Center for Lifespan Psychology

Director: *Ulman Lindenberger*

"But ... its eminent modifiability, and its predisposition to self-initiated action, may it develop little or much, and may it differ in amount between different individuals, is among the immutable features of humankind, which can be found wherever humans exist."
Johann Nicolaus Tetens, 1777, I, p. 766

J. N. Tetens (1736–1807), philosopher of the Enlightenment Era

Introductory Overview

Founded in 1981 by Paul B. Baltes (1939–2006; Lindenberger, Delius, & Staudinger, 2015), the Center for Lifespan Psychology (LIP) pursues lifespan psychology as a distinct conceptual approach within developmental psychology. Since 2004, the Center has continuously extended its research program into developmental neuroscience. Work at the Center is guided by three propositions: (1) to study lifespan changes in behavior as interactions among maturation, learning, and senescence; (2) to develop theories and methods that integrate empirical evidence across domains of functioning, timescales, as well as behavioral and neural levels of analysis; (3) to identify mechanisms of development by exploring age-graded differences in plasticity. The Center continues to pay special attention to the age periods of late adulthood and old age, which offer unique opportunities for innovation, both in theory and practice. At the same time, it has continuously extended its research on behavioral development to earlier periods of life.

Three Guiding Propositions

The Center's research agenda can be summarized by three interrelated theoretical propositions (Kühn & Lindenberger, 2016; Lindenberger, 2014; Lövdén, Bäckman, Lindenberger, Schaefer, & Schmiedek, 2010). In line with general tenets of lifespan psychology, these propositions emphasize conceptual and methodological issues in the study of lifespan behavioral development and thereby provide a conceptual foundation for formulating research questions in specific domains of interest.

Proposition 1: Lifespan Changes in the Individual's Behavior as Interactions Among Maturation, Learning, and Senescence

The general goal of developmental psychology is to identify mechanisms that generate invariance and variability, constancy and change, in behavioral repertoires from infancy to old age. By identifying the commonalities, differences, and interrelations in the ontogeny of sensation, motor control, cognition, affect, and motivation, both within and across individuals, developmental psychologists and developmentally oriented neuroscientists attempt to arrive at more or less comprehensive theories of behavioral development. To provide explanations that qualify as psychological and developmental, the effects of agents external to the developing individual, such as parents' affect attunement, teachers' classroom behavior, or a state's retirement policies, need to be mapped onto mechanisms and organizational laws that operate and evolve within developing individuals. Hence, as John Nesselroade, Peter Molenaar, and others have emphasized, individual people, rather than groups of people or domains of functioning within persons, form the privileged system of analysis and explanation.

Individuals organize their exchange with the physical and social environment through behavior (see Figure 1). On the one hand, the changing brain and the changing physical and cultural environment shape behavioral development. On the other hand, behavior alters both the brain and the environment. Hence, environment and brain act as antecedents but also as consequents of moment-to-moment variability and long-term changes in patterns of behavior. The components of this system, brain, behavior, and environment, are constantly coupled and cannot be reduced onto each other, as they jointly condition an individual's life trajectory through recursive self-regulation.

In attempts to explain the age-graded evolution of this system, *maturation* and

Key References

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Lövdén, M., Bäckman, L., **Lindenberger, U., Schaefer, S.,** & **Schmiedek, F.** (2010). A theoretical framework for the study of adult cognitive plasticity. *Psychological Bulletin, 136,* 659–676. doi:10.1037/a0020080

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Lindenberger, U., Li, S.-C., & Bäckman, L. (2006). Delineating brain–behavior mappings across the lifespan: Substantive and methodological advances in developmental neuroscience. *Neuroscience & Biobehavioral Reviews, 30,* 713–717. doi:10.1016/j.neubiorev.2006.06.006

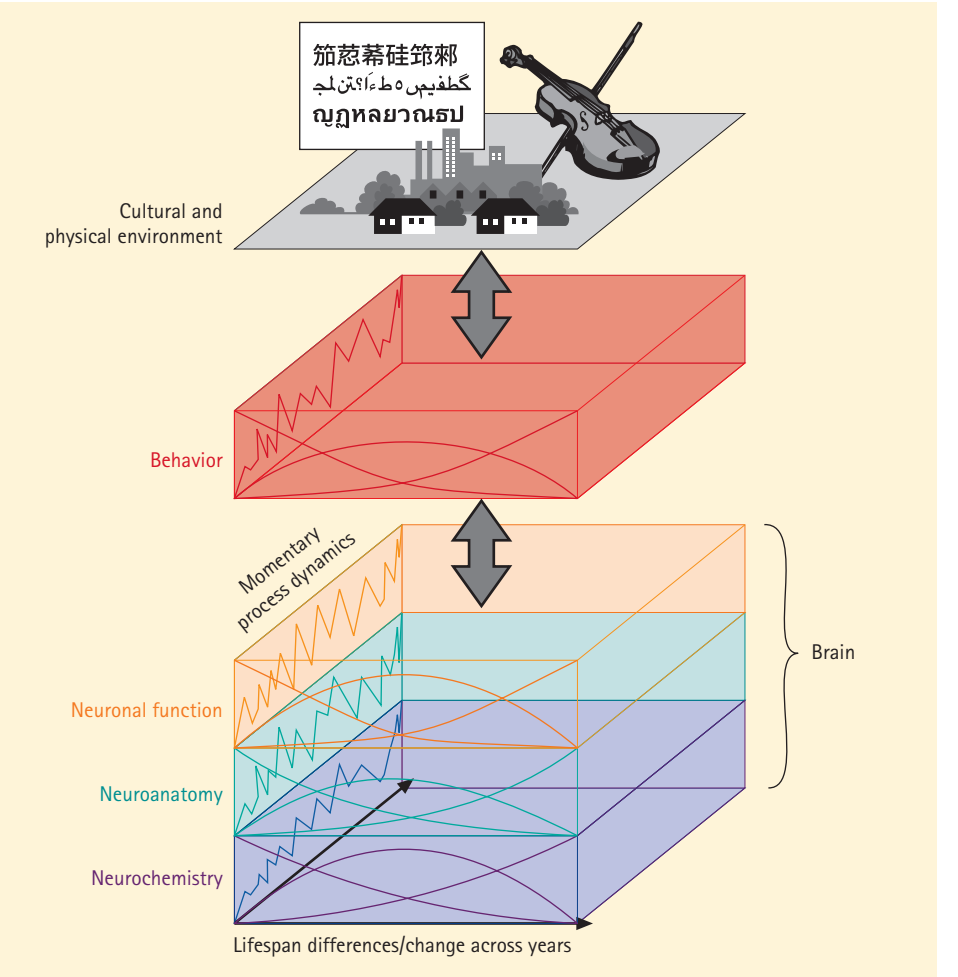

Figure 1. Environment and brain as antecedents and consequents of moment-to-moment variability and long-term changes in patterns of behavior. Lifespan changes in brain–behavior mappings are shaped by interactions among processes related to maturation, learning, and senescence. The identification of key players in the ontogeny of brain–behavior dynamics requires a coalition between formal tools for synthesis across levels of analysis and timescales as well as empirical methods to study variability and change in brain and behavior (adapted from Lindenberger, Li, & Bäckman, 2006).

senescence denote the operation of age-graded brain mechanisms and their effects on changes in behavior, which are especially pronounced early and late in life. In addition, *learning,* at any point during ontogeny, denotes changes in brain states induced by behavior–environment interactions. Note, however, that maturation cannot take place without learning and that learning cannot take place without maturation. Similarly, the ways in which senescence takes its toll on the brains of aging individuals depend on their past and present learning and maturational histories. To complicate matters even more, processes commonly associated with maturation are not confined to early ontogeny and processes related to senescence are not restricted to old and very old age. For instance, neurogenesis and synaptogenesis, which qualify as maturational mechanisms promoting plasticity, continue to exist in the adult and aging brain; conversely, declines in dopaminergic neuromodulation, which indicate senescence-related changes in brain

chemistry, commence in early adulthood. Thus, maturation, senescence, and learning mutually enrich and constrain each other throughout the entire lifespan and must be understood and studied as interacting forces constituting and driving the brain–behavior–environment system. Psychologists occupy a central position in this endeavor because they possess a rich and adequate repertoire of experimental and methodological tools to describe and modify the organization of behavior. In particular, direct comparisons between children and older adults help to identify commonalities and differences in the mechanisms that drive child and adult development.

Proposition 2: Lifespan Theory and Methodology Need to Integrate Evidence Across Domains of Functioning, Timescales, and Levels of Analysis

Developmental psychology is faced with three challenging integrative tasks. First, there is the need to integrate theorizing and research practice across functional domains to attain a comprehensive picture of individual development. For instance, sensorimotor and cognitive functioning are more interdependent in early childhood and old age than during middle portions of the lifespan, and developmental changes in either domain are better understood if studied in conjunction. Similar observations can be made for many other domains of functioning whose changes have generally been studied in isolation, such as the ontogeny of social interaction and cognition; of emotion regulation and motivational states; or of memory, working memory, and attention.

Second, there is a need to understand the mechanisms that link short-term variations to long-term change. Short-term variations are often reversible and transient, whereas long-term changes are often cumulative, progressive, and permanent. Establishing links between short-term variations and long-term changes is of eminent heuristic value, as it helps to identify mechanisms that drive development in different directions. For instance, aging cognitive systems show a decrease in processing robustness, which may signal impending long-term changes in other characteristics of the system (see Figure 2). In contrast, other forms of neural and behavioral moment-to-moment variability may indicate an individual's ability to bring a wide variety

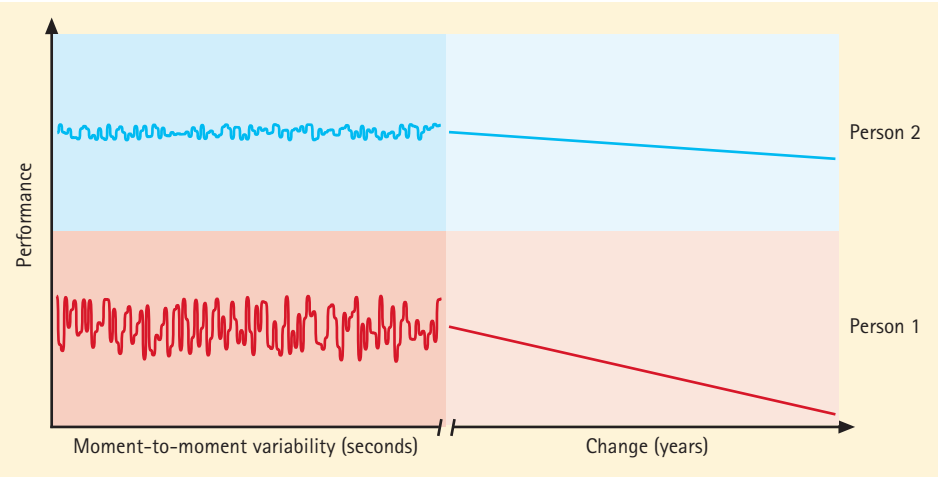

Figure 2. Example for predictions linking moment-to-moment variability to long-term change and brain changes to behavioral changes. Senescent changes in neuromodulation lead to greater moment-to-moment fluctuations in neural signaling, enhance the prominence of background noise, reduce the distinctiveness of processing pathways and representations, and increase variability of cognitive performance. Aging individuals with greater moment-to-moment process fluctuations at a given point in time are expected to show greater subsequent longitudinal decline in mean levels of functioning than individuals who fluctuate less (adapted from Lindenberger et al., 2006).

Key References

Freund, J., **Brandmaier, A. M.,** Lewejohann, L., Kirste, I., Kritzler, M., … **Lindenberger, U.,** Kempermann, G. (2013). Emergence of individuality in genetically identical mice. *Science, 340*(6133), 756–759. doi:10.1126/science.1235294

Lindenberger, U. (2014). Human cognitive aging: Corriger la fortune? *Science, 346*(6209), 572–578. doi:10.1126/science.1254403

of different strategies to the task and are positively related to long-term change in both childhood and old age (e.g., Hertzog, Lövdén, Lindenberger, & Schmiedek, in press). To articulate these perspectives, we need to gather multivariate time-series data that capture short-term variability and long-term changes in across-domain dependencies.

Third, to arrive at mechanistic explanations of behavioral change, there is the need to integrate behavioral and neural levels of analysis. At any given point in the lifespan, one-to-one mappings between brain states and behavioral states are the exception rather than the rule, as the brain generally offers more than one implementation of an adaptive behavioral outcome. Therefore, ontogenetic changes in behavioral repertoires are accompanied by continuous changes in multiple brain–behavior mappings. Some of these remapping gradients may be relatively universal and age-graded, whereas others may be more variable, reflecting genetic differences, person-specific learning histories, the path-dependent nature of developmental dynamics, or a combination of all three. The resulting picture underscores the diversity and malleability of the organization of brain and behavior as well as the constraints on diversity and malleability brought about by (a) universal age-graded mechanisms associated with maturation and senescence, (b) general laws of neural and behavioral organization, and (c) cultural-social as well as physical regularities of the environment.

Proposition 3: The Exploration of Age-Graded Differences in Plasticity Is a Powerful Tool for Identifying Mechanisms of Development

Both from scientific and societal perspectives, plasticity, or the alteration of developmental trajectories through experience, is a precious phenomenon (Freund et al., 2013, 2015; Kühn & Lindenberger, 2016; Lindenberger, 2014). Scientifically, inquiries into the plasticity of brain and behavior are a rich source of developmental information. Through the assessment of "changes in change," they offer the promise to observe the operation and proximal consequences of developmental mechanisms. For instance, studies in which research participants of different ages are instructed and trained to perform one or more cognitive tasks come with important validity benefits, such as (a) an increase in experimental control, (b) the identification of age differences near asymptotic performance levels, and (c) the assessment of transfer and maintenance effects. If neurochemical, neuroanatomical, and neurofunctional imaging measures are assessed before, during, and after training, intervention studies also offer new insights into relations between behavioral and neural manifestations of plasticity. By partly taking control over behavior–environment interactions, mechanisms of learning can be studied in the context of maturation and senescence (Lövdén et al., 2010).

From the larger perspective of societal evolution, cognitive intervention studies explore the range of possible development, or what could be possible in principle if conditions were different (see Figure 3). The resulting

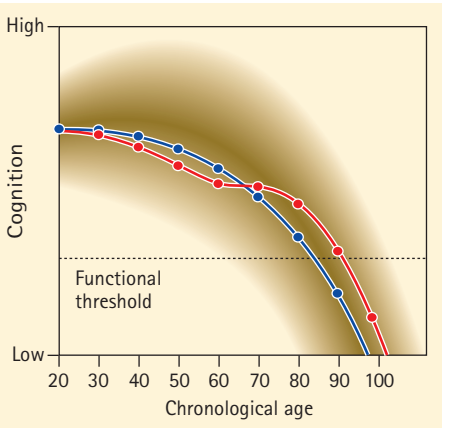

Figure 3. An individual's range of possible cognitive developmental trajectories from early to late adulthood. The blue curve shows the most likely developmental path under normal circumstances. The fading of the background color indicates that more extreme paths are less likely. The functional threshold represents a level of functioning below which goal-directed action in the individual's ecology will be severely compromised. The red curve represents the hope that changes in organism–environment interactions during adulthood move the individual onto a more positive trajectory. Beneficial changes may consist in the mitigation of risk factors, such as vascular conditions, metabolic syndrome, or chronic stress; the strengthening of enhancing factors, such as neuroplasticity; or both (adapted from Lindenberger, 2014).

knowledge about the plasticity of developmental trajectories is essential for improving human welfare. Hence, investigations of age changes in the plasticity of development carry the potential to explain and ameliorate the expression of human potential.

For all of these reasons, age-comparative intervention studies with a focus on behavioral and neural manifestations of plasticity form the core component of empirical research at the Center. At the conceptual level, researchers at the Center have aimed at identifying distinct features of plasticity in relation to other types of behavioral and neural variability and change (Lövdén et al., 2010; see Figure 4). At the empirical level, the Center has carried out pioneering studies on plastic changes in brain and behavior, such as the COGITO study (see *Intra-Person Dynamics* project, pp. 157–159). In recent years, we have launched a new generation of experiments that combine behavioral skill training with repeated functional and structural imaging to directly observe the temporal progression of plasticity in individual people. Going beyond the canonical pretest–posttest design of intervention studies, these studies seek to observe how plastic changes unfold over time. In this context, Lövdén, Wenger, Mårtensson, Lindenberger, and Bäckman (2013) have noted that neural manifestations of plasticity are often marked by initial tissue expansion (e.g., overproduction of new synaptic connections) followed by renormalization (e.g., pruning of these connections). Recently, we have been able to delineate this pattern empirically in human adults (Wenger et al., 2017; see *Plasticity* project, pp. 153–156; see also Lindenberger, Wenger, & Lövdén, 2017).

Methodological Innovation

Since its foundation in 1981, the Center has sought to promote conceptual and methodological innovation within developmental psychology and in interdisciplinary context. Special attention is paid to methods and research designs apt to integrate (a) multiple domains of functioning, (b) multiple timescales, and (c) multiple levels of analysis. Random coefficient modeling, latent growth

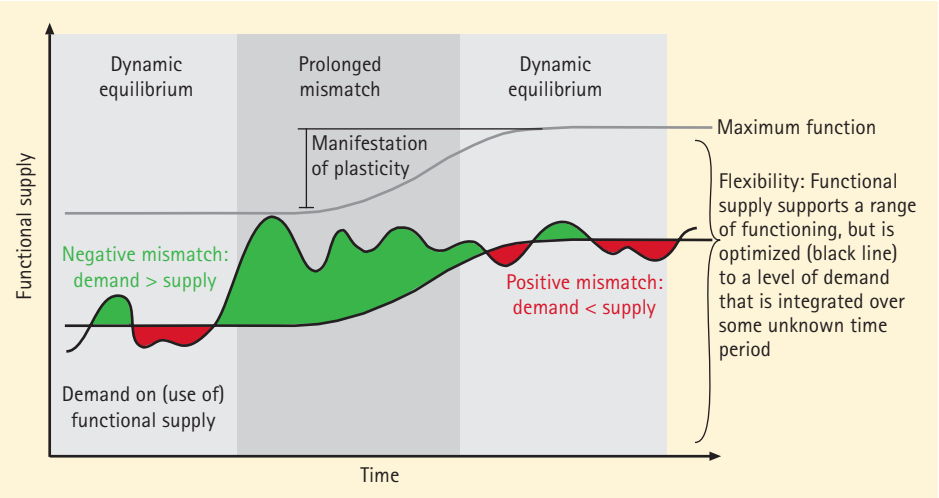

Figure 4. Schematic model of a mismatch between functional supply and experienced environmental demands caused by primary changes in demand (e.g., altered experience through cognitive training). Functional supply (i.e., the structural constraints imposed by the brain on function and performance) allows for a range of performance and functioning. Flexibility denotes the capacity to optimize the brain's performance within the limits of the current state of functional supply. Due to the sluggishness of plasticity, structural supply optimizes its support for function to a level of demand (i.e., use of functional supply) that is averaged over some unknown time period. Mismatches need to be prolonged to overcome the inertia and sluggishness of plasticity and to push the system away from its dynamic equilibrium. Deviations in demand that are within the current range of functional supply induce the mismatch that constitutes the impetus for plastic change (adapted from Lövdén, Bäckman, Lindenberger, Schaefer, & Schmiedek, 2010).

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Lindenberger, U., Wenger, E., & Lövdén, M. (2017). Towards a stronger science of human plasticity. *Nature Reviews Neuroscience, 18,* 261–262. doi:10.1038/nrn.2017.44

Lövdén, M., Wenger, E., Mårtensson, J., Lindenberger, U., & Bäckman, L. (2013). Structural brain plasticity in adult learning and development. *Neuroscience & Biobehavioral Reviews, 37,* 2296–2310. doi:10.1016/j.neubiorev.2013.02.014

curve modeling, and related statistical techniques have served as versatile tools for the analysis of multivariate data with nested time structures, such as trials, blocks of trials, days, weeks, and years. Recently, time-delay embedding and clustering methods for time-series data, continuous-time structural equation modeling, combinations of classifier and structural equation modeling techniques, as well as machine-learning tools have been added to the repertoire (see *Formal Methods* project, pp. 172–174). Under the leadership of Gerd Kempermann from the Dresden site of the German Center for Neurodegenerative Diseases, and in collaboration with Antonio Krüger from Saarland University, Andreas M. Brandmaier and Ulman Lindenberger have continued their collaboration on an animal model of epigenetic contributions to individual development (Freund et al., 2013, 2015). Finally, the Center closely collaborates with the Max Planck UCL Centre for Computational Psychiatry and Ageing Research (see pp. 195–200).

Research Awards (Selection)

During the reporting period, several research awards were bestowed upon visitors and members of the Center. Andreas M. Brandmaier received the Heinz-Billing-Award

Table 1. The Center for Lifespan Psychology and the Max Planck UCL Centre for Computational Psychiatry and Ageing Research at the Max Planck Institute for Human Development: Overview of Research Projects

Name of project	*Researchers, including postdoctoral fellows*	*Predoctoral research fellows*
Lifespan Neural Dynamics Group within the Max Planck UCL Centre	Douglas D. Garrett**; Niels A. Kloosterman*, Iris Wiegand*	Julian Q. Kosciessa
Cognitive and Neural Dynamics of Memory Across the Lifespan (ConMem)	Myriam C. Sander**[1], Markus Werkle-Bergner**; Andrew R. Bender*, Attila Keresztes*, Ulman Lindenberger, Yee Lee Shing°, Claudia C. Wehrspaun*	Martin J. Dahl, Anna Karlsson, Beate E. Mühlroth, Laurel Raffington, Verena R. Sommer
Mechanisms and Sequential Progression of Plasticity	Yana Fandakova**, Elisabeth Wenger**; Simone Kühn°, Ulman Lindenberger	Oisin Butler, Neda Khosravani
Intra-Person Dynamics Across the Lifespan	Manuel C. Voelkle**°; Annette Brose°, Ulman Lindenberger, Florian Schmiedek°	Janne Adolf, Charles C. Driver
The Berlin Aging Studies (BASE)	Julia A. M. Delius**, Sandra Düzel**, Ulman Lindenberger**; Julia Schröder*, Gert G. Wagner[2]	
Interactive Brains, Social Minds	Viktor Müller**; Ulman Lindenberger	Caroline Szymanski
Sensorimotor–Cognitive Couplings	Julius Verrel**; Whitney G. Cole*, Ulman Lindenberger	Maike M. Kleemeyer
Brain Imaging Methods in Lifespan Psychology	Nils C. Bodammer**; Ulman Lindenberger, Naftali Raz, Davide Santoro*	
Formal Methods in Lifespan Psychology	Andreas M. Brandmaier**; Julian D. Karch*, Ulman Lindenberger, Manuel C. Voelkle°, Timo von Oertzen°	Janne Adolf, Charles C. Driver

Note. Research manager of the Center: Imke Kruse. The table refers to projects and project members as of 03/2017; for updates, visit www.mpib-berlin.mpg.de.
**principal investigator; *postdoctoral fellow; °adjunct researcher (primary affiliation with another institution).
[1] Myriam C. Sander leads a Minerva Research Group (see Box 2, p. 152).
[2] Gert G. Wagner is Max Planck Fellow at the MPI for Human Development (see pp. 263–268 for more information).

2015 of the Max Planck Society for the Advancement of Computational Science for his multiple statistical and computational contributions to behavioral science. Ulrich Mayr (University of Oregon, Eugene, USA) and Silvia Bunge (University of California, Berkeley, USA) were awarded Alexander von Humboldt Research Awards in 2014 and 2016, respectively, and are currently collaborating with the Center on several research projects. Simone Kühn (now at University Medical Center Hamburg-Eppendorf, Germany) and Markus Werkle-Bergner both received the Jacobs Early Career Research Fellowships of the Jacobs Foundation in 2015 and 2016, and Simone Kühn has been awarded a Starting Grant from the European Research Council. In addition to research grants from the German Research Foundation, the Federal Ministry for Education and Research, and the European Union, research at the Center has continued to profit from the Gottfried Wilhelm Leibniz Award 2010 of the German Research Foundation (DFG) given to Ulman Lindenberger, and from continued support from the Innovation Fund of the Max Planck Society.

Overview of Research Projects at the Center for Lifespan Psychology

Currently, in March 2017, empirical and conceptual work at the Center is structured into eight research projects (see Table 1). The activities pursued in these projects cover a wide array of research areas in human behavioral development. For example, the following questions have been addressed during the reporting period: (a) How can we experimentally disentangle knowledge accumulation from other age-correlated processes such as cortical maturation when studying age differences in memory retrieval (Brod, Lindenberger, & Shing, 2016)? (b) Is the female menstrual cycle associated with changes in the volume and functional connectivity of the hippocampus (Lisofsky, Mårtensson et al., 2015)? (c) How can we build a unified statistical framework for the study of within-person and between-person structures (Voelkle, Brose, Schmiedek, & Lindenberger, 2014)? (d) How can we help researchers in the a-priori identification of longitudinal research designs that optimize the statistical power to detect individual differences in change (Brandmaier, von Oertzen, Ghisletta, Hertzog, & Lindenberger, 2015)? We provide our current answers to these questions and many more on the following pages.