Assistive Technology for Successful Aging: Perspectives from Developmental Behavioral and Neuroscience

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Abstract. Growing into old age is a personal privilege and a societal achievement. However, it is also a challenge for both the individuals and societies. The impressive gains in extending average physical longevity to 75 years and beyond is not necessary accompanied by high-levels of physical, psychological, and brain "fitness". Thus, it is important to seek ways to help older adults maintaining functions in these domains in order to maintain life quality in old age. Adaptive assistive devices and environments are promising technological advancements for promoting successful aging. Sufficient plasticity in the aging psychological and neurocognitive systems are necessary for technologies to engender desired effects. Designs and evaluations of assistive technologies need to consider dynamic changes in developmental resources across the lifespan. This paper reviews evidence of behavioral and neurocognitive plasticity in old age and highlights psychological principles for successful aging technologies.

Keywords: Successful aging, Plasticity, Assistive technology, Resource allocation

1 Aging and declines in fundamental functions central for life quality in old age

Although longevity is generally regarded a personal privilege and a medical achievement, extended average life expectancy resulting in rapid increasing old and very old populations becomes a challenge to societies worldwide, for instance in terms of establishing new retirement laws, pension systems and healthcare costs. Even more so, as the gain in average physical longevity is not always accompanied by high-levels of psychological, cognitive, and sensorimotor fitness in old age, at the individual level longevity does not necessarily imply good life quality in old

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age. The motto of the Gerontological Society of America states that, with the rapid growth of aging populations worldwide, a major challenge is for societies to give life to old age beyond merely giving age to life. In other words, societies need to seek ways to help old people maintaining important psychological and physical functions so that they can maintain their life quality at high levels even in very old age (i.e., with possibilities of high degrees of mobility, independent living, and social networking). Such goals may be achieved by reducing declines and enhancing environmental compensatory functions through technological resources in the forms of assistive trainings, devices, and environments.

Three fundamental functions that are central for good life quality and independent living, unfortunately, decline with advancing old age. Ample evidence from aging research indicates that advancing age continues to be associated with increasing frailty, marked by brain, cognitive, and sensorimotor declines [see 1-3 for reviews].

1.1 Aging and cognitive declines

With respect to aging-related cognitive declines, the neurobiology-based component processes of intelligence (e.g., usually including memory functions, information-processing speed, and processing robustness) decline substantially in old age [4] (Fig. 1). Declines in basic cognitive processes set constraints on older people's overall level of functioning, as they can not process and remember information as efficiently and reliably as they could when they were younger.

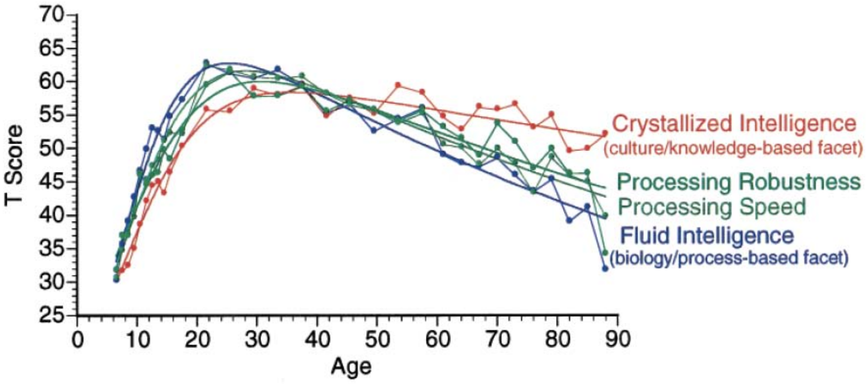

Fig. 1. Gains of biology-based fluid intelligence, information-processing speed and robustness during childhood, but clear losses in old age. Data from Li et al. [4]. Copyright *Psychological Science*, 2004.

1.2 Aging and sensorimotor declines

With respect to sensorimotor processes, much research findings show that, not only do basic sensory abilities (such as hearing and vision) decline during old age [5], but also can older individuals not control their posture (i.e., keep balance during standing or walking) as efficiently as younger adults (Fig. 2). When the degrees of body sway are measured on a force platform with computerized posturography (Fig. 2a), older individuals tend to show larger stabilograms (e.g., [6], see [7] for review), which indicates more unbalanced standing stance (Fig. 2b). Instability in postural control can have serious consequences in older adults' life, as falls in old age often result in limited physical functions, major comorbidities, and substantial restrictions on independent living.

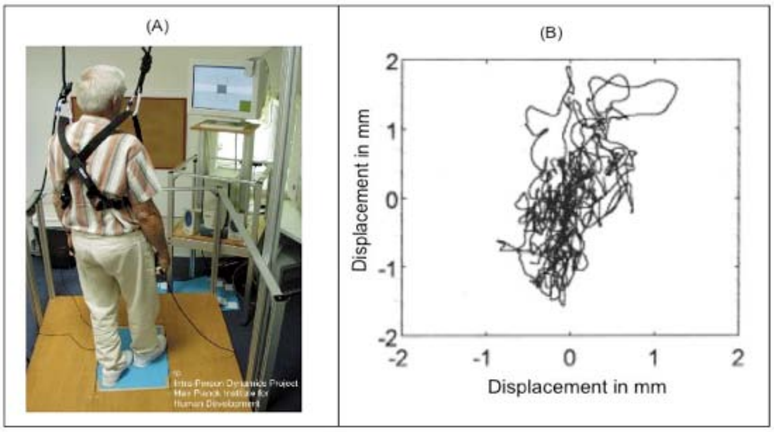

Fig. 2. Aging and loss of stability in postural control. (A) Measuring older adults' posture instability with computerized posturography (MPIfB Annual Report, Intra-person Dynamics Project, 2005). (B) Greater area of stabilogram, indicating less stability in older adults' postural control (data adapted from Huxhold et al. [6]).

1.3 Aging and declining navigation ability

Spatial navigation ability is another function that is also crucial for older people to maintain independent living. However, this ability unfortunately also declines during old age. Spatial navigation requires both cognitive and sensorimotor processes. Given that many aspects of basic cognitive processes (e.g., working memory, cognitive control, and attentional mechanisms) as well as sensorimotor functions do decline with advancing age, aging-related decrements in spatial navigation performance are to be expected. At the behavioral level, evidence from studies on aging and spatial navigation clearly shows that on average old people perform much worse than young adults [8]. For instance, a recent study by Lövdén et al. [9] tested younger and older adults’ navigation ability in virtual environments and found that older adults had to take many more trials and walk much longer distances in order to learn the routes that connect different landmarks in the virtual environment (Fig 3). The ability to navigate through the environment is a very fundamental aspect of daily living. If older adults cannot rely on their navigation ability to find their ways through their environment, the physical realm and ranges of social activities in their daily living will certainly become much more limited, thus consequently lower the quality of life.

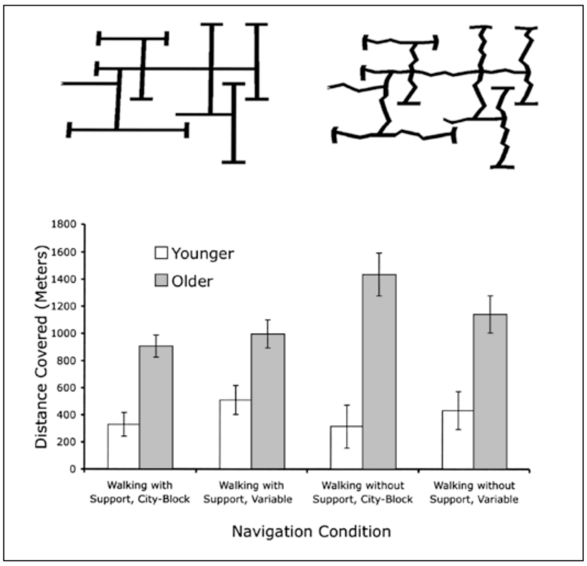

Fig. 3. Virtual environments with easy and difficult topographies. Older adults needed to walk longer distances in more trials than younger adults to learn the routes. Environmental support (hand railing) improved older adults’ performance. Data adapted from Lövdén et al. [9]. Copyright *Psychology and Aging* 2005.

1.4 Aging and brain declines

Over the past two decades, studies investigating brain aging have found evidence for declines at neuroanatomical, neurochemical, and neurofunctional levels (see Lindenberger, Li, & Bäckman, 2006 [10] for review). At the neuroanatomical level, the volumes of various brain regions involved in cognition decline with increasing age. For instance, Raz, Lindenberger et al. [11] recently found cross-sectional age differences as well as 5-year longitudinal declines in the prefrontal, hippocampal and the striatal brain regions.

At the neurochemical level, dopaminergic as well as the serotonergic and cholinergic systems are subject to change during aging. Regarding aging-related deficits in episodic memory including memory of the spatial environment and sensorimotor functions, aging-related declines in the dopaminergic systems are of specific relevance (see Bäckman et al., 2006 [12] for a recent review). Two recent studies [13,14] show that, on average, there is about 10% decline in dopamine receptor binding efficacy across a variety of brain regions, including the regions important for executive control and episodic memory. Neurocomputational modeling suggests that the functional consequences of aging-related declines in dopaminergic modulation are twofold: noisier and less distinctive neural information processing [15,16]. This theoretical link is supported by converging evidence about dopaminergic effects on performance variability in older adults, schizophrenic patients and individuals with frontal pathology [17]. Aging-related increase in neurocognitive and behavioral fluctuations is an important factor to keep in mind for designing assistive technologies for older adults, as the expected functional outcomes of a given assistive device may not be as stable as desired, if the assistive devices can not themselves adapt to the increased stochasticity in aging systems.

2. Behavioral and Brain Plasticity in Old Age

A major challenge for promoting "successful aging" [18] is to make use of the reserved behavioral and neurocognitive plasticity that is still available in old age to *maximize gains and minimize losses* of functioning for old people. An important question in this context is the extent to which sufficient behavioral and cortical plasticity is still retained in the aging brain to support the technology-brain-behavior co-construction [19-22]. The evidence to date suggests that, though being more limited than in other life periods, training-induced changes in brain activity are still present in old age (see 22 for review). In the following we selectively report evidence from two studies showing behavioral and cortical plasticity of memory processes in older adults.

2.1 Behavioral memory plasticity as a function of mnemonic training

Associative mechanisms in learning and memory in humans have mostly been studied with word pairs (paired associates). Although plasticity is commonly regarded as the hallmark of youth, memory plasticity has been studied more extensively among adults than among children of different ages. In behavioral studies of adult age differences in memory plasticity, the effects of using cognitive support to augment the reserve developmental plasticity that is still available in old age have been extensively investigated. Specifically, Paul Baltes and colleagues [e.g., 23] had applied the so-called "testing-the-limits" procedure to train individuals to remember a long list of memory items by associating each item with the famous landmarks in a city they were familiar with. Evidence based on this paradigm had yielded a dual picture: On the one hand, the associative memory of cognitively healthy older adults (ranging from 60 to 80 years of age) could be significantly improved after the mnemonic training, thus showing a sizeable amount of plasticity. On the other hand, the extent of plasticity in old age was much reduced compared to younger adults in their 20s and 30s.

One recent memory training study extended procedures similar to those applied in adult development to cover the age periods from middle childhood to old age [24]. This study provides the first empirical evidence that compares associative memory plasticity in young children and older adults. Specifically, younger children aged 9 to 10 years were found to possess a greater extent of developmental reserve plasticity than older adults around 70 years of age (Fig. 4). The greater extent of developmental reserve plasticity in children compared to old adults reveals that cognitive and neuronal mechanisms associated with implementing the memory strategy are more sensitive to training experience during childhood than in old age. Nonetheless, older adults still have plasticity to benefit from external cognitive supports.

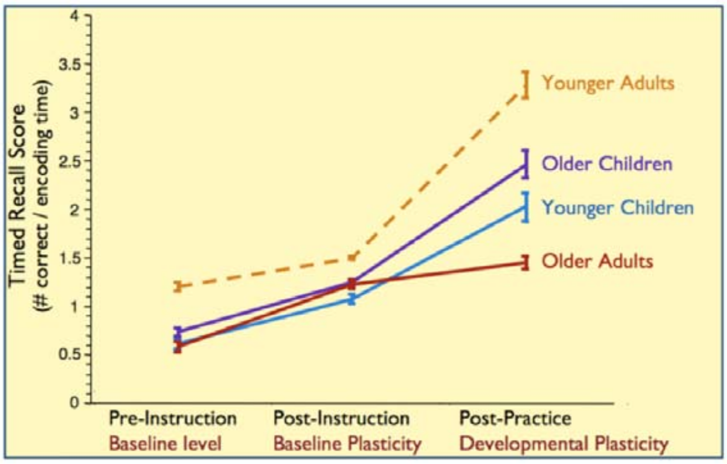

Fig. 4. Memory plasticity in four age groups across the lifespan. Memory plasticity is preserved but more limited in old age. Data adapted from Brehmer et al. [24]. Copyright *American Psychological Association* 2007.

2.2 Brain Plasticity as a Function of Culturally Derived Mnemonic Training

Recent findings from brain imaging studies provide evidence for the effects of memory training on functional neural circuitry. Nyberg et al. [25] investigated adult age differences in the functional plasticity of brain circuitry as a function of memory training, using a mnemonics involving spatial landmarks similar to what was used in behavioral studies [23,24]. Encoding after strategy instruction was associated with activity increase in frontal as well as occipito-parietal regions in their younger adult sample. In contrast, accompanying their reduced memory plasticity as indicated by poor memory performance even after memory strategy training, older adults in the Nyberg et al. study did not show training-related increase in frontal activity, and only those older adults who benefited from the memory training showed increased occipito-parietal activity (see Figure 5).

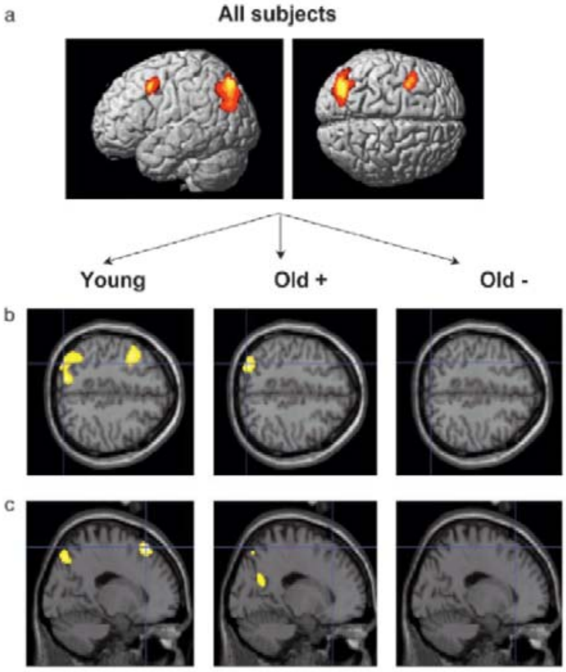

Fig. 5. Adult age differences in functional brain activity as a function of mnemonic training. (a) Left occipito-parietal cortex and the left dorsal frontal cortex showed increased activity when using mnemonics in comparison to baseline. (b) Training-induced changes in functional brain activity differ as a function of age as well as the extent of obtained benefits from training. Data adapted from Nyberg et al. [25]. Copyright PNAS 2003.

3. Psychological Principles of Successful Aging Technologies

Integrating evidence of developmental plasticity even in old age with the progresses that are been made in human engineering to put a vision of “lifespan technology” into practice requires a conceptual framework that considers the evolving capabilities and constraints of aging individuals. Based on resource allocation/generation views of successful lifespan development proposed by the late Paul and Margret Baltes on minimizing losses and maximizing gains [18, 26], Lindenberger et al. [21] recently proposed three psychological principles, or guidelines, for the design and evaluation of assistive technology. Specifically, three criteria were proposed: (a) net resource release, or marginal resource benefit;

(b) person specificity, and (c) proximal versus distal frames of evaluation (see Figure 6).

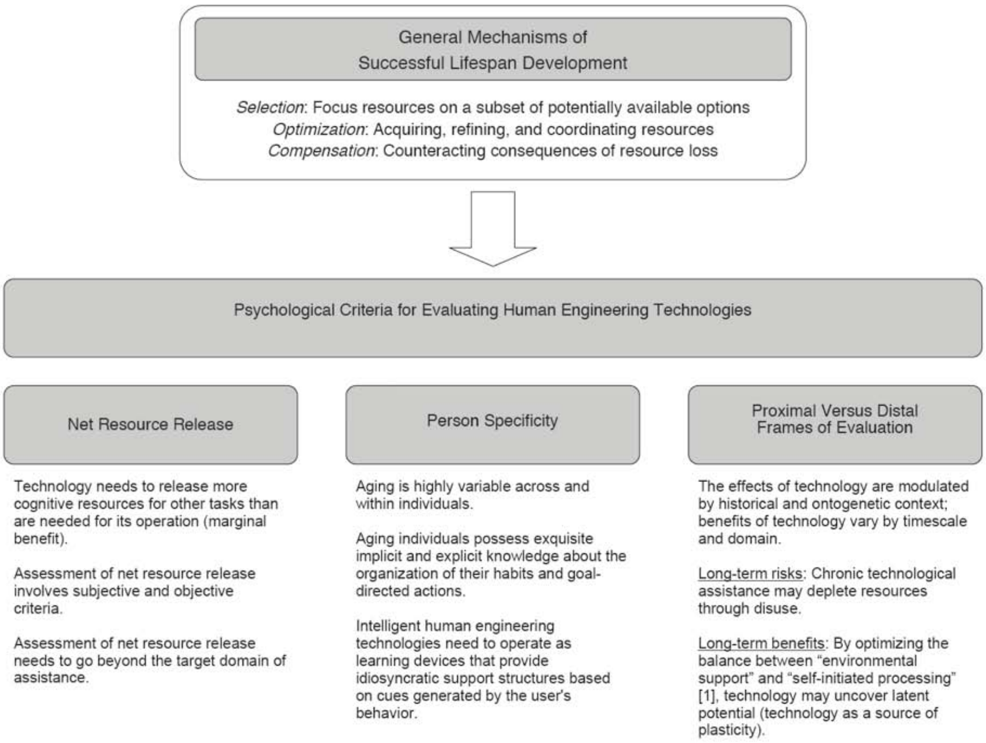

Fig. 6. Principles derived from lifespan psychology for designing and evaluating successful aging technologies as proposed by Lindenberger et al. [21].

3.1 Net Resource Release (Marginal Resource Benefit)

The operation of technology usually requires an investment of physical and mental resources. It follows that the use of technology is adaptive only if these operation costs are lower than the payoff associated with other changes in processing when using the technology (cf. [27]). For instance, when the use of a notepad as a memory aid requires memorization of complex instructions, then the payoff of using the device may be negative, at least initially. This point is analogous to the definition of successful aging in terms of maximization of gains and minimization of losses.

Objective and subjective facets of net resource release, or the marginal resource benefit of technology use, need to be set apart, and should both be taken seriously. Older individuals' perception of net resource release is likely to determine the actual use of technology more than the cost/benefit ratio assessed in some objective manner (for a recent example, see [28]). Thus, human engineering technologies fall short of their central objective if their use does not result in net resource release, both objectively and subjectively defined, at least in the long run.

3.2 Person Specificity

The second criterion refers to person specificity and person adaptability. Older individuals differ greatly and fluctuate more with respect to cognitive, sensory, and motor functioning [4,16,29]. Likewise, average age trends do not apply to all members of the aging population. Some individuals in their 80s perform above the average level of people in their 50s in central aspects of everyday competence such as memory, visual acuity, or hearing (e.g., [5]). Therefore, knowledge about the average aging individual provides little more than a viable starting point for the development and use of intelligent assistive technology. Beyond this starting point, the technology needs to fine-tune itself to the idiosyncrasies of the individual's behavior to his or her specific competences, habits, and preferences.

Thus, technology not only needs to adapt to differences between individuals but it also needs to learn the behavioral ecology, or life space (cf. [30]), of the individual user, preferably at a point in time when this ecology has not yet been severely compromised by disability and frailty. Later, when impairments in sensory, motor, and cognitive functions may become more prominent, the acquired knowledge of the individual's habits and life space can be used to assist the individual in maintaining his or her lifestyle as long as possible.

3.3 Proximal and Distal Frames of Evaluation: Plasticity versus Disuse

Assistive use of technology also has to be evaluated on proximal and distal frames of reference, both on temporal and substantive dimensions. Prior exposure to the same or related technologies is likely to influence the amount of net resource release that can be achieved in old age. For example, today's generation of middle-aged adults will make use of mobile communication devices when aged 80 in a different way than many members of today's generation of 80-year-olds do now.

Within individuals, short-term and long-term benefits of technology may not always be congruent. For example, the use of GPS-based spatial navigation aids may have positive short-term effects upon way-finding behavior. However, this support may be harmful in the long run if it promotes chronic disuse of navigation skills and spatial orientation abilities. In fact, in light of associations between the size of brain structures involved in spatial behavior, such as the posterior hippocampus, and exposure to environments with high navigational demands, such as Inner City London for taxi drivers [31], one may speculate whether long-term reliance on GPS-based devices may compromise spatial navigation skills and abilities, and reduce the size and functional integrity of relevant brain structures. If this holds true, then the short-term gains associated with the use of navigation aids would be offset by a severe long-term loss.

Conversely, technology may not only enhance the allocation of currently available resources through net resource release, but actually foster the generation of new resources by activating developmental reserves, or latent cognitive potential. Just like other tools for the mind, such as mnemonic techniques for the encoding and retrieval of word lists (e.g., [32]), technology has the potential to enhance performance through external support while keeping the task environment challenging at the same time. With this in mind, intelligent assistive technology is no more and no less than a new voice in the co-constructive dialogue between culture and biology that constitutes human ontogeny (e.g., [20,21]). As reviewed above, behavioral and neuronal aspects of plasticity are reduced but not fully lost in old age and the functional circuitry of the human cortex is capable of short-term adaptation to changes in experience or internal milieu at all ages. Therefore, providing individuals with an optimally challenging environment does indeed carry the promise to activate behavioral and neuronal reserves.

4. Conclusions

Given that the aging neurocognitive and behavioral processes still possess a fair range of plasticity (see [22] for a recent review) and that “neurocognitve computation” is very much embedded in the space (environment) the individuals reside in [34], in theory it is possible to envision assistive technology in supporting the impaired “neurocognitive computation” with “ubiquitous technological computing” [33] that is embedded in the elders’ living environment available as assistive trainings, devices, and space (e.g., apartments).

When it comes to gauging the long-term consequences of intelligent and assistive technology, both risks and opportunities need to be kept in mind. On the one hand, chronic reliance on technological aids may deplete resources through protracted disuse of skills and abilities, undermine motivation, and engender loss of autonomy. On the other hand, intelligent and assistive technology may activate latent potential by combining support with challenge, thereby enhancing motivation, social participation, and a sense of autonomy, with positive repercussions on cognitive development in old age.

As the specific needs and demands of a growing population of aging individuals compel engineers and industry to build technologically assisted environments, these environments will reshape the architecture of the aging mind and brain to an extent that we do not and cannot yet fully know and understand at this point in time. To promote plasticity and avoid disuse, the effects of intelligent assistive technology on the mind and brain need to be carefully monitored and evaluated on multiple timescales and dimensions. Clearly, determining the right balance between “environmental support” and “self-initiated processing” [34] is a central task in this process.

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