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Editorial commentary on the special issue emerging psychoneuroimmunology research: Future leaders in focus



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ABSTRACT

The theme of this BBI-Health special issue is to promote the research, creativity and forward-thinking of future key opinion leaders in the field of psychoneuroimmunology (PNI). We asked contributing researchers to identify new ideas and spaces for innovation to map out the future trajectory of our discipline. This special issue provides global and diverse views from early career investigators focused on science, society, and/or policy, with an emphasis on diversity in all its aspects. The common thread weaving through the articles contained in this special issue is that all authors were invited to consider the future of PNI while they were experiencing the global COVID-19 lockdowns that slowed down or even prevented them from access to their “hands-on” research. The contributors vary from Master level to assistant professors, and all have already significantly contributed to the field of PNI. Each contributor has provided a photograph and short biography alongside their written perspectives. We hope that you will enjoy learning about their visions for the future of PNI and will join us with enthusiasm as we watch our field grow through the advancement of their scientific careers.

1. Introduction

The New Year is traditionally viewed as a time of renewed energy and hope. A time to look to the future and reassess our trajectories in both work and life in general. January 2020 began like any other New Year. Scientists at all career levels were busy planning new research directions or continuing and growing their current research programs. Most days were filled with the regular hustle and bustle of laboratory life. On other days, there were faint whispers in hallways about some far-away virus and questions about whether it would reach the very hallways in which these scientists walked and worked. By March 2020, many laboratories were thrown into chaos due to rapid lockdowns and restricted access to their research environment (Byrom, 2020). As with most challenges in life, some fared better than others as they were fortunate enough to be able to change their research direction or had other advantages that granted them resilience during this time. But as the COVID-19 pandemic continues into 2022, the loss of productivity has impeded the progress of research in most scientific fields (Harrop et al., 2021), including psychoneuroimmunology (PNI).

Early career investigators (ECIs), specifically undergraduate students

through to those at the assistant professor (or similar) level, are facing extra challenges in the already difficult battle to establish and continue a career in science (Termini and Traver, 2020). For PNI to continue to grow as a discipline, we need a diverse network of researchers who bring a variety of fresh perspectives and experiences from across the globe. Unfortunately, many ECIs with these perspectives and experiences have been some of the most vulnerable to the impacts of the pandemic-related disruptions (Arnold and Woolston, 2020; Byrom, 2020; Cardel et al., 2020; Gibson et al., 2020; Maas et al., 2020), which may limit their ability to continue in this important research area.

Like many others, ECIs have experienced a loss of time to undertake experiments and have had fewer networking opportunities which has resulted in social and scientific isolation (Termini and Traver, 2020). They have observed a reduction in grant funding opportunities, with funding agencies shifting focus to COVID-19 associated projects, leaving fewer opportunities for funding non-COVID-19 related work (Walker et al., 2022). Furthermore, their productivity was further delayed by social distancing mandates and reduced lab densities. Together, these limitations have in turn slowed the reopening of laboratory research. ECIs have been further impacted by a stalled job market and an inability

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to begin new positions due to large spread lockdowns and hiring freezes (Termini and Traver, 2020; Gibson et al., 2020). Additionally, there has been a general lack of support to address promotion and tenure concerns (Harrop et al., 2021; Gibson et al., 2020). Alongside this is the added difficulty of having fewer opportunities to assert themselves as independent scientists and establish themselves in the PNI field, separate from their advisors.

The adversity facing ECIs sparked the idea for the present collection of papers published in *Brain, Behavior, and Immunity – Health* with ECIs as lead authors. ECIs were defined as those with at least a master's degree and less than 15 years beyond their last professional qualification. In this special issue, we encouraged the viewpoint of hope, asking the ECIs to look to the future and map out how they see their research shaping the PNI landscape in years to come. Alongside each article, you can find a photograph of the author and a short biography outlining their career accomplishments in PNI to date. We had over 50 submissions to this special issue, highlighting the many diverse perspectives and research questions that enrich our field.

1.1. Mental health: A futuristic focus on PNI, biomarkers, and depression

The topic of mental health was widely explored by ECIs throughout this special issue. Some notable contributions include a series of papers that focused on perinatal depression. In one commentary, Hazelgrove (2021) advocates for a shift in PNI research methodology from using primarily cross-sectional designs, to the use of more longitudinal studies. It was argued that this approach can more clearly establish whether immune dysfunction is present prior to symptom onset, which may improve prediction of postpartum associated illness. The use of objective measures, such as biomarkers, was identified as an important tool to help identify women at risk for postpartum depression (Fransson, 2021). In line with these suggestions, Szpunar et al. (2021) explored the complex relationships between estradiol, inflammatory markers (e.g., interleukin (IL)-1 β and IL-6), cortisol, and depressive symptoms across both pregnancy and the postpartum period. Sawyer (2021) proposed that further research needs be done to understand the important interactions between maternal mental health, the breast milk composition of immune factors, and offspring outcomes. Moreover, Bind (2021) highlighted the impact that depression in pregnancy can carry on mother infant interactions, including difficulties with psychological, physical, and social functioning. Together, this research could identify novel biomarkers that could help predict offspring developmental trajectories. It was underscored that in the future, transdisciplinary treatment teams should focus on inter-individual care situated within a variety of healthcare settings to test the feasibility of implementing the use of standardized PNI-biomarker based screening tools (Kautz, 2021).

With respect to PNI-associated biomarkers and the diagnosis of mental illnesses, such as depression, ECIs provided fresh methodological perspectives to help move our field forward. Worrell (2022) suggested that we embrace the concept of heterogeneity as few studies evaluate the specific 'types' of symptoms expressed when testing associations between childhood trauma, inflammation, and depression. Measuring and understanding specific symptom dimensions that occur in response to childhood trauma could improve diagnostic and treatment opportunities. Indeed, alongside the important considerations of individual lived experiences, integrating clinical data and the identification of multiple biomarkers to create a 'biosignature' may be the future of precision medicine for diagnosis and tailored treatments (McQuaid, 2021).

One example of using biomarkers is to investigate inflammation and its association with mRNA expression of inflammation-related genes. For example, in the context of treatment resistant depression these genes may predict lack of response to particular treatments. It is suggested that instead of selecting genes *a priori*, that the entire transcriptome be analyzed based on whole-genome approaches, which may reveal gene candidates not previously associated with depressive disorders (Sforzini, 2021). Additionally, using an absolute, rather than a relative quantitative

approach will better allow for the identification of defined thresholds of mRNA values of pro-inflammatory cytokines (Mariani, 2021). Using this approach, absolute mRNA values from individuals can be compared against a standard value to determine if their values are higher or lower than a suggested threshold, which could lead to tailored treatments. A patient with a higher inflammatory status could then be treated with antidepressants alongside anti-inflammatory treatments, which may improve the efficacy of the traditional antidepressant treatment.

When it comes to evaluating biomarkers, Madison (2021) emphasized the importance of matching measurement time points with the kinetics of the biomarker of interest. For example, cardiovascular, autonomic, and catecholamines are "faster-moving" biomarkers and require more frequent sampling compared to "slower moving" biomarkers, such as cortisol and inflammatory cytokines. The trajectory of the biomarker presence and its association with symptoms should be temporally considered in future studies.

Using a PNI lens, ECIs also examined the evidence surrounding potential treatments for mental health disorders. For example, the antidepressant effects of minocycline were explored by Nettis (2021), while Audet (2021) discussed the intricate connections between the microbiota-immune-brain axis by focusing on the potential for dietary interventions in the treatment of depressive symptoms.

Meditation-based treatments were also recognized as being important to the future of the PNI field, in terms of their therapeutic potential. For example, Estevao (2022) discussed the efficacy of yoga interventions, mechanistically linking the attenuation of mental health symptoms such as depression to immune mediators such as IL-6, TNF-alpha, and IL- β , among others. Some of our ECIs provided specific recommendations on how to implement meditation-based treatments into research and clinical practice. In particular, Lindsay (2021) proposed that future research in mindfulness-based interventions (MBI)'s should: 1) evaluate the direct impact of MBIs on inflammatory processes in early-life stress exposed populations, and 2) evaluate the feasibility of implementing MBI programs into community and healthcare settings. Importantly, this commentary recognized the potential for remote online programs to increase accessibility to and participation in MBI interventions. Relatedly, Neupane (2021) argued that as a field, PNI should employ rigorous scientific methods to evaluate the more holistic health perspectives and treatments adopted by some Eastern traditions (e.g., mindful awareness, different exercise forms, diets). Adopting a more global approach and integrating scientific approaches from psychological, neurological, and immunological perspectives may lead to a better understanding of the biological mechanisms underlying mental illnesses and their treatment. Indeed, this perspective will be important for the future growth of the field, as Zajkowska (2021) points out that most studies are focused on high, but not low- and- middle income countries. This is a critical point when it comes to evaluating the effectiveness of psychological interventions given that the intensity and frequency of stressors in these countries may impact the generalization of success/benefits from higher income countries.

1.2. Interactions between the brain and periphery

Interactions between the periphery and the brain are central to core questions that have fostered several areas of PNI research including cancer research. Borniger (2021) elegantly elucidated how tumors can signal the brain and alter homeostasis in non-metastatic preclinical cancer models, altering sleep via modulation of hypothalamic hypocretin/orexin neurons. Future research directions include further dynamic sensing and integration of signaling pathways in the brain that alter physiology i.e., fatigue, nausea, and pain, by applying state of the art neuroscience methodology, such as trans-synaptic tracing. While basic and translational research and interventions have focused on biobehavioral connections mainly in adults, Taylor et al., 2021, highlight the necessity to further focus on adolescents and young adults with poorer mental health and cancer-related outcomes. Biobehavioral treatment of young patients holds strong promise to modifying the impact of the

disease trajectory. Assessment of biobehavioral measures include heart rate variability as a potential readout of autonomous nervous system activity, cytokines, behavioral outcomes, and neuroendocrine measures such as the appetite and the energy expenditure regulating hormone leptin. In addition, activation of the hypothalamic-pituitary-adrenal axis i.e., measures of glucocorticoids, are recommended to be commonly evaluated PNI research. [Salehzadeh and Soma \(2021\)](#) discussed some novel insights for better analyses of low glucocorticoid levels by applying sensitive mass spectrometry. Moreover, the authors emphasize that appropriately measured local levels of glucocorticoids may be more meaningful than reporting circulating plasma or serum levels, at least in the thymus (immunosteroids) and the brain (neurosteroids). The authors proposed to apply such approaches to future research on early life adversity and their effects on dynamic immune and brain development.

In a brief but compelling review, [Caulfield \(2021\)](#) discussed the current state of preclinical and clinical research in the field of lung-brain axis research. The author highlights that inhaled glucocorticoids may represent a potential treatment strategy for disease. Moreover, they emphasize the need to improve our knowledge of involved brain structures (i.e., prefrontal cortex, hippocampus, and amygdala) and associated signaling pathways when studying the interaction of chronic inflammation in peripheral organs, like the lung, with the brain. [Dangarembizi \(2021\)](#) focused on cryptococcal meningitis, a fungal infection and “neglected threat to African brain health” with potential deadly consequences in particular for immunocompromised patients. This fungal disease has primarily been characterized for its interaction with the immune system in the periphery. However, its action in the brain with typical symptoms including headaches, cranial neuropathies and fever remains poorly understood. The author asks for more advanced investigation on neuro-immune interactions in this disease. Specifically, it is suggested that applying state of the art *in vivo* and *in vitro* approaches will reveal new insights for the generation of affordable therapeutic strategies.

1.3. Food and inflammation or psychoneuroimmunology and nutrition

Several manuscripts included in this special issue focus on the emerging field of Nutritional Psychiatry and its intersection between PNI and mental health. First of all, [Butler \(2021\)](#) nicely summarized the striking consequences of consuming saturated fatty acids and a moderate amount of carbohydrates, in the context of so-called “western diets,” that induce inflammation in the brain. Immune-cell recruitment to the brain is discussed, with a call for future research on the interactions between infiltrating dendritic-, T-cells, and resident immune cells in the context of high-fat diets and aging. [Décarie-Spain et al. \(2021\)](#) showed that anxiodepressive-like behaviors are induced by saturated high-fat feeding in male and female mice. Interestingly, underlying mechanisms involved signaling of the pro-inflammatory transcription factor nuclear factor kappa-B in the nucleus accumbens of male, but not female mice. This suggests that further research on sex-related differences is necessary. [Chang \(2021\)](#) focused a short review on child and adolescent attention deficit hyperactivity disorders (ADHD). Knowing that deficiency in omega-3 polyunsaturated fatty acids (n-3 PUFAs) severely alters brain development, the author suggests that a subgroup of patients with severe inflammation may benefit from treatment with n-3 supplementation. The causal relationship remains to be further assessed for n-3 deficiency and ADHD to support current data on correlations and conflicting results in clinical trials. Another novel treatment strategy involving the combined inhibition of n-3 fatty acids metabolism with n-3 fatty acids supplementation is presented by [Borsini \(2021\)](#). This review summarized evidence, from both basic and clinical studies, supporting the use of soluble epoxide hydrolases (sHE) inhibitors (e.g., GSK2256294A and EC5026) in combination with other valid therapeutic approaches, in treating clinical depression. One unifying factor of “unhealthy” nutrition involves a state of low-grade inflammation that may serve as a predisposing risk factor for a variety of morbidities, including mental health disturbances. [Bujtor](#)

[\(2021\)](#) reviewed the influence of dietary intake on low-grade inflammation, with a focus on children and adolescents. The current observational and interventional evidence supports the therapeutic potential of diet in controlling inflammation. For example, using a “Mediterranean” diet to ameliorate low-grade inflammation. Further interventional studies to establish a better understanding of the underlying mechanisms involved in dietary control of inflammation are needed. Moreover, the influence of co-morbid conditions should also be addressed and biomarker panels to define low-grade inflammation require improvement and validation.

1.4. Relationships between immune activation, social behavior, memory, and sleep

Both the loss of social contact during the COVID-19 lockdowns and the emergence of “long-COVID-19” have highlighted the important PNI links between social behavior, cognitive functioning, and inflammation. [Fadipe et al. \(2021\)](#) undertook a study to determine the rate, as well as correlates of anxiety and depressive symptoms, among patients being treated for COVID-19 in Lagos, Nigeria. They identified that there is a high burden of psychological/psychiatric morbidity amongst individuals treated for COVID-19, particularly in persons with existing emotional concerns. Thus, closely monitoring the mental health of people during disease outbreaks and including psychosocial interventions in treatment plans is vital. In a short review, [Lins \(2021\)](#) explored the relationship between maternal immune activation and the neuropsychiatric-like effects seen later in the offspring with a particular emphasis on the consequences of SARS-CoV-2 infection in pregnancy on emerging birth cohorts. In line with the research area of Immunopsychiatry, [De Picker \(2021\)](#) provided their vision for the future trajectory of this field, which included defining patients who fall within the immunopsychiatric continuum and critically acknowledging that immune responses are intricately linked with other biological processes.

The role played by inflammation in regulating social behavior is explored by [Smith \(2021a\)](#) who interrogates the important roles for microglia and microbiota in social circuit formation during development and [Muscatell and Inagaki \(2021\)](#) strongly urge fellow researchers to move beyond a singular focus on inflammation and social withdrawal to allow a more comprehensive understanding of the effects of inflammation on a variety of social behaviors. [Shattuck \(2021\)](#) explored the exciting field of social immunology and how the COVID-19 pandemic has highlighted the need for a holistic understanding of the effects of social contexts on immune function and the patterning of morbidity and mortality related to disease. Common symptoms experienced by many COVID-19 sufferers have been impaired sleep and cognitive functioning. In line with this, [Piber \(2021\)](#) explored new evidence linking sleep disturbances and inflammation to impaired spatial memory and highlighted the benefits of integrated strategies in managing spatial memory impairment. The lockdowns imposed during the COVID-19 pandemic changed many of our daily routines and affected many of our personal relationships. In their review, [Shrout \(2021\)](#) discussed how psychological, behavioral, and biological health is influenced by marriage. Here, an intriguing Dyadic Biobehavioral Stress Model is proposed to inspire transdisciplinary research integrating psychoneuroimmunological and relational lenses. Research applying this model will undoubtedly improve our current understanding of dyadic stress across the lifespan, and how to detect and report it.

1.5. Other novel PNI-based therapeutic interventions

The global and diverse opinions from early career investigators, which focused on science, society, and/or policy, with an emphasis on diversity in all its aspects has great importance nowadays. Especially when related to therapeutic interventions in the field of PNI. The choice to deny the facts, as a way of escaping them, known as “negationism”, returned during the SARS-COV-2 pandemic. The adoption of unproven

therapies has spread around the world similarly to the pandemic itself, for instance, the use of chloroquine (CQ) and hydroxychloroquine (HCQ) against SARS-CoV-2 infections. Likewise, there was the formation of a legion of people who began to question science in general. Therefore, the propagation of scientifically proven therapeutic interventions by future leaders has a predominant role in confronting this tragedy called denial.

Huang (2021) reviewed the therapeutic potential of Ursodeoxycholic acid (UDCA) in neurodegenerative disorders, proposing that this substance could potentially be used as an alternative therapeutic approach for patients suffering from neurodegenerative disorders. Evidence has shown that UDCA can reduce apoptosis, inhibit reactive oxygen species and tumor necrosis factor - α production, in neurodegenerative models. In addition, UDCA is able to induce apoptosis of brain blastoma cells in homeostatic conditions. **Matt (2021)** proposes that it is critical to define the neurotransmitter-mediated mechanisms by which psychiatric drugs alter immune function to allow the interactions of psychiatric drugs and other immunomodulatory drugs, which are often used in combination. Having this information will enable the identification of novel targets that may be translated into more efficacious diagnostic, preventive, and therapeutic interventions. Through an interdisciplinary approach, we will be better placed to offer precision polypharmacy for combating adverse events associated with multimorbidity and polypharmacy in the future.

Microglia are highly sensitive to chronic psychological stress, inadequate diet, viral/bacterial infection, pollution, and insufficient or altered sleep, especially during critical developmental periods, but also throughout life. **Tremblay (2021)** reviews how these environmental challenges can compromise microglial physiological functions, resulting in defective neuronal circuit wiring, altered brain functional connectivity, and the onset of behavioral deficits into adolescence, adulthood, and aging. It is proposed that exploring the impact of these challenges on the various emerging microglial subtypes and states might provide novel targets for prevention or treatment strategies. **VanRyzin (2021)** further provides a conceptual overview on the role of microglial phagocytosis in shaping the developing brain in a region- (i.e., amygdala and hippocampus), age-, and sex-dependent manner. He asks the question if and to what extent phagocytosis induces long-lasting reprogramming of microglia, for example, via epigenetic modifications. In their review, **Corsi-Zuelli et al. (2021)** provided a detailed characterization of regulatory T cell (Tregs) studies in psychosis, recognizing important methodological limitations and perspectives for scientific innovation. They highlight emerging preclinical research suggesting the potential benefit of Treg-enhancing therapies. The authors declare the necessity for longitudinal studies conducted with drug-naïve or minimally treated patients using more sophisticated techniques for testing the suppressive capacity of Tregs. Therefore, the authors do believe potential benefits in targeting emerging immunomodulatory treatment modalities on person-specific immune dysregulations may be available.

Related to therapeutic interventions focused on depression, **Nikheslat (2021)** reviewed aspects of inflammation associated with major depressive disorders and provided an overview of the antidepressant properties of ketamine. The author showed that the effects on peripheral and central inflammation helps to better understand the mechanisms underlying the therapeutic action of ketamine as an anti-inflammatory antidepressant target in psychiatric emergency. **Zonca (2021)** highlighted the global burden of adolescent depression and the importance of understanding the risk for developing depression in adolescence. In order to reduce this burden, the author underscored the potential of identifying biomarkers and signatures underlying adolescent depression, to aid in the development of novel preventive strategies. **Rebecchini (2021)** reviewed evidence for effects of music on mental health and immunity and with the current literature showing beneficial results involving music as primary tool, calls for development of music-based therapy services in health care systems.

1.6. Sex differences in psychoneuroimmunology

Sex differences in basic and clinical PNI research are of increasing interest. In this special issue, **Posillico (2021)** provides a brief overview on synaptic plasticity for learning and memory involving neurons and astrocytes, a process also assisted by microglia. Sex differences in synaptic plasticity range from estrogen receptor distributions, transcription during hippocampal-dependent memory formation, intracellular signaling cascades, hippocampal neurogenesis, to differences in mechanisms and mediators of neuroinflammation. Overall, Posillico suggests potential sex specific pathomechanisms. Thus, sex specific treatment strategies may be needed for the multifaceted complexity of diseases with sex specific prevalence like during neurodegeneration. **Shaw (2021)** further addresses the interplay between estrogens and mitochondria, which represent pivotal markers and regulators of disease states like neurodegeneration. Mitochondria are not only involved in steroid production, but sex steroid hormones, like estrogen can directly alter mitochondrial biogenesis and function. Treatment strategies targeting mitochondrial function, or their transplantation are suggested as a promising avenue for more personalized treatment schedules.

Krukowski (2021) summarizes evidence for sex differences in models for traumatic brain injury (TBI) and space radiation. Overall, it is revealed that neuroimmune alterations, like microglial responses, appear to be more severe in male than female animals or even absent in females exposed to space radiation. Moreover, it is proposed that investigators should more frequently share resources (e.g., open data) repositories allowing for multidimensional analysis of clinical and preclinical TBI research. **Lombardo (2021)** reviewed data supporting a role of the immune system in suicide vulnerability in men and women. The author points out that although several studies identify gonadal hormones as mediators of the immune system, no studies specifically investigate the interaction between sex hormones and the immune system in suicide vulnerability. This will be an important consideration for the design of future studies. **Tsyglakova et al. (2021)** present data on short-term (6 days) variable stress-induced sex- and region-specific microglial alterations. Morphological changes in microglia were only observed in the nucleus accumbens and the dentate gyrus of the hippocampus in female mice. The authors highlight that sex differences may not only be related to the brain site, but also the length and type of stressor. Finally, **Bollinger (2021)** focused on the fact that women show a higher prevalence of major depressive disorders (MDD). The author elegantly illustrates sex differences in rodent models and human research during chronic stress, not only in microglial morphology, but also in their function and transcriptional profile. In addition, differences in vulnerability to defined types of stress, their duration, and sensitive time window are highlighted. A call for precision and personalized medicine is given.

1.7. Research design considerations in psychoneuroimmunology

The success of all good quality research lies in the design of the studies irrespective of the field. In terms of the field of PNI, **Moriarty (2021)** identified three areas of work that should be emphasized in future research to maximize the replicability and clinical impact of research in the field of immunopsychiatry. These included: 1) planning data collection and statistical analyses with measurement properties and conceptually important sources of variance in mind, 2) characterizing inflammatory phenotypes of psychopathology, and 3) the integration of inflammatory processes into robust, extant psychosocial theoretical frameworks of psychopathology risk. **Mac Giollabhui (2021)** highlighted the benefits of research designs that manipulate constructs of interest (depression/inflammation) using intervention or treatment designs and intensive sampling approaches with an ultimate goal of better understanding the temporal sequence and causal relationships of depression, inflammation, cognitive dysfunction, and their shared risk factors. Potential benefits of these research designs are discussed in terms of their contribution to a better understanding of the etiology of

depression and a pro-inflammatory phenotype, their relevance to structural health inequalities, and better characterizing the heterogeneous clinical presentation of depression, particularly relating to the etiology of cognitive dysfunction in depression.

In their review, **Smith (2021b)** lays the foundation for the perspective that while traditional approaches in animal models have focused on modeling a single prenatal exposure or second exposure later in life, a translational approach would begin to incorporate the most prevalent co-occurring prenatal exposures. Long-term follow-up in humans is extremely challenging, so animal models can provide timely insight into neurodevelopmental consequences of complex prenatal exposures. Animal models that represent this translational context of comorbid exposures behind maternal obesity or comorbid exposures behind maternal opioid use may reveal potential synergistic neuroimmune interactions that contribute to cognitive consequences and neurodevelopmental disorder risk. Finally, translational co-exposure models can identify concerning exposure combinations to guide treatment in complex cases and identify high-risk children starting in the prenatal period, where early interventions, improve prognosis. Another model for future PNI research is proposed by **Renna (2021)** dealing with the potential of negative emotions being linked to inflammation and *vice versa*. The author suggests applying their model to further elucidate how negative emotionality could promote immune system dysregulation. Finally, **Lasselin (2021)**, the PNI research society Robert Ader Award winning researcher for 2022, presents her view on a traditional topic in PNI research, namely, inflammation-induced sickness behavior, which has been intensively studied in animal models and more recently in humans as well. The author proposes to further intensify investigations on remaining open questions including inter-individual variability in vulnerability and resilient factors during sickness. Yet, several features and dimensions involving subjective feelings, objective behavioral changes, and overt manifestations of sickness are not understood and necessitate further detailed mechanistically related research efforts.

2. Conclusions

Despite the challenges faced with the COVID-19 pandemic and imposed lockdowns, through this special issue we have given ECIs the opportunity to pause, think and plan their future research directions. As we try to emerge out from the pandemic and find new innovative ways to move forward with research in our field, the ECIs have provided an exciting vision for the future of PNI. Our task now is to support the ECIs in achieving this exciting vision.

Declaration of competing interest

There are no conflicts of interest to disclose besides us serving as guest editors for this special issue.

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