



Review

A Competing Neurobehavioral Decision Systems model of SES-related health and behavioral disparities



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ABSTRACT

We propose that executive dysfunction is an important component relating to the socio-economic status gradient of select health behaviors. We review and find evidence supporting an SES gradient associated with (1) negative health behaviors (e.g., obesity, excessive use of alcohol, tobacco and other substances), and (2) executive dysfunction. Moreover, the evidence supports that stress and insufficient cognitive resources contribute to executive dysfunction and that executive dysfunction is evident among individuals who smoke cigarettes, are obese, abuse alcohol, and use illicit drugs. Collectively these data support the dual system model of cognitive control, referred to here as the Competing Neurobehavioral Decision Systems hypothesis. The implications of these relationships for intervention and social justice considerations are discussed.

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Socioeconomic disparities in overall health, morbidity, and mortality are pervasive and prodigious, and remain largely unaffected with current approaches (Adler and Rehkopf, 2008). In western society a strong inverse relationship exists between employment grade and mortality among British civil service workers (Marmot et al., 1984) in addition to educational level and mortality among American men (Kitagawa and Hauser, 1973). The relationship between SES and health status shows a relatively smooth monotonic gradient that extends from those at the lowest to those at the highest end of the socioeconomic spectrum and thus, is not entirely accounted for by poverty-induced deprivation or access to health care (Adler and Stewart, 2010b).

In health research, SES is a broad construct describing relative access to the basic resources required to achieve and/or maintain good health (Galobardes et al., 2006a, 2006b; Shavers, 2007). Given that the SES construct is complex consisting of numerous measures, indicators, or proxies, it demonstrates that no single measure is best for all studies and populations. Individual measures of SES have varying degrees of relevance depending on context. Measures often used include educational achievement, income, occupation, and wealth; each of which assesses different, albeit related, aspects of SES. Measures composed of multiple components often provide more multifaceted assessments (Galobardes et al., 2006a, 2006b). Educational achievement is a widely used indicator of SES in health research and is particularly useful in relatively homogeneous populations (Miech and Hauser, 2001) where it is likely to capture important aspects of lifestyle and behavior that have a significant effect on future occupational opportunities and earning

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potential (Galobardes et al., 2006a, 2006b). Educational achievement, however, comprises a variety of influences, which individually contribute to an educational gradient in health behaviors. For example, material resources account for about 30% of the education gradient in health behaviors, 10% of knowledge, and 20% of cognitive ability (Cutler and Lleras-Muney, 2010). Household income, often highly correlated with educational achievement, is considered the single best indicator of material living standards (Galobardes et al., 2006a, 2006b) and is a particularly useful SES indicator for a family's primary wage earner (Adler and Newman, 2002). The components of SES are dynamic, multidimensional, and complex reinforcing the appreciation of its multiple pathways for achieving and maintaining good health.

Conceptual models propose that socioeconomic health disparities emerge because of higher levels of stress, less access to physical and environmental resources, greater environmental constraints, fewer affective and cognitive resources, and important health behaviors associated with preventable death, such as cigarette smoking, eating and physical activity, and alcohol and illicit drug use (Adler and Newman, 2002; Adler and Stewart, 2010a; Gallo and Matthews, 2003). Taken together, these health behaviors account for the vast majority of preventable death and disease in the U.S. (see Table 1, National Research Council, 2013; Rimm et al., 1999; Schroeder, 2007; Mokdad et al., 2004). While the relationship between SES and health behaviors is dynamic and multiply determined, an important commonality among all these health behaviors is that they entail repeatedly choosing to engage in behaviors despite long-term negative outcomes, and oftentimes, despite serious intentions to change the behaviors and many attempts to do so. We propose that the experience of SES contributes to a particular type of decision-making that serves as a conceptual and functional link between SES and health behaviors. We propose that the tendency to choose immediate over long-term rewards is likely to contribute to the development and maintenance of unhealthy behaviors. Alternatively, the tendency to choose long-term over immediate rewards is likely to contribute to the development and maintenance of healthy behaviors. We propose that the environment associated with lower SES perpetuates the former decision-making and restricts tendencies toward the latter thus accounting for a portion of the socioeconomic gradient in health behaviors and perhaps offers new targets for prevention and treatment interventions.

The model we use to describe and interpret this decision-making style is the Competing Neurobehavioral Decision Systems model (Bickel et al., 2012). This model views decision-making processes as resulting from the competing influences from (1) the impulsive decision system, embodied by the limbic and paralimbic brain regions, which engenders individuals to choose immediate reinforcers; and (2) the executive decision system, embodied in parts of the prefrontal cortices, which engenders individuals to favor long-term outcomes and inhibit impulses. The balance between these systems is affected by a variety of factors including perceived need, motivation, context, and perceived stress level. This model is grounded in the work of Bechara (2005) and Jentsch and Taylor (1999) and consistent with a variety of dual decision system models. For example, Jentsch proposes inhibitory and impulsive systems (Jentsch and Taylor, 1999) and Strack and Deutsch outline reflective and impulsive systems (Strack and Deutsch, 2004) as conceptualizations of normal behavior (see Evans

and Stanovich, 2013, for a review of the different attributes of dual systems). The Competing Neurobehavioral Decision Systems hypothesis provides a conceptual framework within which we can conceptualize how neurological dysfunction of the dual system can lead to behaviors with negative health outcomes (see Fig. 1 and Table 2).

We propose that the experience of SES affects the balance of these two competing systems. When the Competing Neurobehavioral Decision Systems are in regulatory balance, individuals demonstrate the capacity to adaptively attend to temporally arrayed events, weigh input from the competing systems, and establish and follow through with decisions that have healthy immediate and long-term outcomes. When the system is dysregulated or out of balance, perhaps due to stress or lack of cognitive resources, the capacity to establish and follow through with decisions that have healthy immediate and delayed outcomes is constrained. When the executive decision system is less effective or compelling than is required for adaptive decision-making, we describe this as executive dysfunction. We will explore how the Competing Neurobehavioral Decision Systems can explain the development and maintenance of negative health behaviors by the tendency to choose immediate over long-term rewards and how this tendency is rooted in neurological functioning. To achieve this end, we present a summary of the literature with reference to these important questions:

- 1) To what extent is the SES gradient a contributing factor in negative health behaviors (obesity, alcohol, tobacco, and substance abuse and dependence)?
- 2) What is the evidence that the SES gradient is associated with executive dysfunction?
- 3) What is the evidence that stress and insufficient cognitive resources contribute to executive dysfunction?
- 4) What is the evidence of executive dysfunction among individuals who smoke cigarettes, are obese, abuse alcohol, and use illicit drugs?

Finally we briefly discuss potential prevention opportunities and treatment interventions that may reduce the disparities seen across the SES gradient in decision-making and the implications for advancements in social justice.

What is the extent of the SES gradient among important health behaviors that negatively affect health?

Cigarette smoking, obesity, and alcohol and illicit drug use, are the major causes of preventable death and disease in western society.

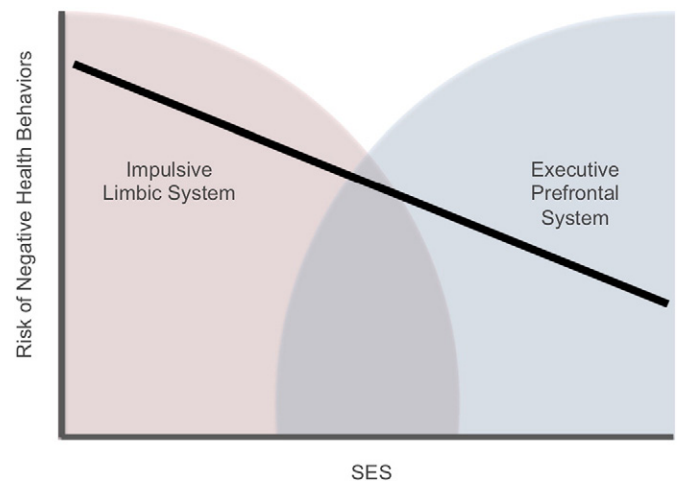


Fig. 1. Conceptual model of relationship between SES gradient, negative health behaviors, and the Competing Neurobehavioral Decision Systems. As SES increases, the risk of negative health behaviors decreases linearly. One explanation for this relationship is a regulatory imbalance between the competing neurobehavioral decision systems. As shown, the impulsive limbic system may be relatively hyperactive and the executive prefrontal system relatively hypoactive in lower SES individuals.

Table 1

Annual U.S. mortality rates and cost of alcohol use, illicit drug use, cigarette smoking, over eating and obesity (McGinnis and Foege, 1993; National Institute on Drug Abuse, 2012; U.S. Department of Health and Human Services, 2001).

| Negative health behavior | Mortality | Cost |
|--------------------------|-----------|-----------------|
| Alcohol use | 88,000 | \$223.5 billion |
| Illicit drug use | 20,000 | \$600 billion |
| Cigarette smoking | 440,000 | \$96 billion |
| Over eating/obesity | 300,000 | \$147 billion |

Table 2

Theoretical description of the different components of each structure in the Competing Neurobehavioral Decision Systems (Bickel et al., 2012).

| | Impulsive system | Executive system |
|-------------------------|--------------------------------------|---|
| Embodied | Limbic and para-limbic brain regions | Prefrontal cortex |
| Function | Valuation of immediate outcomes | Valuation of delayed outcomes, planning, memory |
| Health characteristics | Regulatory balance | Regulatory balance |
| Disease characteristics | Relatively hyperactive | Relatively hypoactive |

They have different etiologies and long-term health consequences, but exhibit significant similarities in the socioeconomic pattern of prevalence rates.

Cigarette smoking

The prevalence of smoking has steadily declined since the initial reports that it negatively affects health raised public awareness; however the decline in prevalence has had a remarkably different rate among higher and lower SES groups. At present, the prevalence of cigarette smoking demonstrates a significant socioeconomic gradient (BRFSS data – Centers for Disease Control and Prevention, 2013). Lower SES groups smoke at 3 to 4 times the prevalence of higher SES groups making tobacco use one of the greatest contributors to health disparities (BRFSS – Centers for Disease Control and Prevention, 2012). While motivation to quit and attempts to quit show no socioeconomic gradient, lower SES groups are less likely to successfully quit once they begin smoking even when provided with a variety of treatments and treatment modalities (Agrawal et al., 2008; Barbeau et al., 2004; Centers for Disease Control and Prevention, 2005; Fagan et al., 2007; Ferguson et al., 2005; Kandel et al., 2009; Kotz and West, 2009; Reid et al., 2010; Sheffer et al., 2012b; Trinidad et al., 2011; Varghese et al., 2014; Wetter et al., 2005). At present, tobacco use is the leading contributor to health disparities in the U.S. and elsewhere, and unlike many other health disparities, tobacco-related cancer health disparities actually appear to be increasing (Jha et al., 2006; Kanjilal et al., 2006; Mokdad et al., 2004).

Obesity

In western culture obesity is generally recognized as an unhealthy condition and it demonstrates a consistent negative linear relationship with SES (BRFSS – Centers for Disease Control and Prevention, 2012). This relationship is the reverse of that observed in some developing countries where food scarcity contributes to a positive relationship between SES and obesity (Sobal and Stunkard, 1989). At present, the prevalence of obesity demonstrates a significant socioeconomic gradient (BRFSS data – Centers for Disease Control and Prevention, 2013). About one-third of the lower SES groups are obese while about one-quarter to one-fifth of the higher SES groups are obese (BRFSS – Centers for Disease Control and Prevention, 2012). The negative relationship between SES and the prevalence of obesity is stronger and more consistent among western women than men, possibly indicating that SES is associated with different cultural norms among different SES groups (Wardle et al., 2002). Alternatively, SES might also be related to gender-specific roles and the socioeconomic positioning of women. Women continue to earn significantly less than men for the same jobs and continue to shoulder a greater burden of household and child-rearing responsibilities (Bianchi and Milkie, 2010). Women are more likely to be of lower socioeconomic status and live and raise children in poverty (U.S. census). Consequently, increased responsibilities of child rearing combined with the stress of managing limited resources might have a more significant effect on obesity-related behaviors, such as physical activity and eating an obesogenic diet, among women than among men. Perceived stress is consistently related to obesogenic dietary behaviors among both men and women (Barrington et al., in press). The negative relationship between SES and obesity is also

greater among older individuals, suggesting that the effects of SES on obesity-related behaviors are, perhaps, cumulative (Baum and Ruhm, 2009).

Alcohol and illicit drug use

The vast majority of individuals who drink alcohol and/or try illicit substances do so without negative health outcomes. However, significant negative linear relationships are observed between SES and alcohol and illicit drug use prevalence, health problems, and mortality (Anthony et al., 1994; Buka, 2002; Curran et al., 1999; Goodman and Huang, 2002; Harder and Chilcoat, 2007; Makela, 1999; van Oers et al., 1999, BRFSS – Centers for Disease Control and Prevention, 2012). The negative relationship between drug use and SES is most robust in those countries with the largest socioeconomic differences in wealth. For example, Japan and Finland have some of the smallest socioeconomic differences in wealth and the lowest proportion of the population participating in illicit drug use; whereas, the United States and United Kingdom have the greatest differences in wealth and the highest proportion of the population participating in illicit drug use (Wilkinson and Pickett, 2011). The greater proportion of alcohol and illicit drug-related problems and mortality are accounted for by higher rates of alcohol and substance abuse or dependence in lower SES groups (Parker and Harford, 1992).

What is the evidence that SES is associated with executive dysfunction?

Conceptual models posit that executive function is embodied in the prefrontal cortices. Many of the models are very similar with significant overlap in the range and type of executive function abilities described and the neurological correlates of specific functions (Chan et al., 2008; Hackman and Farah, 2009). Bickel et al. (2012) provide a comprehensive model that is particularly useful for understanding decision-making comprised of eight systems: attention, behavioral flexibility, behavioral inhibition, planning, future valuation, working memory, control of affective states, and metacognitive processes.

Unlike most models of executive function, the Bickel et al. (2012) model includes future valuation, which is the ability to project value into the future. Future valuation is often assessed by delay discounting tasks, which assess the decline in value of a reward as a function of time. Delay discounting, using psychophysical titration procedures (Bickel and Marsch, 2001; Hackman et al., 2010), is a frequently used and highly validated research tool (Bickel et al., 2012). Extreme discounting signals an inability to modulate value by time, and is often an indicator of executive dysfunction and/or functional or neurological impairment. Surveys of large samples of individuals ($n = 42,863$) show that lower SES groups tend to discount the value of future rewards more than higher SES groups (Reimers et al., 2009; see Green et al., 1996) suggesting a constrained capacity to modulate future valuation. Delay discounting using psychophysical titration procedures shows a consistent relationship between discounting and educational attainment (Jaroni et al., 2004; Lee et al., 2013), while use of truncated methods has failed to find that relationship (Cutler and Lleras-Muney, 2010).

The development of many executive function abilities including visuospatial skills, declarative memory, working memory, and cognitive control, appears to be affected by SES (Noble et al., 2007). The inverse

relationship between executive dysfunction and SES is noticeable in the early academic career of children (Hackman et al., 2010), persists across the lifespan (Green et al., 1996; Richards and Wadsworth, 2004), and appears to be influenced and/or ameliorated by modifiable environmental factors (Mani et al., 2013). Working memory, cognitive control, and language skills demonstrate a positive relationship with SES in children as young as 6 months old (Farah et al., 2006; Hackman et al., 2010; Lipina et al., 2005). However, not all executive function abilities are dramatically affected by SES. For example, visual cognition appears to have only a moderate relationship with SES (Farah et al., 2006). Although not an executive function ability per se, it is worth noting that differences in reward processing as a function of SES are not observed (Farah et al., 2006) suggesting that the reward-seeking impulsive decision system is not deficient in lower SES individuals.

Language ability, a component of some models of executive function (Hackman and Farah, 2009), shows significant positive relationships with SES, similar to most executive functions (Farah et al., 2006; Fluss et al., 2009; Hackman and Farah, 2009; Hackman et al., 2010; Perkins et al., 2013). For example, 2 1/2 year old children raised in professional families used, on average, 1116 unique words, while children from working class families used 749 unique words, and children living in homes receiving welfare benefits used 525 unique words (Hart and Risely, 1995).

Finally, a restriction of resources appears to have an immediate impact on certain executive functions. A real-world extension of laboratory findings showed that lower SES groups demonstrate significant declines in executive function abilities in high-cost, high stress conditions (Mani et al., 2013). Executive functioning was assessed in a sample of sugar cane farmers in India who naturally experience significant variability in financial resources throughout the year. The farmers demonstrated decreased attention and reasoning abilities during real-world conditions with decreased financial security.

What is the evidence that stress contributes to executive dysfunction?

Stress and stress regulation are significant components in biopsychosocial models of health, have a long history of being associated with the development of disease (Juster et al., 2010; Schulz et al., 2012), and are prominent in models of socioeconomic health disparities (Jackson et al., 2010). All individuals experience external events as stressful to varying degrees and evidence indicates that perceived stress contributes to differences in executive function ability. Stress regulation includes critical decision-making such as the modulation of stress exposure and the performance of various restorative activities. Individuals act reciprocally within their environments to enhance or diminish the probability of experiencing stress. Restorative processes return individuals to baseline arousal levels and include retreating from daily stress, various relaxation behaviors, and sleep. Restorative activities play a significant role in the recovery from stress and presumably on the impact of stress on executive function abilities.

Being employed by multiple low-paying jobs with little flexibility and few available sick days and/or living arrangements that are not safe or not conducive to obtaining needed rest are likely to reduce individuals' opportunities to retreat from daily stress, engage in relaxation behaviors, and obtain restorative sleep. Poor sleep is itself associated with impaired immune function and all-cause mortality (Dew et al., 2003; Lange et al., 2003; McEwen, 1998). Individuals in lower SES groups get less sleep and the sleep is of poorer quality than individuals in higher SES groups (Moore et al., 2002; Van Cauter and Spiegel, 1999). High pre-sleep arousal is associated with poor executive function abilities, a strong prognostic indicator of sleep disruption and chronic sleep difficulties (Bastien et al., 2008). Poor sleep quality can cause significant decreases in mental flexibility, the ability to accurately identify stressors, and the ability to inhibit rumination (Williams et al., 2009). Environmental factors and learned behaviors can also limit opportunities to engage in adequate restorative activities.

What is the evidence of executive dysfunction among individuals who smoke cigarettes, are obese, abuse alcohol, and use illicit drugs?

A plethora of evidence has linked executive dysfunction to cigarette smoking, obesity, and alcohol and illicit drug use as well as the recovery from these conditions. Much of this evidence has been reviewed elsewhere. See Bickel et al. (2012) for a review of executive dysfunction in substance abuse by type of executive dysfunction and Blume and Marlatt (2009) for a review of the role of executive function in substance abuse recovery. Smith et al. (2011) provide a systematic review of the association between executive function and obesity across the lifespan. Raman et al. (2013) integrate executive function in a multifaceted model of clinical obesity. Thus, we provide a limited summary here.

Patterns of executive dysfunction are widely documented among adolescents, college students, adults, and older adults who smoke cigarettes (Cervilla et al., 2000; Richards and Sacker, 2003), and abuse alcohol (Alterman et al., 1984; Beatty et al., 1995; Bechara et al., 2001; Bickel et al., 1999; Chamberlain et al., 2012), cannabis, opiates, and stimulants (Beatty et al., 1995; Berry et al., 1993; Bickel et al., 2012). Excessive discounting of delayed rewards is associated with a poorer treatment response for some cigarette smokers (MacKillop and Kahler, 2009; Sheffer et al., 2012a; Washio et al., 2011) and alcoholics (Blume et al., 2005; Houben et al., 2011). Nonetheless, executive function appears to remain impaired well into recovery from alcohol abuse (Bates et al., 2005). Whether substance use causes executive dysfunction and/or is a pre-existing vulnerability for developing substance abuse is unclear.

Executive function abilities are associated with the development and maintenance of obesity in children, adolescents, and adults (Davis, 2004; Galioto et al., 2012; Guxens et al., 2009). Obese individuals show deficits in a wide variety of executive functions including attention (Cserjesi et al., 2009), behavioral flexibility (Cserjesi et al., 2009; Verdejo-García et al., 2009), behavioral inhibition (Maayan et al., 2011; Verdejo-García et al., 2009), planning/reflection impulsivity (Lokken et al., 2010), discounting of delayed rewards (Bickel et al., 2010; Epstein et al., 2010), working memory (Gunstad et al., 2007; Maayan et al., 2011), emotional information processing and initiating and maintaining goal-directed responding (Bonato and Boland, 1983). Greater discounting of delayed rewards is predictive of treatment outcome for obese children (Best et al., 2012). Although causal relations between obesity and executive dysfunction abilities may be reciprocal, the mechanisms by which obesity might result in executive dysfunction are, as yet, unclear.

Discussion

Based on our review of the literature, we found evidence that the SES gradient is associated with negative health behaviors and executive function abilities. We found evidence that SES is associated with stress regulation and that increased stress levels contribute to executive dysfunction. We also found evidence of significant executive dysfunction among individuals who smoke cigarettes, are obese, and abuse alcohol or illicit drugs. This associative evidence supports our proposal that the experience of SES affects executive function and the regulatory balance of the Competing Neurobehavioral Decision Systems; that is, SES diminishes the capacity for individuals to establish and follow through with immediate and delayed healthy decisions.

Most would agree that multiple factors play a role in the development and maintenance of these important health behaviors. Once a behavior becomes entrenched, the biological, behavioral, and psychological aspects feed back into the bio-behavioral system through multiple iterative and multidirectional processes that make altering the behavior difficult. Nonetheless, the executive decision system provides a potential target for intervention. Executive function abilities are becoming more prominent in empirical and conceptual investigations of these complex processes (Bickel et al., 2012; Blume and Marlatt, 2009). As noted above, executive dysfunction can result in dysregulation of the dual systems

such that the impulsive decision system exerts greater influence than the executive decision system. This dysregulation could result in preference for immediate reinforcers consistent with choosing to smoke, over consume food and alcohol, and use illicit drugs, even when serious long-term adverse consequences may result. If executive function skills are not suitably developed or are dysfunctional, the result is greater difficulty in making optimal decisions in a wide variety of health-related situations as well as greater difficulty in achieving and maintaining good health.

The implications of this line of investigation are wide reaching. The prefrontal cortices, the primary seat of executive function abilities, are highly plastic and highly adaptive to extant conditions. This plasticity is consistent with the view that executive dysfunction is likely an adaptation to environmental conditions and is a potential strength in treatments designed to improve executive function and its influence on health behavior (see Bickel et al., *in press*). The recognition of significant executive dysfunction among individuals who abuse alcohol and illicit substances, and use tobacco has generated interest in the use of executive function remediation strategies as part of treatment. For example, in a random assignment study, Bickel et al. (2011) examined the effects of working memory versus control training among individuals with stimulant abuse and dependence and found that working memory training improved the ability to value delayed outcomes. Similarly, Sheffer et al. (2013) used neuromodulatory brain stimulation of the dorsolateral prefrontal cortex to improve the value of delayed outcomes among smokers. Other studies have also documented the positive effects of working memory training on alcohol consumption and obesity treatment outcomes (Houben et al., 2011; Verbeke et al., 2013). At present, whether executive function interventions will result in long-term abstinence from substances and improve other health behaviors is unclear (Bickel et al., 2011; Blume and Marlatt, 2009). Most likely these techniques will need to be paired with cognitive-behavioral approaches to achieve optimum results. Additionally, interventions could be offered to children at an early age to improve executive function alone or as part of prevention efforts aimed at improving long-term health behaviors (c.f., Ramey et al., 2012). Considerable research remains to be conducted.

All of the health behaviors and conditions mentioned here are modifiable with standard cognitive-behavioral interventions, biofeedback, meditation, and other stress reduction techniques, but are particularly effortful for individuals with limited executive function abilities. Compliance and treatment outcomes could be improved by using contingency management to increase adherence with executive function interventions among alcohol and drug dependent individuals in treatment (Silverman et al., 2012), the obese (Jeffery, 2012) and individuals with other problematic health behaviors (Higgins et al., 2012).

Given that the effects of SES on executive function are a result of adaption to the local environment and circumstances and are amenable to change supports the consideration of social justice. Indeed, social justice is an important component of conceptualizing the various policy responses to SES disparities (Greenberg and Renne, 2005; see U.S. Environmental Protection Agency (EPA), 1998, pp 7–8 for a discussion of environmental justice). For example, Adler and Stewart (2010a) have advocated for behavioral justice, which we think may be more aptly referred to as resource justice; that is, they state, “that no group should bear a disproportionate share of health problems resulting from inadequate resources for engaging in healthy behaviors.” (p. 12) (see also Adler and Stewart, 2009). We agree and wish to support another sense of what we call ‘behavioral justice.’ Specifically, we consider it unjust for an individual not to learn the skills or be provided the means and motivation to prevent, diminish, or change health risky behaviors. The extant evidence suggests that this necessarily includes the opportunity to achieve relative balance between the executive and impulsive decision systems that enable individuals to follow through with healthy choices as predicted by the Competing Neurobehavioral Decision Systems hypothesis. Such efforts would not only address behaviors that result in poor health and costly later stage interventions,

but would also improve the quality of the lives of individuals at lower and middle segments of the SES gradient.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

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