

Understanding the Trajectory of Metacognitive Capacity in Aging and Implications for Measuring Subjective Experience

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Executive Summary

On May 2, 2022, the National Academies Division of Behavioral and Social Sciences and Education's Board on Behavioral, Cognitive, and Sensory Sciences (BBCSS) convened a seminar to educate staff from the National Institute on Aging on new research in the science of metacognition across the lifespan. At the seminar, titled Understanding the Trajectory of Metacognitive Capacity in Aging and Implications for Measuring Subjective Experience, experts shared their research on metacognition (the ability to think about and reflect upon one's own cognitive processes), the measurement of metacognition, changes in metacognition during healthy aging, and implications for individuals with Alzheimer's disease and related dementias (ADRD). Experts spoke on two overarching topics: (1) examining metacognitive capacity and (2) interoception and the subjective experience of pain. Talks illustrated how research on metacognition can inform research on cognitive processes themselves. Talks also identified gaps in basic research and opportunities for identification of targets for interventions that can support healthy aging.

Examining Metacognitive Capacity

Metacognition reflects the ability to engage in introspection about one's own mental state across distinct cognitive domains (e.g., memory, perception). Researchers can isolate the parameters of an individual's metacognitive performance independent of their primary task performance (e.g., memory tasks) to understand an individual's awareness of their cognitive abilities.

Evidence suggests that older adults do not necessarily experience a general deficit in metacognition, relative to younger adults, but that elements of metacognitive functioning nonetheless may shift with aging. For example, older adults maintain their performance levels on a feeling-of-knowing (FOK) test, which assesses individuals' convictions that they possess information even if they are unable to retrieve it from their memory at a given time. Likewise, though age-related differences in confidence levels for incorrect metacognitive judgments may appear to observers to indicate metacognitive decline, they may actually reflect an accurate awareness of an underlying age-related memory deficit.

Though awareness of cognitive decline is one form of metacognition that potentially holds promise for diagnosing and monitoring progression of ADRD, research suggests subjective cognitive decline is heterogeneously expressed in individuals with mild to moderate ADRD. Different awareness measures have differential utilities for understanding mechanisms and clinical implications of impairment. Mapping these mechanisms will enable greater understanding of the metacognitive errors that contribute to the clinical symptom of lack of awareness of cognitive decline, which can influence self-reports and negatively impact clinical care. Meeting attendees identified some gaps and opportunities of interest, which are listed below.

Gaps and Opportunities

- Research in diverse populations to determine how robust differences in metacognition are across cultures and what variables may be driving these differences
- Research to determine what variables drive heterogeneity in metacognition within populations already studied (i.e., Western, predominantly White, urban populations)
- Additional studies of memory retrieval processes across the lifespan
- Connectome-based neuroimaging to investigate connections across brain regions during studies of consciousness

Interoception and the Subjective Experience of Pain

Interoception is the process by which the nervous system senses, interprets, and integrates signals originating from within the body, providing a moment-by-moment mapping of the body's internal landscape across conscious and unconscious levels. Researchers can compare these afferent signals and neural activity to self-reports to measure metacognition for interoceptive processes. Some studies have found that dissociations between self-report and accuracy measures may be greater for interoceptive senses relative to exteroceptive senses, and that this dissociation may be heightened in some clinical conditions (e.g., autism spectrum disorder).

Pain represents a common and salient subjective experience that is informed by interoception. Self-report is the gold standard of pain measurement in clinical and experimental settings, but researchers have noted substantial inter- and intra-individual differences in pain reporting, even in lab-based studies in which the intensity of the objective noxious stimulus is held constant. Metacognition in pain perception allows individuals to monitor and evaluate their nociceptive processes in ways that may affect the subjective experience of pain. Meeting attendees identified some gaps and opportunities of interest, which are listed below.

Gaps and Opportunities

- Research to determine whether pain metacognition (and the associated influences of arousal) is consistent across the lifespan
- Research to determine whether pain scale usage changes with age (e.g., based on prior pain experiences)
- Studies on differentiation of pain regulation abilities or strategies across the lifespan
- Research to determine how pain metacognition relates to distinctive aspects of subjective pain experience (e.g., high vividness, inter- and intra-individual variability)

Prioritizing Future Research Directions

Based on the wide variety of topics discussed during the meeting, participants prioritized potential future research directions that seek to expand on the gaps and opportunities identified above and that may in turn yield additional opportunities in the future:

- Design studies to understand what causes metacognitive failures and why some individuals have reduced to no awareness of these failures.

- Develop training on metacognitive techniques for individuals with mild cognitive impairment (MCI).
- Conduct longitudinal studies of judgments of memory or interoception to better understand changes across the lifespan and address the potential survivor bias present in extant cross-sectional studies of metacognition and aging.
- Perform research on the connection between metacognition and sense of self in aging individuals, particularly those with ADRD.
- Improve the representativeness of metacognition studies by deliberately capturing a more diverse population of both healthy adults and patients with ADRD and by considering potential cultural components embedded in measures of metacognition, interoception, pain, and other dimensions of self-awareness.

Meeting Summary

Introduction

Terrie Moffitt, Duke University and Chair, Board on Behavioral, Cognitive, and Sensory Sciences

Connections between patients' subjective experience and their health outcomes across the lifespan are well-documented. However, the measurement of subjective experience depends on the potentially unreliable metacognitive abilities of the individuals whose experience is being assessed. The science of metacognition across the lifespan is emerging and maturing rapidly. On May 2, 2022, the National Academies Division of Behavioral and Social Sciences and Education's Board on Behavioral, Cognitive, and Sensory Sciences (BBCSS) convened a seminar to educate staff from the National Institute on Aging (NIA) in order to open the metacognition field to new initiatives in this area. At the seminar, titled Understanding the Trajectory of Metacognitive Capacity in Aging and Implications for Measuring Subjective Experience, experts shared their research on metacognition, changes in metacognition with healthy aging, and consideration for individuals with Alzheimer's disease and related dementias (ADRD). To address these areas, experts spoke on two overarching topics: examining metacognitive capacity and measuring interoceptive and subjective experience of pain.

Introductory Remarks from NIA

Elizabeth Necka, Program Director, Individual and Behavioral Process Branch, Division of Behavioral and Social Research, NIA

NIA is interested in understanding subjective experiences across the lifespan in the context of both healthy aging and disease. Of particular interest is the subjective experience of individuals living with ADRD. Caregivers of people living with ADRD often worry their care recipients may be in pain, but care recipients are often unable to provide a self-report of their condition. Another exemplary subjective experience of interest to NIA is the experience of social connection, and particularly loneliness in older adults. Loneliness is a known precursor to cognitive decline, but mapping the association between loneliness and progression of ADRD following diagnosis is challenging due to deficits in self-awareness and self-report for individuals experiencing cognitive decline. Ongoing efforts at NIA focus on developing objective measurements of cognition for these patients; however, being able to capture subjective, lived experience is also critical for characterizing the experience of healthy aging and aging with ADRD to enhance health and well-being. To advance research on how subjective experiences influence health across the lifespan, especially in the context of ADRD, researchers should understand how metacognition and self-awareness evolve throughout the lifespan in both healthy aging and disease. NIA requested that the BBCSS convene this seminar to determine the state of the science of metacognition in healthy aging and neurodegeneration, and what gaps, opportunities, and barriers may be present.

Examining Metacognitive Capacity

Human Metacognition Across Domains: Insights from Individual Differences and Neuroimaging

Stephen Fleming, University College London

Cognition is a process that transforms inputs into outputs, such as making a decision based on a stimulus in the environment. *Metacognition* is the ability to think about and reflect upon one's own cognitive processes, allowing introspection about an individual's mental state across distinct cognitive domains (e.g., memory, perception). Metacognitive assessments have functional consequences: to the extent that individuals can identify gaps in their own cognition, they can compensate for these limitations. Metacognition spans a hierarchy of abstraction, from local evaluations of individual decisions to global judgements about the self.

Over the past few decades, researchers have worked to develop tools for measuring local metacognitive judgements in a laboratory setting with the goal of quantifying the mapping between objective performance and an individual's perception of their performance. In metacognitive literature, decisions required by performance tasks are sometimes referred to as Type 1 decisions, which involve responding to a stimulus (e.g., a memory test); reflective judgments about Type 1 decisions (e.g., ratings of confidence in performance on a memory test) are Type 2 decisions. Researchers are able to determine an individual's metacognitive performance—i.e., the accuracy of their metacognitive judgments—by comparing Type 1 and Type 2 decisions. This comparison is commonly quantified by measuring the overlap between the distribution of Type 2 decisions when a Type 1 decision is incorrect and the distribution of Type 2 decisions when a Type 1 decision is correct. For example, if an individual has a high degree of confidence when they are correct, and a low degree of confidence when they are wrong, then they have good metacognitive perception because their degree of confidence aligns with their actual performance. The measure of an individual's performance on Type 1 tasks is known as d' (d-prime) and the capacity to discriminate the correctness of one's own Type 1 responses is known as metacognitive performance or metacognitive sensitivity and is measured as meta- d' (meta d-prime). Metacognitive efficiency (the ratio of meta- d' to d') quantifies metacognitive performance (meta- d') relative to task performance (d').

Tremendous heterogeneity is observed in metacognitive performance across individuals, even when their primary task performance is held constant. A substantial body of research suggests that the pre-frontal cortex (PFC) is implicated in metacognition. Yet multiple computational steps underly the formation of confidence—the brain needs to compute reliability of sensory or mnemonic information (uncertainty estimation), combine this with the choices available (choice), and then take into account a mapping function, such as a confidence report or behavior (mapping function). Thus, even simple tasks involve a wide variety of brain regions in neural encoding of confidence. To unpack these computational steps, researchers have developed novel paradigms that manipulate these parameters and measure how those manipulations affect neural encoding of confidence. Changes in these parameters lead to changes in subjective confidence, which in turn correlates with fluctuations in activity in the

perigenual anterior cingulate cortex within the medial PFC. In addition, other work suggests that the construction of self-report may require interactions between multiple prefrontal subregions.

Domain Specificity versus Generality

To determine whether individual differences in metacognitive capacity were domain specific or domain general (i.e., to answer the question of whether having good metacognition on one task predicts good metacognition on a different task), researchers asked participants to perform a variety of tasks—including perception, memory, and executive function tasks. Although the researchers found limited correlations in *performance* across the different types of tasks, *metacognitive efficiency* was tightly correlated and appeared to be domain general (i.e., applicable across tasks). Likewise, neuroimaging research demonstrates that the medial PFC shows strong domain general confidence signals. These findings do not suggest that a single brain region is responsible for metacognition, and other work has shown that domain-specific deficits in metacognition may emerge following inactivation or damage to specific brain networks. However, these results do illustrate the importance of prefrontal cortex to domain-general metacognitive processes.

Metacognition and Aging

New work is investigating the links between confidence at a local level (e.g., on a trial-by-trial level) and confidence at a global level (e.g., by using questionnaires or reports). Researchers have hypothesized that fluctuations in confidence in both individual judgments and global assessments should modulate how individuals think about themselves. To measure this hypothesis, researchers asked young adults to judge their confidence in their performance on individual tasks (individual assessments) and across different types of tasks (global assessments). Researchers found that, behaviorally, people build up their global self-performance estimates from local confidence fluctuations. Yet in a recent study with participants aged 18-83 years, though task performance and local metacognition were consistent across the lifespan, older adults consistently reported lower global levels of confidence in their performance—possibly due to negative biases regarding performance and aging. In studies using neuroimaging, subsets of brain regions (e.g., vmPFC, precuneus) appear to correspond to both local and global confidence estimates—and these results might apply to larger scales of judgements, including those made across the lifespan.

Conclusions

Metacognition can be measured across different tasks as the statistical association between behavior and self-evaluation. Adopting a signal detection framework allows researchers to estimate both first-order performance and metacognition. The confidence in metacognition is encoded in the PFC, partially independent from behavioral performance. Evidence suggests that metacognitive ability is domain general. In aging individuals, global negative biases appear to increase over time.

One area for future research is connectome-based neuroimaging to investigate connections across brain regions during cognition and studies of consciousness during decision-making

tasks. Additionally, though researchers have found preliminary, subtle differences in metacognition across cultures, more work is needed in diverse populations to determine how robust these differences are and what variables may be driving them. Additional work is also needed to determine what variables (such as anxiety) may drive differences in metacognition in the populations already studied.

Metacognition and Healthy Aging

Christopher Hertzog, Georgia Tech

Metacognition is a broad construct domain with three main facets: belief, knowledge, and monitoring. Belief is defined as what a person holds to be true about themselves and others. Knowledge is awareness and understanding of how memory operates. In contrast, monitoring is a *process*—attending to the status of the cognitive system—that may or may not connect with other facets of metacognition. Adults may have implicit beliefs due to aging stereotypes that cognition and memory decline with age. In general, older adults believe that their memory has declined and rate their current memory functioning lower than younger adults rate theirs. However, people’s beliefs about their own memory ability are not a good predictor of memory performance (that is, older adults perform better than expected).

Though memory performance is not typically aligned with beliefs about memory, other variables—including mental health characteristics such as self-rated depression and anxiety and personality—are strongly correlated with memory beliefs. For example, in a large sample of individuals from the Health and Retirement Study, agreeableness and conscientiousness were strongly correlated with memory performance. Interestingly, conscientiousness and agreeableness also predict the alignment between confidence in memory and objective memory, such that those with higher conscientiousness and agreeableness have better metacognition.

Researchers need to further investigate the connection between *belief* and self-report. Researchers have found evidence that individual differences in memory self-efficacy (i.e., one’s belief in their own capacity to use memory *effectively* in a domain of function) are highly stable over years. These persistent and highly schematic beliefs shape how individuals create their self-reports in memory tasks. Memory self-efficacy is highly relevant for changes in metacognition as individuals age: perceived change in performance is more strongly correlated with memory self-efficacy than it is with objective change in memory performance. In fact, objective changes in memory, longitudinally, are only weakly related to perceived change. This suggests that memory self-efficacy may be an important target to intervene upon to enhance metacognition in aging.

Memory Monitoring in Healthy Aging

Confidence judgements made by individuals about their acquisition, retention, and retrieval of knowledge depend not on direct access to memories but instead on access to cues that assist in the retrieval process. Early literature on metacognition focused on overconfidence in metacognitive assessments, because older adults tend to report high confidence even when they perform poorly (despite their biased belief that older adults perform poorly in general).

However, some researchers suggest that confidence levels themselves may not vary over time, but instead that a performance drop-off leads to the increasing confidence-performance gap. To better understand variation over time, researchers have turned to measuring within-person covariation of judgments associated with cognitive performance (i.e., metacognitive resolution).

The traditional method of measuring metacognitive resolution is through Goodman-Kruskal gamma correlations—although gamma has estimation problems due to high standard errors of measurement, it is still considered the best measure of resolution available and is the standard in the field. Goodman-Kruskal gamma correlations capture the strength of association between memory success and confidence judgment, such that individuals who are confident when they are correct and unconfident when they are incorrect have higher gamma scores. Evidence suggests equivalent relative accuracy of younger and older adults' metacognition in most cases. However, researchers have found stronger evidence of equivalence between younger and older adults for judgments about encoding memory (how well something was learned) than for judgments about memory recall (how likely one would be to be able to retrieve that information from memory).

Types of Monitoring

Judgements of learning (JOLs) assess monitoring of new learning. Researchers have found little evidence of age-related JOL deficiencies. One large, cross-sectional 2010 study found no age differences in adults' JOL accuracy. Researchers did find that JOLs were influenced by item relatedness and spontaneous use of effective strategies (e.g., interactive imagery), but found no age differences in these influences.

Feeling-of-knowing (FOK) is another monitoring approach that combines measures of acquisition and retrieval. FOK is a metacognitive state associated with an unsuccessful retrieval attempt, in which people are confident about their ability to correctly *recognize* information that they cannot *recall*; people may be confident that even though they were unable to retrieve information, they would be able to correctly recognize the information if presented to them. Researchers have found that accuracy of semantic FOK (i.e., FOK with respect to facts like capital cities or trivia) is not impaired in older adults. Some studies have found age-related differences in episodic FOK accuracy, but others have not. These findings may be explained by age-related changes in PFC function that may cause changes in episodic FOK accuracy; that explanation is supported by correlations between FOKs and neuropsychological tests.

Feeling of Knowing in Younger and Older Adults

Researchers have suspected that accurate FOKs may be based on memory of an *encoding process* rather than of a memory itself; this memory of encoding is called non-criterial recollection. To test this theory, researchers asked individuals to perform a memory task and asked whether the individuals remembered how they studied the items on the task in addition to whether they recalled those items. Researchers found that for older adults, FOK is slightly less accurate for a single presentation of abstract items, but both younger and older adults showed non-criterial recollection of their encoding process regardless of their ability to recall a

specific item itself. Further, older adults are influenced by non-criterial recollection cues to the same extent as younger adults.

In another study, researchers prompted individuals to identify a distinct feature of a single target item among a category of items to memorize. Researchers hypothesized that the distinctive coding would reduce false memories. They found no age-related differences in the frequency of high-confidence false alarms (i.e., incorrect metacognitive judgements of performance). Furthermore, the distinctive approach to learning decreased the number of incorrect responses in both age groups. Therefore, researchers determined that poor recollection in older adults is a function of memory deficits but not metamemory deficits.

Metacognitive Control

Individuals can use metacognitive monitoring to control how they approach learning new material. For instance, in a state of retrieval failure, an individual with a high feeling-of-knowing may continue to search for the information they seek, attempting to resolve what they experience as a retrieval block. Currently there are divergent results on whether aging in healthy older adults affects optimal use of cognitive strategies to control learning and memory processes. Older adults have been shown to be selective when working with information given different values (e.g., monetary rewards), focusing their efforts on learning high-value items. Faced with a body of information varying in difficulty, older adults appear to avoid trying to learn the most difficult information, such as rare foreign language vocabulary, opting instead to work more with information they have recently learned. Metacognitive control failures in older adults may be more likely when their performance is challenged by the cognitive demands of the task they are performing. It is unknown whether the efficacy of control behaviors can be improved through training focused on either increasing accuracy of monitoring or improving adaptive metacognitive control.

Conclusions

Older adults do not have a general deficit in episodic FOK resolution; however, they may have less accurate FOKs when access to valid cues about target accessibility is constrained. Age differences in high-confidence false alarms and resolution deficits during memory tests may indicate memory deficits, not metacognitive judgment deficits. Additional research is needed to address discrepancies in the literature about latent individual differences in metacognitive skills and about whether metacognitive control can be improved through training.

Metacognition in Alzheimer's Disease and Related Disorders

Stephanie Cosentino, Columbia University

In a perfect world, researchers and clinicians would have objective measures to be able to understand the cognitive status of their patients with ADRD; however, many measures rely on self-reports of an individual's subjective experience. Metacognition sits at the intersection of subjective cognitive experience and objective cognitive trajectory and allows clinicians and researchers to better understand how these phenomena relate. However, disorders in metacognition can lead to discrepancies between subjective and objective dimensions of

cognition. Metacognitive accuracy can measure the degree of that discrepancy for a given individual, providing insight into the accuracy of an individual's subjective report regarding cognitive functioning.

Importance of Metacognitive Measures for ADRD

The ability of an individual to recognize their cognitive and functional limitations associated with AD can affect their quality of life, and this ability is highly variable in the early to moderate stages of the disease. When researchers asked a group of individuals with mild AD to report about their memory, some individuals expressed concern over a noticed impairment while others reported a certainty that their memory was unimpaired. These results illustrate the lack of a direct relationship between awareness of cognitive impairment and severity of cognitive impairment. In fact, only about 50 percent of individuals with mild AD are moderately or fully aware of their cognitive decline. The causes of this metacognitive variation between individuals need to be better understood.

Researchers also need to better understand the clinical effects of heterogeneity in self-awareness of cognitive decline over the course of ADRD. For example, caregiver burden is higher and mood is lower for individuals caring for patients who are unaware of their memory loss. Additionally, individuals unaware of their memory loss often engage in risky behaviors (e.g., driving). Additionally, families of individuals unaware of their decline are more likely to hire home health aides due to the increased difficulty of caring for these patients.

Measuring Metacognition in ADRD

Disordered awareness of memory loss (a form of anosognosia) in AD/ADRD should be studied at a number of levels, including seeking to understand its clinical relevance as well as its mechanisms (including metacognitive mechanisms and neuroanatomic substrates). Doing so requires focusing on how disordered awareness is measured. Most of the research on cognitive impairment in a variety of disorders (e.g., ADRD, traumatic brain injury [TBI], stroke) relies on subjective measures from informants (e.g., caregiver, clinician) and a patient's awareness of their own cognitive abilities to create a discrepancy score. Because of the inaccuracies in subjective reporting, researchers should work toward identifying objective measures of awareness to supplement the results of these traditional subjective measures. Objective measures (e.g., metacognitive memory tasks) can help to quantify the degree and type of metacognitive errors that lead to disordered self-awareness.

One commonly used task for studying disordered awareness of individuals with AD/ADRD is the FOK task. One episodic FOK task provides individuals with a set of fictitious trivia items and then tests participants' memory for these items across several learning trials. Before answering each test question, participants make a metamemory judgment (Will you know the answer to this question? Yes, maybe, or no?). The gamma score can be used to measure whether people adjust their expectations of their performance in line with their actual performance. Researchers have found that individuals with mild AD who are aware of their memory loss have more accurate metamemory than those who are unaware, despite similar levels of memory impairment.

Another cognitive test related to metamemory performance requires individuals to play a game in which Xs and Os fall from the top of a computer screen and individuals move the cursor to try to catch the Xs and avoid the Os, but sometimes the computer interferes with their cursor control. Individuals are asked to report on whether they were in control during each trial, requiring them to evaluate their degree of agency. Researchers have found that agency scores, that is their awareness of when they were and were not in control, were associated with metamemory. These associations were independent of any contribution from primary cognitive abilities. Results from these studies illustrate that objective measures can be used to assess self-evaluative ability, adding another dimension to the way that researchers can characterize the metacognitive profile of ADRD.

Anatomical Substrate of ADRD Metacognition

The PFC is often mentioned in research on metacognition, but midline structures, including the cingulate, insula, and precuneus, appear to play critical roles in supporting metacognition and self-awareness. Moreover, there appears to be a particularly important role for the right hemisphere, which has been consistently implicated in studies of self-awareness, both in healthy aging and in cognitively impaired individuals. Researchers have found evidence that the right insula is important in metamemory, especially for reflecting on higher-level metacognitive abilities and interoceptive functions.

Conclusions

Awareness of impairment is heterogeneous in individuals with mild to moderate ADRD and different awareness measures have unique utilities for characterizing metacognitive mechanisms and clinical implications. For example, local objective measures provide insight into mechanisms, and mapping the relationship between such measures and global levels of awareness will enable greater understanding of metacognitive errors that contribute to the clinical symptomology of disordered awareness of memory loss—which is not necessarily synonymous with disordered subjective experience more broadly. Such experiences are likely influenced by numerous factors related to measurement and the individual.

Interoception and the Subjective Experience of Pain

Dissociating Interoceptive Accuracy from Interoceptive Insight

Sarah Garfinkel, University College London

Senses can be split into two groups: exteroceptive and interoceptive. Exteroception is the process by which individuals interpret the outside world through their senses of vision, hearing, smell, taste, and touch. By contrast, interoception is the process by which the nervous system senses, interprets, and integrates signals originating from within the body, providing a moment-by-moment mapping of the body's internal landscape across conscious and unconscious levels. Interoception is composed of six dimensions that move from brain/body signals toward metacognition: (1) afferent signal, (2) preconscious impact of afferent signal, (3) interoceptive accuracy, (4) subjective report, (5) interoceptive metacognitive insight, and (6) attention/attribution. Researchers have shown that interoceptive ability influences numerous

conditions, including anxiety and pain, and interoceptive awareness varies among different groups of individuals (e.g., individuals with autism spectrum condition [ASC]).

Brain/Body Signaling

Much of the work in interoception research focuses on the heart, because it provides a discrete and easily quantified afferent signal but also reliably distinguishes between individuals with different health conditions—in particular, mental health conditions. Furthermore, neurological and cardiac signals can be measured simultaneously to determine the degree to which internal signals are integrated with neural activity. New research found that heartbeat-evoked signals in the brain are greater in older individuals, and that these signals correlate with individuals' metacognition scores such that those with lower heartbeat-evoked signals have higher metacognition scores. This research is preliminary but seems to imply a relationship between heartbeat and brain activity that could be meaningful for our understanding of metacognition and subjective experience.

The preconscious impact of an afferent signal refers to the effect of internal bodily signals on the way we think and feel. To test the preconscious impact of the afferent signal from the heart, researchers can time lock an external stimulus (e.g., a word, sound, or pain) to different points in the cardiac cycle when the heart-brain channel is “active” (e.g., when afferent signaling occurs, such as during systole) or when it is “quiet” (i.e., during diastole, when there is a break between heartbeats). Garfinkel and colleagues found that individuals are more likely to forget words that were presented exactly when the heart is beating (systole) as opposed to between heartbeats (diastole). Therefore, researchers concluded that internal signals can interfere with memory consolidation and subsequent memory performance. Preliminary evidence suggests, however, that they interfere with external signals and cognitive processing less in those with greater accuracy in detecting these interoceptive signals; however, more research is needed to confirm this finding.

Interoceptive Accuracy

Interoceptive accuracy is the accuracy with which an individual can detect internal bodily signals. Historically, researchers have used cardiac perception tests—comparing the number of heartbeats reported to the actual number that occurred during a given time frame—to determine interoceptive accuracy. Researchers have found that as people age, their interoceptive awareness (e.g., ability to detect their own heartbeat) decreases. However, the reliability of heartbeat detection tests is contested, and researchers are actively working to identify better tests of interoceptive accuracy, but these have not yet been studied in the context of aging.

Researchers can also utilize questionnaires that ask about heartbeat and other signals in order to capture an individual's interoceptive awareness (i.e., subjective report of one's own accuracy). Researchers speculate that human brains process signals unceasingly, and that if people were constantly interoceptively aware, that awareness would be problematic for general functioning. Instead, individuals benefit from awareness of a specific subset of signals, such as signals of hunger or threat. To test this hypothesis, researchers contrasted cardiac and

respiratory interoception to a somatosensory control (touch acuity). Although confidence (interoceptive awareness) and interoceptive accuracy correlated for the somatosensory task, they did not correlate for cardiac or respiratory interoception. In addition, cardiac and respiratory interoceptive accuracy did not correlate with each other. Interestingly, the correspondence between interoceptive awareness and interoceptive accuracy for cardiac signals and respiratory signals did correlate with each other, suggesting a domain general metacognitive sensitivity.

Interoception and Autism

ASC is a neurodevelopmental condition displaying difficulties in emotion recognition in the self and others that is often comorbid with anxiety. Individuals with ASC experience altered reactivity and connectivity in the insula, which is related to interoception. Individuals with ASC have heterogeneous interoceptive accuracy results, with some individuals being accurate, most being slightly impaired, and some being severely impaired. However, when asked for self-report of awareness of internal bodily sensations, individuals with ASC often report being very aware of them. Moreover, individuals with ASC who have low interoceptive accuracy but high self-reported awareness of internal signals also have high rates of anxiety.

Researchers sought to determine whether training an individual to have greater interoceptive accuracy would affect their interoceptive awareness and anxiety levels. To do so, researchers worked with 30 individuals with ASC to increase interoceptive accuracy through exercises to bring heart rate signal to consciousness. As a training task, the individuals were asked to perform heartbeat tracking and heartbeat discrimination (either with or without cardiovascular exercise) and were provided feedback on accuracy as they performed the tasks. This group was compared to a control group that did not undergo training. Interoceptive accuracy increased across the different interoceptive tasks only in the interoceptive training group. Moreover, researchers saw reductions in both state and trait anxiety in the interoceptive training group. From these results, researchers derived three key observations regarding interoception and anxiety: (1) it is important to detect internal bodily signals with precision, (2) it is important not to worry about internal bodily signals when detected, and (3) it is important to be able to flexibly attend to signals or focus on the world as needed.

To confirm these findings, researchers performed a clinical trial using MRI imaging in 120 individuals with ASC to measure emotion and anxiety preceding and following interoceptive training or exteroceptive training. Individuals who underwent interoceptive training improved in their interoceptive accuracy. Moreover, increased interoceptive accuracy was associated with decreased reports of awareness of internal signals and decreased levels of anxiety. In other words, great precision in accurately detecting signals seems to correspond with fewer reports of them infiltrating consciousness. Furthermore, the reduction of anxiety in these individuals was maintained after 1 year post-training. Researchers also noted increased insula connectivity in those individuals who received interoceptive training. Garfinkel speculated that this sort of training may be helpful for individuals who, due to aging or other conditions, have decreased access to interoceptive signals.

Conclusions

Interoception can be delineated across different levels and axes. Dissociations between self-report and accuracy measures may be greater for interoceptive senses relative to exteroceptive senses. Dissociation may also be heightened in some clinical conditions (e.g., ASC). However, even in individuals with dissociation, interoceptive accuracy can be trained.

Metacognitive Contributions to Self-Report and the Subjective Experience of Pain

Brianna Beck, University of Kent

Self-report is the gold standard of pain measurement in clinical and experimental settings. Pain self-reports can take many forms, but most often are based on a rating scale ranging from 0 (no pain) to 10 (worst pain imaginable). While pain is associated with nociception (the process by which noxious stimulation is signaled through the peripheral and central nervous system), pain reports do not refer directly to the properties of a given stimulus and in fact can occur independent of a stimulus. Instead, pain refers to an individual's own sensory or affective state; pain is a private experience without a "ground truth" outside the self. Pain self-reports rely on both pain perception and nonperceptual factors, such as interpretation of the pain scale. For example, researchers have noted substantial inter- and intra-individual differences in pain, even when stimulus energy is held constant. Pain can also occur in the absence of apparent physical cause (e.g., fibromyalgia).

Metacognition and Pain

Studies that have investigated the brain activity associated with intrinsic variability and perception of pain tend to highlight regions that are not associated with nociceptive processing but instead with motivational value, emotion value, and emotion control, such as the hippocampal and parahippocampal cortices. These findings illustrate that pain is a multidimensional experience, considered to have at least three different dimensions: sensory/discriminative, affective/motivational, and cognitive/evaluative.

To measure the experience of pain in individuals, researchers may rely on metacognitive approaches. Metacognition in sensory perception (e.g., pain perception) is the monitoring and evaluation of one's own perceptual processes linked to a subjective experience (e.g., pain). To test whether increased awareness of pain through interoceptive perception may increase the confidence of pain self-reports, Beck and colleagues conducted a study of metacognitive reporting for a painful stimulus, a perceptual touch task, and a perceptual visual task. Individuals reported their Type 1 and Type 2 responses, and researchers applied the meta-d' model to measure the association between confidence levels and scoring accuracy (based on objectively correct scoring for perceptual tasks and anticipated scoring for the pain task). Researchers found that metacognitive efficiency (i.e., the comparison of meta-d' to d') differed across the modalities, with a specific lack of correlation between perceptual metacognition and pain metacognition. Therefore, researchers concluded that variance exists between metacognition of pain and metacognition of perceptual tasks—meaning that metacognition is domain specific for outward stimulation (perception) and internal stimulation (interoception).

Reporting Pain Across the Lifespan

Research has shown that pain rating scales can be used by individuals from a young age through older adulthood, including in individuals with mild and sometimes moderate cognitive impairment. However, severe cognitive impairment often limits capacity for scale-based pain self-report. Researchers thus need to identify reliable measures of pain that do not require self-report and may instead rely on a combination of behavioral or biomarker indices that correlate with pain.

Even in non-cognitively impaired individuals, rating scales are prone to bias. For example, the FACES pain rating scale often results in higher scores when the scale begins with a smiling face compared to when it begins with a neutral expression. In addition, the upper end of pain rating scales is subjective and often based on an individual's experience, making it an ambiguous anchor. Researchers may track the interpretation of the upper end of pain scales as it changes across the lifespan to better understand how prior experience changes the use of these scales.

Monitoring pain across the lifespan is also challenged by the tendency for older adults to underreport pain. This underreporting may be due to an expectation of pain during aging: that expectation may change the interpretation of pain signals or may lead adults to redefine the baseline for pain reporting. Researchers may measure how metacognition changes over the lifespan and whether changes correspond with differences in pain reporting.

Conclusions

Several outstanding research questions about pain metacognition require attention. Key questions include: (1) whether pain metacognition (and the associated influences of arousal) is consistent across the lifespan; (2) how pain scale use changes with age (i.e., based on prior pain experiences); (3) whether older adults differ from younger adults in their pain regulation abilities or strategies; and (4) how pain metacognition relates to distinctive aspects of subjective pain experience (e.g., high vividness, inter- and intra-individual variability).

Prioritizing Future Research Directions

Roundtable discussion following talks identified gaps in basic research and opportunities for identification of targets for interventions that can support healthy aging.

Training for Metacognition in Individuals with Neurodegeneration

Although metacognitive strategies can be trained, such training is unlikely to improve the ability of individuals with moderate or more advanced ADRD to provide self-reports about their own cognitive functions. Unlike the acute impacts of stroke or TBI, which are single events that may be associated with neurologic and cognitive recovery over time, ADRD causes progressive neurodegeneration which at some point will impair an individual's metacognitive capacity; thus at this time, without effective treatment for moderate to severe ADRD, training-based modifications to improve awareness are not feasible or even desirable. Individuals with MCI or mild ADRD, however, might benefit from training in metacognition to improve awareness of cognitive and functional limitations. Improved awareness in these early stages of disease would

enable individuals to develop compensatory strategies to maintain independent functioning for a longer amount of time, but this possibility has yet to be explored in depth.

In addition to training, simply enhancing individuals' insight into metacognitive gaps may serve to improve their metacognitive abilities and their day to day function, similarly to how individuals who are provided feedback on their gasoline usage adjust their driving habits. This possibility is uncertain, because researchers do not yet understand what causes metacognitive failures and why some individuals have reduced to no awareness of these failures; moreover, the reasons for these discrepancies in performance are likely heterogeneous. Still, metacognitive failures might be particularly amenable to interventions in individuals with MCI who are aware of their gaps in metacognitive abilities.

Longitudinal Metacognitive Research

Studies comparing individuals who are 30 years old versus 70 years old cannot track changes over the lifespan as accurately as longitudinal cohort studies. The main problem with comparative studies is that the enrolled individuals from older age groups are representative of only a portion of their generation (i.e., those that have survived to that age), and may not accurately represent all individuals, including those deceased or too ill to participate. Therefore, to obtain an accurate characterization of aging across the lifespan, longitudinal studies of metacognition and interoception are necessary. Such longitudinal studies have not yet been conducted for metacognition or interoception.

Longitudinal work *has* been conducted on global ratings of memory performance and how those change across the lifespan, although this work has tended to cover a relatively short stretch of the lifespan (e.g., 5-15 years). Such studies have shown changes over time in individuals' ratings of their own subjective memory (i.e., perceived memory ability, independent of objective standards or performance). These longitudinal studies have also shown that these ratings lack predictive validity for changes in actual memory performance as people age. Although this fact may reflect differences in the kinds of memories that subjective ratings and objective standards capture, it likely also suggests that the subjective memory degeneration associated with aging is connected to the beliefs that people have about what will happen as they age.

Variables Differentiating Metacognition in Early Cognitive Impairment

As Cosentino showed above, individuals with early cognitive impairment associated with AD/AR range in awareness of this decline from concerned and aware to unconcerned and unaware. These differences do not appear to be driven by demographic variables. Researchers have investigated differences between cognitive tests of right and left hemisphere tasks and have found that higher gamma scores (association between memory success and confidence judgment) correlated more with cognitive test results for right hemisphere tasks. These findings suggest that the distribution of pathology in the brain associated with awareness of cognitive impairments follows a differential pattern that can be observed and measured. Other studies could focus on measuring personality and cultural factors to identify other variables linked to metacognitive abilities in MCI.

Interoceptive Awareness as Therapy

Emerging evidence suggests that interoceptive training is a promising means of reducing anxiety, with an effect size slightly smaller than that of cognitive behavioral therapy (CBT). In one trial of reduction of anxiety in autistic individuals, one-third of participants successfully reduced anxiety levels below a predetermined threshold. Quotes from participants noted that interoceptive sensitivity aided in the awareness and regulation of anxiety.

These findings are complementary to a parallel line of work that has found that individuals with greater accuracy at reporting pain also report fewer instances of pain. Further research is needed to understand why greater interoceptive accuracy is associated with fewer subjective reports of the interoceptive experience itself.

Metacognition and Sense of Self

Older adults with advanced cognitive impairment have reported that their sense of self, or identity, remains intact even as the cognitive underpinnings to express their emotions have been removed. This discrepancy has also been reported in individuals with pacemakers, for whom interoceptive awareness of the newly regulated heartbeat seems to cause dissociation with emotions. Some researchers (such as psychologist Steven Sabat) have examined how others' impressions of a person can affect sense of self, particularly in the context of AD/HD and brain injury. Further research is needed into the connection between metacognition and sense of self in aging individuals, particularly those with AD/HD.

Memory Accuracy in Dementia

Memory of single items in a metamemory test is what generates a gamma score (the association between memory success and confidence judgment). Some individuals who are aware of age-related memory loss are metacognitively accurate despite severe underlying memory loss and thus have high gamma scores.

Some studies have shown that presenting a memory cue to older adults before an FOK judgment improves performance on FOK tasks, compared to performance when no memory cue is presented. These findings suggest that some of the performance loss associated with older age is due to a failure to access the cues available to assist with memory. Thus, while structural brain deficits certainly occur in patients with AD/HD, additional "softer" constraints shared by all aging individuals may also affect these patients' memory.

Metacognition in Different Populations

Much of the metacognitive testing research has focused on Western cultures. Studies of individuals from different cultures and with varied demographic characteristics (e.g., race, socioeconomic status) are few, but researchers have begun to turn their attention to studying larger, more diverse populations. Prior studies have shown connections between metacognition and educational achievement in healthy adults, but further studies are needed to capture a more diverse population of both healthy adults and patients with AD/HD. Researchers also need to consider cultural components embedded in measures of

metacognition, interoception, pain, and other forms of self-awareness as they diversify study populations.

Reliability of Metacognitive Measures

Pain scales are often unreliable: their use depends on a patient's ability to interpret the scale, and that interpretation is heavily influenced by the patient's prior life experiences. The variance in pain reporting may be due to cues beyond nociception in a manner that differs from other domains of metacognitive reporting. Reporting competence in something that is purely personal and nested within the self, such as pain, may differ from reporting competence in something that is objectively measurable, such as memory. Research has indeed shown greater correspondence between confidence and accuracy in reports of exteroceptive processing than of interoceptive processing.

Appendix 1. Meeting Agenda

- 1:00 Welcome and Opening Remarks
Terrie Moffitt, Duke University and Chair, BBCSS
- 1:10 Introductory Remarks from NIA
Janine Simmons, Branch Chief, Individual and Behavioral Process Branch, Division of Behavioral and Social Research, NIA

Elizabeth Necka, Program Director, Individual and Behavioral Process Branch, Division of Behavioral and Social Research, NIA
- 1:20 Examining Metacognitive Capacity

Human Metacognition Across Domains: Insights from Individual Differences and Neuroimaging
Stephen Fleming, University College London

Metacognition and Health Aging
Christopher Hertzog, Georgia Tech

Metacognition in Alzheimer's Disease and Related Disorders
Stephanie Cosentino, Columbia University
- 2:50 BREAK
- 3:05 Interoception and the Subjective Experience of Pain

Dissociating Interoceptive Accuracy from Interoceptive Insight
Sarah Garfinkel, University College London

Metacognitive Contributions to Self-Report and the Subjective Experience of Pain
Brianna Beck, University of Kent
- 4:05 Prioritizing Future Research Directions
Moderator: Ulrich Mayr, University of Oregon, BBCSS member
- 4:50 Final Reflections
Elizabeth Necka, Program Director, Individual and Behavioral Process Branch, Division of Behavioral and Social Research, NIA
- 5:00 Adjourn

Appendix 2. List of Participants

BBCSS Board Members

Terrie Moffitt, Chair

Ulrich Mayr, University of Oregon

NAS Staff

Tina Winters, Associate Program Officer, Division of Behavioral and Social Sciences

Samantha Chao, Associate Executive Director, Division of Behavioral and Social Sciences

Carlotta Arthur, Executive Director, Division of Behavioral and Social Sciences

Presenters

Brianna Beck, University of Kent

Stephanie Cosentino, Columbia University

Stephen Fleming, University College London

Sarah Garfinkel, University College London

Christopher Hertzog, Georgia Tech

National Institute on Aging, Division of Behavioral and Social Research (BSR) Attending in Person

Lis Nielsen, Division Director, BSR

Elizabeth Necka, Program Director, BSR

Janine Simmons, Branch Chief, Individual and Behavioral Processes Branch, BSR

Luke Stoeckel, Program Director, BSR

Rose Li & Associates (Contractor)

Rebecca Lazeration, Rose Li & Associates