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ACADEMIC LITERATURE REVIEW

Aging and inactivity—capitalizing on the protective effect of planned physical activity in old age

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Abstract The paper discusses two parallel biocultural trends—aging and inactivity. The principle of economy in movement in modern society versus the dependency of human beings on movement for their development and health is described. The results of inactivity are sometimes mistakenly considered irreversible losses caused by aging, but in actual fact, inactivity accelerates the irreversible losses caused by the aging process. The paper then describes the contribution of physical activity in terms of increasing positive aspects or decreasing risks: increasing life expectancy or decreasing risk of mortality, increasing cardiovascular fitness or decreasing risk of cardiovascular disease, increasing muscle mass or decreasing falls and instability, improving cognitive performance or reducing cognitive decline and neurological disorders, and improving well-being or reducing depression. The optimal dose of physical activity is then described, followed by recommendations for further research on mechanisms determining physical activity behavior.

Keywords Aging · Inactivity · Planned physical activity · Physical and mental health

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Remedy versus prevention

Why has the public become increasingly aware of the interrelationship of health, physical activity, and age? Soaring health costs are becoming more and more difficult to finance. One of the effects of this cost explosion is the expression of the long-repeated promise that medicine will reconsider the consequences of its virtually exclusive role as a pervasive "repair system" and will instead place the emphasis on prevention. One of the bases for this promise is the positive effects evinced by a training-related intervention on the physical and mental performance abilities of older people. This evidence is by now so convincing that it can no longer be ignored. The possibility of spending today's prolonged life span in health and activity and of minimizing the period of age-related restrictions and diseases makes the significance of changes in behaviors and lifestyle difficult to overstate [28]. Compared to many other products marketing "successful aging" as a selling point, exercise is low-cost and low-tech, accessible to nearly everyone, and thus highly suited for potentially widespread participation [45].

Consequently, interest has been growing in recent years concerning the effects of physical activity on the aging process [1, 3, 20, 65, 85, 86]. The purpose of this paper is to describe two parallel biocultural trends—aging and inactivity—and to examine the role of intended, planned physical activity as protection against their outcomes. All aspects presented in the paper are viewed in a two-dimensional dichotomous approach, sometimes on a complementary continuum and sometimes as contrasts.

Movement economy versus movement necessity

As current developments in medicine as a preventive measure lead to possible conflict with medicine as a remedial system, two elemental human phenomena are clearly moving toward a crisis relationship. They may even reach their “critical mass” along with the looming development of obesity and the current developments in longevity. On one hand is the *principle of economy*—the human aspiration to reduce physical and mental efforts to a minimum through the use of cutting-edge technological development. This development has caused a decrease in physical activity in all ages, including the very young [15]. On the other hand is the *adaptation principle*—the natural dependence of human beings on movement, environmental stimuli, and physical loads to trigger beneficial development from childhood to advanced adult age [37]. While this movement economy/movement necessity issue may be described as a biocultural conflict, its roots are solely biological. Apparently, there is a biological basis for the age-related decline in physical activity among both nonhuman subjects [41] and humans [75]. The dopaminergic neurotransmitter system appears to be a possible neurobiological mechanism that can explain this decline (Ingram). Interestingly, this mechanism not only affects the ability to move but also involves motivational factors or the “will” to participate in physical activity.

Demography of inactivity versus demography of aging

Whether cultural or biological, the principle of movement economy is unfortunately stronger than the need to move. The clear reduction in physical activity with age has been reported in quite a few statistical sources [85]. Statistics continue to show that the majority of older adults do not engage regularly in moderately intense physical activity [48, 83]. Furthermore, although increasing physical activity participation has been a major goal of several initiatives especially in the USA [86], little change in physical activity patterns has been reported across any age group, so that the relevant statistics have remaining largely unchanged over the past 15–20 years [64].

With the biocultural reduction in physical activity related to the aging process, there has been a dramatic growth in the older adult population throughout the world [84, 87]. The causes responsible for this change and associated phenomena, e.g., a drop in birthrate, optimized medical care, increased life expectancy, and especially longevity, have led to an increase in causal research and have raised new questions about the developments in health care.

Life expectancy in Germany, for example, is 82.0 years for women and 77 years for men, in Italy 84 and 78 years, in the UK 81 and 77 years, and in the USA 80 and 75 years, respectively. These figures are even higher when life expectancy is calculated at the age of 65–69. Women in Germany are expected to live 20.4 and men 17.1, in Italy 21.5 and 17.7, in the UK 19.7 and 169, and in the USA 20 and 17.3, respectively (World Health Organization, http://www.who.int/whosis/whostat/2008/en/index.html). In the USA, the over 65 population is expected to more than double between 2000 and 2030, from 35 million to 70 million [64].

Inactivity versus age-induced adaptation

Although prolongation of life is an important public health goal, a more important one is the preservation of functional health. The high rate of sedentary behavior that characterizes the older adult population exacerbates the impairments of physiological and structural systems typically observed with the aging process. Living a sedentary life into older age can lead to a loss of functional health, due to deficits in strength, endurance, and flexibility that are consistently related to inactivity [1, 3]. “Use it or lose it” is a key rule for maintaining physical independence as a person grows older [73].

In the traditional way of looking at motor development, performance variations are often erroneously characterized in cross-sectional studies as age-induced [61]. However, what is often understood as an aging process is to a great extent the result of inactivity [73]; aging and physical activity are reciprocally interactive. Aging affects the ability to move, but lack of movement in turn accelerates the aging process.

The significance of biological aging processes as limiting factors for different physical, psychological, and socially related performances has been known for a long time [6]. The central question to be answered is twofold: (1) to what extent do aging processes influence physical performance ability and (2) how can physical performance ability that has been improved or maintained by means of physical activity and training affect the biological–physiological as well as the psychological and socially related aging processes?

Aging—irreversible losses versus adaptation and plasticity

Although aging naturally involves processes of loss, it cannot be sufficiently characterized by these alone. Potential strengths and gains during the process of aging can be listed as experience-, knowledge-, and skill-based performances which human beings can produce even in old age

[52]. These include being able to deal with psychological demands and stresses in everyday and job situations, as well as the ability to compensate for losses that are induced by age [7]. In this way, biological and physiological losses are compensated for by culture-bound, experience-induced differences. Baltes et al. [8] describe this compensation as pragmatism which is associated with *crystallized intelligence* and *procedural knowledge*. Plasticity in terms of organic and neural adaptation is an important prerequisite for the maintenance of physical and mental performance ability as well as for independence and autonomy in terms of rehabilitation measures. This maintenance of physical and mental performance abilities is closely connected with the "compression of morbidity" paradigm introduced by Fries [28]. This paradigm aims at postponing the start of morbidity and compressing the time period between the start of morbidity and death. During the last two decades, this compression process has become more prominent and will obviously become even more so in the future [28]. Even if this period of time is shortened by a multitude of factors and no single cause can be found responsible, some interdependencies may be identified through longitudinal studies. For example, the effects of a healthy way of life can be extremely significant. The cumulative duration of morbidity is four times as high among smokers and overweight and physically inactive persons than slim and trained nonsmokers (Fries), which obviously affects health care costs. This means that the health of the aging and older population is of decisive importance also as far as the economy is concerned. To find and implement solutions to this problem so that they can contribute to successful and less costly aging is of extreme urgency today.

The revised point of view that regards aging not as irreversible changes of the living substance as a function of time [14] but primarily as any positive or negative changes in the adaptative capacity of an organism [5], combined with the construct of "plasticity" that enables available structures to be exploited functionally, opens up new perspectives of physical trainability and motor learning in old age [45].

Normal aging versus pathology

Biologically and physiologically, it should be assumed that a body or human being does not age as a whole. Rather, the aging phenomenon must be regarded as a highly differentiated process, and although it may be observed holistically as the result of aging processes in the physical systems that affect the whole, these changes occur at different times and entail different dynamics. This means that aging takes place to a different extent and at a different rate in diverse parts of the body [36]. Characteristic limitations or losses can be characterized as follows: reduced functional reserve, decreasing vital capacity, decreasing muscle mass and deterioration of the capillary blood supply, biochemical changes and an increase of connective tissue, reduction of bone mineral density, high blood pressure, fat metabolism disorder, diminished glucose tolerance as well as sensory problems such as clouding of the eye lens, a decrease of eye muscle adaptability, and a reduction in the ability to hear high frequencies (Hayflick). Reductions in the motor system [43] are described as neuronal losses of between 25% and 50% in different areas of the central nervous system. These losses are closely connected with psychological dimensions, for example, the speed of information processing or the ability to solve new kinds of cognitive problems [76]. Negative influences of individual phenomena or the summation of several of those described do not generally occur before the age of 30 [89]. The restrictions resulting from cumulative individual effects are described by Fried and colleagues [26, 27] as the biological syndrome of frailty, which is not synonymous with impediment or comorbidity, but rather represents a preliminary stage of aging. Fried and colleagues have proven that frailty, despite the continued existence of functionality, is an independent predictor of the risk of falls, hospitalization, impediment, and death. This approach is consistent with the clinical markers of frailty as used in geriatrics and gerontology. Fried et al. describe two roads to frailty: (1) age-induced physiological changes (e.g., sarcopenia, anorexia) and (2) severe diseases and comorbidity. The characteristics of age-induced physiological changes are loss of weight, a state of exhaustion, loss of strength, reduced walking velocity, and a low degree of physical activity. Intervention measures including physical and sports activities can significantly contribute to a delay of these developments [1, 3].

As far as possible interventions relating to these aging processes are concerned, a distinction must be made between primary and secondary aging. Furthermore, gerontology differentiates between *normal aging processes*, understood as optimization of the influences of secondary aging, and the *pathological side effects* (diseases/accidents) of aging [7]. *Primary aging* characterizes the genetically determined part of the aging process of a species, the aging-induced changes such as puberty or menopause. Primary aging, which is regarded as almost independent of diseases and environmental influences, is understood as the unavoidable, "fateful" part of aging that is multigenetically molded and therefore not easily influenced genetically [38]. *Secondary aging* concerns the interaction between the primary aging processes and the influences of personality, lifestyle behaviors, society, environment, diseases, and accidents. As far as primary aging is concerned, intervention possibilities for slowing the aging processes are very limited. Therefore, intervention measures are primarily targeted at secondary aging processes. These measures pertain to medical progress and reducing negative environmental influences, as well as reducing narcotics and drug consumption. Secondary aging can also be influenced by changes in lifestyle, such as the optimization of nutrition and an increase in social, intellectual, and cognitive activities [52]. The greatest effect can be evidenced by changes in the level of physical activity in movement, play, and sport [60, 73, 80, 83]. In combination with conscious attention to nutrition and lifestyle, regular physical activity is one of the strongest factors influencing health in aging industrial societies.

Successful aging—being in need versus being needed

The concept of successful aging was introduced by Havighurst [35]. He defines successful aging as a state of inner satisfaction and happiness both in retrospect and as related to the present situation. Social contacts, health, and positive dealing with the events of life are important influencing factors. The feeling of being needed plays an important role. The indicator of this concept of successful aging is life satisfaction. Baltes [5] adds functional ability to subjective life satisfaction as an indicator of successful aging. Functional ability includes the objective state of health and the state of feeling healthy. Considering the prognosis for even greater longevity, the additions of Fillip and Ferring [24] are particularly significant. For them, successful aging does not only mean staying psychologically and physically as healthy as possible for as long as possible but also being able to maintain one's independence during old age. This means that for successful aging, health, education, and social participation must be considered, and lifestyle changes, especially physical activity and sport, must be taken into account in the biological and physiological spheres.

Physical activity—maximization versus optimization

People who exercise systematically and set load stimuli trigger adaptation processes which impact positively on health [53]. However, the load stimuli in terms of training intensity and volume are not always clear. In all areas, even outside sports science, training is understood as a systematically planned and goal-oriented measure for increasing or maintaining one's performance ability. In the exercise sciences, physical activity means any kind of movement produced by muscle work. These movements can be moderate sports activity, other leisure-time activities such as hiking, or even everyday activities such as walking, stair climbing, cycling, and house or garden work. Physical activity is a broader term for exercise. It is best defined as "bodily movement involving the skeletal muscles that results in energy expenditure" [17] and is generally assessed as a function of kilocalories expended per unit time in work or leisure activity. Exercise, on the other hand, involves planned repetitive and structured activity with the goal of improving fitness and is typically expressed in terms of frequency, duration, and intensity of that physical activity.

Physical fitness is the product of physical activity and/or exercise. It refers to flexibility, strength, coordination, and balance, but for the most part, studies have tended to focus on cardiovascular (aerobic) components of fitness. The measure of aerobic fitness is VO2max, which is reported in milliliters of oxygen consumption per kilogram of body mass per minute [2].

Training measures, in combination with physical activities and sports in old age, are primarily aimed not at maximizing but rather optimizing the general physical state—that is to say, minimizing damage and maximizing performance—maintaining influences. However, even in old age, a focus on sports is recommended and desirable because sports offer an immense variety of movements that is not possible by focusing merely on physical activity.

Physical activity—decrease in mortality versus increase in life expectancy

There is extensive evidence that moderate sports activity can contribute to an increase in life expectancy, although not to a prolongation of the life span. By reducing the influence of risk factors, physical activity and sports act as a moderator but do not directly increase the life span. The results of epidemiological studies [22, 55, 58, 67–69] clearly indicate a reduction in the mortality rate relative to weekly expenditure of kilocalories in physical activity, particularly in the 60–84 year-old age group.

Based on these studies, an expenditure of less than 500 kcal/week has been set as a reference value. While physical activity which causes an additional energy expenditure of 500–1,999 kcal/week leads to a reduction of the mortality risk by 28% among 60–69 years old, the same physical activity energy expenditure reduces mortality risk by 37% among 70–84 years old. Lee et al. [56] have indicated that regular physical activity generating 1,000 kcal/week or more should be recommended for lowering mortality rates. Furthermore, among those with no major risk factors, even infrequent bouts of exercise (e.g., 1–2 episodes/week generating 1,000 kcal/week or more) can postpone mortality. Physical activity which surpasses an energy expenditure of 2,000 kcal/week causes a further decrease of the mortality rate. Another study has indicated that maximal performance ability and fitness level are decisive in determining the risk of mortality [63]. However, training intensity and volume entailing an expenditure of more than 3,500 kcal/week [68] seem to have the opposite effect. At the other end of the activity continuum, a reduction in mortality risk is associated with even modest participation in activities of low intensity [88] or slight improvements of physical fitness [22].

Physical activity—increase in aerobic fitness versus decrease in cardiovascular disease

The trainability and plasticity of the cardiovascular system was noted in the past by Hollmann [39], who increased maximal oxygen uptake in 60- to 70-year-old individuals. In the last decades, quite a few epidemiological studies have shown an inverse relationship between physical activity and risk of cardiovascular disease. For example, an additional expenditure of only 150–300 kcal/day as a result of physical activity reduces infarction risk by about 20–50% in men [10, 53]. This corresponds to 2–4 km of fast walking or climbing about four floors of stairs. Different forms of training (jogging, rowing, fast walks) lead to a significant reduction of coronary artery calcification [82]. Other studies have demonstrated an inverse association between relative intensity of physical activity and risk of cardiovascular disease among men [54], where vigorous activities showed the strongest reductions in coronary heart disease (CHD) disease [77]. The association between physical activity and a reduced risk of CHD also extends to men with multiple coronary risk factors [77] and reduced the risk of mortality in infarction patients [42].

A study of more than 70,000 women showed that a medium walking pace of about 4 km/h (2.5 h/week) caused a significant reduction in the risk of cardiovascular disease [59]. Another study of women indicated that obesity and physical inactivity independently contributed to the development of CHD in women [57].

Physical activity—increase in muscle mass versus decrease in falls and instability

Against the backdrop of the previously mentioned discussion of “frailty” and “compression of morbidity”, target-oriented strength training becomes increasingly important in terms of health [50]. It is widely recognized that the loss of muscle mass associated with aging (sarcopenia) is one of the main determinants of musculoskeletal frailty and reduced locomotor function in old age [21]. The decrease of muscle functional ability leads to a deterioration of postural regulation and balance [72], which increases the risk of falling and bone fracture. The reduced mechanical activity caused by the loss of muscle mass also affects the risk of osteoporosis [31, 32].

There is little doubt that resistance training has a positive effect on both the hormonal and metabolic physiology of older adults. It is also evident that prescribing physical activity as a means of rehabilitation or treatment is both valid and reliable [13]. Moreover, a training frequency of only one session per week may be sufficient to restore strength and therefore aid in the performance of daily activities and the maintenance of independence [81].

A less obvious function of muscle and strength training is that of metabolic storage and its potential influence in pain therapy [34]. It has been shown that strength training, aerobic training, or a combination of the two resulted in significant improvement in pain symptoms in knee osteoarthritis [25].

The trainability and plasticity of the muscle strength factor extends to a very high age. Fiatarone et al. [23] demonstrated strength trainability in over 90-year-old subjects in an old people’s home. After 6 weeks of training, rates of increase of up to 180% in strength were reported as well as a considerable improvement in activities of daily living. The contribution of fitness-orientated training for the improvement of postural ability and balance has also been shown in 65 to 90 years old [40].

Muscle weakness and poor balance have been well established as risk factors for falls [30]. Fall-related injuries and deaths in older adults are a major health problem worldwide, with the number of these injuries continuing to increase [44]. For several years now, it has been clear that exercise can reduce the risk of falls and fall-related fractures [16, 30, 71]. A wide variety of exercise interventions have been tried using different exercise frequencies, intensities, and duration periods. Interventions have included strength training and endurance, balance, flexibility, Tai Chi, and a combination of these exercises ([16, 30, 71]). However, strength and balance have been central to most successful fall-prevention programs [30]. A meta-analysis of exercise programs for prevention of falls suggests that balance may be more effective in lowering the risk of falls than the other exercise components [71].

Physical activity—improvement in cognitive performance versus reduction in cognitive decline

There is now a substantial body of literature suggesting that a lifetime of exercise can result in enhancement of a number of aspects of cognition [37]. Staying physically active can maintain and even enhance cognition and brain function, as well as reduce the risk of age-associated neurological disorders such as Alzheimer’s disease [45].

Longitudinal observational studies have clearly indicated a negative association between physical activity—mainly aerobic—and cognitive decline [9, 51, 90]. Of special interest is the 1986 nurses' health study which examined the physical activity (translated into energy expenditure) of 18,766 women using self-reported data and assessed their cognitive functioning 10 years later [90]. This study indicated an association between physical activity and attention, memory, executive function, and general cognition, with active women evincing better cognitive function and less cognitive decline.

In a large-scale, prospective cohort study, Laurin et al. [51] found a significant protective effect of regular physical activity against the risk of cognitive impairment and dementia, particularly the Alzheimer type. These associations were observed mainly in women and revealed a significant dose–response relationship showing decreasing risk with increasing levels of physical activity. Furthermore, some studies [19, 33] were able to show morphological differences between active and nonactive older adults, indicating that aerobic fitness reduced loss of brain tissue.

Results of intervention studies are even more noteworthy. Rather than showing reduced risk of cognitive decline as a function of physical activity along the years, they aim to examine the extent to which relatively short-term physical activity can improve cognitive performance. While some of them are inconclusive, possibly for various methodological reasons [45], others are quite convincing. Kramer et al. [46] demonstrated that improvements in cardiovascular fitness following 6 months of aerobic training improved tasks requiring higher levels of central nervous system activity (executive control functions). Colcombe and Kramer [18] concluded from their meta-analysis of intervention studies that aerobic fitness training has a beneficial effect on all cognitive aspects in old age; however the effect appeared to be most beneficial for executive control tasks. They also indicated that a combination of endurance and strength training had more of an effect than an endurance program alone, and a short training program was as effective as a moderate-length program.

Physical activity and well-being—improved positive factors versus reduced negative factors in healthy versus clinical populations

In general, many studies have revealed a link between physical activity and reduced risk of depression [29, 47, 49] or improved self-efficacy [62, 70]. Arent et al. [4], in their meta-analysis of physical activity and mood in older adults, reported a large effect on both positive and negative affect across all forms of physical activity.

A meta-analysis assessing the effect of physical activity on psychological well-being in advanced age [66] demonstrated that in older adults, physical self-efficacy and view of self, more than any other aspect of well-being, including mood and life satisfaction, were affected by exercise. This effect was indicated in aerobic as well as strength training. Furthermore, this meta-analysis showed that improvements in strength and specifically improvement in functional capacity contributed to increased self-efficacy and view of self. A recent study [74] supported the findings of this meta-analysis and indicated that physical activity, more than discussions on successful aging, was an effective means of intervening in self-efficacy and satisfaction with physical function in prefrail older adults.

The effect of physical activity on well-being is even more significant in clinically depressed individuals. Two groups of researchers should be mentioned. Both Blumenthal and colleagues [11, 12] and Singh and colleagues [78, 79] indicated that aerobic exercise and strength training, respectively, are quite effective in reducing depression in clinically depressed individuals.

The optimal dose—moderate versus vigorous intensity

What is the optimal dose of physical activity in terms of intensity, frequency, and duration? The American College of Sports Medicine and the American Heart Association, in a joint paper (see [65]), provide recommendations for physical activity in old age. They employ a ten-point scale in which sitting is 0 and all-out effort is 10, moderate-intensity activity is 5 or 6, and high/vigorous-intensity activity is 7 or 8. In terms of aerobic (endurance) physical activity, intensity refers to heart rate and breathing, where moderate intensity produces noticeable increases and vigorous intensity produces large increases in heart rate and breathing. In terms of muscle-strengthening (resistance) activity, moderate intensity and high intensity refer to the effort of a muscle group.

Older adults are advised to perform moderate-intensity aerobic activity for a minimum of 30 min 5 days a week, or vigorous-intensity activity for a minimum of 20 min 3 days a week. These activities are in addition to light-intensity activities performed as a part of daily life (walking to the parking lot or shopping, for example). It is also recommended that eight to ten strength exercises be performed on at least two nonconsecutive days per week using the major muscle groups. The level of resistance used should allow ten to 15 repetitions. Flexibility activities are also recommended at least 2 days a week for at least 10 min and also exercises to maintain or improve balance.

These recommendations are considered basic. Older adults who wish to further improve their fitness and reduce the risk of chronic disease will likely benefit by exceeding the minimum recommended amount of physical activity. On the other hand, older adults with medical conditions for which physical activity is therapeutic should perform physical activity in a manner that effectively and safely treats their condition.

Conclusions—what we know versus what we do not know

1. We know that human beings generally try to reduce physical and mental efforts to a minimum by using advanced technological development.
2. We also know that there is a biological basis for age-related decline in physical activity in humans and in nonhumans.
3. At the same time, we know that human beings depend on movement and physical activity to ensure beneficial development, from childhood to the highest adult age.
4. We know that there is a dramatic increase in the older adult population.
5. We know that the results of inactivity are sometimes mistakenly considered irreversible losses caused by aging, but in actuality, inactivity accelerates the irreversible losses caused by the aging process.
6. We also know that the aging process not only entails irreversible losses but also adaptation and plasticity.
7. We know that there is a need to differentiate between normal aging and pathology in order to determine the contribution of physical activity to the aging process.
8. We know that successful aging primarily means independence, which could be promoted most effectively by physical activity.
9. We know that physical activity should be planned and implemented consciously as today's daily routines do not include sufficient physical activity.
10. We also know that physical training is aimed not at maximization but rather at optimization of the general physical state.
11. We know that physical activity increases life expectancy and decreases the risk of mortality.
12. We know that aerobic activity increases cardiovascular fitness and decreases the risk of cardiovascular disease.
13. We know that physical activity, specifically strength training, increases muscle mass and decreases instability and falls.
14. We know that physical activity, mainly aerobic activity, improves cognitive performance and reduces cognitive decline and age-associated neurological disorders such as dementia.
15. We know that physical activity improves well-being. It reduces negative factors such as depression and anxiety and improves positive factors such as self-efficacy and view of self.
16. We know the recommended optimal intensity, frequency, and duration of physical activity needed for health benefits.
17. *We also know* that although increasing physical activity participation has been a major goal of several initiatives, especially in the USA, little change in physical activity patterns has been reported across any age group. *What we do not know is why.*

What are the mechanisms that restrain people from being active, although in most cases, they are quite aware of the need to be active? Are the inhibitors biological, cultural, psychological, or social, or perhaps a combination of them all? What are the best means to overcome these barriers? Changing behavior is a complicated process and knowledge is both necessary and insufficient at present. To clarify these questions, behavior-related gerontology must cooperate with psychological–cognitive and biomedical gerontology to develop a common interdisciplinary focus concerning movement, physical activity, sport, and aging.

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