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The Positive Plasticity of Adult Development: Potential for the 21st Century

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We are living longer than ever before in human history. But longer lives are at the same time a gift and a challenge for individuals and society alike. Longer lives highlight an extraordinary feature of the human species and, that is, the capacity to intentionally or unintentionally positively modify their own development and aging. This positive plasticity of human development and aging is based on the fact that human aging is neither biologically nor contextually determined. Instead, development and aging are the result of perpetual interactions between biological, sociocultural forces and a given person's behaviors. Rethinking adult development implies that research needs to intensify its efforts to investigate and uncover the conditions and mechanisms facilitating the positive plasticity of adult development and aging. We need to accumulate scientific knowledge about which trajectories of constellations of sociocultural and physical context characteristics, a person's behavioral patterns and genetic endowment are apt to optimize aging. Research examples from cognitive and personality functioning are presented to illustrate the positive plasticity of adult development as well as its limits. Cohort- and country-comparative long-term longitudinal data including physiological as well as behavioral measures besides sociodemographic information and information pertaining to the physical environment are needed to gain a deeper understanding of how to leverage the positive plasticity of human aging. Such evidence is then in a position to provide specific and therefore effective evidence to inform social policy as well as life(style) choices.

Public Significance Statement
Investigating the positive plasticity of adult development aging and accumulating knowledge about it are pivotal in times of population aging. It can inform social policy to create effective and efficient interventions to optimize aging for as many individuals as possible.

Keywords: aging, plasticity, cohort comparison, country comparison, longitudinal studies

Humans are living longer than ever before. Average life expectancy at birth has increased by almost 40 years since 1840. In 1840, the highest average life expectancy at birth was 45 years, observed in Sweden (Vaupel, 2010). In 2017, the worldwide highest life expectancy (at birth) was 84.1 years, observed in Japan. Even though the prevalence of chronic diseases has continued to rise (Bellantuono, 2018)—in large part due to better diagnosis and treatment, which extends life with disease—reductions in the prevalence of dementia and physical disability have been observed as well (Crimmins, 2015). A recent forecast based on the data collected by the Global Burden of Disease Project predicted the highest average life expectancy (at birth) for 2040 would be 85.9 years and would be observed in Spain (Foreman et al., 2018). If public health efforts continue to be strong and successful, the projection even forecasts 87.4 years for Spain in 2040. This increase in average (healthy) life expectancy is a success story of sociocultural development. Driven by economic development that enables improvements in medical knowledge and treatment, public health interventions (hygiene, healthy lifestyle), but also expansion of education and gradual improvements of work environments, positively impacted human health and likelihood to survive into later adulthood. To be clear, in the beginning, these gains in life expectancy were due to decreases of mothers' and infants' deaths as well as death due to infectious diseases and accidents addressing the chance of

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survival during the first 20 to 30 years of life. Yet, since the Second World War, the continued increase in average life expectancy has primarily been due to increases in survival in the second half of life (Vaupel, 2010).

Having achieved longer lives is at the same time a gift and a challenge for individuals and society alike. Living longer—and for the most part, healthier—lives is not the result of biological evolution in the Darwinian sense, but rather it results from continuous interactions of biopsychosocial forces. Thus, it requires never abating societal and individual efforts to maintain or further expand these positive trends (Koh, Parekh, & Park, 2019; Skirbekk, Staudinger, & Cohen, 2019). And indeed, there are admonitory examples to support this argument. The increase of average life expectancy in the United States slowed and fell behind other developed nations toward the end of the 20th century; after 2014, it even started to decrease (Woolf & Schoomaker, 2019). In 2017, the Centers for Disease Control and Prevention reported an average life expectancy at birth of 78.6 (CDC, 2019) as compared to 84.1 in Japan (World Bank, 2019). This development has been driven by preventable reasons such as drug overdoses, suicides, and organ system diseases (Woolf & Schoomaker, 2019).

In the same vein, not all groups in society profit from positive trends in life expectancy. The difference in life expectancy between the lowest and the highest 1% of the income distribution is as high as 12.35 years in the United States (Chetty et al., 2016), emphasizing the point that we need to better understand mechanisms driving such variations to change future trends. Rethinking adult development implies that research needs to intensify its efforts to investigate and uncover the conditions and mechanisms facilitating the positive plasticity of adult development and aging.

Rethinking Adult Development by Focusing on Its Positive Plasticity

This success story of historically unprecedented increase in average (functionally healthy) life expectancy highlights an extraordinary feature that evolution has bestowed on the human species and that is its capacity to intentionally or unintentionally change or (co-)create physical and social environments which subsequently require adaptation and thus impact human development and aging. Anthropologists have called this characteristic of the human species biological adaptability. Three types of adaptability have been distinguished: first, adaptive selection as described by Darwin; second, reversible acclimatization to environmental circumstances; and third, the enduring modification of individuals' development which has been labeled "plasticity" (Lasker, 1969, p. 1484). Lasker further argued that there may be an evolutionary tendency shifting human adaptability from genetic selection to genetic plasticity to reversible adaptability, as greater resilience to contextual change is achieved if adaptations are reversible between generations or even within a lifetime.

Encompassing Lasker's ontogenetic plasticity and reversible adaptation, life span psychology has described plasticity as a constituent characteristic of human development and aging, that is, the potential for modification, as human development and aging are neither biologically nor contextually determined but rather need to be considered as a probabilistic process (P. B. Baltes, Lindenberger, & Staudinger, 2006; P. B. Baltes, Reese, & Lipsitt, 1980; Lerner, 1984).

Three-Tier Interactive Model of Adult Development and Aging Enables Plasticity

Developmental trajectories are the result of perpetual interactions between organism, context and person creating, within biologically and contextually set limits, the potential for variation. Complementing classical formulations in life span psychology, which have put the interaction between biology and context on center stage (e.g., P. B. Baltes et al., 1980), here, we explicitly add the person as agent of their own development as a third influence. The three tiers have equal weight. Figure 1 depicts these three tiers and their interactions, and it highlights that each tier in turn needs to be conceptualized as a system with multiple levels. For organism and person, these within-tier differentiations reflect increasing levels of complexity. For context, the three levels are addressing different types of contextual influences rather than a hierarchy of increasing complexity ranging from objectively measurable characteristics of the environment (e.g., air or water quality, noise, toxins, population

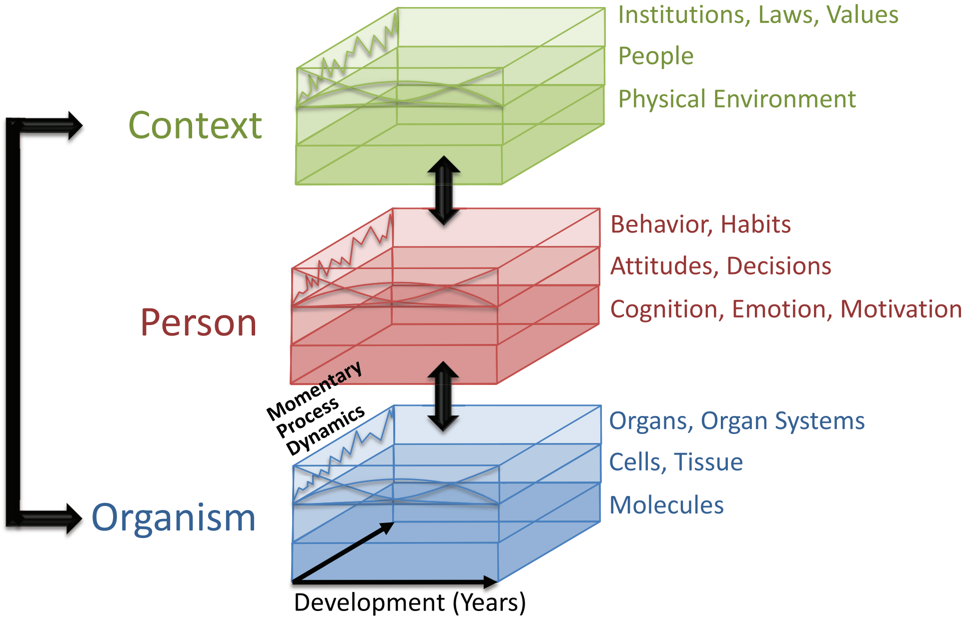

Figure 1. Human aging as multilevel dynamic system (modified after Staudinger, 2015; see also Lindenberger, Li, & Bäckman, 2006). See the online article for the color version of this figure.

density, access to green spaces), to social contexts in terms of immediate social relations such as family or friends but also neighbors or colleagues and people in the street, but also institutions (e.g., labor market, education and health system), laws and political systems as well as societal values and norms.

Multiple streams of psychological research describe, explain and predict a person's behavior and its development. There are three basic areas of psychological functioning, that is, cognitive, emotional, and motivational functioning and their interactions. Second, these three areas are building blocks feeding into attitudes and decisions. Attitudes have been defined as "a relatively enduring organization of beliefs [cognition], feelings [emotion], and behavioral tendencies [motivation] towards socially significant objects, groups, events or symbols" (Hogg & Vaughan, 1995, p. 150), informing decisions that in turn are guiding (volitional and nonvolitional) behavior. As decisions and resulting behaviors are repeated many times, habits are formed which increasingly may diverge from attitudes and conscious decisions.

The complexity of interactions between these three levels of analysis, that is, organism, person, and context, as well as within each of the three tiers, is best modeled using dynamic systems theory, recognizing that cross-level interactions do not only occur at one point in time but also across time (Li, 2003). The dynamics encompass at least three diachronic rhythms, that is, the microgenesis (moment-to-moment changes), ontogenesis (developmental periods), and phylogenesis (epochs of human history). To enhance our understanding of the interrelations between these different rhythms requires appropriate assessment and analytical paradigms that are derived from multiple disciplines ranging from genome analysis, proteomics, or metabolomics and behavior tracking techniques to dynamic systems modeling and big data analyses (Boker, Molenaar, & Nesselroade, 2009).

Coincidentally, the geroscience movement (Kennedy et al., 2014) as well as molecular epidemiology recently acknowledged the need to systematically account for influences on health (and aging) that are not biological and for that purpose introduced the concept of "exposome" (Wild, 2012). Even though life sciences and epidemiology are using different terminology and methods, and a focus on pathology rather than growth, they share the goal to develop a more comprehensive model of human aging.

The Notion of Positive Plasticity

Plasticity of human development as such is a neutral characteristic encompassing positive (increased level of functioning) as well as negative (decreased level) longer term deviations from typically observed developmental trajectories (Staudinger, Marsiske, & Baltes, 1995). When determining the degree of plasticity, longer term deviations from developmental trajectories need to be differentiated from short-term fluctuations, in the same way as developmental changes and fluctuations need to be separated. Combining a measurement burst with a standard longitudinal design (e.g., annual assessments) and using change score models allow researchers to estimate the relation between intraindividual variability and longitudinal change in latent space and hence to arrive at rather reliable change estimates (e.g., Salthouse & Nesselroade, 2010).

Once negative deviations pass the threshold to dysfunctionality, they receive research attention in clinical psychology and medicine with an aim to develop treatments as well as preventive measures. Research on negative deviations, however, does not necessarily inform about how to leverage positive plasticity. There has been extensive discussion that understanding weaknesses and pathology is not synonymous with understanding how to best promote strength (Aspinwall & Staudinger, 2003). In fact, even two notions of positive plasticity need to be distinguished: resilience and growth. The notion of resilience refers to positive plasticity that supports the maintenance or recovery of functioning under conditions of developmental stress (e.g., unemployment, illness, widowhood) and has received recent attention also in medical research (Whitson et al., 2016). When resources support a positive deviation from typical developmental trajectories (with or without the presence of stressors), this type of positive plasticity is called growth or thriving (Carver, 1998; Staudinger & Greve, 2016; Staudinger et al., 1995).

The direction and degree of plasticity observed depend on the vulnerabilities and resources characterizing a person's internal (genetic, psychologic) and external (sociocultural, physical environment) developmental contexts (P. B. Baltes et al., 1980; Lerner, 1984; Staudinger et al., 1995). Constellations of vulnerabilities and resources and their cumulation across time differ between individuals implicating a need to consider personalized plasticity. Applying the notion of personalization to positive plasticity highlights the necessity to investigate which type of longitudinal pattern of biological, psychological and external contextual resources best facilitates plasticity. In contrast to the notion of personalized (or precision) medicine (Hodson, 2016) which prioritizes genetic differences between individuals, personalized plasticity aims to incorporate biological, psychological, sociocultural and physical features of environments as well as their interactions. Certainly, interindividual differences in aging and in risks and resources impacting aging have been considered before using the label "differential aging." The added value of the notion "personalized plasticity" is that it alerts to the modifiability of aging and the fact that promoting positive plasticity of aging may not follow the "one size fits all" rule.

Positive plasticity comprises manifest and latent components. The manifest component depends on internal and external resources a person has readily available at a given time during development. It is indicated by intraindividual differences in levels of functioning across time or approximated by interindividual differences among developmental trajectories. Furthermore, country and cohort differences in developmental trajectories allow researchers to approximate plasticity linked with social–cultural, environmental, and historical differences. Latent components of positive plasticity denote modifications in developmental trajectories that depend on acquiring new resources or strengthening available resources. Even though the degree of positive plasticity is declining across the life span, in principle it is maintained throughout life unless severe pathological processes interfere. Thus, in the case of Alzheimer's dementia the ability to profit from cognitive training is severely curtailed (M. M. Baltes, Kühl, Gutzmann, & Sowarka, 1995), yet not completely lost (Bahar-Fuchs, Martyr, Goh, Sabates, & Clare, 2019).

For the positive-plasticity paradigm, rethinking adult development implies that research needs to intensify its efforts to investigate and uncover the conditions facilitating positive plasticity of adult development and aging in times of population aging. We need to accumulate scientific knowledge about constellations of sociocultural and physical context characteristics, persons' behavioral patterns and biological endowments that help to optimize aging for as many individuals as possible. Historical increases in average as well as (functional) healthy life expectancy, described above, are two pieces of evidence supporting the tenet that human aging in principle is characterized by positive plasticity. In the following, empirical evidence of positive plasticity of cognitive and personality functioning will be presented.

Positive Plasticity of Cognitive Aging: Potential and Limits

Cognitive Aging

It is well-established that fluid intelligence (Horn & Cattell, 1967) or cognitive mechanics (P. B. Baltes et al., 2006) which denote the biological basis of cognitive functioning, such as the number of neurons, of synaptic connections and metabolic brain function, decline with age impacting speed of information processing, executive functioning, logical reasoning, or memory. Based on cross-sectional and longitudinal evidence the decline process starts rather early in the mid-20s (Salthouse, 2004). More positive trajectories derived from longitudinal studies are attributable to practice effects due to repeated assessments as well as positive selectivity of longitudinal samples across time (Singer, Verhaeghen, Ghisletta, Lindenberger, & Baltes, 2003).

Cognitive aging is linked with modifications in the structure and function of the brain. It has been associated with overall volume loss in white and in gray matter across the adult life span as well as with changes in neuromodulation and neural networks (Kalpouzos, Persson, & Nyberg, 2012; Raz et al., 2005). The extent of decline varies by brain region. There is plenty of evidence that better executive functioning is associated with larger gray matter volume in the prefrontal cortex, that hippocampal shrinkage mediates age differences in episodic memory, and that faster processing speed is associated with more gray matter in frontal, parietal, and occipital regions (Salthouse, 2011).

The positive-plasticity paradigm asks whether and under which circumstances this trajectory of age-related decline in the cognitive mechanics is modifiable. Modification can impact the trajectory intercept, its inflection point, and the slope of decline. Different types of evidence need to be considered here: (a) comparisons of birth cohorts, (b) comparisons of countries in different phases of sociocultural development, and (c) experimental and quasi-experimental evidence demonstrating improvements in cognitive performance. Thus, the positive-plasticity paradigm of adult development reaches beyond the comfort zone of psychology focusing on the individual to also include a macro perspective targeting countries as unit of investigation as usually done by demography, economics or sociology.

Cohort Improvements in Cognitive Aging/Performance

First to consider is evidence on cohort improvements in mean levels of cognitive performance. The seminal Seattle Longitudinal Study (e.g., Schaie, 1996) showed that across 50 years of historical time (birth years 1890–1940) the level of cognitive functioning in a number of cognitive tests improved by 1.5 *SD*. This is an impressive indication of positive plasticity of cognitive performance that has been attributed to societal development such as improved health system and protein-rich diet, better educational system, smaller family size, modern parenting styles, the rise of digital media, more complex jobs, and more leisure devoted to cognitively demanding pursuits, and it has also been called the Flynn effect (Flynn, 1987; Trahan, Stuebing, Fletcher, & Hiscock, 2014). Some evidence indicates that the Flynn effect recently may have come to a halt. Yet, it needs to be interpreted with care as reference populations used to assess the effect have changed across historical time (e.g., discontinued mandatory military service or increasing migrant populations with lesser language skills; Skirbekk, Stonawski, Bonsang, & Staudinger, 2013). Originally, the Flynn effect referred to the improvement of cognitive performance levels in early adulthood but more recently it was found that the improvement is maintained into middle and later adulthood (Gerstorf et al., 2015; Skirbekk et al., 2013). Also, cognitive improvements in later life likely will continue even after the Flynn effect may come to a halt in early adulthood as sociocultural changes linked with the lengthening of lives are only starting to unfold and will trigger positive plasticity in current and future cohorts of middle-aged and older adults. To illustrate the scale of societal impact of such cohort improvements in cognitive aging, it is informative to project them to the population level. When doing so, the United Kingdom, for instance, will on average show higher levels of cognitive performance in the year 2040, even though chronologically it will be older (Skirbekk et al., 2013). In other words, the sociocultural scaffolding linked with increased average population cognition levels not only counterbalances age-related cognitive decline but overcompensates it.

Sociocultural Differences Between Countries and Cognitive Performance

Second, there is evidence from studies comparing age-related levels of cognitive functioning across countries. Such studies only yield a rough cross-sectional proxy of aging trajectories and can therefore only be considered a first step, yet it is a start for tackling the daunting task of investigating sociocultural influences on aging.

Socioeconomic country differences. Thanks to major efforts to harmonize large-scale population surveys around the world, it is now possible to compare age-related levels of cognitive performance and sometimes even aging trajectories across many countries around the world. Comparable surveys of older adults include, for instance, English Longitudinal Study of Aging, Health and Retirement Study, World Health Organization Study on Global Ageing and Adult Health, and Survey of Health, Ageing, and Retirement in Europe, which together cover 45.5% of the world population above age 50. Statistically significant negative age differences in immediate word recall were found in all countries within the age range of 50 to 85 years of age. But there were also tremendous differences between countries: Older adults in the United States, Northern and Central European countries had the highest immediate recall performance, whereas their age peers in Southern Europe, China, India, and Mexico performed worse. The average memory performance of 70-year-olds in the United States was found to be higher than the average performance of 50-year-olds in India or China. These analyses suggest that the same chronological age is associated with different levels of cognitive performance in countries representing different phases of sociocultural development (Skirbekk, Loichinger, & Weber, 2012). The authors suggested that the expansion of the educational system, increase in cognitively stimulating occupations as well as the general level of exposure to information in everyday life seems to be among the drivers of these country differences. And indeed, education, or cognitive stimulation in the sense of learning has been linked with increased neocortical synaptic density.

Cultural differences: The sample case of gender equality. Beyond sociostructural country differences, there is also some initial evidence on the importance of cultural influences such as social norms. In particular, attitudes toward gender equality as compared to traditional gender roles have been found to positively impact cognitive performance in later life. This is particularly the case for women, but to a lesser degree also for men. Gender differences in cognition are based on biopsychosocial interactions throughout the lifecourse. In that vein, social–cognitive theory of gender development suggests that gender roles play an important mediating role. When analyzing country differences in the gender differential in cognition after midlife, using samples from 27 countries aged 50 and above (N = 226,661), older women indeed performed relatively better in countries characterized by more equal gender role attitudes (Bonsang, Skirbekk, & Staudinger, 2017). This result was robust against cohort differences as well as reverse causality. Educational and labor force participation partially mediated this finding. This is a first indication that social norms as part of the sociocultural context can trigger positive plasticity.

Impact of the physical environment on cognitive aging. Most of the evidence in this area of research to date has focused on negative plasticity effects. For instance, longitudinal studies have found associations between accelerated age-related cognitive decline and long-term exposure to ambient air pollution (Power, Adar, Yanosky, & Weuve, 2016) or lead in the area of residence (Shih, Hu, Weisskopf, & Schwartz, 2007). Living quarters that are subject to sun deprivation, often a characteristic of low-income housing, may lead to vitamin D deficiency which has been linked with cognitive decline (Llewellyn et al., 2010). Also, environmental noise is associated with higher levels of stress, which has been shown to have adverse effects on learning and memory through neurodegeneration and hippocampal restructuring (McEwen & Gianaros, 2011). Recently, in line with the positive-plasticity paradigm, studies found nature experience to be a resource for cognitive functioning mostly mediated through improved attention and stress reduction (Bratman, Hamilton, & Daily, 2012).

Limits of Cognitive Plasticity

Although cognitive performance levels in old age have been increasing in most countries, recent evidence documents a slowing of cohort gains or even a drop in cognitive performance when comparing successive cohorts in highly developed countries. Thus, trends and determinants in cohort gains in cognitive functioning among older individuals, and the question whether cohort gains are indeed levelling-off in most advanced countries deserve further scrutiny. Using data for individuals aged between 50 and 84 years from the Survey of Health, Ageing, and Retirement in Europe in 10 European countries between 2004 and 2013 (N = 92,739), performance in immediate word recall was found to improve in all countries between 2004 and 2013 (Hessel, Kinge, Skirbekk, & Staudinger, 2018; for replication, see Ahrenfeldt et al., 2018). However, cohort gains were significantly smaller in countries with initially higher performance levels. These results were robust when controlling for retest effects and regression to the mean. Also, no ceiling effects were present in the data. Changes in sociodemographic and health conditions, including decreases in cardiovascular disease, increases in work activity (among men), physical activity and educational achievement, were associated with larger secular cohort gains. Results may either reflect that some countries are approaching the biological limits of cognitive plasticity, are slowing in their progress, or that societal structures have not yet been optimized to leverage the positive plasticity of cognition in later life, or a combination of these interpretations (Hessel et al., 2018).

"Assigning" Individuals to Contexts Attenuating Cognitive Decline

Finally, there is a rich array of studies using experimental or quasi-experimental designs providing encouraging evidence that exposing individuals to cognitive stimulation or by increasing their physical fitness improves cognitive performance well into old age (Leshner, Landis, Stroud, & Downey, 2017; Lindenberger, 2014; Simons et al., 2016). Cognitive stimulation can consist of learning strategies to better solve cognitive tasks (i.e., [brain] training), repeated exposure to solving cognitive tasks (with and without feedback; i.e., practice), or exposure to stimulation in everyday settings (work or leisure). The following overview of this large and still growing literature is not meant to present another comprehensive review but rather convey a broad-brush summary for the purpose of illustrating the positive plasticity of cognitive aging. This summary is organized in three sections: cognitive practice or training interventions, physical fitness interventions, the effect of exposure to stimulating everyday life settings.

Cognitive training. Since the 1970s, cognitive-training studies have demonstrated that older adults can improve cognitive performance both based on practice of a given task (e.g., memory, reasoning) or when provided with training in strategies to better solve the cognitive task at hand (P. B. Baltes & Willis, 1982). Ten years later, such performance improvements were reduced but not completely eradicated and were easily regained after short refresher trainings suggesting that cognitive decline was attenuated (Willis & Nesselroade, 1990). The training literature, however, also suggests limited transfer of performance improvements from trained cognitive tasks to untrained cognitive tasks tapping the same cognitive ability as well as to different but related cognitive abilities training (Noack, Lövdén, & Schmiedek, 2014). A multisite clinical trial confirmed a lack of training transfer across cognitive tasks at the 10-year follow-up, yet showed that speed, reasoning and memory training had positive effects on self-reported instrumental activities of daily living but not on performance-based tests of everyday problem-solving (Rebok et al., 2014). Training studies focusing on cognitive control processes have suggested that providing structured and massed experiences in situations demanding executive coordination of skills—such as complex video games, task-switching paradigms, and divided attention tasks—show immediate improvement in intermediate transfer tasks but no far transfer when compared with treated control conditions (Melby-Lervåg, Redick, & Hulme, 2016).

The mediating mechanisms underlying such training gains are not yet fully known but partially they seem to be compensatory in nature such that participants learn a strategy which helps them to attain better cognitive performance. In that vein, classical memory training effects in older adults using the method of loci to improve immediate recall performance (e.g., P. B. Baltes & Kliegl, 1992) were found to be primarily based on changes in the visual cortex linked with the mnemonic strategy "method of loci," which requires to visualize the to-be-remembered word in a place, rather than changes in brain areas known to undergo age-related declines such as the prefrontal cortex (Nyberg et al., 2003).

Physical fitness. Since the late 1990s, a rich and still growing body of evidence has revealed a modest positive influence of improved aerobic physical fitness on cognitive functioning in older adults (and mammals in general) in particular on executive-control processes (Kramer & Colcombe, 2018). Studies examining the behavioral and neurophysiological effects of type and longer-term duration of physical training, however, are still rare. A 12-month longitudinal study that compared the effects of cardiovascular and coordination training (control group: relaxation and stretching) on cognitive functions (executive control and perceptual speed) in older adults that used spirometry to monitor actual improvements in physical fitness, found that after 6 months of cardiovascular training (3 $\times$ 45 min per week) increases in perceptual speed as compared to the control group. All training sessions took place in a group setting. Neuroimaging revealed that improved cognitive functioning was linked with reduced activation of prefrontal brain areas that have been linked with controlling cognitive processes and undergo age-related decline (Voelcker-Rehage, Godde, & Staudinger, 2011). Studies that have combined physical fitness training with training of cognitive control processes have found that the combination of both is more effective still than either of them alone (Hötting & Röder, 2013).

Even though large-scale, well-controlled prospective cohort studies replicating the impact of aerobic fitness on cognitive aging are still missing, it is very promising that evidence is available from animal and human studies investigating the biologic mechanisms that may mediate the positive effects of aerobic fitness on cognitive performance (Mandolesi et al., 2018). This evidence helps to answer the crucial question whether aerobic fitness facilitates cognitive performance, throughout the life span but in particular in later life by modifying the biological mechanisms underlying cognitive decline or by better compensating for neurodegenerative processes (Hötting & Röder, 2013). Evidence has accrued that the following mechanisms get triggered by improvements in aerobic fitness: neurogenesis, synaptogenesis, angiogenesis, gliogenesis in neocortex and hippocampus; modulation in neurotransmission system (serotonin, noradrenalin, acetylcholine); increased neurotrophic factors (brain-derived neurotrophic factor, insulin-like growth factor-1; Mandolesi et al., 2018). Further, muscle and bone play an important role in this mediation (Obri, Khrimian, Karsenty, & Oury, 2018). This evidence is consistent with the assumption that aerobic exercise actually alters the biological structures and mechanisms underlying neurodegeneration.

Personalized cognitive plasticity. This last study investigating the impact of aerobic fitness on cognitive performance also provided evidence for personalized plasticity. Genetic predispositions influence cognitive performance, particularly in older adults. In this context, the catechol-O-methyltransferase (methionine [met] and valine [val] alleles) gene is a candidate gene associated with executive functions (Goldberg & Weinberger, 2004). Met allele carriers demonstrate about 40% lower prefrontal enzymatic activity than val allele carriers (Chen et al., 2004), which is associated with less prefrontal cortical dopamine degradation linked with more efficient cortical processing (Witte & Flöel, 2012). Accordingly, met/met allele carriers show advantages in tasks of executive functioning. In this vein, it was demonstrated that physical exercise interventions with older adults showed greatest benefits for catechol-O-methyltransferase val/val and val/met allele carriers (Pieramico et al., 2012; Voelcker-Rehage, Jeltsch, Godde, Becker, & Staudinger, 2015). Such findings underscore that beyond the main effect of a given plasticity-triggering intervention, the degree of efficiency of a given intervention may vary between subgroups of older individuals. Genetic predispositions are, however, only one kind of personalization. Ideally, it is socioeconomic circumstances, characteristics of personality functioning and/or environmental exposures as well as their cumulative interactions that need to be considered when differentiating between groups of individuals to test for moderation effects of a given intervention, requiring further elaboration of statistical techniques that allow us to test longitudinal multivariate moderation effects.

Cognitive stimulation "in the wild": The sample case of work and leisure. "In the wild" approaches denote studies investigating cognitive stimulation provided by everyday activities such as learning a new language, playing a musical instrument or the tasks pursued at work (e.g., Hultsch, Hertzog, Small, & Dixon, 1999; Park et al., 2014; Schooler, Mulatu, & Oates, 1999). Ample research has investigated the cognitive stimulation or "use it or lose it" hypothesis (Hultsch et al., 1999; see also Denney, 1984), that is, the idea that cognitive aging processes can be attenuated by engagement in everyday activities at work or during leisure time. In contrast, the lack of such engagement is assumed to result in a faster and more pronounced decline. Over the last 50 years, research on the cognitive stimulation hypothesis has revealed promising results. Older individuals who expose themselves to cognitively stimulating leisure-time activities and/or work environments over a prolonged period of time demonstrate higher levels of cognitive functioning later in life and less cognitive decline. There is correlational (e.g., Wilson, Barnes, & Bennett, 2003), longitudinal (e.g., Bosma et al., 2002; Schooler et al., 1999), and also experimental work (Park et al., 2014; Stine-Morrow, Parisi, Morrow, & Park, 2008) to support this notion. Adding to the "use it or lose it" hypothesis, experimental studies demonstrated that it is particularly learning new skills and processing novel information that seems to buffer cognitive decline and increases neural efficiency in prefrontal areas that are known to undergo age-related neurodegeneration (McDonough, Haber, Bischof, & Park, 2015; Oltmanns et al., 2017). In that sense, it may be even more fitting to talk about "challenge it or lose it" than "use it or lose it."

In particular, the facilitative effect of cognitive stimulation experienced at work has received support, as population-based longitudinal studies have become available which allow us to study the effect of cognitive stimulation on cognitive change and have rich information about participants enabling sophisticated statistical control to minimize the likelihood that the facilitative effects are the mere results of baseline differences in cognitive functioning which are preserved across time (Salthouse, 2007). Cognitively stimulating occupations have been shown to buffer age-related decline in cognitive functioning in middle and later adulthood. Occupations of higher job complexity, specifically with data and people, are associated with better cognitive performance, slower cognitive decline and a reduced risk of dementia/Alzheimer's disease (Andel et al., 2005; Fisher et al., 2014).

As groundbreaking as the job-complexity investigations have been, they leave the question unanswered which specific cognitive mechanisms underlie this positive plasticity of cognitive aging or what happens with employees working at lower levels of complexity. Thus, it might be useful to identify job characteristics reflective of cognitive stimulation at work that are more closely linked with specific cognitive processes and may also profit workers with less complex jobs. Novel information processing at work, which can also occur at lower levels of job complexity, has been investigated as to whether it might serve that function. In a case-control study, it was confirmed that the recurrent exposure to work-task changes at low levels of job complexity had significant positive effects on gray matter volume and cognitive functioning of middle-aged production workers across a time window of 17 years. Specifically, more work-task changes were linked with faster processing speed and higher levels of working memory as well as with more gray matter volume in brain regions associated with learning and showing pronounced age-related decline. Hence, introducing recurrent novelty at work may serve as a positive-plasticity intervention that helps buffering detrimental long-term effects of lower job complexity (Oltmanns et al., 2017). In a follow-up study, the buffering effect of novelty processing at work was confirmed using longitudinal data from 4,255 participants of the Health and Retirement Study (50 years and older) covering 14 years of cognitive change (Yu, Cheng, & Staudinger, 2020). This replication is encouraging as it also used a different operationalization of novelty processing at work. The replication study took advantage of the O*NET, a data platform that contains continuously updated information about work characteristics of more than 1,000 occupations.

Positive Plasticity of Personality Aging

Personality Aging

Research on the positive plasticity of aging of personality traits is still in its infancy compared to that on the positive plasticity of cognitive functioning. There seems to be less reason to study it as rather few age-related trends with dysfunctional consequences for everyday life have been observed in this domain of personality functioning. Longitudinal studies have shown that mean levels of emotional stability, conscientiousness, agreeableness increase across the adult life span (for a meta-analysis, see Roberts, Walton, & Viechtbauer, 2006). This positive change pattern was found for most of adulthood, whereas the patterns seems to change in very old age (>80 years). The few longitudinal studies that also covered the last phase of life mostly demonstrated a reversed trend, as conscientiousness, agreeableness, and emotional stability were found to decrease (Mõttus, Johnson, & Deary, 2012). There are, however, also some studies suggesting stability or increases toward the end of life in conscientiousness, agreeableness, and emotional stability (Lucas & Donnellan, 2011). The positive change pattern for conscientiousness, agreeableness and emotional stability across most of adulthood has been labeled maturation (e.g., Roberts & Wood, 2006) or maturation toward adjustment (Staudinger & Kunzmann, 2005).

In the realm of personality aging there is only one age trend that can be considered dysfunctional and that is the decline in "openness to new experience." Openness increases somewhat from early adolescence until age 20, then remains stable, and declines subsequently starting in midlife by 1 *SD* (Roberts et al., 2006). With increasing age, adults become on average less behaviorally flexible and show decreasing motivation to seek out new and varied experiences and ideas. Longitudinal studies showed that openness seems to attenuate cognitive decline (Luchetti, Terracciano, Stephan, & Sutin, 2016). The plasticity-triggering effect of openness on cognitive aging seems to be mediated by activity engagement (Hogan, Staff, Bunting, Deary, & Whalley, 2012).

Positive Plasticity of Openness to New Experience

Personality plasticity "in the wild." As openness is a crucial characteristic supportive of learning as well as of staying in touch with an ever-changing world, it may useful to test the assumption that the level of openness observed in adults 50 years and older will show positive plasticity. Supporting this contention, there is experimental evidence supporting the positive plasticity of openness to new experience as a result of participating in a cognitive-training intervention study (Jackson, Hill, Payne, Roberts, & Stine-Morrow, 2012). In the same vein, it was found that exposure to volunteering activity in later life, in combination with a 9-day competence training, predicted a significant increase in openness of about 1 *SD* as compared to a waiting-list volunteer control group across 15 months, and over and above observed cognitive change (Mühlig-Versen, Bowen, & Staudinger, 2012). The training program provided volunteers with competencies relevant for volunteering activities and to support them in initiating their own personal volunteering project(s) in their neighborhood or community (e.g., practical organizing and management skills, personal competencies to master challenges).

This positive-plasticity effect was concentrated on participants with above median levels of internal control beliefs. Hence, it can be taken as another unidimensional indication of personalized plasticity. Across 15 months, openness significantly increased (instead of decreased), particularly for persons who believe that they can influence their life, and who at the same time are exposed to new tasks and to task-specific training. This interaction effect is in line with findings that adults with higher internal control beliefs can better profit from opportunities because they are more active, are better able to buffer contextual stressors, and demonstrate more motivation to learn (Lachman, Neupert, & Agrigoroaei, 2011).

Sociocultural characteristics of countries and positive plasticity of openness. From middle to later adulthood, labor-force participation rates and participation in lifelong learning are declining in most developed economies even though there has been an increase in later-life employment as compared to the 1980s (Staudinger, Finkelstein, Calvo, & Sivaramakrishnan, 2016), which is particularly problematic because the need for cultural scaffolding increases as biological potential wanes with aging (P. B. Baltes et al., 2006). A recent study tested the assumption that sociostructural and sociocultural resources pertaining to active engagement in later life accounted for national variations in the age—openness associations after age 50 (Reitz, Shrout, Weiss, & Staudinger, 2020). Using the European Social Survey (29 nations, $N = 25{,}152$) revealed an overall negative association between age and openness that, however, as expected, varied systematically across countries. Countries with more opportunities for adults aged 50 years and older to participate in the labor force, in volunteering and training programs showed less negative age—openness associations or no association with age at all. It seems that societies supporting engagement of individuals after midlife can help them maintain levels of openness and thus contribute to their ability and willingness to learn. In addition to structural influences, the degree to which countries entertained a negative old-age stereotype was associated with more pronounced negative age differences in openness in later adulthood most likely by turning into self-fulfilling prophecies. There is a cross-cultural consensus that older adults are perceived as decreasing in their ability to perform everyday tasks and to learn (North & Fiske, 2015). The internalization of negative perceptions of old age (Levy, 2009) contributes to the typical decrease of openness across adulthood.

Further Examples for Positive Plasticity of Personality Aging

Quasi-experimental studies show that social roles may play an important role in personality adjustment across adulthood (e.g., marriage, job promotion, chronic disease; Hutteman, Hennecke, Orth, Reitz, & Specht, 2014). In that vein, marriage stability predicted increases in conscientiousness in midlife women, whereas getting divorced predicted decreases in this trait (Roberts & Bogg, 2004). Comparing developmental patterns in people who were promoted versus those who were laid off (Costa, Herbst, McCrae, & Siegler, 2000) showed job loss to be associated with decreases in emotional stability and conscientiousness. In a prospective study the onset of chronic disease predicted decreases in emotional stability and conscientiousness (Jokela, Hakulinen, Singh-Manoux, & Kivimäki, 2014). By and large, as confirmed in a recent review, critical life events seem to have the potential to trigger personality change (Bleidorn, Hopwood, & Lucas, 2018).

Positive Plasticity of Adult Development and Aging: Conclusions and Challenges

In sum, there is evidence (even if it is not yet reflecting all the complexity depicted in Figure 1) to support the tenet of positive plasticity of cognitive aging, and at least some that supports the positive plasticity of personality aging. As harmonized country- and cohort-comparative longitudinal data sets have become available, the limits of positive plasticity have been started to be investigated. And first evidence has shown that positive trends seem to level off in certain countries and for certain cohorts. Multiple interpretations of this trend are possible, ranging from approaching biological limits to underdeveloped sociocultural scaffolding. Future studies will decide which interpretation or which combination matches reality most closely. For both personality and cognition, it seems that exposure to novelty and challenge (e.g., work tasks, physical fitness, critical life events) are important triggers of positive plasticity. Insight into the mediating mechanisms is somewhat advanced for the positive plasticity of cognitive aging (i.e., compensation, reactivation) but is still in its infancy for the positive plasticity of personality aging. Also, first evidence—even though unidimensional—has been collected that highlights the usefulness of the concept of personalized plasticity. Pursuing the notion of personalized plasticity is not an easy task as it requires large representative data sets that provide the statistical power to detect moderation effects as well as sound theoretical approaches informing the derivation of moderation hypotheses.

Cognition and personality were chosen as sample cases to illustrate positive plasticity of aging. There is, however, also research supporting positive plasticity beyond cognition and personality. For instance, in the area of self-regulation there is evidence for the positive plasticity of internal control beliefs (i.e., expectancies about personal mastery and environmental contingencies; Lachman et al., 2011), which have been found to be highly functional and tend to decline with age. Further areas for research on positive plasticity of adult development and aging concern, for instance, emotional functioning, social relations and social support, or coping.

For the positive-plasticity paradigm to progress, population-based cohort- and country-comparative long-term longitudinal data are needed that include biomarkers as well as a rich set of behavioral measures, sociodemographic (ethnicity, race, gender, socioeconomic status) as well as sociocultural (e.g., norms, values) information and objectively measured information, such as levels of air pollution or lead exposure, pertaining to the physical environment. It is such multilevel longitudinal data, in combination with creative experimental approaches using subgroups that will allow us to gain a deeper understanding of how to best and most efficiently leverage the positive plasticity of human aging for as many people as possible. Based on such evidence highly specific and therefore effective evidence will be available to inform social policy, human resource practices as well as life(-style) choices. The positive plasticity paradigm of adult development and aging highlights the need for continuous monitoring of aging trajectories to identify historical trends in time, while acknowledging the ethical issues pertaining to privacy which have to be addressed. Interdisciplinary cooperation on a level playing field is pivotal for progress. (Lifespan) Psychology needs alliances with the life, neuro and medical sciences, as well as with lifecourse sociology, economics, social history, and demography.

Why hasn't there been more progress? Certainly, one hindrance has been and continues to be the availability of multilevel longitudinal data sets, but this is not the only hindrance to overcome. The positive-plasticity paradigm aims high and hosts a number of challenges that need to be addressed for substantive progress to occur (Staudinger, 2015): (a) University curricula in adult development and aging have to strike a balance between disciplinary depth and interdisciplinary breadth. A foundation for interdisciplinary breadth needs to be established during doctoral studies and the strengthening of interdisciplinary skills have to become a standard part of the postdoctoral phase. (b) It is pivotal to hone assessment tools across levels (organism, person, context) including valid, reliable, and scalable biomarkers; unobtrusive behavioral measures based, for instance, (but not only) on big data; accurate and broadly available measures of environmental exposures (air quality, noise, etc.); or more comprehensive assessments of sociocultural characteristics. Given that ideally such assessment tools should be available worldwide, the challenge is immense and requires research infrastructure investments unheard of to date in the behavioral and social sciences. Yet, they are comparable to investments that have been made in global research infrastructure in the field of physics (e.g., Conseil Européen pour la Recherche Nucléaire). Striving toward the implementation of such data infrastructure is essential for progress in the science of aging and the positive-plasticity paradigm. (c) Statistical methods need to be developed further and newly created to accommodate different types of data, improve causal inferencing based on observational data and further refine typological trajectory analysis to include multivariate approaches as well as the testing of multivariate longitudinal moderation effects. (d) Impactful interdisciplinary publications outlets for positive-plasticity research are needed to accommodate research findings based on the interaction between organism, person and sociocultural as well as physical environment across time. (e) Finally, an implementation science focusing on how to make use of the (personalized) positive-plasticity evidence is required. Similarly to the medical and life sciences (Handley, Gorukanti, & Cattamanchi, 2016), it is now time for the behavioral and social sciences to turn the implementation of well-replicated evidence into a science in itself and aim for a systematic analysis of critical barriers and facilitators. This kind of implementation science is likely to be more complex than that developing in the health sciences as the targets of implementation are not only focused on the health system but include all aspects of society such as the educational system, the labor market, or urban planning. Nevertheless, lessons can be learned from health-related implementation science, for the positive-plasticity endeavor.

The tasks ahead seem overwhelming, yet let me close on an optimistic note: Even though we are still in the early stages of mastering the positive plasticity of adult development and aging, the pathway for advancement has been laid out and very promising building blocks have become available that will allow us to take the next steps.

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