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Health Neuroscience: Defining a New Field

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Abstract

Health neuroscience is a new field that is at the interface of health psychology and neuroscience. It is concerned with the interplay between the brain and physical health over the life span. A chief goal of health neuroscience is to characterize bidirectional and dynamic brain-behavior and brain-physiology relationships that are determinants, markers, and consequences of physical-health states across the life span. The motivation behind this goal is that a better understanding of these relationships will provide mechanistic insights into how the brain links multilevel genetic, biological, psychological, behavioral, social, and environmental factors with physical health—especially vulnerability to and resilience against clinical illnesses. This review provides a conceptual introduction to health neuroscience, focusing on its major themes, representative studies, methodologies, and future directions.

Keywords

health, psychology, neuroscience, cognitive, public, behaviors, physical

How does the brain influence physical health? How does physical health influence the brain? We propose that these are inseparable and open questions, and a new field at the interface of health psychology and neuroscience is poised to answer them—a field called *health neuroscience*. But what is this new field, and what are its conceptual themes, goals, and methods? What are its challenges and opportunities moving forward? This review addresses these questions and highlights recent studies illustrating health-neuroscience approaches to understanding the dynamic interplay between the brain and physical health over the life span.

Health Neuroscience: Definition and Scope

Here, we adopt the definition of *health* as the absence of physical or mental illness, disease, pain, or discomfort. However, we would expand on this by arguing that health could be viewed as the absence or lack of physiological (e.g., insulin resistance), social (e.g., loneliness), cognitive (e.g., slow processing speed), or emotional (e.g., anxiety) risk factors. Our reasoning is that these may explain the etiology, prevention, and progression of disease and specific endpoints. As we discuss below, we distinguish physical health from mental health with the awareness that there are ambiguous boundaries, and significant comorbidities, between physical- and mental-health conditions (e.g., between cardiovascular disease and depression), along with clear physical (i.e., biological) substrates for mental-health conditions. These definitions provide some clarity to what we view as the defining attributes of health neuroscience.

Given several ongoing international efforts to better understand brain function, such as the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative, we can expect that neuroscience and its methodologies will continue to play central roles in psychology. Indeed, the widespread integration of neuroscience into the fabric of psychology has been fostered over the past few decades by the rapid ascendance of neuroimaging technologies and their applications to the study of cognition, emotion, social behavior, personality, psychopathology, development, aging, and other areas of inquiry. Over this same period, we have gained a deeper and multilevel understanding of the biological, psychological, and social (biopsychosocial) determinants of

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physical health. This understanding has been enabled by the growth of health psychology and its allied areas of research and clinical practice (e.g., social epidemiology and behavioral medicine). Notwithstanding the ascendance of neuroscience and the simultaneous—but largely independent—traction of health psychology, we still lack answers to many fundamental questions about the brain and physical health. Accordingly, we believe that now is the time to formally define a new and integrative field of health neuroscience.

More precisely, health neuroscience can be defined as an emerging field focused on understanding how the brain affects and is affected by physical health. This definition artificially splits the brain from the other organs of the body; however, we make this conceptual separation because both research and education in neuroscience and psychology have traditionally been conducted independently from other fields of physiology and medicine. It is precisely this false distinction between the brain and body that research in health neuroscience is positioned to refute. Thus, to test hypotheses about the interdependent nature of the brain and the body, we necessarily distinguish them in our definition of health neuroscience. From this perspective, health neuroscience is thematically rooted in health psychology while adopting neuroscience methodologies for studying brain function and structure in human and nonhuman-animal models. It is distinct from the broader area of health psychology in its primary theoretical and empirical focus on the brain, and it differs from other areas of neuroscience in its primary focus on physical health.

A chief goal of health neuroscience is to characterize bidirectional and dynamic brain-behavior and brain-physiology relationships that are determinants, markers, and consequences of physical-health states across the life span. The motivation behind this goal is that a better understanding of these relationships will provide mechanistic insights into how the brain links multilevel genetic, biological, psychological, behavioral, social, and environmental factors with physical health—especially vulnerability to and resilience against clinical illnesses. Moreover, such mechanistic insights will provide new cross-disciplinary platforms to develop brain-based prevention and intervention efforts to improve physical health, inform health policies, and promote successful development and aging.

Figure 1 illustrates key concepts of health neuroscience. Here, the brain is considered as the central organ that affects and is affected by states of health, which span a continuum from optimal well-being to clinical illness. In this regard, health-neuroscience research may conceptualize the brain as the primary, or *top-down*, determinant of downstream mediating processes that proximally influence physical-health states (see the right side of Fig. 1). Downstream mediating processes would thus be considered as emergent phenomena under the control of the brain and could include processes related to cognition and decision making, stress and emotion, health behaviors, and facets of peripheral physiology.

Likewise, health-neuroscience approaches may conceptualize the brain as a target organ that is affected by health states via *bottom-up* pathways. For example, health-neuroscience studies may examine changes in brain structure and function that result from smoking, systemic inflammation, or other factors related to physical health (see the left side of Fig. 1 and ”Empirical Illustrations” below for more examples).

Finally, health-neuroscience approaches conceptualize these brain-health relationships and pathways as subject to the contextually modifying influences of social, cultural, environmental, and other higher-level factors, as well as the modifying influences of life histories, genetics, and other individual-level factors (see the top and bottom of Fig. 1). In sum, health-neuroscience studies may operationalize direct measurements of brain function and structure (e.g., using neuroimaging or electrophysiological recording methods) as predictor (independent) or outcome (dependent) variables, depending on the particular brain-health relationship (or relationships) that are under investigation or targeted by intervention.

There may be questions about the position of mental health (i.e., psychopathology) within the definition of health neuroscience. Indeed, research on psychopathology and mental health may be included as a part of health neuroscience to the extent that the research questions involve the examination of reciprocal associations or comorbidities between mental and physical health. For example, psychopathology (e.g., depression) is often coexistent with physical-health problems and may predict health outcomes (e.g., obesity) or be modified by health behaviors (e.g., physical activity). Insofar as the neural substrates mediating these relationships are of interest, such topics would fall under the auspices of health neuroscience.

Empirical Illustrations

To illustrate applications of the above concepts, we will highlight health-neuroscience studies and consider some major methodological, computational, and conceptual challenges and opportunities in health neuroscience.

Stress, emotion, and social factors

For decades, health psychologists have been interested in the connections among physical health and stress, emotion, and a vast spectrum of social factors (e.g., Adler &

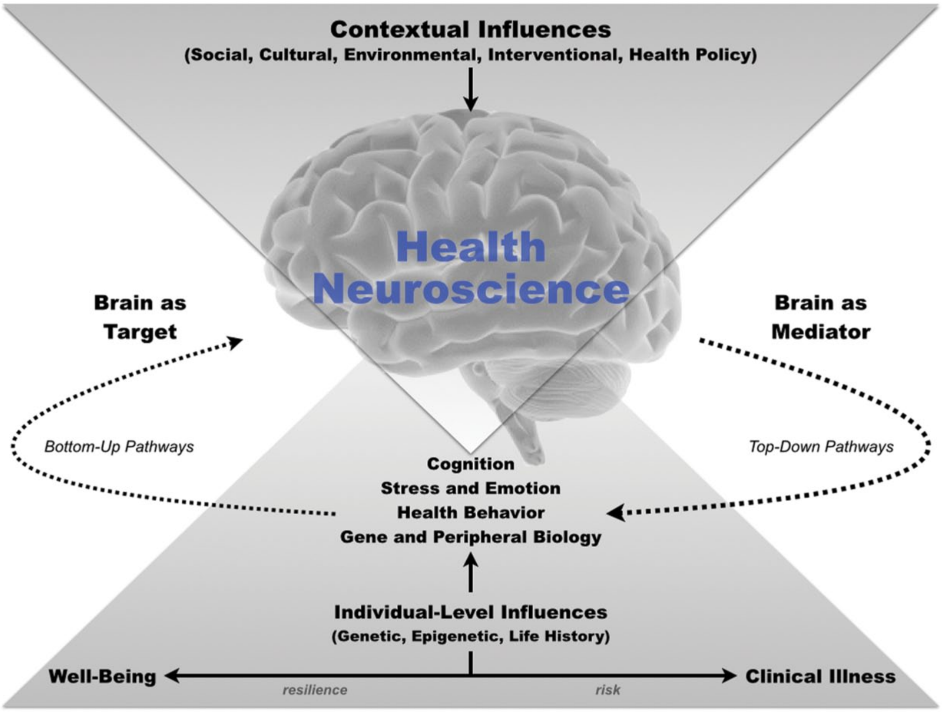

Fig. 1. Health neuroscience is an interdisciplinary field at the interface of health psychology and neuroscience. Thematically, health neuroscience is concerned with understanding how the brain influences and is influenced by physical health across the life span—extending along a continuum, as shown at the bottom of the figure, ranging from optimal states of health and well-being to states of disease risk, symptom expression, and clinical illness. Distal contextual influences, shown at the top of the figure, are viewed as impacting physical health via downstream effects that are mediated by the brain, including social (e.g., familial and peer networks), cultural (e.g., valued group identities and shared practices), environmental (e.g., counties, neighborhoods, workplaces), interventional (e.g., efforts to change physical activity, diets, lifestyles, psychological states), and health-policy (e.g., laws affecting the distribution of health resources, public health campaigns) influences. Proximal influences, shown at the bottom of the figure, are viewed as impacting physical health via direct and interactive effects on the brain, as well as via mediating processes that affect and are affected by the brain, including genetic, epigenetic, developmental, and aging influences. Processes that bidirectionally and dynamically link the brain to states of health throughout life include factors that are widely studied in health psychology but have also been studied historically in separate fields of study; namely, cognitive, stress, emotion, health-behavioral, peripheral-physiological, and gene-expression processes. Health-neuroscience studies are diverse and integrative, insofar as these processes are viewed as being regulated by the brain via top-down (efferent) pathways and as influencing the brain via bottom-up (afferent) pathways. In this way, health-neuroscience studies conceptualize measurements of brain function and structure as outcome variables that are dependent on bottom-up pathways and as independent variables that determine health processes via top-down pathways.

Matthews, 1994). Such interest has led to conceptualizations of psychological and social determinants of health that emphasize health-related behaviors and peripheral biological mediators as common downstream pathways to health endpoints (e.g., Cohen, Janicki-Deverts, & Miller, 2007).

For example, anger, anxiety, and depression are thought to confer risk for cardiovascular disease by leading to disadvantageous health behaviors (e.g., smoking) and to alterations in systemic inflammation, neuroendocrine outflow, and autonomic physiology that adversely impact the heart and vasculature (Suls & Bunde, 2005). A health-neuroscience approach builds on this conceptual framing in several ways. First, as indicated on the right side of Figure 1, health-neuroscience studies are integrating theoretical models and empirical findings from social, cognitive, and affective neuroscience to consider the brain as the central, top-down regulator (i.e., determinant) of behaviors and parameters of peripheral physiology that impact physical health (e.g., McEwen & Gianaros, 2010). Second, these models and findings consider stress, emotion, and social processes as being functionally instantiated in neural circuits that also influence health behaviors and peripheral physiology (e.g., Eisenberger & Cole, 2012). Finally, as illustrated on the left side of Figure 1, health-neuroscience studies are beginning to consider the bottom-up influences of health behaviors and peripheral physiology on brain systems and circuits that mediate stress, emotion, social, and other behavioral processes (e.g., Critchley & Harrison, 2013).

To elaborate, recent studies incorporating peripheral-physiological recordings have shown that exaggerated cardiovascular reactions (e.g., large rises in heart rate and blood pressure) to acute psychological stressors (e.g., time-pressured cognitive tasks with negative feedback and social-evaluative-threat paradigms) are associated with concurrent alterations in stress-induced neural activity within the amygdala (Gianaros et al., 2008) and medial prefrontal cortex (Wager et al., 2009). Importantly, exaggerated cardiovascular reactions have been established by health psychologists to confer risk for cardiovascular disease (Chida & Steptoe, 2010). And both the amygdala and anatomically networked regions of the medial prefrontal cortex participate in stress- and emotion-related processes, as well as in the regulation of peripheral physiology (Phelps & LeDoux, 2005; Roy, Shohamy, & Wager, 2012). Accordingly, health-neuroscience findings are furthering our understanding of the brain systems involved in stress-related factors (cardiovascular stress reactions) important for physical health (e.g., cardiovascular disease).

Moreover, such health-neuroscience research has been extended to show that neural-activity changes within the anterior cingulate cortex, as evoked by the cognitive regulation of negative emotions, are associated with the severity of preclinical atherosclerosis in major blood vessels, and that this association is mediated by systemic inflammation (Gianaros, Marsland, Kuan, et al., 2013). This work identifying a brain-body pathway to atherosclerosis complements a growing movement in health psychology toward emotion-regulation interventions to improve physical health and is consistent with some models of allostatic load that describe the impact of stress on the brain, mind, and body (McEwen & Gianaros, 2011).

In addition to health-neuroscience studies of stress and emotion, there is emerging work on social factors and interpersonal processes known to predict wide-ranging health outcomes, including work on socioeconomic status (Gianaros, Marsland, Sheu, Erickson, & Verstynen, 2013), social ties and support (Eisenberger, 2013), and social discrimination (Akdeniz et al., 2014). Collectively, the work highlighted above promises to increase our brain-based understanding of how stress, emotion, and social factors "get under our skin" to influence our physical health (Miller, Chen, & Cole, 2009).

Health behaviors

Health psychology holds a longstanding interest in health behaviors that increase (e.g., smoking) or decrease (e.g., mammography screening) health risks. Emerging health-neuroscience studies are extending this interest to conceptualize the brain as both a determinant and target of behaviors linked to physical health. For example, greater brain activity evoked by rewarding food cues predicts subsequent weight gain over 6 months (Demos, Heatherton, & Kelley, 2012). Moreover, weight gain may subsequently alter the function of brain systems that are responsive to food-related reward cues: Women who gained weight over a 6-month period had reduced striatal reward responses when consuming a milkshake (Stice, Yokum, Blum, & Bohon, 2010). Moreover, recent work has suggested that weight gain negatively affects the structure of gray- (Raji et al., 2010) and white-matter tissue (Verstynen et al., 2013; Verstynen et al., 2012), illustrating bottom-up influences of physical-health states on the brain.

Emerging neuroscience research is also informing psychological models of health-behavior change. For example, increased neural activity in brain regions important for inhibitory-control processes predicts smoking cessation among smokers attempting to quit (Berkman, Falk, & Lieberman, 2011). The brain may also mediate the efficacy of targeted health messages for health-behavior change. For example, greater activity in the medial prefrontal cortex predicts subsequent sunscreen use (Falk, Berkman, Mann, Harrison, & Lieberman, 2010), healthy food choices (Hare, Malmaud, & Rangel, 2011), and smoking cessation (Chua et al., 2011). Moreover, some of this work has suggested that brain activity may predict the success of national public-health ad campaigns in changing individuals' behavior (Falk, Berkman, & Lieberman, 2012).

Interventions

Recent studies have also characterized the role of the brain in determining how behavioral interventions (e.g., aerobic exercise, mindfulness-meditation training) improve health. For example, randomized controlled trials of aerobic-exercise training may increase hippocampal volumes (Erickson et al., 2011; see Fig. 2), functional correlations in the activity within brain networks (Voss et al., 2010), and task-related functional activity in regions involved in executive function, memory, and attention (Colcombe et al., 2004). Importantly, these changes to the brain account for exercise-related improvements in cognitive performance (Erickson et al., 2009; Erickson et al., 2011), which has implications for understanding how health behaviors are associated with dementia and memory problems in adulthood via brain-body pathways (Erickson et al., 2010). Recent randomized controlled trials have also suggested that mindfulness-meditation interventions can reduce pain and stress reactivity,

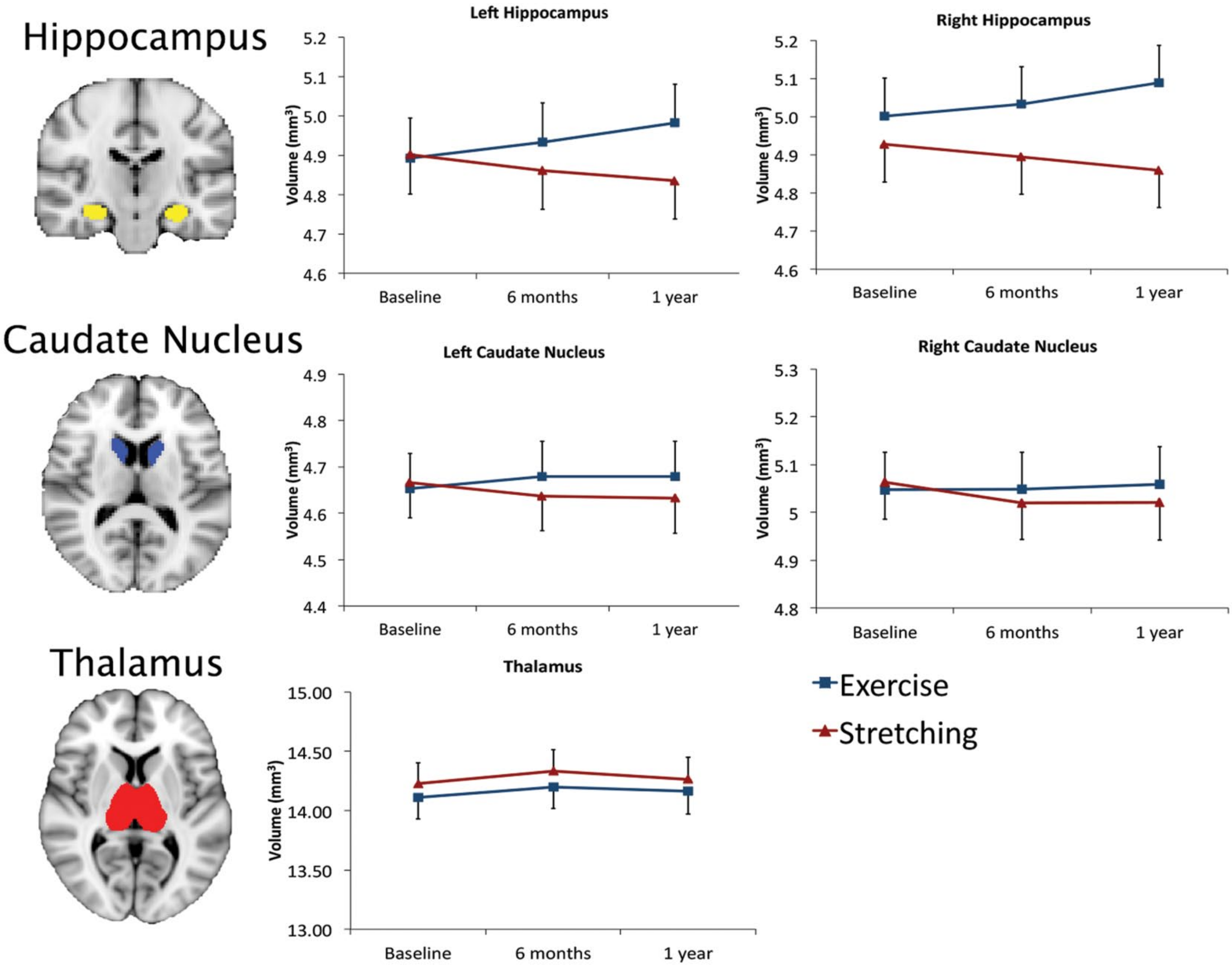

Fig. 2. Results from Erickson and colleagues (2011) demonstrating that a 1-year randomized exercise intervention resulted in an increase in the size of the hippocampus in the treatment group (exercise condition) relative to the control group (stretching condition), but no significant changes in the size of the caudate nucleus or thalamus. This example illustrates how a health-behavior intervention (in this case, exercise) can affect brain structure in ways that influence cognitive functioning. Adapted from "Exercise Training Increases Size of Hippocampus and Improves Memory," by K. I. Erickson, M. W. Voss, R. S. Prakash, C. Basak, A. Szabo, L. Chaddock, . . . and A. F. Kramer, 2011, *Proceedings of the National Academy of Sciences, USA, 108*, p. 3019. Copyright 2011 by the United States National Academy of Sciences. Adapted with permission.

possibly via functional alterations in cortical and limbic brain circuits important for stress and emotion regulation (Creswell, in press). These are only some of many examples (e.g., pain management; Hong et al., 2013) that illustrate how health-neuroscience approaches are extending the study of major topics in health psychology, particularly by conceptualizing and considering the bidirectional relationships between the brain and health behaviors.

Methodological and Computational Considerations

The conceptual and empirical goals of health neuroscience engender multilevel and often expansive methodological approaches—which, in a single study, may span genetic, molecular, organ-systems, psychological, behavioral, social, and environmental levels of analysis. Accordingly, the computational challenges posed by health neuroscience may be expanded in size and complexity relative to other fields of psychology and neuroscience.

This is particularly true in research employing popular neuroimaging tools and analysis pipelines to study brain-health relationships. Most "off-the-shelf" analytical tools for neuroimaging data are tasked with estimating functional responses or morphological (structural) features of volumetric parcels of space, resulting in up to several hundreds of thousands of correlated observations per subject. This not only results in challenges related to controlling for the possibility of reporting chance findings and other quantitative issues affecting study inferences but also forces health neuroscientists to confront so-called "big data" problems. Thus, in size alone, typical neuroimaging data sets can easily run into several gigabytes of data per person. When scaled to the larger sample sizes typical of health-psychology studies (e.g., hundreds of subjects), this can easily mushroom into terabytes or more of data per study. Indeed, the challenge of scaling to population-level neuroscience studies is an immensely complex topic that has been detailed elsewhere (Falk et al., 2013).

Computational challenges may be further compounded by the use of analytic approaches that examine both individual brain areas and neural-network dynamics across hundreds or thousands of connected brain areas. Furthermore, many questions in health neuroscience are mediational in nature (e.g., does the brain mediate the relationship between a health-behavior intervention and improvements in physical health?). This means applying computationally demanding techniques often used in health psychology, such as mediation analysis and structural equation modeling, to neuroimaging data, which could result in estimating hundreds of thousands of hierarchical or mediational models across the brain. In fact, such techniques have already been used to elucidate complex relationships, such as the influence of psychosocial factors on the neural representation of pain (Atlas, Bolger, Lindquist, & Wager, 2010) or the influence of social and physiological systems on global myelin integrity (Verstynen et al., 2013). These analytical approaches, along with machine-learning techniques designed to refine hypothesis generation within neuroimaging data sets (Voytek & Voytek, 2012; Yarkoni, Poldrack, Nichols, Van Essen, & Wager, 2011), can dramatically expand the utility of assessing complex brain-health relationships.

Opportunities and Future Directions

As health neuroscience continues to grow, we anticipate an expansion of our knowledge about the role of the brain in physical health and the reciprocal relationships between physical and mental health via brain pathways. Such knowledge will be driven in large part by questions that are cross-fertilized by interdisciplinary perspectives. For example, common questions asked in cognitive neuroscience (e.g., what are the neural correlates of response inhibition?) can be extended as health-neuroscience questions (e.g., do the neural correlates of response inhibition relate to health behaviors such as smoking cessation?; Berkman et al., 2011). Likewise, traditional social-affective-neuroscience questions about the neural correlates of emotion regulation can be extended to questions about how the neural systems supporting emotion regulation also relate to health-relevant aspects of hypothalamic-pituitary-adrenal axis functioning (Urry et al., 2006) or behavioral-treatment efficacy (Lieberman et al., 2004). Hence, what will define creative future health-neuroscience approaches and questions is whether there is a brain-based focus on physical-health mediators and outcomes.

As this field grows, we also anticipate the continued refinement of conceptual and analytical perspectives with respect to the parent disciplines of health psychology and neuroscience and allied fields of study. We maintain that in health neuroscience, the brain can be thought of as an outcome, or dependent, variable—but in a unique interpretive framework. Thus, some studies noted above have examined the extent to which health behaviors (e.g., engagement in exercise) influence brain morphology, function, or integrity (Fig. 2). However, in addition to conceptualizing the brain as an outcome, health neuroscience views the brain as a potential mediator of health outcomes or as a predictor of health behaviors (Fig. 1). Thus, health neuroscience envisions the brain as an important node that could be positioned as a predictor, a mediator, or an outcome, depending on the particular framework of the research question being studied. And we expect that work on the horizon will fill in the details of this general conceptual framework.

We acknowledge that we have selectively reviewed only a manageable subsample of studies illustrative of health-neuroscience approaches and that there are other avenues and directions by which to incorporate neuroscience methods, theories, and models into topics of health psychology. We fully recognize the importance of integrative questions, methods, and findings from other disciplines relevant to health neuroscience and also recognize the importance of circumspect interpretations of studies that are correlational in nature and the need for methodological rigor when designing and interpreting results from health-neuroscience studies.

Over a decade ago, Sung and colleagues (Sung et al., 2003) argued that the most exciting science in the 21st century is likely to evolve among, not within, traditional disciplines. Our hope is that our initial description of health neuroscience as a field situated among the traditional disciplines of health psychology and neuroscience will result in the growth of this exciting interdisciplinary area. As this new field is defined and shaped, we will face important questions about how to fund this research, how to effectively train individuals in both neuroscience and health, and how to build programs of research that can offer mechanistic and translational impacts. Nonetheless, health-neuroscience investigations are poised to address longstanding questions in both health psychology and neuroscience—by helping the field develop new mechanistic models and understand factors that confer risk and protection for physical-health outcomes. In doing so, health neuroscience can have a significant impact on improving and transforming public health.

Recommended Reading

Berkman, E. T., Falk, E. B., & Lieberman, M. D. (2011). (See References). An article that examines brain regions involved in self-control that are associated with smoking, craving, and the attempt to quit smoking.

Erickson, K. I., Voss, M. W., Prakash, R. S., Basak, C., Szabo, A., Chaddock, L., . . . Kramer, A. F. (2011). (See References). An article that describes the results of an exercise intervention on hippocampal volume in older adults, in which one year of exercise increased the size of the hippocampus in a treatment group relative to a control group.

McEwen, B. S., & Gianaros, P. J. (2010). (See References). A review of neuroscience studies on the impact of stress and physical-health factors on brain pathways in humans and nonhuman animals.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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