Technology Innovations in Dietary Intake and Physical Activity Assessment: Challenges and Recommendations for Future Directions

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INTRODUCTION

Dietary intake (DI) and physical activity (PA) data are used in a variety of ways, including to determine nutrient adequacy and deficiency; to assess nutritional, fitness, and health status; to develop health promotion and behavioral interventions; and to understand food chemical and microbiological exposure, food–drug interactions, and pharmacokinetic effects. 1-3 Methods used to capture these data must therefore be reliable and accurate to ensure confidence when determining quantitative DI and energy intake (EI), food behaviors, and energy expenditure (EE), especially for real-time monitoring and interventions. Moreover, because the underlying pathways and mechanisms regulating energy homeostasis are not fully understood, improved measures can help address challenges in understanding interrelationships between DI and PA.

The increased prevalence of diet-related chronic diseases, obesity, and sedentary behavior has intensified interest to understand the long-term effects of diet and PA on aging and health. Although the use of biomarkers and new “omics” technologies has enhanced understanding of genotypic and biological effects, assessment of DI and PA has not progressed as rapidly. 4 Current DI and PA assessments are typically based on self-report and thus have inherent biases. 5-9 New technology-enabled methods designed to objectively measure DI and PA hold promise in addressing these shortcomings.

In 2016, NIH and the Interagency Committee on Human Nutrition Research intensified support to develop new objective tools to improve the accuracy and reliability of DI and PA measures. 10,11 An expert forum (Tech Summit: Innovative Tools for Assessing Diet and Physical Activity for Health Promotion) was convened at the University of California, San Diego (UCSD) in December 2016 to address the state of the science and technology innovations in DI and PA assessment across the life span. Scientists from the U.S. Department of Agriculture Agricultural Research Service, American College of Sports Medicine, and NIH helped plan the program, and a multidisciplinary group of experts in the field discussed the current state of technology-enabled tools and methods for DI and PA assessment and identified challenges and future needs. Attendees comprised researchers, technology developers, commercial applicators, practitioners, ethics professionals, and policy makers from multiple disciplines, including statistical modeling, device development, software and biomedical engineering, nutrition and food sciences, behavioral sciences, psychology, sports medicine, biology, regulatory science, law, and ethics.

KEY LEARNINGS

Advancing Dietary Intake and Physical Activity Assessment Through Multidisciplinary and Cross-Sectoral Methods

Increasingly, data collection and application involves digital devices, big data, human subjects, and behavioral interventions expertise; thus, understanding across this range is seldom found in any one discipline. Scientists involved in DI and PA assessment come from many disciplines (e.g., computer science, behavioral sciences, and engineering) and sectors (e.g., industry, academia, and government). Moreover, they use such assessments for a variety of reasons, including research, commercial application, biomedical assessment and practice, counseling, and public health.

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and policy development. This diverse ecosystem combined with the wide versatility of data use, although beneficial, also raises new concerns and challenges. These include different approaches to (1) framing theories and hypotheses; (2) research study design and methods; (3) guidelines for ethical practices for informed consent, privacy protections, bystander rights, and data management protocols; (4) methods for data capture, processing, quality control, statistical modeling, and analysis; (5) data reporting, interpretation, and extrapolation; and (6) data translation for developing guidelines.

Because of this wide range of perspectives, the forum was specifically structured to share cross-disciplinary efforts on DI and PA assessment tools for EE and health status. The forum resulted in expert review papers on technology innovations in three age cohorts that are published concurrently with this commentary: “Advances and Controversies in Diet and Physical Activity Measurement in Youth”11; “Dietary Intake and Physical Activity Assessment: Current Tools, Techniques, and Technologies for Use in Adult Populations”13; and “Diet and Physical Activity Assessment and Interventions Using Technology in Special Populations: Older Adults.”14

Convergence of Innovation Is Advancing New Tools
The rapid pace of development of new tools to measure DI and PA can be attributed to the convergence of innovation in several areas, including computational science, statistical modeling, device and software engineering, artificial intelligence, biomedical engineering, behavioral sciences, nutrition, and food science. This convergence has led to new technologies that support improvements in the quantitative, qualitative, frequency, and speed of DI and PA data capture and aim to enable improved understanding about how these data relate to both individual and population-level health outcomes.

Some of these improvements center on combining assessment tools to improve accuracy, such as biomarkers, omics, doubly labeled water for total EE, visual imaging, digital and smart devices, and interactive and wearable sensors for DI and eating patterns. Smart sensors placed at different positions on the body enable measurement of the event itself (e.g., chewing, swallowing, standing, or sitting). Along with new objective measurement tools, researchers are investigating innovations to further enhance analytic capacity involving big data analytics, computational modeling, statistical techniques to recalibrate data obtained from multiple sources, and artificial intelligence to capture behavior patterns and simulate individualized behavior. Approaches and tools currently in place to measure DI and PA across the lifespan are discussed in this mini-review series. Although these innovations are promising, it is critical that the foundational work be done to establish whether these tools/strategies are acceptable, accessible, and easy to use by participants and consumers. Moreover, these technologies must be evaluated to ensure that they are accurate, cost effective, and produce valid and reliable data.

Incorporating New Science on Circadian Rhythms
Satchidananda Panda, PhD (Salk Institute), presented results of a scalable method using a smartphone (equipped with a mobile app, camera, and push notifications) to longitudinally monitor the effect of circadian rhythm on human food intake and fasting patterns.15 This technology enabled the study of diurnal regulation of eating and fasting patterns, sleep—wake cycles, and their relation to metabolic function. Circadian rhythm regulation of behavior, physiology, and metabolism constitutes a large regulatory network that coordinates biochemical processes both within and between cell types. Most genes in mammals show tissue-specific daily expression rhythms. These rhythms sustain health by temporally separating incompatible processes, optimizing nutrient utilization, and coordinating interorgan communications. Therefore, factors that perturb or augment these daily rhythms may have a profound impact on health. Vollmers et al.16 found that the daily feeding—fasting cycle sustains robustness of gene expression rhythms. In preclinical animal models, a robust feeding—fasting cycle without altering nutrient quality and quantity could prevent or reverse several chronic metabolic diseases, including obesity, insulin resistance, fatty liver disease, and dyslipidemia.17 A human feasibility study revealed that daily rhythms in activity/rest and feeding/fasting may be erratic even among non—shift workers.15

KEY CHALLENGES
Energy Expenditure Assessment
Forum participants debated whether self-reports should be replaced altogether by a more accurate objective method in EE assessment. David B. Allison, PhD (Indiana University), presented the current challenges and debates in energy balance research. Of concern is the difficulty in measuring energy balance in humans outside of confined settings. Considerable evidence indicates that self-reports, the most common method for assessing EI in large-scale studies, are of such poor quality that some investigators have suggested the data not be used at all. Another issue is the lack of strong theory to reliably predict the extent to which energy compensation would occur in response to any perturbation of one component of energy balance in the short term. The absence of such a theory makes it challenging to generalize beyond any one setting or experiment.
with any confidence. Dr. Allison proposed options to move forward, such as establishing agreement that self-reports were of insufficient quality to use in EI assessment and that abandoning self-reports for estimating EI would lead to fewer misleading paths in the field and would catalyze new efforts to develop more precise and reliable methods of measuring EI. An example was to use doubly labeled water, which was accurate within 1% (coefficient of variation 2%–12%) in free-living normal-weight individuals. The National Cancer Institute concluded that food frequency was not valid for EI or protein intake determination and that biomarkers should be used. Although a single-day 24-hour protocol can estimate true EI within 3% of the actual value in normal-weight individuals, underreporting was reported with increased body weight.

Other participants argued that doubly labeled water is expensive and not practical for wide in-field use because it requires special training, equipment, and patient approval. Until a more optimal objective replacement is available, use of subjective methods should be augmented with other more accurate objective tools, such as computer-assisted recalls, sensors, and visual imaging smart devices (wearables, smartphones). It is important for researchers to select tools that have been tested for accuracy and have appropriate privacy protections and acceptable data management protocols in place—especially when choosing an app or device that has not been vetted by the U.S. Food and Drug Administration.

A Data-Rich But Decision-Poor Environment
In a presentation on the state of technology and innovation related to PA and healthy eating, Eric B. Hekler, PhD (Arizona State University, now UCSD), warned of a growing data-rich but decision-poor environment. Three emerging trends were identified as disruptors of current models of health promotion and disease treatment: (1) unsustainable growth in the complexity and cost of health care; (2) a movement toward more human-centered and personalized strategies for fostering health and treating disease; and (3) an explosion in information, communication, and computing technologies and the big data these systems produce. Despite great interest in leveraging the second and third trends to tackle the first, many challenges remain to be resolved before the vision of a human-centered, preventive, cost-effective healthcare system and corresponding “culture of health” could be realized.

Considering Ethical Decisions
Camille Nebeker, EdD, MS (UCSD), spoke of the importance of informed consent, risk assessment regarding participant privacy and bystander rights, as well as rigorous data management protocols (e.g., collection, storage, and sharing). Digital and mobile technologies have enabled the collection of unprecedented amounts of personal health data, allowing researchers to learn about free-living individual behaviors in real-time 24 hours a day, 7 days a week. These data can be captured through wearable sensors or by tapping into the global positioning sensors and other apps installed on a smartphone. By using pervasive sensors (e.g., wearable or home placed) or accessing existing phone, text, and social media data, researchers have access to volumes of granular individual-level data from which they can identify behavioral patterns that map to participant health and illness indicators. It is not surprising that technology-enabled health research tools and methods have introduced new ethical and regulatory challenges for both researchers using these techniques and the IRBs charged with protecting study participants.

As innovations in technology develop at exponential speed, the academic research landscape is rapidly attempting to respond, yet the regulatory infrastructure is lacking. To be competitive in accelerating medical discovery, including new preventions and treatments, researchers need the flexibility to deploy new methods using unconventional tools. Yet they lack an ethical playbook to guide the risk to benefit calculus that both researchers and IRBs must consider. This lack of guidance can either hinder advancement of important research by not permitting studies to move forward or by allowing studies to advance without the appropriate risk management strategies in place. Results of formative research have identified key areas of concern being the informed consent process, bystander rights (e.g., individuals who are not the research participant but whose information is captured due to their proximity to a participant, through a wearable camera or passive microphone), and data management.

In 2015, an interdisciplinary team at UCSD launched the Connected and Open Research Ethics (CORE) initiative (https://thecore.ucsd.edu). The CORE is a global learning community of more than 500 health-technology stakeholders who share a commitment to advancing responsible digital health research by proactively shaping ethical practices. The CORE provides its network with resources to navigate the ethical, legal/regulatory, and societal dimensions of technology-enabled research. The CORE community includes researchers, ethicists, legal scholars, participants, and IRB affiliates who share their expertise and resources.

Conundrum of Diversity of Tools, Data, and User Needs
Forum participants identified challenges related to differences in research models, study designs, tools and devices,
statistical approaches, and outcome interests, depending on discipline and investigator training. Problems related to multiple devices and technologies used include universal usability, user burden, error tolerance, cost, and interface design. Needs vary among different stakeholders, including test populations and end users (e.g., patients, caregivers, healthcare providers, researchers, and public health officials); tools and validation approaches are lacking for unique/customized application in special populations (e.g., children and youth, older adults with health and cognitive impairments, pregnant and lactating women, individuals with low SES, or those otherwise marginalized or on the periphery). The lack of a common system for data sharing and sourcing (from researcher to researcher, person to person) is a concern, raising questions of ability to maintain data quality. Approaches to dealing with different data types and variety (signal, image, sound, biomarker, ecologic momentary assessment) and reporting results, including data integration and interpretation/meaning, are inconsistent. This raises concerns about how to preserve data integrity. There is a need for more consistent definitions of data sources/databases (e.g., data ownership, standards, and ontologies) among the various disciplines. There is insufficient shared learning and training among the cross-disciplines. The lack of a common terminology and system for data management creates researcher and user silos. Although the field is growing rapidly, there is limited opportunity in partnership growth (e.g., between developers and researchers).

**RECOMMENDATIONS FOR FUTURE DIRECTIONS**

Participants identified many areas for improvement.

**Improve the Data Infrastructure**
The current mix of existing and emerging technologies for DI and PA would benefit from organization into an overall framework that describes the relationships between these technologies and their corresponding infrastructures; the research methods that leverage these technologies; and the theoretic basis for their use for decision making by individuals/patients, providers, and policy makers. Much of the present-day research infrastructure, methods, and theories were devised within a “data-poor” context. Future paths may learn from data-rich sciences (e.g., meteorology) to provide a partial roadmap for a 21st century health research enterprise model. A data-rich “agile” health science will likely require increased democratization of current scientific processes with a goal to create a “usable” evidence base that produces evidence-based answers for individuals/patients, providers, and policy makers to adequately answer the question “What do I do now to produce the desired outcome?”

To counteract the unintended consequence of increasing disparities that “precision” efforts could create, tools for curating knowledge and resources must be carefully integrated into precision technology infrastructures.

**Create Open Architecture**
Increase efforts to facilitate a plug-and-play open architecture system that allows for modular systems to be assembled for specific assessments. Success would include smartphone links with various software applications.

**Establish Curated Technologies**
Establish a committee or international working group to evaluate, manage, or channel the huge influx of new apps and emerging technologies to measure DI and PA. This would help ensure there is a focused and effective effort in this direction.

**Encourage Transdisciplinary Training**
Establish transdisciplinary educational/workshops for broader training on data science, computational modeling, and the science and insights behind the technology. This will enable users to better understand the data for making decisions on future actions.

**Develop Novel Biomarkers**
Use technological capabilities to develop biomarkers that can increase objectivity of the measures and customize them for subpopulations.

**Establish Cross-Sector Collaboratory Opportunities**
Bridge the gap between technology developed for research and consumer wearable technology. This will be particularly important if research on DI and PA is to be optimized at the population level.

**Prioritize Tool Development**
Deploy a convergence approach to develop inexpensive combination tools that are easy to use, validated, precise, and accurate for estimates of intakes of food components (e.g., for nutrients, bioactive compounds, additives, and contaminants).

**CONCLUSIONS**
Despite the many challenges in measuring DI and PA, there is much promise on the horizon because of both the highly innovative research currently underway and the continued rapid pace of convergence in science and technology. Our hope is that the papers in this special section of the *American Journal of Preventive Medicine* inspire even further cross-disciplinary collaborations to
accelerate the pace for high-quality research that will, in turn, greatly improve population health.

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