and perinatal environments have lifelong health effects (Gillman, 2005). In contrast, Krieger (2004, 2005) does not emphasize developmental health. Some archetypal examples of embodiment refer to developmental health issues, such as low birth weight (Krieger & Smith, 2004), while others relate to health in adulthood, such as the prescription of hormone replacement therapies at menopause (Krieger et al., 2005).

Secondly, the study of biological pathways is not assigned equal importance within the two concepts. Hertzman (2012) defines an “archeology of biological embedding” with three layers: surficial (population-based patterns of developmental health), shallow (biological systems functioning) and deep (cell-level processes). He identifies five biological systems as candidates “with the capacity to transduce experience from the social environment to human biology”: “the HPA–cortisol axis (McEwen, 1998, 2000); the autonomic nervous system; the memory, attention, and other executive functions of the

prefrontal cortex (D'Angiulli et al., 2008); the immune system; and the social affiliation system" (Hertzman, 2012, p. 17164). Among these he refers to the HPA axis as the "first place to look" because of the close interactions between the central nervous system and the immune, hormone, and clotting systems (Hertzman, 1999, p. 89). Deep archeology deals with epigenetic modifications of the genome and their effects on gene expression. Krieger (2005) mentions several types of responses to embodiment "from macroscopic (for example, waist to hip ratio) to microscopic (for example, gene expression)" (p. 351). However, she warns against an excessive focus on the functioning of certain biological systems (notably, altered neuroendocrine functions), which she believes goes hand in hand with an excessive focus on psychosocial exposures and their stress responses (Krieger, 2001; Krieger and Davey Smith, 2004). Finally, she calls for integration of the study of embodiment pathways within a broader research posture in epidemiology that she describes as "embodied analytic approach" (Krieger, 2012, p. 942): "'embodiment' for epidemiology is best understood: (a) As a construct, process, and reality, contingent upon bodily existence; (b) As a multilevel phenomenon, integrating soma, psyche, and society, within historical and ecological context, and hence an antonym to disembodied genes, minds, and behaviours; (c) As a clue to life histories, hidden and revealed; and (d) As a reminder of entangled consequences of diverse forms of social inequality" (Krieger, 2005, p. 352).

These differences thus question the fact that the concepts of embedding and embodiment are sometimes defined in relatively similar ways: "Science tells us that early experiences are embedded biologically (i.e., 'built into our bodies') for better or for worse" (Shonkoff, 2012, p. 17302); "[embodiment is] the idea that humans – as biological and social beings – biologically incorporate their social and physical environment" (Evans et al., 2021, p. 2).

We propose to examine how both concepts have been used from the 1990s onwards and to analyze the styles of thought that have developed around these concepts, by identifying shared references, methods and research objects.

3. Materials and methods 3.1. 1. Data sources

Using the Web of Science core collection, we assembled two sets of scientific articles referring to the concepts of biological embedding or embodiment of social experiences, and published between January 1st, 1990, and December 21st, 2021. This search yielded 177 articles on biological embedding (80 original articles and 97 reviews, conceptual papers, methodological articles and commentaries) and 145 articles on embodiment (70 original articles and 75 reviews, conceptual papers, commentaries and editorials) (see Fig. 1).

A complete list of the collected articles can be found in the supplementary material where they are numbered from 1 to 322. When these articles are referenced in our results section, we cite them by article number. For instance, [Embedding, 1] refers to article number 1 of 177 in the biological embedding corpus; [Embodiment, 300] refers to article number 300, which is part of the embodiment corpus of articles 178–322. Due to limited space, we could not list them in the bibliographic references.

3.2. 2. Data analysis

Scientometric analysis. We conducted the scientometric analysis with the free software CorText Manager v2 (<https://www.cortext.net/>). For each set of articles, we produced statistical descriptions (publication journals, authors, research areas) and conducted analysis of co-citation networks, also called bibliographic coupling. Co-citation networks are networks of references that have been co-cited in a series of publications. In this article we use them as an indicator of articles' proximity in terms of content (Andrés, 2009) and to identify the shared references which play a significant role in the formation of a style of thought. Co-citation networks were computed using the top 100 co-cited references; their structure was

detected through a clustering algorithm (Senellart and Blondel, 2008). We used the free software Gephi (<http://gephi.org>) for the graphical representations. We identified the main themes of each cluster after studying their most frequently cited references. Each cluster was labeled to facilitate interpretation of the graphs.

Qualitative content analysis. Content analysis was performed independently by each author on the 155 original articles and 182 re-view articles. Analyses were then cross-checked to address disagreements. Unlike a systematic review, our purpose was not to review evidence, identify research gaps and indicate future research directions. Rather, it was to examine the contribution of these articles to the initial research agendas put forward with the concepts of biological embedding and embodiment on six dimensions: 1/method; 2/approach to social environments; 3/period of life considered for social environments (original articles only); 4/period of life considered for health outcomes (original articles only); 5/biological processes and/or bodily consequences; 6/implications for intervention. Precisions can be found in the supplementary material.

4. Results

4.1. 1. Biological embedding: a thought style shared by research communities working within the DOHaD paradigm

The concept of biological embedding gained popularity in the 2010s, but its use remained modest, appearing in about 25 papers per year. These include a high number of reviews, conceptual papers and commentaries (97 in total). The number of original population studies drawing on the concept remains low overall but recently has shown a marked increase, with more than four-fifths of original papers published after 2016 (67 out of 80). The top disciplines are psychology with 32.7% of the articles, psychiatry with 18.9%, public health with 18.9% and neuroscience with 15.8%. The concept is also used in behavioral science, pediatrics, biomedical social sciences, and endocrinology and metabolism (see Fig. 2).

Beyond this diversity of scientific fields, research on biological embedding shares three main characteristics: (1) the importance given to the Developmental Origins of Health and Disease hypothesis; (2) the centrality of the identification of biological processes; and (3) the pre-dominance of psychosocial exposures. First, research on biological embedding puts emphasis on the latent health effects of early social environments [Embedding, 36] and periods of exposure range from early-life—which covers gestation (7 articles) and childhood up to age 12 (41 articles)—to adolescence from age 12 to 18 [Embedding, 41] and early adulthood [Embedding, 51]. Second, gaining accurate knowledge on the “deep archeology” [Embedding, 38] involved in the biological embedding of social experiences is a central aim of this research. The analysis of co-citation networks shows three biomedical research fronts, partly intertwined, on which the search for biomarkers and biological pathways is based: stress biology, epigenetics, and the study of multisystem biological embedding (see Fig. 3).

The first research area is stress neurobiology: the most often co-cited references in this area are in the purple and orange clusters, such as McEwen (2007), Lupien et al. (2009) and Ellis et al. (2011). As noted above, the neurobiology of stress was a major influence in the formulation of the research agenda on biological embedding. The often-cited review by Lupien et al. (2009) summarizes the effects on brain, behavior and cognition, mediated by the regulation of the HPA axis and the production of glucocorticoids, of exposure to stress at different life stages. It also differentiates effects that are reversible (consequent to exposure during adulthood) from programming effects (following exposure during childhood and teenagerhood). The biology of stress is often used to investigate the consequences of early exposure to intense psychosocial stress: toxic stress (Shonkoff, 2012), trauma, maltreatment or Adverse Childhood Experiences (Danese et al., 2007; Danese and McEwen, 2012). The second research area deals with the

analysis of long-lasting epigenetic alterations—essentially, DNA methylation marks—caused by intense psychosocial stress during early childhood. The most often co-cited references are in the green cluster. Initiated by research on the effects on young rats of the absence of maternal care ([Weaver et al., 2004](#)), this field of research was then extended to human populations ([McGowan et al., 2009](#)). The third and final area of research deals with the effects on several biological systems (the nervous, immune, and endocrine/metabolic systems) of early exposure to psychosocial stress and/or of living in socially disadvantaged environments. The most often co-cited references are in the blue cluster. [Miller et al. \(2009\)](#), among others, pioneered this perspective by showing an association between low socioeconomic status in early-life and “resistance to glucocorticoid signaling, which in turn facilitates exaggerated adrenocortical and inflammatory responses” (op. cit., p. 14716). This research area has strong connections with stress physiology, for example with the measurement of allostatic load ([McEwen, 1998](#))—defined as the physiological response to stress and quantified by a score based on assessment of the state of several physiological systems—and with social epigenetics ([Borghol et al., 2012](#)). These three biomedical research fronts are well established in the original articles incorporating the concept of biological embedding with the search for stress biomarkers (16 articles), epigenetic biomarkers (14 articles), and biomarkers from several

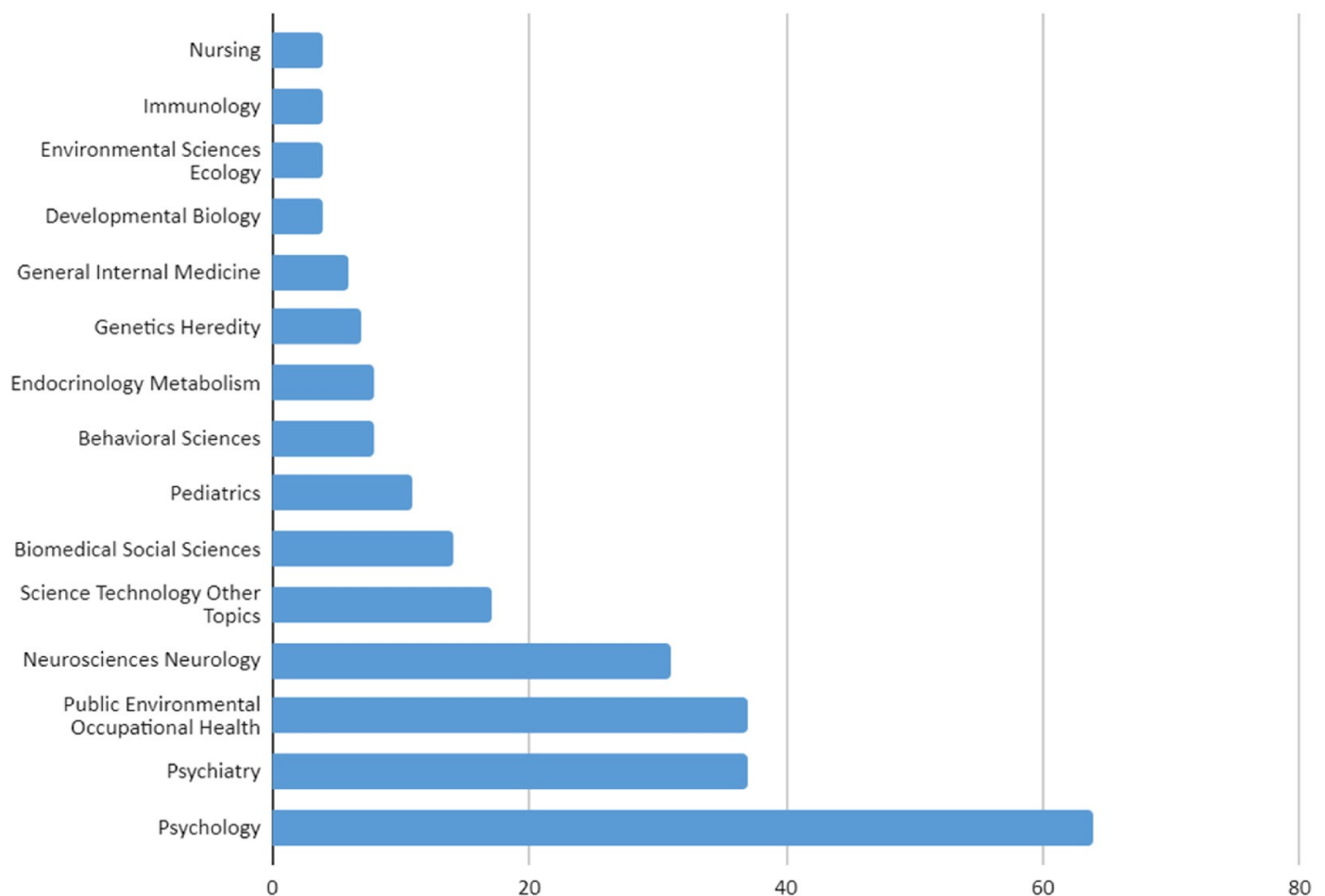


Fig. 2. First 15 Web of Science categories of articles on biological embedding (total number of articles published).

Epigenetics

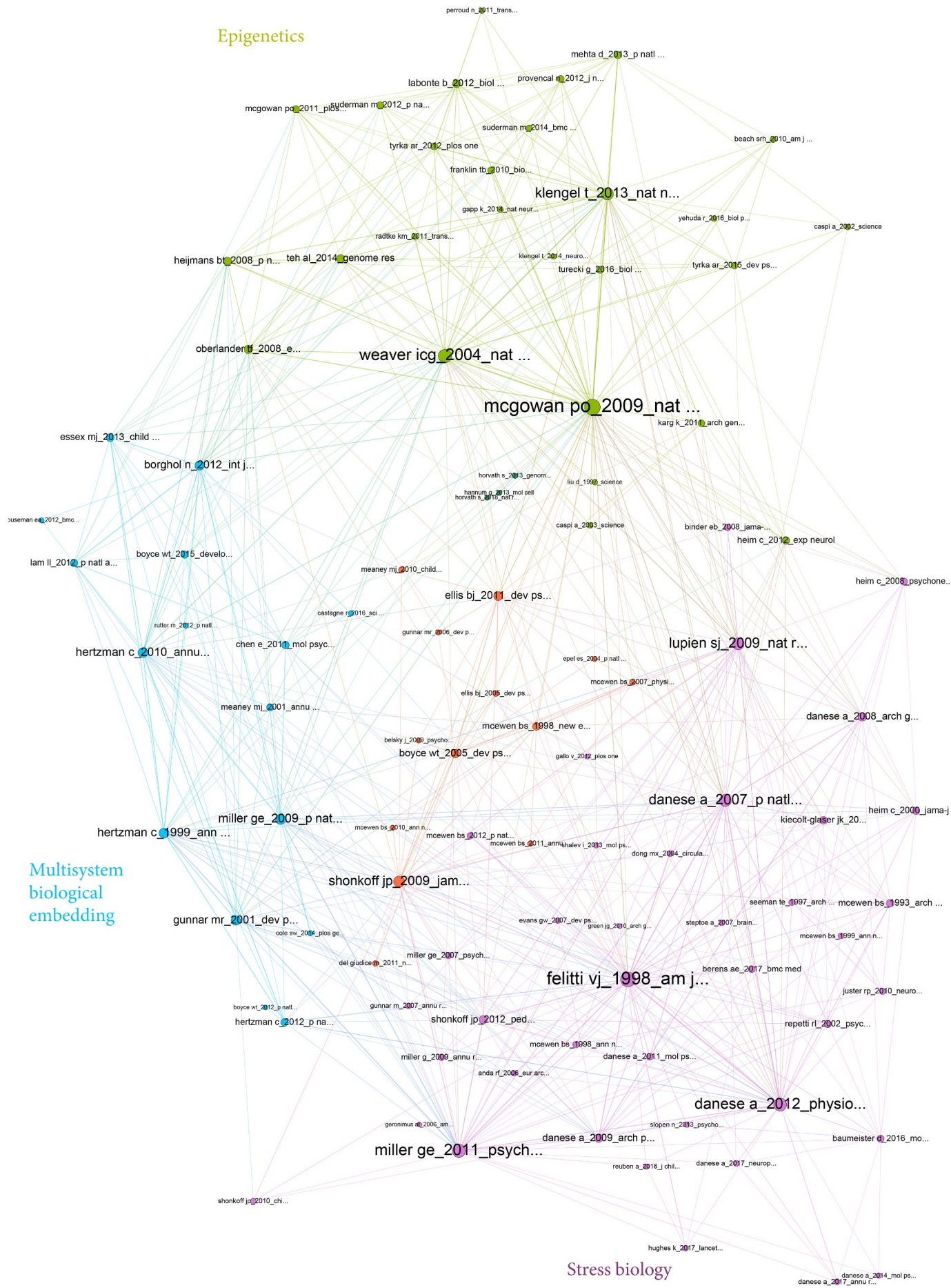


Fig. 3. The three biomedical research fronts that support research on biological embedding. Legend: top 100 co cited references in articles on biological embedding (node color depends on their cluster assignment; node size scale is proportional to the node's degree, i.e. the number of connections to the node).

biological systems (29 articles) (see Fig. 4). Finally, research on biological embedding is mainly concerned with

psychosocial environments, taken in isolation or combined with situations of material and/or socioeconomic disadvantage (see Fig. 5). This can also be assessed based on the number of reviews devoted to this topic—psychosocial exposures in general (23), childhood maltreatment and trauma (11), gender-based violence and trauma (1), and racial trauma (1)—as well as inclusion of such environmental exposures in broader reviews on early-life adverse experiences (15 reviews).

Over half of the original studies focus exclusively on psychosocial stress (44 of 80 studies). Research was initially conducted on situations of child maltreatment [Embedding, 115], violent social interactions during adolescence [Embedding, 120], adverse childhood experiences [Embedding, 129], and childhood abuse [Embedding, 107]. The range of psychosocial exposures considered subsequently extends to discrimination, unsupportive family environments, bullying, family member incarceration, quality of maternal care, perceived social status, minority stress, gender role stress, etc. Psychosocial stress is most often measured using scales developed in clinical psychology and psychopathology for trauma [Embedding, 107; 140; 160], such as the Adverse Childhood Experiences study scale [Embedding, 129, 165, 168, 145, 156, 173, 121, 123]. In addition, 20 studies developed composite scores to investigate the joint effects of psychosocial stressors and socioeconomic and/or material disadvantages. This research developed concurrently with studies focused on socioeconomic position (13 articles) and material conditions such as neighborhood disadvantages and financial hardship (3 original studies, e.g., [Embedding, 131]).

Research on biological embedding forms a relatively coherent style of thought emphasizing the DOHaD perspective, the search for biological pathways and the predominance of psychosocial exposures. This does not mean, however, that there are no disagreements between the scientific communities that integrate the concept into their study of the formation of health inequalities early in life. The most notable area of discord has to do with recommendations made in review articles regarding policy and practice. A majority of articles propose clinical interventions (51 articles), including behavioral and pharmaceutical intervention strategies in psychiatry, psychology, pediatrics and clinical nursing. But another significant percentage of reviews (32 articles) draw on the model of biological embedding to persuade public authorities to recognize that the primary causes of ill health in adulthood are toxic stress during childhood [Embedding, 84; 66], early-life socioeconomic environments [Embedding, 36], adverse psychosocial exposures [Embedding, 5; 60; 61], childhood poverty [Embedding, 72; 80], and child maltreatment [Embedding, 32; 59]. Some recommendations are very general, such as focusing public health interventions on windows of opportunity in child development [Embedding, 51]. A few are more specific: for instance, that knowledge of biopsychosocial mechanisms

Fig. 4. Biomarkers studied in original studies on biological embedding, 2008-2021.

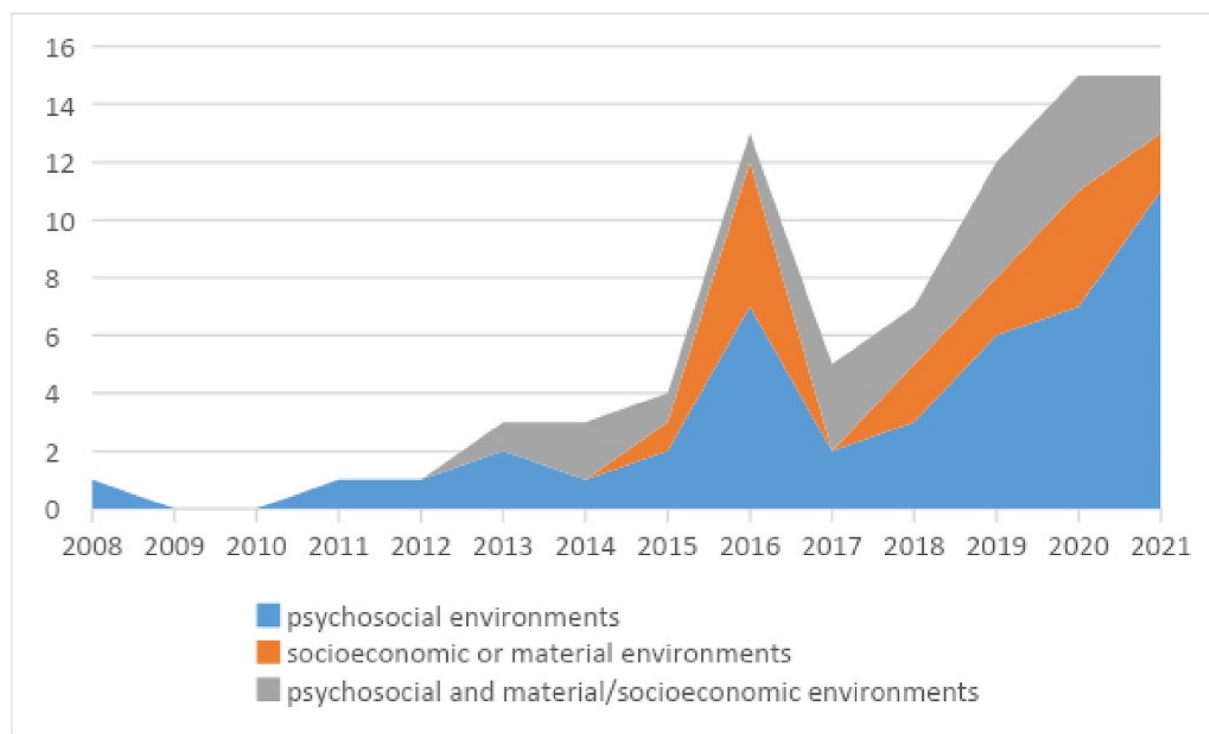


Fig. 5. Social environments studied in original studies on biological embedding, 2008-2021.

contributing to food addiction should support public policies to reduce youth exposure to foods containing sugar [Embedding, 92].

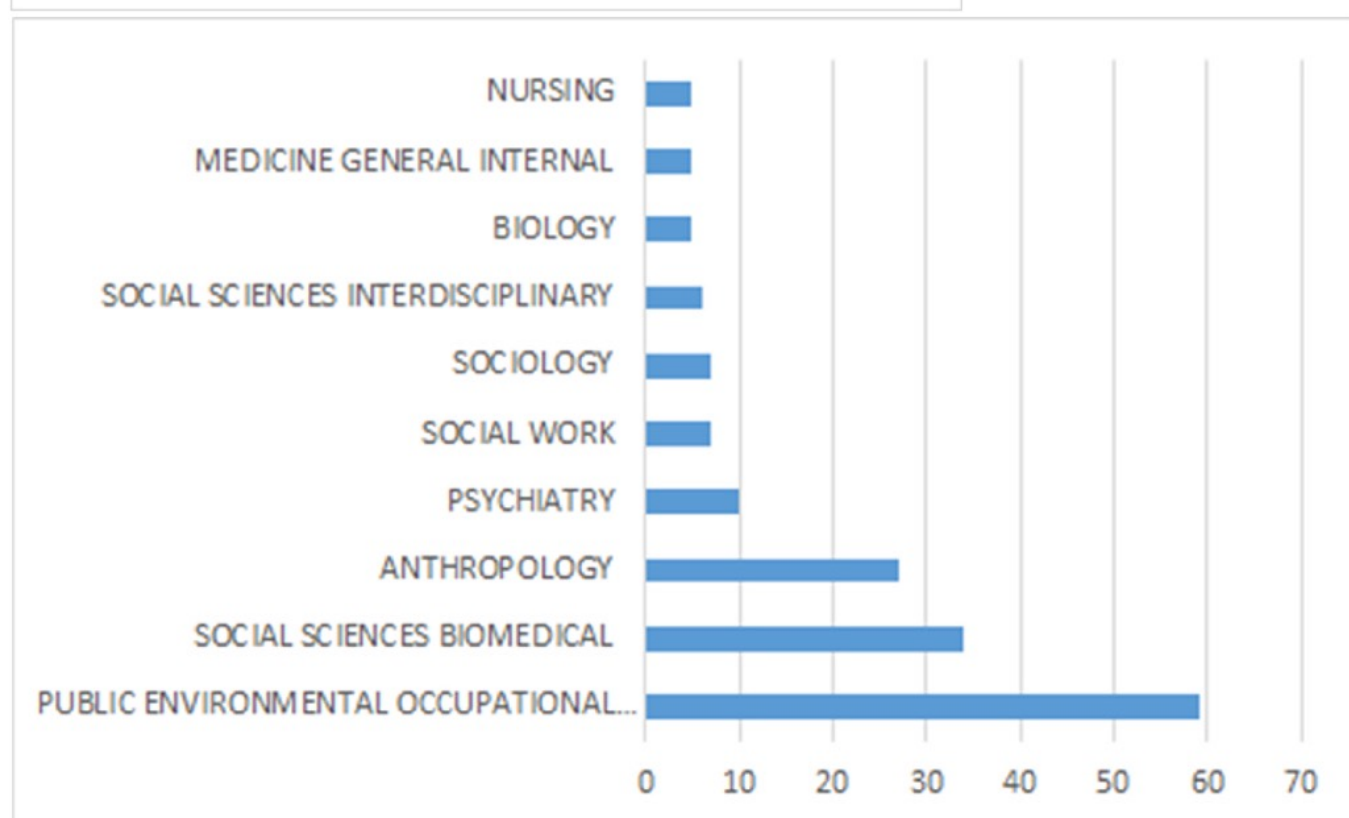
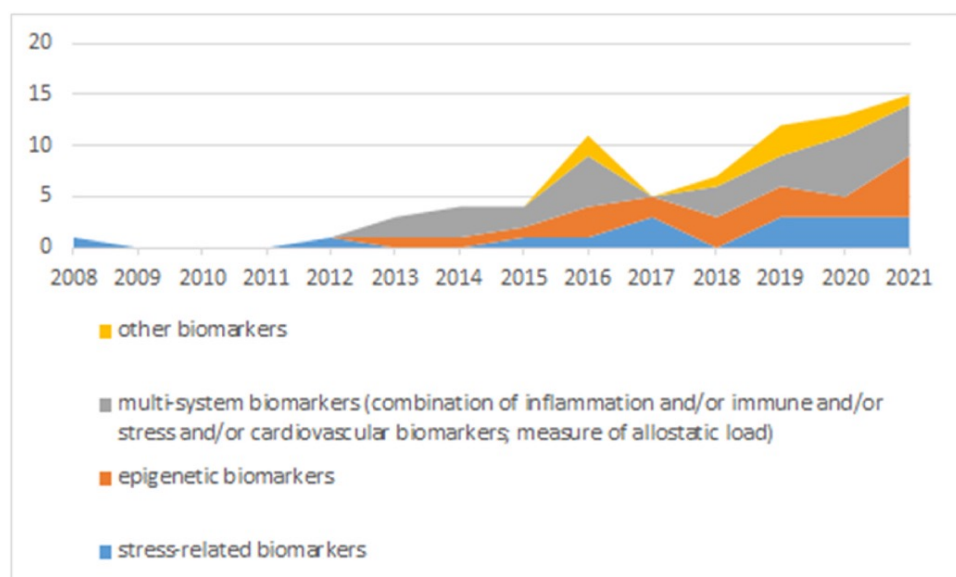
We will now demonstrate that various uses of the embodiment concept have resulted in the formation of three distinct thought styles, one of which is identical to that of biological embedding (see Fig. 1). If these concepts are not synonymous, are there spaces for dialogue between them?

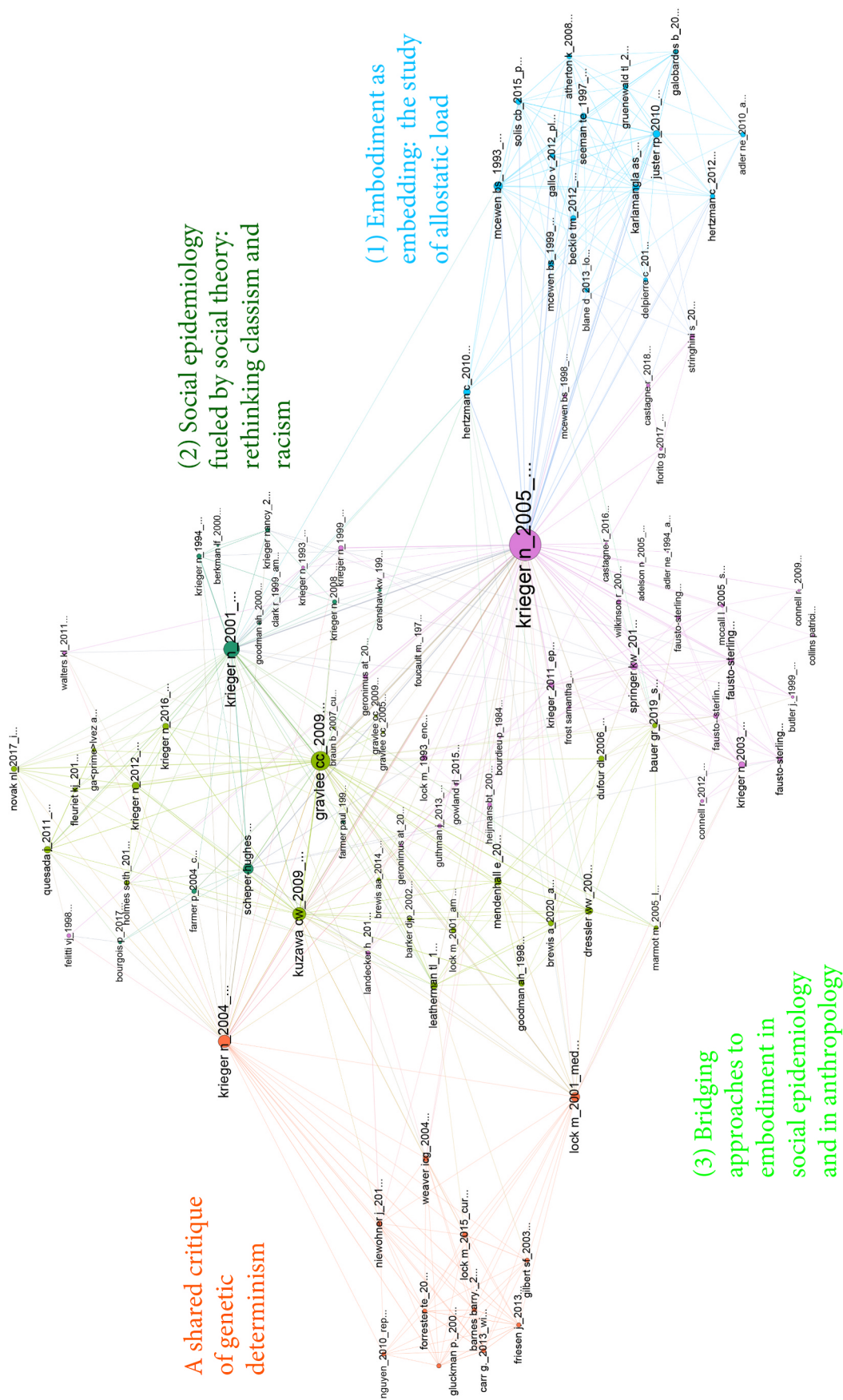
4.2. 2. Embodiment of social environments and health inequalities: three distinct thought styles

Krieger's concept of embodiment has appeared in about 15 articles per year since 2016, primarily in the category of public health (59 articles), followed by the social sciences of health (34 articles) and anthropology (27 articles). It has also been used in many areas of the human and social sciences (e.g., archeology, geography, sociology) and biomedicine (e.g., neurosciences, psychiatry, dentistry; See Fig. 6).

Three thought styles formed following the circulation of Krieger's (1996, 1999, 2005) definition of embodiment among these multiple research communities. The thought styles can be distinguished based on their method, their approach to social environments, their emphasis (or lack thereof) on biological processes, and their shared references, which are identified by networks of co-cited references (see Fig. 7). It should be noted that a critique of the importance of genetic determinism in the medical world—backed up with references to epigenetics—can be found in articles contributing to the three thought styles. It is based on citation of articles in the orange cluster (see Fig. 7).

Fig. 6. First 10 Web of Science categories of articles using Krieger's concept of embodiment of social environments (total number of articles published).





A shared critique
of genetic
determinism

(3) Bridging
approaches to
embodiment in
social epidemiology
and in anthropology

(2) Social epidemiology
fueled by social theory:
rethinking sex, gender
and intersectionality

(1) Embodiment as
embedding: the study
of allostatic load

(2) Social epidemiology
fueled by social theory:
rethinking classism and
racism

Fig. 7. Three thought styles in research using Krieger's notion of embodiment. Legend: top 100 co cited references in articles using Krieger's notion of embodiment (node color depends on their cluster assignment; node size scale is proportional to the node's degree, i.e. the number of connections to the node).

4.2.1. The biological embedding thought style in papers that discuss embodiment

A first set of papers discusses embodiment but adopts the thought style characteristic of biological embedding. This thought style is found in 18 original studies, as well as in review articles in social epidemiology, biomedical sciences and biological anthropology. Frequently co-cited references are in the blue cluster (see Fig. 7). Among these articles, some use embodiment and biological embedding relatively interchangeably.

These studies make several contributions to the research program on biological embedding. First, all original articles in this set studied biological pathways linking social experiences and environments (especially during childhood) to poor health in adulthood, with an emphasis on psychosocial stressors alone (8 studies) or combined with deprived material or socioeconomic environments (3 studies). The remaining 5 studies focus on socioeconomic position. In addition, these articles are primarily concerned with stress-sensitive biological systems, allostatic load, and/or epigenetic alterations. Second, these articles suggest implications for two types of health interventions. The first have a biomedical orientation: for example, the development of psychological empowerment strategies [Embodiment, 235] or the design of high-precision intervention in oral health [Embodiment, 192]. A second type of intervention relates to public health and social policy: promoting access to oral care for unauthorized persons and their families [Embodiment, 287], developing interventions targeting parents and young children [Embodiment, 216; 292], reducing inequalities in education [Embodiment, 239], and developing culturally-relevant smoking policies and prevention practices (e.g., by taking into account self-reported pain induced by racial discrimination [Embodiment, 282]).

4.2.2. 2. 2. A thought style rooted in social epidemiology and fueled by social theory

A second group of articles develop a thought style clearly distinct from that associated with the concept of biological embedding. While the original articles in this set are all in social epidemiology (with 12 cohort surveys), the reviews, conceptual papers and methodological papers are in public health, sociology of health, health geography, and community health research. These articles are fueled by social theory on sex/gender (references in the purple cluster), critical race theory, and sociological theory of social position and stratification (references in the dark green cluster).

First, biology remains a 'black box'. Articles seek less to elucidate biological pathways than to highlight how cultural, economic and social environments are incorporated throughout the life course "by pathways spanning multiple levels and spheres of social organization" [Embodiment, 278, p. 8] and to explain patterns of disease distribution.

Secondly, articles emphasize the material and structural causes that generate health inequalities. Epidemiological studies question the effects of insurance coverage and the financial burden of disease among minority and low-SES groups [Embodiment, 269]; institutional and inter-individual racial discrimination [Embodiment, 305]; history of incarceration and substance abuse [Embodiment, 297], accumulated social and material adversity starting early in childhood and forming a "social chain of risks" [Embodiment, 277; 292], material living conditions of LGBTQ people [Embodiment, 278], and macroeconomic conditions [Embodiment, 320]. Some articles recall the theory of "fundamental causes" or of the "causes of the causes" of health inequalities, and criticize excessive attention to stress experienced by individuals [Embodiment, 204; 278].

Third, articles defend the relevance of social theories for analyzing social pathways of embodiment

[Embodiment, 24]. They criticize the categorical understanding of social position [Embodiment, 206], gender [Embodiment, 178; 187; 188; 198], race [Embodiment, 190; 238] and place [Embodiment, 288; 237], which drive the design of inequality metrics. They call for the use of relational social theories that emphasize the non-deterministic nature of these determinants [Embodiment, 240], including critical realism [Embodiment, 247], critical race theory [Embodiment, 190], feminist theory [Embodiment, 187], gender theory and sex/gender conceptualizations [Embodiment, 178; 181; 198; 227], and disability studies [Embodiment, 187]. In health geography, there is a call for “engaging ‘relational’ and dynamic notions of place that are defined not by arbitrary administrative lines, but by lived spatial realities and patterns of mobility” [Embodiment, 228, p. 294]. This understanding of space can only be achieved using a participatory methodology inspired by community-based research. Other methodological proposals deal with how to operationalize intersectionality in statistical surveys [Embodiment, 180; 271], a notion primarily used in qualitative studies [Embodiment, 204].

Fourth, articles call for the adoption of social policies for health, targeting material living conditions and access to health care, health insurance and education [Embodiment, 225]. They promote empowerment and capacity building, at the scale of a community [Embodiment, 184; 199; 226; 241] or a profession [Embodiment, 204]. Lastly, they denounce institutional policies in the name of accountability principles for health inequalities, social (in)justice, and violation of human rights [Embodiment, 203; 240; 278].

4.2.3. . A thought style at the intersection of social epidemiology and anthropology

The third and final group of articles refer to the concept of embodiment as defined by Krieger (1996, 1999, 2005), as well as by biocultural and medical anthropologists. These articles frequently cite the anthropology references included in the light green cluster.

Complementarities and differences between epidemiology and anthropology are the subject of a dozen review articles and conceptual papers in anthropology. Anthropologists praise the advent of a research agenda on embodiment in social epidemiology, whereas it has been a long-term concern in their discipline, dating back to the work of Franz Boas [Embodiment, 196]. They question the formation of a research agenda common to social epidemiology on the one hand, biocultural anthropology [Embodiment, 183; 194; 196; 217; 244], medical anthropology [Embodiment, 218; 219; 220], and bioarchaeology [Embodiment, 195; 251; 252] on the other hand. While reviews acknowledge that “cultural-biological research” has renewed anthropological approaches to embodiment, by paying attention to the local variations of human biology [Embodiment, 202], the original anthropological studies that refer to Krieger’s concept of embodiment more broadly investigate the imprint of culture and society on bodies.

Three main themes are developed in 40 original articles. First, anthropologists propose to enrich social epidemiology by “adding to it a more overtly political perspective” (Nguyen and Peschard, 2003, p. 453). Following Galtung (1969) and Farmer et al. (2006), medical anthropologists use the concept of “structural violence” to refer to the prejudices suffered when social structures or institutions prevent people from meeting their basic needs, and adapt this concept to issues surrounding health. They also speak of structural vulnerability (Quesada et al., 2011), and social suffering (Kleinman et al., 1997) which connects bodily fragility with systemic violence and the global political economy. The health effects of these various forms of violence range from the occurrence of chronic pathologies such as polycystic ovary syndrome [Embodiment, 295] or obesity [Embodiment, 257]; to the deterioration of general health states in situations of great precariousness or migration causing chronic stress [Embodiment, 317; 264] or placing constraints on pregnancy and childbirth [Embodiment, 298; 303; 279]. The social forces leading to structural inequalities include racial and/or gender-based discrimination, sexual violence inflicted on women, police violence [Embodiment, 256; 273], urban poverty, inequalities between rural and urban areas, difficulties accessing prevention [Embodiment, 299; 272], political instability, major North/South imbalances, globalization [Embodiment, 295; 302] and global warming [Embodiment, 293]. These articles

put emphasis on the Global South (10 articles). They focus on migrants (5 articles), Indigenous populations (4 articles), and women

(21 articles), in particular victims of sexual violence and/or gender-based discrimination, sometimes combined with racial discrimination and economic, social and political insecurity [Embodiment, 298; 299]. These studies draw on feminist studies (Butler, 2004; Fausto-Sterling, 2012), critical race theory (Sharpe, 2016), decolonizing methodologies (Smith, 1999) and critical fatness/weight studies (Farrell, 2011). Some articles develop an intersectional approach to embodiment, and consider, for instance, how race, youth and rurality [Embodiment, 304], or race and disability [Embodiment, 284] may interact.

Secondly, anthropologists study the embodiment of health inequalities as situated processes [Embodiment, 311]. They insist on the necessity “to spatially and temporally locate specific institutional processes and mechanisms of harm” to better characterize systemic phenomena, such as structural violence [Embodiment, 273, p. 569]. They approach social situations as worlds whose massive effects on the lives of individuals should be conveyed using ethnographic observations and interviews. Some articles combine medical anthropology, health geography and political ecology, to suggest a geography of embodiment, where place is not a background but an inhabited space experienced and made sense of by individual subjects. Articles value efforts to capture “the salient experiences of individuals among diverse communities in their own words” [Embodiment, 221, p. 1771]. Health and illness narratives are put forward as a way to understand how people make sense of their bodily sensations in relation to their social and ethnic context [Embodiment, 254; 316]. This is exemplified by one study in particular: in her article about the unique fatigue marked by extreme *zor* (“constraint” or “difficulty”) experienced by Romani women in Albania “as a result of their repeated exposure to intersecting racialized and gendered marginalization”, medical anthropologist Chelsi West Ohueri shows how “systemic racism can become embodied”, and lead to disparate health outcomes [Embodiment, 316, p. 241]. While biomedical conditions tend to be presented as universal, *zor* is at the same time biological, emotional, social, and deeply rooted in community experiences. This article and others [Embodiment, 311; 254; 293] emphasize situated knowledge and understand bodies as capable of delivering individual as well as group stories (Brave Heart, 2000).

Finally, the articles provide insights as to how to combine anthropological and epidemiological perspectives. First, combining ethnographic and cohort studies should allow for a fine-grained contextualization of embodiment situations, and for identification of the experiences that make sense to individuals. Some anthropologists define ethnography as complementary to biological measurements and as necessary to grasp the complexity of local environments that produce “local biologies” [Embodiment, A study by Pike et al. (2010) on the differential impact of intercommunity violence on community health in Northern Kenya is an example of use of a mixed-method approach to analyze the lived experience of violence and its costs on health [Embodiment, 229]. Second, community-based participatory research is presented as a way to avoid “de-placed, de-politicized, and ironically disembodied accounts of place-embodiment” [Embodiment, 296, p. 295]. By involving local actors, anthropologists acknowledge them as “full people—as constituents with political voice, networked social power, and agency”, “respect their ‘expertise’ of/with their own embodiment histories”, and facilitate community agency (op. cit., p. 295), a notion central to both the anthropological approach to embodiment and Krieger’s eco-social framework. These methodological innovations should lead to the design of public health interventions tailored to local situations [Embodiment, 221; 273; 296].

5. Discussion and conclusion

In this paper we have shown that articles that refer to the concepts of biological embedding (Hertzman and Wiens, 1996; Shonkoff et al., 2009) or embodiment (Krieger, 1996; 1999, 2005) of social experiences have different ways of addressing how social environments produce health inequalities, in terms of both

research practices and policy recommendations. We have shown that these concepts initially address the same overarching issue and share some conceptual perspectives, but that later research related to these works differs greatly. Fleck's (1935/2008) analysis of 'thought styles' is helpful for considering how differences between the initial research agendas of embedding/embodiment consolidate, and additional differences arise as the concepts gain traction and travel across scientific communities. Indeed, Fleck (1935/2008) emphasizes that the formation and evolution of thought styles result from the circulation of concepts and methods within and between research collectives, with each bringing its own nuances. This circulation takes place either diachronically or synchronically. Not only do the thought styles associated with biological embedding/embodiment differ significantly, but they also evolve differently along with synchronic and diachronic exchanges of ideas.

A thought style characteristic of studies on the biological embedding of social experiences has formed synchronically through exchanges between research in public health and the biomedical sciences. Its core dimensions are a focus on the long-term health effects of early environments, the search for biological pathways—with an emphasis on stress-sensitive biological systems—, a key interest in psychosocial stressors and an emphasis on clinical interventions. This thought style has evolved along with progress in neurobiology, stress physiology and epigenetics, enabling the accumulation of biological knowledge on the cellular- and system-level processes at stake. It has also benefited from developments in research on health inequalities (Bouchard et al., 2015) such as the study of the joint effects of psychosocial stressors and socioeconomic and/or material disadvantages, and the expansion of research on spatial inequalities (Collyer and Smith, 2020). On the other hand, research on the embodiment of social experiences follows three thought styles as a result of its diachronic circulation in the humanities and social sciences—philosophy, then sociology and anthropology—and of synchronic exchanges between social epidemiology, biomedical research, and the human and social sciences. This circulation has brought conceptual nuances as well as diversity in scientific practices, references and writing styles. Exchanges between social epidemiology and studies in stress biology and epigenetics have inspired epidemiological studies that use concepts of biological embedding and embodiment interchangeably. Other epidemiological studies treat biology as a 'black box'. They borrow from health sociology, health geography, and community health research to emphasize the material and structural causes that generate health inequalities, and advocate for changes in social policy. Lastly, ethnographic studies in medical anthropology aim to connect epidemiology and anthropology in order to study the health costs of situations of marginalization and exclusion in the North or in the Global South. While denouncing global institutional policies causing health disparities, they advocate for local reforms that build on the knowledge and expectations of the involved communities.

Far from being monolithic blocks, thought styles entail nuances and tensions. Even the one characteristic of research on biological embedding, which appears relatively homogeneous with regard to ways of doing research, is polarized between clinical and policy-oriented implications. However, each thought style has its own way of approaching objects and issues. Their salient features and main points of divergence can be illustrated using the example of trauma.

A first set of studies in trauma follow the thought style of biological embedding. Most of the studies place emphasis on childhood trauma and measure it using scales such as the Childhood Trauma Questionnaires (McCormack et al., 2021), the Comprehensive Trauma Interview Screen (Shenk et al., 2021), and the Risky Families Questionnaires (Carroll et al., 2013). Articles mention that deciphering the biological links between trauma and specific adverse health outcomes may offer the possibility of targeted prevention strategies for at-risk children (Carroll et al., 2013; Shenk et al., 2021). A few of these studies research historical trauma, for instance Indigenous residential school attendance (Moon-Riley et al., 2019). While authors acknowledge this trauma to be both psychosocial and material, they operationalize it as a psychosocial stressor with potential effects on allostatic load, whose intensity they measure using the Adverse Childhood Experiences scale.

A second set of studies contributes to the effort of bridging anthropological and epidemiological approaches to embodiment. While differing in their attention to biology, they all begin from the lived experiences of trauma and its health legacy. For instance, a review by [Walters et al. \(2011\)](#) employs a definition of trauma established by and with Indigenous populations, and connects the concept of embodiment with American Indians and Alaska Natives' "spatial and relational worldviews that recognize the interdependency between humans and nature, the physical and spiritual worlds, the ancestors and the future generations" (op. cit., p. 184). In this respect, although the authors are interested in its biological expression, their approach to trauma does not align with the model of biological embedding. Other anthropological studies go one step further in defining trauma not as a well-identified stressor but as a fundamentally destabilizing event. This is notably the perspective of [Pike et al. \(2010\)](#): "(m)ore than simply imagining violence as triggering stress responses or being exclusively linked to traumatic events, this project traces the importance of stress to threats to identity" (op. cit., p. 48). Ethnography is considered the only relevant method for approaching trauma as a multifaceted experience, which destabilizes the construction of individual personhood and the memory of a group. Narratives of trauma and healing are also put forward as helping to shape the design of effective interventions to mitigate the health effects of trauma. For instance, studying an Indigenous community that has historically endured land confiscation and forced displacement, [Fernandez et al. \(2021\)](#) invited a dozen Indigenous women to walk along the Choctaw Trail of Tears, to study how this place "in which historical trauma events occurred may invoke both positive and negative feelings" (op. cit., p. 123). Based on their narratives, the authors propose a vision of these women's health that is not located in individual bodies but in their relationship to a place that is inextricably linked to ancestors, community, and future generations. If Indigenous women experience intense physical and emotional stress when reflecting on ancestral trauma, they build resilience through the group experience of a specific place.

These approaches to trauma exemplify distinct thought styles, and indicate very different research paths, conceptual approaches and intervention modalities. Even if concepts of biological embedding and embodiment have been presented as renewing the old ontological debate on the relationship between nature and culture ([Eikemo and Øversveen, 2019](#)), we have shown in this article that research using these concepts has followed rather unrelated lines of development.

In this paper, we draw attention to conceptual distinctions that may not be familiar to all researchers studying social health inequalities. We invite all researchers to engage with the differences between thought styles—either by criticizing, clarifying or sharpening them - —to explore the potential for dialogue and reflect on the potential implications.

First, health inequality research has been described as fragmented ([Collyer and Smith, 2020](#)) and the site of crucial conceptual and methodological debates ([Kelly-Irving and Delpierre, 2021](#)). Identifying areas of discussion between thought styles, as well as exploring reasons for a lack of dialogue between them, can provide a valuable contribution to these debates. One of them touches on how to operationalize the complex and multilevel nature of situations leading to health inequalities. The thought style characteristic of research on biological embedding embraces an additive conception of the social world characteristic of most epidemiological surveys: it defines summary constructs (e.g., early-life adversity) which capture a range of social environments/exposures considered relevant for embedding processes. It could potentially be fruitful to further explore the complementarities between this thought style and studies on embodiment in social epidemiology, for example regarding how social theory may help inform the choice of variables ([Kramer et al., 2017](#); [Dijkstra and Horstman, 2021](#); [Sparke, 2017](#)), or on the relevance of refining the constructs that add group-level measurements and structural variables to individual-level ones ([Evans et al., 2021](#)). But it is equally relevant to acknowledge that, on the contrary, dialogue is almost non-existent between the thought style of biological embedding and studies on embodiment in medical anthropology, even though biological measurements appeal to some bio-cultural and medical anthropologists, who see them as tools for revealing the variable imprints of environments on

bodies (Lock et al., 2021). This lack of connectivity is first due to the difficulty of integrating conceptions of the social world as lived experiences in epidemiological surveys, despite calls to take into account what makes sense to actors, for instance by implementing mixed-method approaches as well as participatory research (Garthwaite et al., 2016). For instance, medical anthropologist E. Yates-Doerr (2020) criticizes research on the social determinants of health for drawing unidirectional arrows between variables and for not allowing researchers “to ask how, for whom and where is the social determinant working well” (op. cit., p. 394). The lack of dialogue between thought styles is also due to differing understandings of the “causes of the causes” leading to inequalities in health. While studies on biological embedding tend to treat them as specific, determining and identifiable causes, anthropological studies of embodiment ground inequalities in complex situations in which several processes of causation are at play (Kelly-Irving et al., 2021). Anthropologists see them as produced by multiple actions and pay special attention to people’s agency, including their struggle or engagement with, and resistance to inequality (Pfeiffer and Chapman, 2010). In this case, emphasizing the differences and even incompatibilities between thought styles is important if we aim to support methodological and theoretical pluralism within health inequality research.

Secondly, there is a long-standing debate among health inequality researchers about the contribution of their research to policy responses (Garthwaite et al., 2016; Kelly-Irving et al., 2021). At the same time, we notice that a significant number of original research articles using the concepts of embedding and embodiment only briefly mention the policy relevance of their work. While presumably meeting journals’ and funding agencies’ requirements for stating the potential impact of their research, these statements do not sufficiently address the possible implications of their research findings.

Acknowledgement of the conceptual differences between research on biological embedding and embodiment of social experiences is useful for deeper reflection on how evidence from health inequality research may fuel policies. In particular, the importance of biology and ideas about the body within the three thought styles may bear on associated policy recommendations. We have argued that the thought style of biological embedding tends to suggest clinical implications. This reflects a conception of the body as subject to the clinic, that is, for which a list of symptoms and a “clinical picture” can be established, which corresponds to biomedical nosology. This research may help legitimize epidemiological research on social inequalities in health and increase its impact on policy as medical evidence bears heavily on public health decisions—due, in particular, to the power of medical actors in the health field and institutional settings such as health ministries (Lynch, 2017). In addition, refining the knowledge of biological pathways can help define evidence-informed policy responses to health inequalities—targeting the most effective populations, time windows, environments and types of interventions—and produce a rigorous evaluation of interventions intended to address inequality (Garthwaite et al., 2016). But some fear that this focus on a biomedical conception of disease and its social determinants will bear the risk of “reinforcing medical, behavioral and neoliberal policy approaches to social inequalities” (Lynch, 2017, p. 653) eventually leading to the pathologization of individuals (Schrecker, 2022), and potential escalation in what counts as strong evidence for substantiating the causes of health inequalities (Schrecker, 2013; Kelly-Irving et al., 2021).

In contrast, we have emphasized that studies of embodiment processes in social epidemiology tend to propose to act on social structures and policies. These policy orientations are consistent with a conception of embodiment processes which is significantly broader than that of biological embedding, as multiple processes of incorporation cannot be captured by physiological or biological measures (Gustaffson, 2016). These recommendations are also based on a conception of the body that approaches bodies as culturally, politically and socially produced, a more comprehensive model than that put forward by studies of biological embedding. Lastly, studies of embodiment in medical anthropology tend to advocate for participatory research linking science to policy. This comes in part from a thought style on embodiment in which bodies are lived and experienced, and on definitions of health and illness as subjective and contextual. The rapprochement of this thought style with social epidemiology has its own difficulties. For

instance, some anthropologists argue that the conception of embodiment adopted by epidemiologists follows “the premise that health is located in bodies” and prioritizes “body-focused orientations to health, foreclosing orientations to health less concerned with bodies” (Yates-Doerr, 2017, p. 150–151). They for their part put forward a relational definition of health instead, which connects people and generations through places and is not in priority body-focused (op. cit.). This leads them to advocate for policy interventions that involve community-based expertise and “treat both health and health interventions as relational processes” (op. cit., p. 380).

In conclusion, not only are concepts of biological embedding and embodiment not interchangeable; their differences and the nuances they introduce are productive for advancing debates about health inequalities. In this respect, they play an important role in the conceptual and methodological pluralism that drives this area of research.

Credit author statement

S  verine Louvel: Conceptualization, Methodology, Investigation, Data curation, Writing – original draft, Writing – review & editing, Funding acquisition. Alexandra Soulier: Conceptualization, Methodology, Investigation, Data curation, Writing – original draft, Writing – review & editing, Funding acquisition

Data availability

Research data is available in the electronic supplementary material

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Appendix A. Supplementary data
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