

# Ten Years of the Science of Behavior Change Common Fund Program: Celebrating Accomplishments and Looking to the Future

**National Institutes of Health**

February 22-23, 2021

Science of Behavior Change (SOBC) Capstone Summary Report



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## Executive Summary

### Introduction

The 2021 [Science of Behavior Change \(SOBC\) Capstone Conference](#) convened for two virtual sessions on February 22 and 23, 2021, to celebrate the accomplishments of the National Institutes of Health (NIH) SOBC Common Fund Program and other NIH-supported mechanisms-based behavior change science; foster cross-disciplinary dialogue around methods, tools, and challenges in the field; and highlight next steps and opportunities for future research.

With support from many NIH Institutes and Centers, development of the SOBC Program began in 2009 as part of an NIH Roadmap effort, and the initiative was approved in 2010 as an NIH Common Fund program. Since its inception, the SOBC Program has worked to advance behavior change research through a focus on mechanisms of change and the integration of basic research with applied and interventional research. In the second phase of the SOBC Program, which began in 2014, researchers were encouraged to adopt the experimental medicine approach to behavior change research to achieve these goals.<sup>1</sup>

In addition to supporting research projects implementing the experimental medicine approach to behavior change research, the SOBC Program also supports a [Resource and Coordinating Center](#) (RCC) at Columbia University that is charged with facilitating development, dissemination, and adoption of methods and tools to advance the field. The SOBC RCC supports the [SOBC Measures Repository](#), which hosts the details of the validation process for each measure in the repository to increase openness and transparency. A coalition of NIH partners is co-funding a renewal of the RCC so that it may continue to provide national leadership, training, and the cross-dialogue among diverse mechanisms-focused behavior change research efforts after the time-limited Common Fund support ends.

### Conference Highlights

The Capstone Conference, developed and led by co-chairs Drs. Paige Green (National Cancer Institute), Christine Hunter (Office of Behavioral and Social Sciences Research), and Lis Nielsen (National Institute on Aging), highlighted innovative examples of behavior change research consistent with SOBC principles, from use-inspired basic research to mechanisms-focused intervention science. The [agenda](#) featured welcome remarks from Drs. [Green](#) and [Richard Hodes](#), keynote presentations from Drs. [Nielsen](#) and [Angela Duckworth](#), five thematic sessions that included presentations from invited speakers and moderated Q&A and discussion, and a forward-looking roundtable discussion. The thematic sessions focused on identifying and understanding causal mechanisms of behavior change ([Panel 1](#)), advances in measuring mechanisms of behavior change ([Panel 2](#)), early clinical investigation of mechanisms of behavior change ([Panel 3](#)), bridging discovery to clinical or public health applications ([Panel 4](#)), and the importance of open science for SOBC ([Panel 5](#)).

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<sup>1</sup> See <https://www.sciencedirect.com/journal/behaviour-research-and-therapy/vol/101>.

The [roundtable session](#), co-chaired by Drs. Green and Nielsen, featured remarks and discussion from Drs. Susan Michie, John Ruiz, Donald Edmondson, Kevin Volpp, and Kim Lavoie on the future of behavior change science. The wide-ranging discussion described a variety of infrastructural needs to promote ongoing behavior change research, including dedicated networks to support behavioral science on national and international scales as well as multidisciplinary collaborations that will help to bring behavior change interventions into real-world settings. The speakers also emphasized the importance of making insights from behavior change science visible to the public, including the imperative to involve behavior change researchers in public policy, so that the field can maximize its impact on the behaviors that underlie some of the world's greatest challenges (e.g., climate change, pandemic-related illness).

The SOBC Program seeks to ensure the sustainability of the Common Fund investment in mechanisms-focused behavior change research and the integration of basic and applied behavioral science and to promote continued innovation in the behavior change field. SOBC researchers and partners recognize the need to identify more targets and mechanisms of change and design studies that elucidate their interactions and causal role in changing behavior. There is a need to extend the SOBC approach to mechanisms operating at individual, community, institutional, or environmental levels. Meeting participants underscored the importance of extending current approaches to incorporate social determinants of health and individual differences that moderate intervention effects. Methodological innovations in real-time measurement, development of psychometrically sound measures of behavior change mechanisms and outcomes, and increased investment in dismantling approaches and experiments to test and refine individual treatment elements *before* combining them into a multi-component intervention have potential to advance the field. Continued efforts to stimulate this work will help to bring about a unified science of behavior change and accelerate progress in the development and translation of behavioral interventions.

To fully realize the potential of behavior change science, the field should invest in research infrastructure to enable behavior change research on a large-scale collaborative level. More pragmatic research is needed in order to have a greater impact on policy and practice. This research requires identifying opportunities to engage in public policy and advocacy to promote the pragmatic value of behavior change science to public health and social welfare. It also requires investing in the development and testing of mechanistically driven behavior change interventions in the contexts in which the behaviors manifest, real-world settings, and with the populations in which they will be delivered.

## Summary Report

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### [NIH SOBC Program Overview](#)

[Lis Nielsen](#), PhD, National Institute on Aging (NIA)

The NIH SOBC Common Fund Program recognizes that behavior change is fundamental to modern human health. However, unlike disease-specific studies, SOBC treats behavior change as a phenomenon unto itself with multiple causes and contributors that operate on different timescales and whose mechanisms can be applied across clinical endpoints and public health silos. Thus, the SOBC Program has embraced three overarching goals: (1) to systematically facilitate integration of basic science, which provides mechanistic insights about malleable behavioral and social processes, and clinical science, which seeks to modify these processes to

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<sup>2</sup> See <https://www.sciencedirect.com/journal/behaviour-research-and-therapy/vol/101>.

affect clinical endpoints; (2) to understand the mechanisms that drive behavior change; and (3) to increase rigor, transparency, and dissemination of methods and measures.

The SOBC Program has focused on accelerating the study of mechanisms, defined as processes at any level of analysis (e.g., neurobiological, psychological, social, institutional) that play a causal role in driving behavior change across a broad range of health behaviors. Recognizing the complexity of causal mechanisms, the program has also emphasized the identification of putative interventional targets as well as the development of measures that can verify target engagement and validate that this engagement leads to behavior change. Upon its renewal in 2014, the SOBC Program encouraged the adoption of the experimental medicine approach to behavior change research, which requires hypotheses about target processes or mechanisms that drive behavior change, experimental methods for engaging such targets, and valid measures of target engagement. Initial efforts that applied the experimental medicine approach focused on three broad domains: self-regulation, stress reactivity and stress resilience, and interpersonal and social processes.<sup>3</sup> In addition to supporting [research projects](#) grounded in this approach, the SOBC Program also supports a Resource and Coordinating Center (RCC) that is charged with facilitating development, dissemination, and adoption of methods and tools to advance the field. Beyond the Common Fund, a [renewal of the SOBC RCC](#), supported by a coalition of NIH Institutes and Centers, will continue to provide national leadership and coordination.

## **Keynote Presentation: Behavior Change**

[Angela Duckworth](#), PhD, University of Pennsylvania

There is no shortage of research on behavior change. However, the resulting evidence base has not yet coalesced into a unified understanding of the basic mechanisms of behavior change, which has limited the development and translation of effective and efficacious behavioral interventions. The process model of behavior change seeks to put forth the simplest and broadest possible framework that can organize scientific insights and lay the foundation for a more cumulative SOBC. The model posits that behavior change is a function of a person and their environment, with the person experiencing three main cognitive processes: attention, appraisal, and impulse. The model is recursive, such that an impulse acted on can influence the environment or modulate the person's own cognitive processes. Within this model, behavior change interventions may target a number of mechanisms to help individuals navigate conflicts between healthy and unhealthy cognitive sequences so that healthier impulses will prevail. Situational strategies that target the environment (e.g., behavioral nudges) may be the most efficient because they are active when impulses are nascent. Cognitive processes can be targeted with attentional strategies (e.g., ad campaigns, mindfulness) or appraisal strategies (e.g., mindset interventions, cognitive therapy). To sustain behavior change over time, interventions may also seek to develop habits that shortcut the appraisal stage and generate

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<sup>3</sup> See *Health Psychology* special issue, [Davidson et al. \(Eds.\), 2020](#).

healthy impulses. Response modulation strategies that target impulses themselves (e.g., “willpower”) are likely to be the least efficient.

## **Panel One: Identifying and Understanding Causal Mechanisms of Behavior Change**

*Co-Chairs: [Joe Kable](#), PhD, University of Pennsylvania, and [Rebecca Ferrer](#), PhD, National Cancer Institute (NCI)*

Bridging the gap between basic science, which provides mechanistic insights about malleable behavioral and biobehavioral mechanisms, and applied/interventional science, which seeks to modify these processes to change behavior—and ultimately clinically-relevant endpoints—has been a major goal of the SOBC Program. Panel 1 highlighted foundational research that advances a collective understanding of the processes or mechanisms that drive behavior change.

### **A Value-Based Choice Framework for Understanding Mechanisms of Behavior Change**

*[Elliot Berkman](#), PhD, University of Oregon*

The factors that drive behavior change can be broadly conceptualized by the cognitive skills or abilities that underlie *how* a behavior is performed (i.e., the “way”) and the motivational wants or desires that underlie *why* a behavior is performed (i.e., the “will”). Emerging evidence suggests that interventions targeting cognitive processes fail to endure or transfer across tasks. Value-based choice is a promising framework for understanding one motivational mechanism of behavior change. In this framework, behavioral choices can be modeled as the end point of a dynamic, noisy, cross-modality value integration process. Motivation to change behavior can be increased by targeting a range of value inputs (e.g., tangible reward, social value, identity value). Value integration unfolds over time in multiple brain regions including the ventromedial prefrontal cortex (vmPFC), and the personal nature of values affords opportunities for tailoring. For example, paradigms that target an individual’s specific core values invoke activity in the vmPFC that has been linked to enduring behavior change.

### **Changing Loss Aversion**

*[Elizabeth Phelps](#), PhD, Harvard University*

Emotions and decision-making are often viewed as competing processes, but emotion has a modulatory role in cognition that can be targeted to support behavior change. In a paradigm designed to capture the impact of attitudes toward risk and loss aversion on behavioral choice, participants chose between a risky gamble and a guarantee. Levels of physiological arousal (i.e., emotional responses) and blood-oxygen-level-dependent (BOLD) signals from brain regions implicated in threat perception (amygdala) and value coding (striatum) were measured as participants made decisions. Arousal that was induced by the threat of loss was shown to modulate subjective valuation of options via amygdala-striatal pathways and ultimately the participants’ choices. These choices could be changed by decreasing loss aversion, which was achieved by either a cognitive strategy of emotional regulation or by pharmacologically

reducing arousal. These results demonstrated that aspects of decision-making may be targeted by changing emotions.

## **Reinforcer Pathology: Application of an Experimental Medicine Approach to Addiction and Obesity**

*Warren K. Bickel, PhD, Virginia Tech*

Addiction and obesity are relatively insensitive to efforts to induce behavior change. The reinforcer pathology model may improve the understanding of behaviors that promote addiction and obesity. This model posits that the temporal window of reinforcer consumption may control subjective valuation of food or drugs, and it is the only contemporary theory of addiction that addresses delay discounting (i.e., reduction in value of a reinforcer as a function of delay to reinforcer delivery) as a determinant of drug value. An experimental medicine approach was leveraged to test whether delay discounting may be a suitable target for behavior change in addiction or obesity. Episodic future thinking (EFT) was utilized to increase or decrease discounting of the future (i.e., to encourage participants to value the future more or less). EFT successfully reduced consumption or demand for food or drugs when participants valued the future more, and the opposite effect was observed when participants valued the future less. Thus, interventions that alter the temporal window of reinforcer integration could alter the valuation of brief, intense reinforcers and therefore benefit treatment of obesity and addiction.

## **Discussion of Next Steps**

### ***Identifying Mechanistic Targets of Behavior Change***

Any model of behavior change can realistically encompass multiple cognitive stages (e.g., attention, appraisal, impulse), but models that are more focused on a specific cognitive process more readily suggest practical interventions. For example, effects of targeting cognitive appraisal underscore the importance of emotion regulation and physiological arousal (although emotion can also influence attention, particularly in the context of a threat) in behavior change. Ongoing studies of physiological arousal and choice continue to refine our understanding of the relationships among different aspects of emotion and different components of decision-making (e.g., ambiguity aversion, risk aversion, loss aversion) implicated in behavior change. The value-based choice framework can be leveraged for interventions that focus on the moment of choice, and the factors that influence that choice can be flexibly defined within this framework to suit a specific context. One important future direction is to identify overlap and associations among mechanistic targets identified in individual research projects to develop a more comprehensive framework for facilitating behavior change. Another is to identify which combinations of mechanisms are necessary for which specific types of health behavior change.

### ***Using Temporal Perspectives on Behavior in Future Mechanisms Research***

Behaviors and choices have a temporal perspective such that individuals who discount the future often make poorer choices. Current theories of behavior change often do not address this temporal perspective, which may be important for influencing choices that are arrayed over extended periods of time, including health behaviors. Sustaining behavior change also has

a critical temporal component, because time is needed to build habits. Different mechanisms are likely at play in different stages of the habit formation process, and ultimately structural or environmental changes may be needed to support habit formation over time. Intervention at the appraisal stage that is practiced and supported over time, as in cognitive therapy, is a promising avenue to produce an initial change that can then be expanded upon long-term. In stressful situations where the environment itself may be driving poor behaviors (e.g., the COVID-19 pandemic and rising alcohol use), short-term substitutes for long-term reinforcers can be leveraged to guide the appraisal process and help reframe circumstances when people experience stress.

### ***Implications for Future Research***

- Identify overlap and associations among mechanistic targets identified in individual research projects to develop a more comprehensive framework for facilitating behavior change.
- Identify which combinations of mechanisms are necessary for which specific types of health behavior change.

## **Panel Two: Measurement Advances for Mechanisms of Behavior Change**

*Co-Chairs: [Inbal Nahum-Shani](#), PhD, University of Michigan, and [Will M. Aklin](#), PhD, National Institute on Drug Abuse (NIDA)*

Tools that precisely measure change in the mechanisms hypothesized to drive behavior change are critical for understanding how and why interventions work. Panel 2 showcased advances in measurement tools, methods, and approaches that allow for the valid assessment of the engagement of social, behavioral, psychological, or neurobiological mechanisms of behavior change.

### **Data-Driven Approaches for Understanding Self-Regulation**

*[Russell Poldrack](#), PhD, Stanford University*

Self-regulation is the ability to behave in service of longer-term goals rather than short-term desires, habits, or environmental affordances. Self-regulation is a central construct for behavior change, but the many ways in which it is measured do not appear to be coherent. Survey and task measures of variables related to self-regulation tend to correlate with each other within their respective domains (i.e., survey measures correlate with other survey measures, and task measures correlate with other task measures), yet there is little relationship between survey and task measures. Furthermore, survey measures have strong predictive validity for outcomes, but task measures do not. Behavior change research would benefit from a new ontology of self-regulation in terms of underlying mechanisms that are amenable to therapeutic manipulation.

## **Measuring Stress, Emotions, and Blood Pressure in Daily Life with MyBPLab: An App-Based Research Study**

*Wendy Berry Mendes, PhD, University of California, San Francisco*

[MyBPLab](#) is an app-based digital health study that leverages smartphones and wearables with embedded optical sensors to assess stress, emotions, and blood pressure. This 3-week ecological momentary assessment study notifies participants three times per day to measure their blood pressure and respond to a series of questions related to their current stress and emotions (e.g., resources available to cope with stress, emotional valence). Some check-ins also include cognitive tasks to ascertain whether immediate changes in stress and emotion might influence cognitive outcomes. Early analyses of the data examined how stress, emotions, and physiology are associated in daily life. The study also launched a series of smaller experiments that introduced interventions aimed at reducing stress and improving sleep quality. Challenges to this app-based study approach include sample constraints on generality, imprecision in blood pressure measurement, and the risk that the most stressful or emotional experiences may be omitted from the data because these experiences depress participant responses.

## **Measuring and Intervening on Ongoing, Person-Specific, Subjective Stress Responses in Free-Range Humans**

*Joshua Smyth, PhD, Pennsylvania State University*

Naturalistic stress is a complex, dynamic process consisting of stressors and resultant stress responses. Using intensive naturalistic data allows specific features of the stress response (e.g., reactivity, recovery, pile-up) to be extracted and personalized to an individual (i.e., person-specific estimates). These distinct stress response features may be differentially malleable and related to outcomes, affording an opportunity to inform and enhance the precision of psychosocial interventions at the person level. Moreover, adopting a dynamic person-centered approach via intensive measurement allows one to construct estimates for a person in real-time, allowing the delivery of just-in-time interventions by identifying and intervening on moments of risk proximal to stress-eliciting triggers that are specific to the individual. This approach may enhance the efficacy of intervention content by more effectively engaging the target mechanism in the context in which it occurs, better capturing moments of risk, and ultimately showing better capacity to positively impact outcomes (e.g., enactment of positive health behaviors in everyday life). Although we apply this logic of personalized assessments of distinct features of complex experiences to stress responses, we hope that this approach may also be broadly applicable to other dynamic processes in everyday life.

## **Discussion of Next Steps**

### ***Balancing Data Collection and Participant Burden***

A fundamental challenge to preserving measurement validity is the tradeoff between collecting large amounts of data and minimizing participant burden. Although a measure may benefit from participants' performance of long tasks or the completion of many survey questions, overly burdensome assessments risk high rates of non-response or attrition from a study. It is

important to reduce burden so that participants remain engaged, as continued participation in behavioral interventions is a strong predictor of outcomes. An adaptive assessment approach that integrates passive and active data collection can be leveraged whereby data are continuously acquired with limited participant engagement and can also be used to distinguish moments in which more effortful sampling should occur. Interventions that successfully engage target mechanisms and influence outcomes are well-positioned to encourage participation. Incentives can also be incorporated. MyBPLab, for example, offers feedback and blood pressure measurements commensurate with participation. Ultimately, however, it is important that assessment frequency is rooted in the timescale of the target mechanism.

### ***Developing Validated Measurement Definitions and Tools***

Another measurement challenge entails distinguishing precisely what is being measured. For example, wearable sensors may register physiological responses to positive and negative states in similar ways (e.g., by increased arousal). These different types of response can be distinguished at the level of appraisal with self-report data. If different features are extracted from the physiological response, then it may also be possible to distinguish responses based on these features. For example, positive and negative stimuli may evoke the same initial physiological reactivity but demonstrate different patterns of recovery from that heightened state. New tools and measures also require validation before they are launched. The optical sensors used with the MyBPLab app, for example, were tested on a diverse group of individuals to assess how the sensor would respond to people of different ages, genders, races, and body types. An interdisciplinary team of psychophysiologicals, engineers, and computer scientists refined this sensor to ensure its clinical validity.

### ***Solving Analytic Challenges in SOBC Measurement***

To increase precision, specificity, and reliability of measurements in situations where data are missing, it is often helpful to have multiple multimodal data streams. For example, a study that collects both sensor and survey data may use one data stream to impute missing data from the other modality. In addition, because data are unlikely to be missing at random, a variety of statistical methods may allow for adjustment in the analysis and interpretation of the dataset. Furthermore, participants that stay engaged with a study may be a non-random, self-selecting population, which must be considered when assessing the generalizability of results.

### ***Implications for Future Research***

- More work is needed to build research on real-time measures of mechanisms across lab, clinic, and real-world settings (e.g., ecological momentary assessment, sensor-based assessment, and other just-in-time active tasks).
- Work is needed to develop assessment strategies that demarcate the measurement of the same construct or different components of a particular construct.

## **Panel Three: Early Clinical Investigation of Mechanisms of Behavior Change**

Co-Chairs: [Shirley Moore](#), PhD, RN, Case Western Reserve University, and [Janine Simmons](#), MD, PhD, NIA

Knowing that we can modify hypothesized mechanisms of change is only the first step in the intervention development process. Panel 3 highlighted research demonstrating how the engagement of a mechanism can produce short-term desired changes in health behaviors.

### **Mechanisms Linking Mindfulness Interventions and Health**

[J. David Creswell](#), PhD, Carnegie Mellon University

Initial randomized controlled trials (RCTs) of mindfulness interventions, which focus on training attention monitoring skills and developing acceptance and equanimity, suggest a broad range of health benefits. Monitor and Acceptance Theory (MAT) provides a mechanistic framework for thinking about the different components of mindfulness training, and specifically posits that acceptance and equanimity skills are the key driver of stress reduction after mindfulness interventions. In a dismantling RCT (n=153), investigators tested this hypothesis by systematically removing acceptance and equanimity skills training from a mindfulness intervention protocol. The RCT revealed that interventions including skills training targeting acceptance and equanimity produced the greatest reductions in cortisol reactivity during a laboratory stress test. Moreover, acceptance training was necessary for mindfulness to reduce feelings of loneliness and increase positive affect in daily life.

### **Time for a Paradigm Shift: The Adolescent Brain in Addiction Treatment**

[Sarah Feldstein Ewing](#), PhD, University of Rhode Island

Although substance use is highly prevalent among U.S. adolescents, many of the existing addiction interventions were designed for adults. However, the adolescent brain is increasingly being recognized as being substantively different from the adult brain. And, likely for related reasons, adolescents engage with substances in different ways than adults. Dr. Feldstein Ewing's team has been focusing on using translational approaches, integrating brain (developmental human neuroscience; functional magnetic resonance imaging [fMRI]) and behavior (clinical intervention programs) to begin to unearth how the adolescent brain responds to active ingredients in therapy. Here, Project MINA examined how therapist behaviors within a session translate to changes in adolescent drinking behaviors following the session, and what adolescent neural mechanisms might underlie post-treatment behavior change. The study showed that while motivational interviewing and mindfulness had comparable outcomes at 3 and 6 months, motivational interviewing performed better at 12 months. Additionally, default mode network activation during therapist language associated with both interventions was significantly associated with treatment response (problem drinking). Examining modifiable targets, such as therapist behaviors, offers one step toward improving the impact and efficacy of addiction interventions for young people.

## **Behavioral Intervention Modifies Neural Circuit Function to Mediate Depression and Problem-Solving Outcomes**

*Leanne Williams, PhD, Stanford University*

The ENGAGE study (n=108) applies an experimental medicine approach to target behavioral interventions for depression in the context of obesity. The study has specifically examined whether changes in a neural target implicated in depression—the amygdala—is the active mechanism by which problem-solving therapy (PST) improves depressive symptoms. ENGAGE is a sub-trial within the RAINBOW RCT, which previously demonstrated that PST can improve depressive symptoms, body-mass index (BMI), and anxiety in a vulnerable population. ENGAGE demonstrated that, relative to standard care, PST elicited more change in levels of amygdala activity that in turn mediated a greater reduction in depressive symptoms. Next steps include the identification of other neural targets implicated in PST, depression, and weight outcomes as well as ascertainment of the generalizability of these findings.

### **Discussion of Next Steps**

#### ***Exploring Interoception as a Potential Common Mechanism Across Health Behaviors***

Like the evolving ontology of self-regulation that was discussed in Panel 2, conceptualizations of mindfulness vary in ways that would benefit from mechanism-based definitions. For example, some approaches to mindfulness focus on making active cognitive distinctions a form of attention while others are centered on a more metacognitive way of experiencing the world with a sense of openness. One mechanism that may be at work in mindfulness interventions and more broadly (e.g., PST for obesity, depression, or anxiety) is interoception, which has been associated with activity in the insula that may mediate the effectiveness of interventions. Importantly, improved interoceptive awareness alone may not be beneficial if skills to cope with that awareness (e.g., acceptance and equanimity skills) are not also offered by the intervention. (See, for example, [NOT-AT-21-002](#).)

#### ***Creating Trial Designs to Support Future SOBC Research***

When designing a dismantling trial to elucidate the mechanism of action of an intervention, researchers must determine the level at which the intervention can be dismantled to provide the most information. For example, given the many different components of the mindfulness-based stress reduction program (MBSR), Dr. Creswell's dismantling trial zoomed out to the level of included skill types and broadly distinguished between those domains in the trial. In contrast, ANCHoR's study of mindfulness zoomed in on the practical elements (e.g., therapist language) of the intervention. Dismantling can be approached creatively, and in some cases may not be the best approach for an RCT. Trial design can also be facilitated by knowledge of relevant neural processes that could enable researchers to tailor behavioral interventions. For example, patterns of neural activity that may predict the success of an intervention for an individual can signal whether an intervention should be adjusted to potentially boost chances of success. Trial design and intervention development must also grapple with issues of scalability and access to in-person treatment. App-based interventions are an attractive solution to these issues, although the interpersonal connectedness component that is lost when treatment is not

conducted in-person may be an important mechanism driving success. Furthermore, more work is needed to develop an evidence base for the many mindfulness apps that are currently available. Scalability of neuroimaging for interventions and trials is another important issue that can be addressed by integrated efforts across basic and applied science.

### ***Implications for Future Research***

- With increasingly widespread use and demonstrated health benefits of mindfulness-based interventions, cross-disciplinary research to test key mechanistic components of different types of mindfulness training (e.g., necessity and sufficiency) and studies focused on generalizability of those critical components to a range of different health outcomes and diverse populations are needed.
- SOBC research should be expanded to include the full lifespan—identification and characterization of malleable targets unique to key developmental time periods (e.g., sensitive periods) and/or those maintained across the lifespan; longitudinal studies to investigate how interventions at one point in time may change long-term health trajectories.
- There should be more widespread adoption of dismantling RCT designs to behavioral intervention development—both to test utility of design in different contexts and to identify critical mechanisms/targets.
- The field should consider the best uses of neuroimaging approaches to probe mechanisms of behavior change (see, for example, a summary of the 2013 NIH SOBC Common Fund–sponsored workshop [Harnessing Neuroplasticity for Behavior Change](#)).
- The field should consider interoceptive mechanisms for behavior change.

## **Panel Four: Bridging Discovery to Clinical or Public-Health Application**

Co-Chairs: [Elissa Epel](#), PhD, University of California, San Francisco, and [Lis Nielsen](#), PhD, NIA

The SOBC experimental medicine approach calls for tests of hypotheses about mechanisms of action when interventions are implemented in the real world. Panel 4 highlighted intervention research that tests an intervention in the intended population, mode of delivery, and setting to determine the validity of the mechanism of behavior change for achieving clinically meaningful endpoints.

### **Acceptance-Based Interoceptive Exposure for Young Children with Functional Abdominal Pain: Feeling and Body Investigators Pain Division**

[Nancy Zucker](#), PhD, Duke University

The Feeling and Body Investigators (FBI) Pain Division program is an acceptance-based interoceptive exposure intervention for young children with functional abdominal pain. Visceral hypersensitivity (i.e., increased sensitivity to changing sensations in the internal organs) has been posited as one factor that increases vulnerability to intense pain experiences and leads children to generalize a fear of abdominal pain to innocuous sensations. FBI targeted the appraisal of abdominal pain as scary by creating a context in which somatic symptoms were viewed with curiosity instead of fear to ultimately change the impact of visceral

hypersensitivity. By changing the quality of attention and focus on the body, FBI was as effective as current best practices for pain treatment in reducing pain distress and pain interference. Challenges for the study included the selection of pragmatic standard treatment as the control condition, rather than a theoretical control condition that would have enabled the direct comparison of mechanisms across treatments, and the inability to directly test visceral hypersensitivity because of the invasiveness of the tools that would be required to do so coupled with the young age of the study cohort.

### **Improving Health and Motivating Healthy Behavior: Mindsets Matter**

*[Alia Crum](#), PhD, Stanford University*

Existing approaches to encourage healthy behaviors (e.g., eating healthy) are not sufficiently effective. These approaches often overlook the mechanism of mindset, or a set of core assumptions about a domain or category that orient us to a particular set of expectations, attributions, and goals. Mindsets not only influence the choice to perform healthy behaviors but also can impact the effect of those behaviors on outcomes (e.g., feelings of hunger after eating foods perceived as depriving). In one environmental intervention targeting mindsets toward healthy food, labeling healthy foods with more indulgent language typically reserved for unhealthy food increased the consumption of healthy foods by 29 percent across students at six universities. Another educational intervention improved mindsets of middle schoolers (n=138) toward healthy food, and this shift in mindset fully mediated the intervention's successful impact on increasing healthy food consumption in these students.

### **Leveraging Sleep and Circadian Science: On the Pathway to Improving Engagement in Sleep Health Behavior**

*[Allison Harvey](#), PhD, University of California, Berkeley*

With the onset and progression of puberty, the tip toward delayed circadian phase in youths is exacerbated by a confluence of psychosocial contributors and results in sleep deprivation and circadian dysregulation. Guided by the [NIH Stage Model](#), the Transdiagnostic Intervention for Sleep and Circadian Dysfunction (Trans-C) was developed to address multiple sleep problems with one treatment. A test of Trans-C in youth with an evening chronotype (i.e., “night owls”; n=176) showed that it successfully engaged its target mechanism—in this case, the waketime discrepancy between weekdays and weekends—and that this mechanism mediated impacts on a broad range of physical, behavioral, cognitive, and other health risk outcomes. However, at 6- and 12-month follow-ups participants indicated that they only occasionally employed the modified behavior, underscoring important and modifiable contributors to youth health behavior choices (e.g., recalling treatment content, forming habits, interacting with parents) remain to be identified. To improve development of multi-component interventions, candidate mechanisms should be systematically inactivated to assess their contributions (i.e., “mini-treatment experiments”).

## **Discussion of Next Steps**

### ***Solving Measurement Challenges to Support Public Health Applications***

Research on mechanisms depends upon accurate and sensitive measurements. Some mechanistic constructs may be difficult to measure reliably, particularly if that construct is broad (e.g., stress, self-regulation). A more specific, dimensional vocabulary will help researchers collaborate on mechanisms-focused research and develop targeted interventions. In addition, some aspects of measurement require training or are otherwise difficult to control; for example, the FBI study collected pain diaries from children and their parents, but the researchers had to train parents on how to recognize pain in their children and ultimately could not control who answered the questions. Even as sensors and similar technologies continue to improve, accurate self-reports will still be an important part of examining how study participants perceive and appraise situations. It is an open question which of these measurement types will be most sensitive to change in the target mechanism or intervention outcome.

### ***Supporting Sustained Behavior Change***

Interventions that support broad and sustained behavior change should not be myopic or overly focused on a single situation. For example, interventions that currently aim to increase use of the COVID-19 vaccine may fail to sustain behavior change related to vaccine acceptance in general, whereas interventions that target broader attitudes or perceptions about how vaccines work or their side effects may more sustainably change this health behavior. Manipulation of some mechanisms may generalize more easily than others (e.g., interoception, mindsets), although it is important to remain specific in terms of the populations to whom the intervention is administered. Heightened interoception, for example, may be a poor choice of target mechanism for a sleep intervention that should divert rather than focus attention on the body.

Collaboration will also be essential to efforts to promote sustained behavior change. Although evidence-based psychological treatments often have the implicit goal of supporting habit formation, these interventions often do not draw from the science of habit formation, underscoring the need to bridge gaps between basic and applied sciences. Sustainability can also be promoted by interventions that focus more broadly on the environment, for example by including tools for parents to supplement interventions in children or modifying environments that consistently reinforce unwanted habits or behaviors, which may be exceptionally difficult if these environments include deeply ingrained cultural attitudes. Building collaborations (e.g., with community organizations) is essential to deployment-focused treatment development that will help to address the challenges associated with dissemination and sustainability. Collaborations will also help advance the field toward a unified theory of behavior change that will enable more integrated models and support a common language for pursuing SOBC questions.

***Implications for Future Research***

- Research needs to consider the importance of mindset, especially in terms of the real-world effects of health behavior change interventions. How do mindsets shape health outcomes? Changing mindsets may require approaches to cultural and social change and not simply individual behaviors.
- Promote research that tests and refines individual treatment elements via a series of brief treatment experiments that target specific mechanisms *before* combining them into a multi-component intervention and *before* conducting an expensive RCT.
- Work is needed to uncover multiple mechanisms along a causal pathway to a health outcome.

**Panel Five: Open Science: Increasing Rigor, Reproducibility, Transparency, and Dissemination**

Co-Chairs: [Edward \(Ted\) Miquel](#), PhD, University of California, Berkeley, and [Luke Stoeckel](#), PhD, NIA

A core tenet of the SOBC Program is to increase rigor, reproducibility, transparency, and dissemination of methods and measures to strengthen scientific, clinical, and policymaker confidence in the field's research advances. Panel 5 focused on existing approaches and included a discussion of how best to continue to achieve these goals in behavior change research.

**Reimagining Science as Truly Open and Inclusive**

[Alison Ledgerwood](#), PhD, University of California, Davis

Current scientific practice is rooted in a history that has catered to the experiences, needs, and values of a small subgroup of individuals—affluent, cis, straight, white men in Western democratic societies—and inherently devalued everyone else. This exclusion contorts and diminishes all aspects of science, leading to a current system that is competitive rather than collaborative, discourages sharing of resources and data, and measures success as individual output rather than by quality of research process or collective output. Moreover, this precarious state perpetuates the crises of replicability, generalizability, and inequity affecting contemporary science. Science cannot be made more open without specifically and intentionally addressing all factors that keep it closed, which will require reimagining the basic elements of how science is done. For SOBC, this reform may look like defining problems with stakeholders instead of in purely academic settings, prioritizing more diverse sample populations, and replacing an academically led approach to intervention dissemination with an open, inclusive, and ecological approach that embraces community collaboration.

## [An Open Science Behavior Change Model from Theory to Practice](#)

[Brian Nosek](#), PhD, Center for Open Science

Published scientific literature is not universally credible and replicable. Replication efforts tend to elicit weaker evidence for claims than the original study. A collection of best practices may improve the credibility and replicability of findings. Pre-registration of studies and analyses is one example of a behavior that could combat publication bias, make negative results discoverable, clarify planned versus unplanned analyses, and improve statistical inferences. To make sustainable change to researcher behavior, systemic factors that elicit and constrain those behaviors must be addressed. First, providing infrastructure (e.g., study registries) will make it possible for investigators to pursue a new behavior. Second, refining the user experience to make the behavior change easy across contexts will encourage early adopters. To break into mainstream practice, reform behaviors must become normative, which can be encouraged by providing training, promoting visibility, and engaging debate. Incentives and reward systems will also help behavior changes establish a foothold. Finally, policy changes that incentivize and/or require new behaviors will help to reach those who are slow to adopt new behaviors. Collectively, these practices work together to promote sustainable cultural change.

## [The Art of Open Science: Imitation, Inspiration, and Innovation](#)

[Channing Jang](#), PhD, Busara Center

The pursuit of open science can take four key lessons from the art world. First, artists often imitate. Replication is an important step in the learning process, and scientists should prioritize sharing data or resources over protecting them. Importantly, replication should not cross the line into plagiarism. Second, artists take inspiration from each other. Researchers should encourage debate and projects that add a fresh perspective to their own work, including perspectives from other disciplines. Being inspired by another researcher should never lead to exploiting that person's work. Third, artists innovate. Innovation can be made easy and equitable through new tools, and the people who enable innovation (e.g., research assistants, participants) should always receive credit. Finally, much great art is inclusive. Open science is a necessary but not sufficient condition to make inclusivity in science a reality. Research should foster talent wherever it may be while avoiding tokenization. Technology and tools (e.g., [SOBC Measure Repository](#), [Experiment Factory](#)) should be leveraged as one of open science's greatest assets for promoting collaboration across disciplines and geographies.

## [Discussion of Next Steps](#)

### ***Balancing Data Sharing and Inclusion***

A fundamental element of open science is the sharing of data and information that will make research more transparent. However, this sharing could create tension with the need for more inclusion in science because new data sharing requirements could unintentionally advantage scholars with more resources available to document and distribute their data. Incentive structures that reward individuals and organizations who create data resources that follow [FAIR](#) (findable, accessible, interoperable, and reusable) and [TRUST](#) (transparency, responsibility, user community, sustainability, and technology) principles could enhance a healthy open science

ecosystem (see [NOT-OD-21-089](#)). It is also important to foster collaboration with researchers from other fields, institutions, and geographies as well as with stakeholders more broadly (e.g., research participants, clinicians) to ensure that open science is conducted in a way that is valuable to everyone. Researchers who are part of or close to historically included groups in science must listen to and collaborate with those who have been historically excluded in order to realize a truly collaborative, inclusive, and representative open science movement. Large-scale collaborations will also enable researchers with substantial resources to extend those resources horizontally and more groups to participate in science. The development of best practices for open science—and interventions more broadly—must be iterative so that it can respond to any unintended consequences that impact a group in an unanticipated way.

### ***Using Pre-Registration to Facilitate Open Science***

A push for reform and open science is occurring across many scientific disciplines incrementally and at different paces. Pre-registration is one example of a step toward open science that is gaining traction in some fields. This practice could eliminate publication bias and improve scientific rigor by providing expert review at a timepoint that is more actionable (i.e., when studies are designed instead of when they have already been completed). Initial evidence from an evaluation of pre-registration suggests that the practice does in fact improve the rigor and quality of research without some of the hypothesized negative consequences; constraints on novelty resulting from pre-registration, for example, have not been observed to date.

### ***Implications for Future Research***

- An inclusive, democratic (i.e., open) behavior change science could be supported by collaborative pursuit of existing opportunities (e.g., [NOT-OD-21-091](#) and [NOT-OD-21-089](#)); resource, training, and network building; and idea development and sharing informally and at national and international meetings such as Metascience; and through careful, thoughtful discussion and development of how to create appropriate incentive structures and requirements for research that follow open science principles and practices with federal partners, including funding agencies.
- Pre-registration is an example of how open science principles and practices can improve the rigor and quality of science. Evaluation of these and other open science practices is critical to determine their potential to enhance or diminish the rigor and quality of science.
- Open science is an international effort, and the growth of an open behavior change science should include increased attention to international partnerships in addition to local, regional, and national efforts. Initiatives to develop and advance the open science data ecosystem, such as those supported through the [NIH Office of Data Science Strategy](#) (ODSS), should include the behavioral and social sciences.
- The COVID-19 pandemic has also highlighted the need to create open and inclusive science systems, communication strategies, and tools to address health-focused problems that depend on behavioral and social science (and scientists) and require fast, flexible solutions, so that we can be more proactive vs. reactive when we face similar, time-sensitive challenges in future.

## **Roundtable: What's Next? Beyond the NIH Science of Behavior Change**

Moderators: [Paige Green](#), PhD, MPH, FABMR, NCI, and [Lis Nielsen](#), PhD, NIA

National and international behavior change research experts discussed how research groups, scientific societies, and other stakeholders can promote a unified science of behavior change, continuing to capitalize on emerging basic science to accelerate investigation of common mechanisms of change, and promoting applications across a broad range of health-related behaviors. What are the core principles that should guide our collective work in behavior change science at NIH and more broadly? Can we collaborate to unify the conceptual and methodological approaches in the field to promote rigorous and systematic behavior change research? Roundtable panelists discussed opportunities to fortify the evidence base, identify near- and long-term needs, and envision the future.

### **Bringing Artificial Intelligence to Behavioural Science to Generate New Knowledge**

[Susan Michie](#), PhD, University College London

The Human Behaviour Change Project (HBCP) is a collaboration of behavioral scientists, computer scientists, and information architects funded by the Wellcome Trust. To help turn ever-growing collections of research into well-organized and useful scientific insights to answer questions about behavior change (e.g., what works, for what behaviors, for how long), HBCP uses an ontology that provides an organizing structure to guide artificial intelligence, natural language processing, and machine learning analyses. All HBCP work is open access.

### **Behavioral Medicine Research Council**

[John Ruiz](#), PhD, University of Arizona

Science is often performed by a loose collection of individuals and labs that share their ideas within specialized networks. The result of this system is a knowledge base that broadens rather than deepens and limits the potential issues that any one researcher can address. The Behavioral Medicine Research Council works as a higher-order coalition to identify strategic, high-priority research goals; encourage multidisciplinary, multicenter research networks; and promote the centrality of behavioral medicine science.

### **Align Individual Behavior Change with Social Change**

*Donald Edmondson, PhD, Columbia University*

Next steps for SOBC should include incorporation of an understanding of how individual changes in behavior influence not only health but also key societal goals, such as mitigating climate change. SOBC research that adopts a health and climate co-benefits paradigm could rigorously estimate the climate impact of behavior at a granular level, starting with a core set of behaviors. In doing so, SOBC researchers would immediately magnify the impact and visibility of SOBC and improve the chances that this research will benefit the health and longevity of all.

### **What's Next? Beyond the NIH Science of Behavior Change**

*Kevin Volpp, MD, PhD, University of Pennsylvania*

SOBC has been very successful in supporting mechanistically elegant studies and should now progress to testing efficacy and effectiveness in field settings by focusing on the nexus between behavioral science and implementation science. As more behavior change ideas are tested in larger populations, this research will produce a better understanding about heterogeneity of treatment effects and the potential for personalized medicine interventions.

### **Global Challenges and Opportunities for Behaviour Change Scientists**

*Kim L. Lavoie, PhD, FCPA, FABMR, University of Quebec at Montreal (UQAM)*

The world's most pressing problems—including climate change, pandemic-related illness, and social injustice—require understanding and changing human behavior on a global scale. These problems, often considered within the domains of technology, public health, and politics, represent an opportunity to demonstrate the importance of behavioral science on a large scale. Because these problems are global in nature, it is imperative that SOBC is embraced worldwide, including in low- and middle-income countries.

### **Discussion of Next Steps**

#### ***Infrastructure for the Next Steps for Behavior Change Science***

A variety of infrastructure developments are needed to pursue behavior change science on a large-scale, collaborative level. Research with large populations outside of laboratory settings will improve understanding of the heterogeneity of treatment effects and of the implications for tailoring interventions based on the responsiveness of different populations. Dedicated networks (e.g., International Behavioural Trials Network, Behavioral Medicine Research Council) can help to organize behavioral science researchers on a national or international scale to support and scale up multi-site trials of behavior change interventions. These networks can also help to bring behavior change science to low- and middle-income countries. Collaborations across disciplines, methodologies, as well as with non-researchers (e.g., urban planners) are also needed to bolster the implementation and sustainability of interventions. Strategic partnerships represent an essential component of shifting behavior change science into real-world settings, as complementary expertise in areas beyond the SOBC Program (e.g., policy,

branding, communication) will be needed for success. Funding models with more nimble application procedures will be needed to support this large-scale team science.

### ***Maximizing the Impact of Behavior Change Science for Public Health***

Behavior change research must become more visible to the public if it is to have maximal impact on the health of individuals as well as entire populations. In the United States, a visible impact will require following in the footsteps of other countries (e.g., Canada, UK) that actively engage behavioral scientists in the creation of public policies. Despite the critical importance of human behavior to curbing the spread of COVID-19, behavioral scientists are often absent from the U.S. government's design of behavioral public health interventions. It is incumbent upon researchers to engage in advocacy in order to find a place in the public policy arena (see, for example, a summary of the [White House Workshop on Psychological Science and Behavioral Economics in the Service of Public Policy](#)), as well as in other levels of policy (e.g., institutional policies). Researchers could pursue policy issues by voicing their professional opinions and experience in the media and speaking directly about concrete policy issues. The visibility of behavior change research could also be increased by researchers converging upon one major challenge (e.g., climate change) to make a significant impact and demonstrate the value of behavior change science to broader society. Similarly, behavior change research needs to move out of the laboratory and into the field (see, for example, [Berkman et al., 2021](#)). While a focus on mechanisms has been vitally important to developments in behavior change research, a broader focus that incorporates attention to issues of implementation and real-world effectiveness at the earliest stages of intervention development and mechanisms testing. This is essential to maximizing the potential impact of behavior change interventions. This focus should include an emphasis on implementation in non-clinical settings, where people spend the vast majority of their time and thus where behavior change can have the greatest impact.

### ***Implications for the Future***

- Invest in research infrastructure to enable behavior change research on a large-scale collaborative level.
- Identify opportunities to engage in public policy and advocacy to promote the pragmatic value of behavior change science to public health and social welfare.
- Invest in the development and testing of mechanistically driven behavior change interventions in the contexts in which the behaviors manifest, real-world settings, and with the populations in which they are ultimately going to be delivered.

## Appendix 1: Conference Agenda

### Day 1: Monday, February 22, 2021

- 12:30 PM Welcome Remarks – Richard Hodes, NIA
- 12:35 PM NIH SOBC Program Introduction – Lis Nielsen, NIA, and Paige Green, NCI
- 12:55 PM Keynote Presentation: Behavior Change – Angela Duckworth, University of Pennsylvania
- 1:15 PM **Panel 1: Identifying and Understanding Causal Mechanisms of Behavior Change**  
Session Chairs: Joe Kable, University of Pennsylvania, and Rebecca Ferrer, NCI
- 1:20 PM A value-based choice framework for understanding mechanisms of behavior change – Elliot Berkman
- 1:30 PM Changing loss aversion – Elizabeth Phelps
- 1:40 PM Reinforcer pathology: Application of an experimental medicine approach to addiction and obesity – Warren Bickel
- 1:50 PM Moderated Discussion/Q&A
- 2:15 PM Break
- 2:25 PM **Panel 2: Measurement Advances for Mechanisms of Behavior Change**  
Session Chairs: Inbal Nahum-Shani, University of Michigan, and Will M. Aklin, NIDA
- 2:30 PM Data-driven Approaches for Understanding Self-regulation – Russell Poldrack
- 2:40 PM Measuring Stress, Emotions, and Blood Pressure in Daily Life with MyBPLab: An App-based Research Study – Wendy Berry Mendes
- 2:50 PM Measuring and Intervening in Ongoing, Person-specific, Subjective Stress Responses in Free-range Humans – Joshua Smyth
- 3:00 PM Moderated Discussion/Q&A
- 3:25 PM **Panel 3: Early Clinical Investigation of Mechanisms of Behavior Change**  
Session Chairs: Shirley Moore, Case Western Reserve University, and Janine Simmons, NIA
- 3:30 PM Mechanisms Linking Mindfulness Interventions and Health – J. David Creswell

- 3:40 PM Time for a Paradigm Shift: The Adolescent Brain in Addiction Treatment – Sarah Feldstein Ewing
- 3:50 PM Behavioral Intervention Modifies Neural Circuit Function to Mediate Depression and Problem-solving Outcomes – Leanne Williams
- 4:00 PM Moderated Discussion/Q&A
- 4:25 PM Closing Remarks – Paige Green, NCI), and Lis Nielsen, NIA
- 4:30 Adjourn for Day

**Day 2: Tuesday, February 23, 2021**

- 12:30 PM Welcome Remarks – Paige Green (NCI), Lis Nielsen (NIA)
- 12:45 PM **Panel 4: Bridging Discovery to Clinical or Public Health Application**  
Session Chairs: Elissa Epel, University of California, San Francisco, and Lis Nielsen, NIA
- 12:50 PM Acceptance-based Interoceptive Exposure for Young Children with Functional Abdominal Pain: Feeling and Body Investigators Pain Division – Nancy Zucker
- 1:00 PM Improving Health and Motivating Healthy Behavior: Mindsets Matter – Alia Crum
- 1:10 PM Leveraging Sleep and Circadian Science: On the Pathway to Improving Engagement in Sleep Health Behavior – Allison Harvey
- 1:20 PM Moderated Discussion/Q&A
- 1:45 PM Break
- 2:00 PM **Panel 5: Open Science: Increasing Rigor, Reproducibility, Transparency, and Dissemination**  
Session Chairs: Edward (Ted) Miguel, University of California, Berkeley, and Luke Stoeckel, NIA
- 2:05 PM Reimagining Science as Truly Open and Include – Alison Ledgerwood
- 2:15 PM An Open Science Behavior Change Model from Theory to Practice – Brian Nosek
- 2:25 PM The Art of Open Science: Imitation, Inspiration, and Innovatoin – Chaning Jang
- 2:35 PM Moderated Discussion/Q&A

- 3:00 PM      **Roundtable: What's Next? Beyond the NIH Science of Behavior Change**  
Moderators: Paige Green, NCI, and Lis Nielsen, NIA
- 3:05 PM      Panelist Remarks
- Panelists:*  
                 Susan Michie, [Human Behaviour Change Project](#)  
                 John Ruiz, [Behavioral Medicine Research Council](#)  
                 Donald Edmondson, [SOBC Resource and Coordinating Center](#)  
                 Kevin Volpp, [CHIBE](#)  
                 Kim Lavoie, [International Behavioural Trials Network](#)
- 3:30 PM      Moderated Discussion/Q&A
- 4:00 PM      Closing Remarks – Paige Green, NCI, and Lis Nielsen, NIA
- 4:15 PM      Adjourn