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A Systems View of Cardiovascular Disease

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A Systems View of Cardiovascular Disease

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Every year, about 610,000 people die of cardiovascular disease in the United States – that's one in every four deaths (Centers for Disease Control & Prevention [CDC], 2015). The term cardiovascular disease describes a group of conditions that affect the heart including blood vessel diseases, arrhythmias, and congenital heart defects. It is the leading cause of death for both men and women (Mayo Clinic, n.d.). Based on data from the National Health and Nutrition Examination Survey (NHANES) 2013-2016, the prevalence of cardiovascular disease (including coronary heart disease, heart failure, stroke, and hypertension) in adults ≥20 years of age is 48.0% overall (Benjamin, Muntner, & Bittencourt, 2019). Though mortality from cardiovascular disease has been decreasing from its peak in 1969, there is still much progress to be made; at least 200,000 of the deaths a from cardiovascular disease annually are preventable (CDC, 2013). However, the reduction of cardiovascular disease morbidity and mortality is not of equal magnitude across all ages and racial, ethnic, and socioeconomic groups.

There is ample evidence of disparities in cardiovascular disease risk (CDC, 2013; Mensah & Brown, 2007). Cardiovascular disease mortality rates are nearly twice as high for blacks than for whites, and are significantly higher in American Indian/Alaska Natives compared to whites. (CDC, 2013). Low socioeconomic status, low levels of education, and status as a racial/ethnic minority, are associated with cardiovascular risk factors. Individuals exposed to an increasing number of social risk factors are less likely to display ideal cardiovascular health behaviors (Caleyachetty et al., 2015). However, across all racial, ethnic, and socioeconomic groups, both cardiovascular disease prevalence and death rate increase with advancing age: the highest death rate occurring in adults aged 65-74 (401.5 per 100,000) and lowest in those aged 0 -34 (1.9 per 100,000). Interestingly, those under 65 experienced a relatively slower rate of decline during 2001–2010 (CDC, 2013).

It is well established that lifestyle factors such as diet, physical activity, abdominal obesity, perceived stress, and sleep patterns are associated with increased cardiovascular risk (Benjamin et al., 2019; Institute of Medicine, 2010; McEwen, 1998). Though healthful dietary shifts and increased physical activity levels have contributed to the decline of cardiovascular disease mortality and incidence (Institute of Medicine, 2010), recent trends may negatively impact this reduction in cardiovascular deaths. For instance, self-reported physical activity levels have risen from 1998 to 2016, less than 23 percent of US adults meet the 2008 federal guidelines for physical activity (Benjamin et al., 2019). Further, chronic stress remains prevalent in US adults, the average reported stress level being 4.9 (on a scale of 1 to 10) (American Psychological Association [APA], 2018). Chronic stress has been associated with low physical activity, disrupted sleep patterns, and poor diet (APA, 2018; Institute of Medicine, 2010).

Obesity and other chronic conditions have been increasing exponentially as a result of lifestyle and behavior change, resulting in a transition from communicable to noncommunicable diseases (Institute of Medicine, 2010). From 1960 – 2016, the prevalence of obesity has nearly tripled (from 13.3 percent to 39.6 percent) in adults (Benjamin et al., 2019; Flegal, Carroll, Ogden, & Johnson, 2002). Of US adults in 2013 - 2016, an estimated 26 million (9.8%) have diagnosed type 2 diabetes mellitus (Benjamin et al., 2019), compared to only 1.6 million in 1958 (Skyler & Oddo, 2002).

The declining prevalence of US adults with no known major cardiovascular risk factors is also worrisome. The proportion of US adults with no self-reported cardiovascular risk factors dropped from 42 percent in 1991 to 36 percent in 2001 (Mensah & Brown, 2007). In fact, an estimated 62 percent of US adults meet three or fewer of the American Heart Association’s ideal cardiovascular metrics (Benjamin et al., 2019).

Given that a significant proportion of the morbidity and mortality caused by cardiovascular disease is preventable, yet it remains one of the leading causes of death among both men and women, indicates the complexity of cardiovascular disease. While creating better surgical techniques and addressing key risk factors to cardiovascular disease (e.g., hypertension, elevated cholesterol, tobacco use, and excessive alcohol use) have been useful in contributing to the declining mortality rate from cardiovascular disease (CDC, 2013) many other factors must be considered. These factors and the relationships between them interact in many complex ways that go beyond simple cause-and-effect relationships.

Cardiovascular disease is a multifaceted and persistent problem that calls for using another lens – a systems lens. A system is made up of different elements that interact with and effect each other, collaborating to produce unique characteristics that could not be predicted from a linear analysis of these elements (Cabrera, Colosi, & Lobdell, 2008; Meadows, 2008). A systems approach, then, seeks to explain the larger system by examining the whole picture, recognizes the dynamic interactions between elements, and considers the prevalence and persistence of cardiovascular disease to be an emergent property of the system structure. In general, a systems approach advocates for intersectoral collaboration and coordination (Institute of Medicine, 2010; Lavizzo-Mourey, 2017; Meadows, 2008; Ureda & Yates, 2005), aligned values and vision (Lavizzo-Mourey, 2017; Meadows, 2008), stakeholder engagement (Lavizzo-Mourey, 2017), and acknowledging the holistic nature of the issue (Checkland, 2000; Meadows, 2008; Trochim, Cabrera, Milstein, Gallagher, & Leischow, 2006).

A systems approach also enables consideration of feedback loops within the system that propel cardiovascular disease morbidity and mortality. Feedback loops are the basic operating unit of a system (Meadows, 2008). They are formed when changes in a variable affect a series of related factors that eventually result in perpetuation or stabilization of the original variable. These stabilizing and reinforcing feedback loops are often interconnected and produce complex effects.

The intricate structure of multiple feedback loops beget a resilient system. The resilience of a system is defined by three important characteristics: the degree to which a system can be disturbed and still retain its basic function, structure, and identity; the ability to self-organize; and the ability to create and evolve self-repairing structures (Meadows, 2008; Moore & Westley, 2011). The adaptive nature of systems can weaken or even negate the effects of intervention efforts. Thus, it is crucial to analyze the feedback loops to identify points of leverage within the system. Leverage points are places in a system where a small change leads to a significant shift in the system's behavior (Meadows, 2008). Leverage points are often counterintuitive; thus, depiction of the system through modeling may allow for the examination of unanticipated side-effects of intervening on key variables.

This paper sought to advance the understanding of how best to act in addressing the complex problem of cardiovascular disease using an established systemic approach, soft systems methodology (SSM) (Checkland, 2000). There is little evidence of the application of a systems approach to cardiovascular disease. Nevertheless, a systems approach may be a useful tool to understand the structure of relationships that characterize and make cardiovascular disease so persistent and resistant to change. The objectives of this paper were to: (1) model the network of relationships produce the epidemic of cardiovascular disease we see today, and (2) identify potential leverage points to more effectively prevent and address cardiovascular disease.

Methods

Soft systems methodology (SSM) is an organized learning approach that has been used effectively since the 1960s to explore complex and confusing problems involving humans, irrationality, and broader social and cultural contexts (Checkland, 2000). The general approach is comprised of four basic activities, shown in Figure 1, and involves developing comprehensive qualitative models to explore how people see a specific situation.

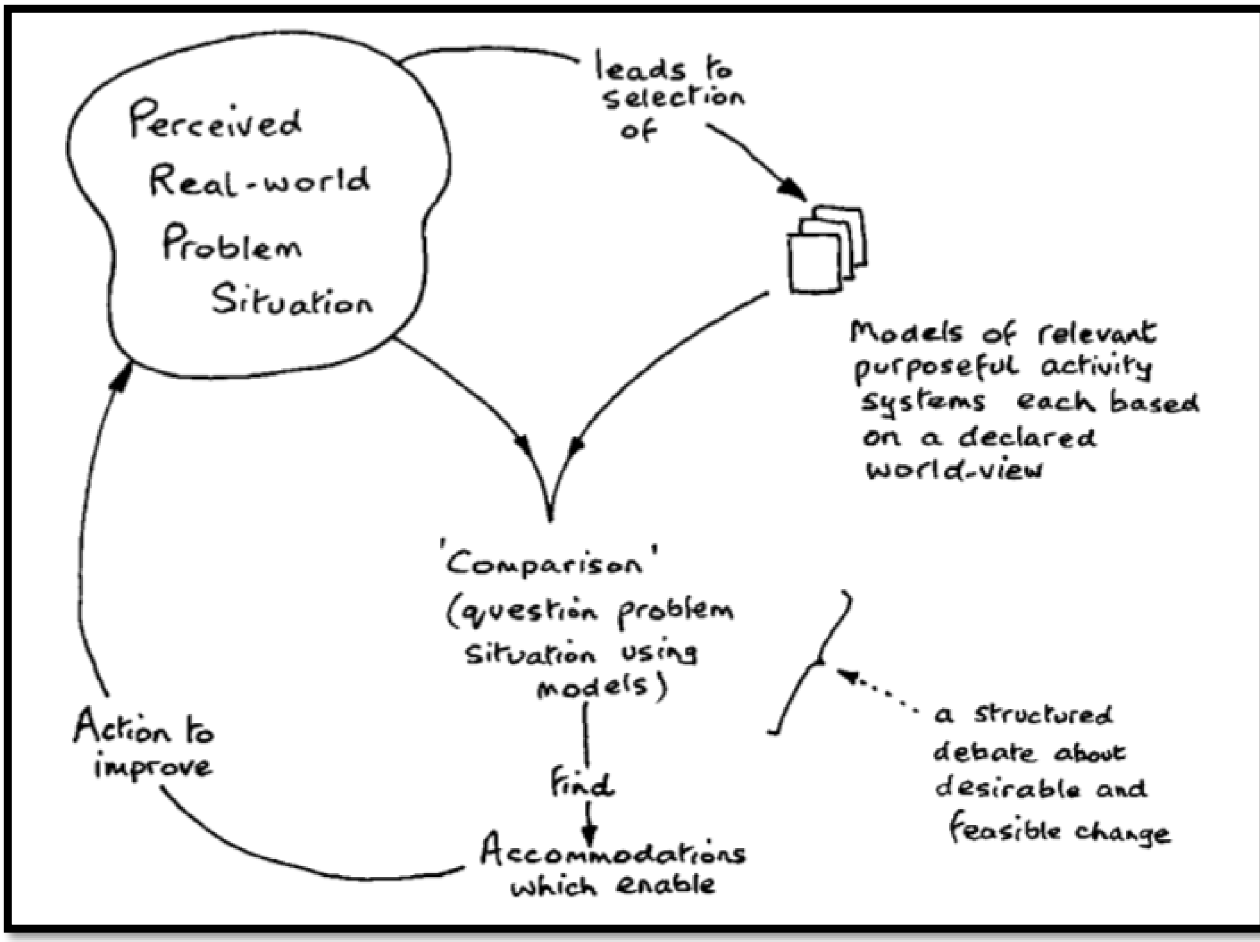

Figure 1. The inquiry cycle of SSM (Checkland, 2000).

Search strategy

The first activity in SSM is to research a problem or situation, paying attention to the broader context (Checkland, 2000). In order to form a more complete discussion within the context of the issue, a literature review was conducted to explore current evidence of a systems perspective on cardiovascular disease. The literature review search strategy was informed by the thesis objectives and previous systematic reviews using qualitative data. A systematic review of the literature was conducted in major databases: PubMed, Web of Science, MEDLINE, Academic Premier, and Google Scholar. Search terms included: systems thinking, systems science, systems view, systems approach, systems dynamics combined with heart disease, cardiovascular disease, and cardiovascular risk. The inclusion criteria were: reviews and original research that either identified systems as an analytical lens applied to cardiovascular disease or that attempted the systems modelling of cardiovascular disease. The literature review did not yield many articles that met inclusion criteria, so the search was expanded to include selected key risk factors for cardiovascular disease (i.e., obesity, tobacco, diet, nutrition, hypertension).

Key exclusion criteria were: articles and books not freely available, articles focused on childhood or school-age interventions, and articles which discussed a system (i.e. the health system, biological systems theory, systems medicine), but were not specific to the broader systems view. Additional books and governmental reports covering systems modeling and systems thinking were used to supplement knowledge of guiding systems principles. There are inherent limitations associated with using search terms to identify literature and drawing system boundaries, so this may not encompass all published work on the subject. Nevertheless, it may provide a broad view of existing literature.

Modeling the system

The second activity in SSM is constructing purposeful activity models (Checkland, 2000). Findings from the literature guided the construction of a system map of cardiovascular disease. The Prevention Impacts Simulation Model (PRISM) model (Homer et al., 2009), shown in Figure 2, is a CDC-sponsored systems dynamic model capable of simulating significant processes driving cardiovascular disease risk. Algorithms used to build the model are based on published evidence and subject matter expert opinion. Possible points of interventions (such as access to primary health care, access to services for mental health weight loss, etc; access to healthy food and safe physical activity options) are noted on the outer edges of the model (Figure 2). While this model depicts the casual mechanisms driving cardiovascular disease risk, its creators did not identify points of the model that resist intervention efforts to reduce cardiovascular disease.

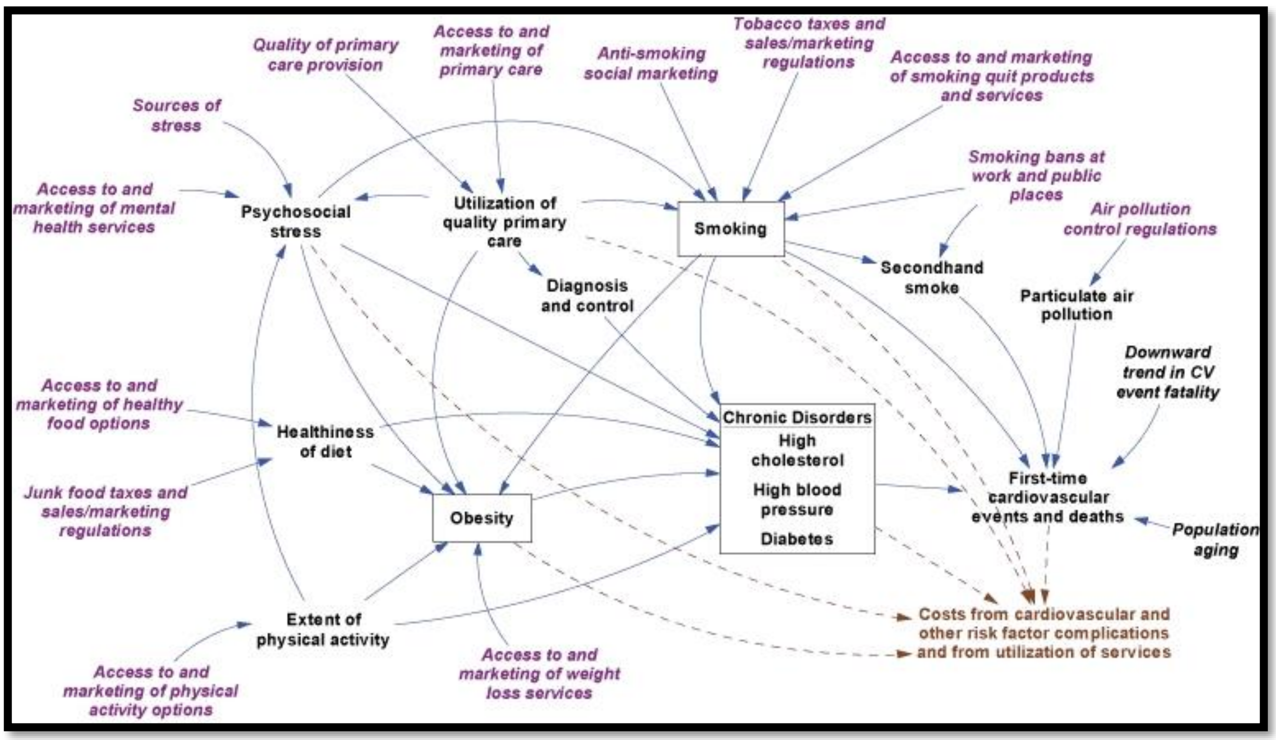

Figure 2. PRISM causal framework of cardiovascular disease risk (Homer et al., 2009).

Figure 2 Key: (Homer et al., 2009).
Blue solid arrows: causal linkages affecting risk factors and cardiovascular events and deaths.
Brown dashed arrows: influences on costs.
Purple italics: factors amenable to direct intervention.
Black italics (population aging, cardiovascular event fatality): other specified trends.
Black nonitalics: all other variables, affected by italicized variables and by each other.

This PRISM model was expanded using findings from the literature review that advanced the understanding of the relationships between the key variables that affect cardiovascular risk factors. The purpose of doing this was to better understand the whole system and begin to identify key leverage points to more effectively address cardiovascular disease.

The steps followed in the construction of the model are described below. The expanded system model was constructed using *CmapTools* Software (University of West Florida: Institute for Human and Machine Cognition, 2000). Similarities and points of overlap were identified and combined into a single map that reflects my understanding of influence and interaction between variables. Reinforcing feedback loops were identified. Literature was reviewed to ensure the relationships identified remained intact and were accurately portrayed by the model. Any changes made to variable names or connections in original maps were noted for discussion with the departmental thesis advisor.

Results

334 articles were found applying a systems perspective to cardiovascular disease. After duplicates and articles that met exclusion criteria were removed, two articles were found to be applicable. The search yielded 156 articles that applied a systems perspective to obesity, of which 22 were relevant. Fourteen articles addressing hypertension through a systems perspective were found, and one was pertinent to this paper.

Leverage points

Thirteen articles provided significant insight into the development of the expanded casual framework were identified through the literature review (Table 1), highlighting article topic, interventions, points of resiliency, and leverage points.

Leverage points identified included improvements to health care quality and access (Loyo et al., 2013), stress (Homer et al., 2009; Loyo et al., 2013; Vandenbroeck, Goosens, & Clemens, 2007), tendency to graze (Vandenbroeck, Goosens, & Clemens, 2007), purchasing power (Vandenbroeck, Goosens, & Clemens, 2007), education (Carey & Crammond, 2015; Vandenbroeck, Goosens, & Clemens, 2007), appropriateness of maternal body composition (Vandenbroeck, Goosens, & Clemens, 2007), willingness to take responsibility for oneself (Vandenbroeck, Goosens, & Clemens, 2007), and policy. Policy levers covered urban planning and built environment (Gortmaker et al., 2011; Institute of Medicine, 2010; Soler et al., 2016; Wang et al., 2014), food and agriculture (Gortmaker et al., 2011; Institute of Medicine, 2010), and tobacco control policies (Best, Clark, Leischow, & Trochim, 2007; Institute of Medicine, 2010; Loyo et al., 2013; Soler et al., 2016). Air quality (Homer et al., 2009; Loyo et al., 2013) and tobacco control were sighted as significant levers for reducing cardiovascular risk, as noted in Figure 2.

Recommendations suggested increased access to healthy food options (Brennan, Sabounchi, Kemner, & Hovmand, 2015; Loyo et al., 2013; Soler et al., 2016) and marketing and advertising of healthy rather than unhealthy food ((Ghosh-Dastidar et al., 2014; Gortmaker et al., 2011; McGlashan et al., 2018) could be useful points of intervention.

Physical activity recommendations included general calls for increased access to physical activity options (Gortmaker et al., 2011; Homer et al., 2009; Loyo et al., 2013; McGlashan et al., 2018), increased physical activity in specific settings such as schools and child-care facilities (Soler et al., 2016); and creating places for physical activity (Brennan, Sabounchi, Kemner, & Hovmand, 2015; Soler et al., 2016).

Though many useful leverage points were identified, modeling efforts focused on three pertinent leverage points and explored greater detail: stress, education, and purchasing power/affordability. To understand anything, it is necessary to make boundaries, even though they are nonexistent. The boundaries of the system, or which variables are included and excluded, depend on the purpose of the discussion. Because the focus of the model was to identify variables relevant to these leverage points and the interplay between them, the system boundaries were set to exclude most wider-level variables pertaining to policy, built environment, and physiological mechanisms of cardiovascular disease risk, as these variables were beyond the scope of this paper.

The models created for this project (Figures 3-6) are included in Appendix I. The expanded causal model is presented in Figure 3, and attempts to represent the impact of stress, education, and purchasing power/affordability on lifestyle risk factors – 'healthiness of diet' and 'physical activity'. It is comprised of 37 variables and 70 connecting arrows, showing the interconnectedness of variables in the system. This model will serve as the foundation for the following models, which have been produced to emphasize the causal pathways by which the selected leverage points influence cardiovascular risk.

Stress

The influence of stress on cardiovascular disease risk is portrayed in Figure 4. 'Stress' is affected by numerous factors, including physical activity levels and demands from work and family life. Its effects are far-reaching. Stress links positively to smoking and tobacco use and alcohol use. Further, discontinuing use of these substances can cause additional stress, making the effort to quit all the more challenging. Increased levels of stress raise 'psychological ambivalence', which has been defined as the conflict between what people often desire (e.g.

highly palatable, energy-dense, nutrient poor foods) and the need to stay healthy (Vandenbroeck, Goosens, & Clemens, 2007). This can increase the individual's propensity to choose unhealthy foods, choose convenience foods or fast foods, increase portion sizes, increase snacking, and eat for reasons other than physiological hunger. All of these dietary habits can result in caloric overconsumption and a perpetual cycle of energy accumulation.

Increased stress levels have a direct effect on the risk of developing metabolic disorders such as hyperlipidemia, hypertension, and diabetes mellitus, all of which are risk factors for cardiovascular disease. Physiological responses to acute stress activate the sympathetic nervous system, increasing blood pressure and stressing endothelial cells. Further, the infiltration and oxidation of low-density lipoproteins (LDL) cause the loosening of tight junctions between endothelial cells, which is an indication atherosclerosis and critical in the development of cardiovascular disease (Yao et al., 2019). Together, chronic and repetitive exposure to psychosocial stress, or a maladaptive response to repeated stressors via endothelial cell damage, may accelerate the atherosclerotic process and accelerate the progression of cardiovascular disease (McEwen, 1998).

Education

Education impacts the system through several pathways, illustrated in Figure 5. 'Level of educational attainment' relates positively to 'self-esteem', a person's overall subjective emotional evaluation of his or her own worth (Leary, 1999). 'Self-esteem' is reciprocally related to 'self-efficacy', one's belief in one's ability to succeed in specific situations or accomplish a task (Lightsey, Burke, Ervin, Henderson, & Yee, 2006). Self-esteem influences one's confidence to perform a specific task or succeed in a situation, and the more one succeeds, especially in areas where they place their self-worth, the more their self-esteem is bolstered. Self-efficacy as a mediator between stimulus and physiological state of stress (Jerusalem & Schwarzer, 1992). As described previously, physiological stress can negatively impact 'healthiness of diet', and has direct effects on the risk of developing metabolic conditions that can be pre-cursors to cardiovascular disease.

'Level of educational attainment' affects 'healthiness of diet' via 'level of health literacy', which connects directly to 'cooking and food preparation skills' decreasing the consumption of convenience foods. Via 'level of general literacy', 'level of health literacy', and subsequently, 'desire to be healthy', education can impact the 'extent of physical activity'.

Purchasing power/Affordability

Affordability is the financial ability to buy products and services. This variable is positively related to 'opportunities for physical activity', 'access to motorized transport', and both 'consumption of nutritious foods' and 'consumption of energy-dense, nutrient-poor foods' (Figure 6). Thus, affordability can either positively or negatively impact 'healthiness of diet' and 'extent of physical activity'. Greater affordability increases options and access to physical activity, while possibly creating a greater reliance on motorized transportation, decreasing levels of physical activity in transport.

The obscurity of these relationships suggest that affordability can have a wide-range of effects on the system, and should be considered in the context of the individual. Specifically, if an individual has a strong desire to be healthy, affordability can increase access and availability to nutritious food and physical activity opportunities. Affordability can amplify the individuals' goals. In this way, affordability has the potential to offer some protection from cardiovascular risk related to lifestyle factors.

Discussion

The application of a systems approach and the expansion of the PRISM model made it possible to organize and analyze complex information while placing emphasis on the whole picture. There is little representation of systems approaches in the cardiovascular disease literature overall. And while the PRISM causal model shown in Figure 2 portrayed the primary risk factors driving cardiovascular disease development, it does not recognize interactions between variables in the model that resist intervention efforts to reduce cardiovascular disease. The expanded causal model created for this project builds upon the PRISM model in two ways: (1) consideration of a wider system that is inclusive of sources of stress, the interconnections of income, education, and employment, as well as variables influencing healthy dietary choices and adequate physical activity; (2) identification additional leverage points for the reduction of cardiovascular disease morbidity and mortality. Furthermore, the expanded model illustrates how changes in one or more variables may have surprising and possibly nonlinear effects on other system variables, impacting cardiovascular risk.

Stress

The extensive effects of stress on other variables in the system (Figure 4) suggest it plays a critical role in the moderation lifestyle-related cardiovascular risk factors. As the extended model shows, stress responses increase one's desire to self-soothe, whether that be through the use and/or abuse substances like alcohol and tobacco (Sinha, 2008; Torres & O'Dell, 2016), consumption of high calorie, highly palatable foods (Wardle, Steptoe, Oliver, & Lipsey, 2000), and can impair efforts to be physically active (Stults-Kolehmainen, & Sinha, 2014). While the primary effects of stress on these variables are important, the underlying reinforcing processes – the side-effects – are critical and often underappreciated. Applying a systems approach facilitated the identification and comprehension of these side-effects.

The self-reinforcing cycle is triggered by perceived stress, and a subsequent physiological stress response, possibly resulting in reduced physical activity levels. Physical activity is associated with improved mental health outcomes and ability to cope with stressors, and reduces the risk of obesity and diabetes mellitus (Stults-Kolehmainen, & Sinha, 2014). Chronic stress independently increases the risk of these conditions, and this effect is compounded by reduced physical activity levels. Further, reduced physical activity level can erode self-esteem, and possibly, self-efficacy, making it more difficult to cope with stressors, increasing the physiological impact of stressors even more, and on and on.

This self-reinforcing feedback loop amplifies an initial change, producing further change in the same direction. However, these reinforcing feedback loops can be interrupted and made to reinforce positive effects rather than negative, as just described. Though stressors are inevitable, an individual's coping strategies play a major role in determining the impact of a stressor. Thus, leveraging stress management interventions can interrupt the reinforcing loop. Psychotherapy, time management training, progressive relaxation training, and meditation have been shown to increase cardiac patient well-being (Dimsdale, 2008).

Another effective approach could be to increase the knowledge and availability of mindfulness-based stress reduction (MBSR) training. MBSR is an 8-week group program focused on training mindfulness meditation that allows one to take on a participant-observer perspective of their own thoughts, promoting a more accurate perception of mental and physiological responses to stimuli. Overall, MBSR can promote improved emotional processing, coping, and improved self-efficacy and control (Kabat-Zinn & Hanh, 2009). Its usefulness has been demonstrated for a range of chronic conditions, including cardiovascular disease (Grossman, Niemann, Schmidt, & Walach, 2004).

Education

It is well known that the social determinants of health play a momentous role in chronic disease risk. Life expectancy is shorter and most diseases, including cardiovascular disease, are more common further down the social ladder (Institute of Medicine (US) 2010; Wilkinson & Marmot, 2003), where people may have lower income, poor or less education, and disadvantageous circumstances. Adults with lower levels of education are significantly more likely to develop heart disease than those with higher levels of education (Kubota, Heiss, MacLehose, Roetker, & Folsom, 2017).

A systems perspective revealed just how education acts with other variables over time to create resilience and persistence in cardiovascular disease disparities. A few feedback loops underlie the behavior of this system: the first is the self-reinforcing feedback loop in the upper-left corner of the expanded causal framework: ‘level of education’ is positively related to ‘level of access to employment’ and subsequently ‘level of household income’. With a higher income, education is more affordable and accessible; thus, the loop continues to cycle and amplify this effect.

Moreover, educational attainment links to other leverage points. As previously discussed, education is associated with higher income, affording an individual with the means to make heathy choices. With more education, the more likely it is that individuals have received education about stress and how to manage it, as well as counseling on what a healthy and balanced diet is. In this way, education can be crucial in developing not only health literacy, but an individual desire for health, which can go on to influence spending on nutritious foods and physical activity opportunities.

Given this, investment in education can be a powerful lever in reducing cardiovascular risk. Though there are numerous policy implications for this leverage point, policy was not the focus of this paper. Investment in education can manifest as: increased availability of learning institutions and classrooms, both physical and online; increased access to cost-free education, including additional costs and fees; and promotion of participation in quality childhood education to support success and inclusion in later education.

Purchasing power/Affordability

One of the key strengths of a systems perspective is that can yield surprising and unanticipated findings. The expanded model uncovered a finding that challenges the assumption that affordability of healthy foods and physical activity opportunities will lead to a subsequent increase in corresponding healthy behaviors. While it is true that unaffordability can prevent access to such things, individuals' desire to be healthy must be taken into consideration when anticipating the effects of purchasing power on lifestyle-related cardiovascular risk factors. Without this knowledge, interventions targeting the affordability of healthy foods and physical activity opportunities may be expected to have a greater impact on health behaviors than that of reality. This dynamic complexity is an important consideration for those who want to intervene most effectively.

Limitations

The expanded model is intrinsically limited by the positioning of boundaries around the system. The boundaries were determined by the purpose of exploring the three selected leverage points: education, stress, and purchasing power. When elements are pulled out from the system, an artificial view is created for the purposes of the study. Defining system boundaries is inherently reductionistic. However, to understand anything requires simplification, which requires boundaries to be drawn. These boundaries should be reconsidered if the problem is reframed or purpose redefined. Further, in the expanded model, the polarities of the connecting arrows do not express the rate of influence. It should be acknowledged that changes in variables may happen at uneven rates within the model. Also, certain variables and relationships may affect certain groups to different degrees. For example, groups experiencing racial discrimination – a significant stressor – have been shown to have increased cardiovascular disease morbidity and mortality (Calvin et al., 2003; Everson-Rose et al., 2015; Lewis, Williams, Tamene, & Clark, 2014).

As a descriptive study, there is the potential for bias and gaps in knowledge. A quantitative system model of the expanded causal framework could provide more insight into the usefulness of the model. Nevertheless, the results of this paper are useful in that they provide greater understanding of the mechanisms behind lifestyle-related cardiovascular risk factors.

A strength of the model is the visual clarity of the findings. The model is likely to be helpful for others not only to visualize the complexity of cardiovascular disease, but other heterogeneous health conditions, as well.

Conclusion

Complex health problems such as cardiovascular disease indicate the need for systems perspective when seeking to implement and intervention or develop policies. This paper has identified three key levers that can be used to address cardiovascular disease, providing a visual representation of how changes in these levers could have an impact on other system variables, eventually influencing cardiovascular risk. If more attention was paid to these levers, public health interventions may be more effective in reducing morbidity and mortality of cardiovascular disease. Furthermore, this paper demonstrates the value of a systems perspective as a lens that provides greater insight into the interconnectedness of these variables, as well as their unexpected side-effects.

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