

# Lifespan Development and the Brain

## *The Perspective of Biocultural Co-Constructivism*

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## Co-Constructing Human Engineering Technologies in Old Age: Lifespan Psychology as a Conceptual Foundation

Ulman Lindenberger and Martin Lövdén

### ABSTRACT

*Human engineering technologies highlight the bioculturally co-constructed nature of human ontogeny. Based on concepts from lifespan psychology, we propose three criteria for evaluating human engineering technologies in old age: marginal gain for the individual, person specificity and adaptability, and conjoint consideration of distal and proximal frames of evaluation. Informed by research on expert memory performance and negative adult age differences in sensory, motor, and cognitive functioning, we propose strategies for incorporating these criteria into the design of human engineering technologies. We expect that intelligent human engineering technologies will alter the aging of future generations by reducing cognitive resource demands through personalized external cuing structures.*

### INTRODUCTION

Recent years have witnessed increasing efforts at improving and expanding human engineering technologies for diverse segments of the adult and elderly population (Charness & Schaie, 2003; Kautz, Etzioni, Fox, & Weld, 2004; LoPresti, Mihailidis, & Kirsch, 2004). In this chapter, we discuss the potential of human engineering technologies to counteract negative adult age changes in sensory/sensorimotor and cognitive domains. We devote special attention to intelligent human engineering technology (IHET), that is, to assistive devices and environments apt to learn from, control, supervise, and regulate behavior (Kautz et al., 2004; Patterson, Liao, Fox, & Kautz, 2003).

Human behavior enmeshed in assistive technology is not fundamentally different from any other form of human behavior. At the same time, the unprecedented capacity of IHET to adapt to, predict, supervise, assist,

and eventually control human behavior sets it apart from less adaptive assistive devices such as canes or reading glasses. It is likely that future cohorts of aging individuals will delegate control over certain aspects of everyday functioning to IHET, while continuing to exert more direct forms of control in others. In this manner, IHET highlights and radicalizes the dialectic tension between environmental and personal control, and forces us to take notice of the societally constructed nature of human agency and self-determination (cf. Prinz, 2004).

Biocultural lifespan co-constructivism (Baltes, Lindenberger, & Staudinger, 2006; Li, 2003; see Chapter 1) highlights both the malleable and the invariant aspects of different age periods in human ontogeny. By reducing, circumventing, or postponing normative losses in functional integrity and the onset of age-associated pathologies, cultural evolution has transformed old age from an exceptional into a normative period of life. However, cultural evolution has not succeeded in abolishing the increasing vulnerability and frailty inherent with advancing old age. Hence, the precariousness of old age, and of very old age in particular, continues to be a motor of cultural innovation for each subsequent generation.

In this chapter, we scrutinize human engineering technologies from the perspectives of lifespan psychology (Baltes et al., 2006); and research on expert memory performance (Ericsson, 1985; Mäntylä, 1986). We draw on the selection, optimization, and compensation (SOC) model of successful development proposed by Baltes and Baltes (1990; Freund & Baltes, 2000) to gauge the developmental benefits of human engineering technologies. We then provide an overview of negative adult age changes in sensory, sensorimotor, and cognitive dimensions of behavior, and propose two strategies for the design of human engineering technologies. First, we suggest that IHET may be used to reduce the cognitive demands of sensory/sensorimotor aspects of behavior, thereby resulting in a net release of cognitive resources that can then be invested into genuinely cognitive task requirements or activities. Second, informed by findings on expert memory performance, we propose that IHET can directly reduce cognitive resource demands through personalized external cuing structures. In conclusion, we stress the need to arrive at a conceptual foundation for human engineering technologies in old age, and argue that lifespan psychology can serve as an organizing force in this endeavor.

#### SELECTION, OPTIMIZATION, AND COMPENSATION AS AN EVALUATIVE FRAMEWORK

The SOC model was originally developed to address the nature of successful lifespan development (cf. Baltes & Baltes, 1990). This model may provide guidelines for assessing the capacity of human engineering



technologies to promote desirable and avoid or ameliorate undesirable developmental pathways and outcomes. Successful development is defined as the conjoint maximization of gains (desirable goals or outcomes) and the minimization of losses (avoidance of undesirable goals or outcomes). The nature of what constitutes gains and losses, as well as the dynamics between them, are conditioned by cultural, ontogenetic, and person-related factors. Thus, a desirable developmental outcome achieved through SOC mechanisms may become dysfunctional later in ontogenetic time or in a different context. Moreover, what constitutes a gain and what constitutes a loss depends on the methods and concepts used to measure and define desirable developmental outcomes (Baltes & Baltes, 1990; Freund & Baltes, 2000). For instance, subjective criteria such as personal well-being may yield different results than objective criteria such as everyday competence.

Within the SOC framework, selection refers to focusing one's resources on a subset of potentially available options, thereby giving development its direction. Development inevitably requires selection because a large number of potential developmental trajectories is transformed into those chosen and those dismissed. Optimization reflects the growth aspect of development. It encompasses the search for beneficial environments, and refers to the acquisition, refinement, and coordinated application of resources directed at the achievement of higher functional levels. Compensation addresses the regulation of loss in development. It involves efforts to maintain a given level of functioning despite decline in, or loss of, previously available resources, either by replacing dysfunctional means to reach a desirable goal with alternative processes, or by changing the goal itself.

When resources are scarce, selection, optimization, and compensation are particularly important for promoting success in development. For instance, with advancing adult age, depleting cognitive resources need to be channeled economically, and SOC theory helps describe and evaluate the effectiveness of these channeling attempts. Assistive technology should serve the goal of minimizing losses and maximizing gains by enhancing the efficiency of SOC mechanisms. Thus, criteria for the developmental utility of human engineering technology in old age can be defined in relation to SOC mechanisms. We specify three such criteria (Fig. 16.1). First, *net resource release* (marginal resource gain) denotes that the costs associated with the use of human engineering technologies must be lower than the gains produced by other changes in task characteristics. Second, *person specificity* mandates that human engineering technologies should adapt themselves to the knowledge structure, habits, and preferences of the individual user. Third, the notion of *proximal versus distal frames of evaluation* helps remind us that a critical assessment of human engineering technologies requires attention to both short- and long-term effects.

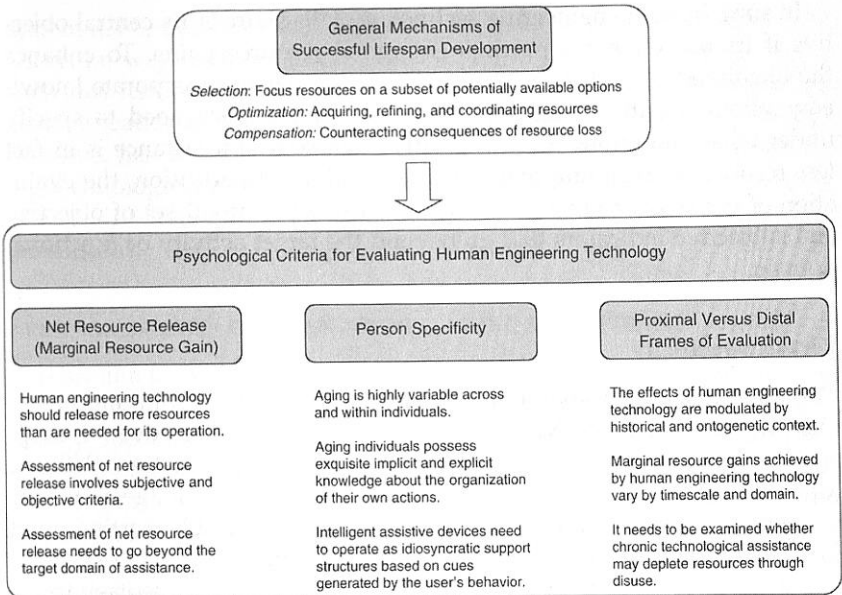


FIGURE 16.1. Toward a conceptual foundation for evaluating the developmental benefits of human engineering technology in adulthood and old age.

### Net Resource Release (Marginal Resource Gain)

Human engineering technology usually comes at a resource cost because its operation requires an investment of physical and mental resources. Its use is adaptive only if this cost is lower than the payoff associated with other changes in processing (cf. Dixon & Bäckman, 1995). Whenever the use of human engineering technology requires fewer resources than it releases, the marginal gain associated with selecting assistive technology is positive. This point is analogous to the definition of successful aging in terms of maximization of gains and minimization of losses.

In this context, objective and subjective (user-perceived) facets of marginal gain need to be set apart. An older individual's perception of marginal gain is more likely to determine usage of human engineering technologies than a cost-benefit ratio assessed in some objective manner. Furthermore, both objective and perceived marginal gain are influenced by the effects of human engineering technologies on individuals' total functioning or life space, which includes not only targeted domains (e.g., cognitive competence and sensory/sensorimotor functioning), but also all other relevant domains (e.g., affective and social dimensions). Comprehensive assessments of net resource release (marginal resource gain) need to consider all of them.

In sum, human engineering technology falls short of its central objective if its use does not result in marginal resource gains. To enhance the likelihood of such an outcome, its design has to incorporate knowledge about negative adult age changes. Psychologists need to specify under what conditions behavior with technological assistance is in fact less resource demanding than behavior without. In addition, the evaluation of net resource release has to be based on a broad set of objective and subjective indicators that go beyond the target activity or functional domain.

### Person Specificity

Cognitive and sensorimotor functioning are variable within and across individuals (Li, Aggen, Nesselrode, & Baltes, 2001). Moreover, average age trends do not apply to all members of the aging population (Baltes & Mayer, 1999; Lövdén & Lindenberger, 2005). Using knowledge about the average aging individual provides little more than a viable starting point for the development and use of human engineering technology in general and IHET in particular. To be successful, IHET must fine-tune itself to the idiosyncrasies of the individual's behavior, that is, to his or her specific competencies, habits, and preferences. As we argue in this chapter, this process of fine-tuning critically involves the evolution of a cuing structure that matches the structure of the individual's action space.

From modeling and human engineering perspectives, the "average aging individual" can provide the starting values, or default parameters, of IHET. The technology then needs to capture the regularities in a given individual's behavior, and needs to react or adapt to the user's fluctuations and long-term changes in competencies (Kautz et al., 2004). Given the sizeable variability in behavioral competence within the elderly population (e.g., Lindenberger & Baltes, 1997), adaptation to individual users is a precondition for enhancing the marginal gains of IHET.

### Proximal Versus Distal Frames of Evaluation

The effects of human engineering technologies are modulated by historical and ontogenetic context (cf. Baltes et al., 2006). Hence, potential benefits of human engineering technology vary across historical and ontogenetic time. Historically, prior lifespan exposure to the same or related technologies is likely to influence the marginal gain of human engineering technology in old age through positive or negative transfer. For instance, today's generation of middle-age adults will make different use of mobile phones than many members of today's generation of individuals older than 80. Also, within individuals, short- and long-term benefits may not always be congruent. For instance, the use of modern global positioning

system (GPS)-based spatial navigation aids may have positive short-term effects on way-finding behavior. However, to the extent that the use of such aids reinforces route learning strategies at the cost of strategies that achieve spatial integration, long-term and transfer effects may actually be negative. Just as any other form of intervention, then, human engineering technologies, especially of the intelligent kind, alter the action space of an individual, and need to be evaluated on multiple time scales and dimensions.

#### AVERAGE AGING LOSSES IN BODILY AND COGNITIVE RESOURCES

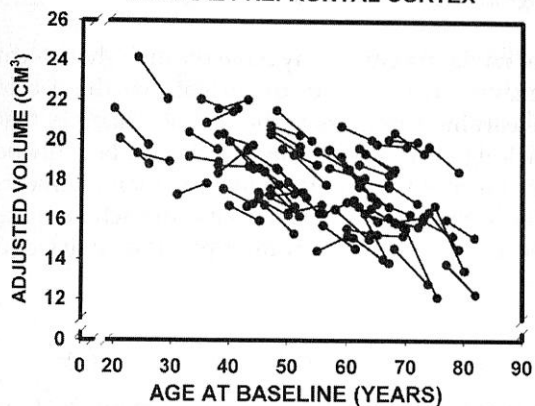
This section provides a selective overview of functional domains that are particularly relevant for theory-guided design of human engineering technology. Specifically, we focus on age-associated declines in cognitive, sensory, and motor domains during adulthood and old age, and on the ways in which age changes in these domains interact with each other in the course of goal-directed action. The overview is confined to normal (healthy) aging, and is targeted to aspects deemed critical for the theory-guided design of human engineering technology. The material covered is therefore selective and cannot do justice to the multidirectional nature of cognitive lifespan development.

### Cognition

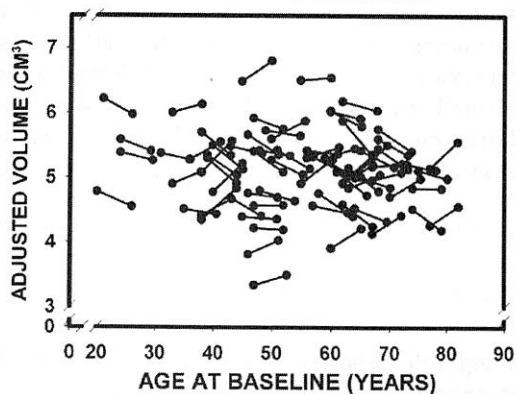
#### *Cognitive Control*

A central task of IHET is to regulate behavior. Therefore, age changes in individuals' abilities to exert cognitive control are at the very heart of IHET design for the elderly. In most situations, the behavior of humans is not directly controlled by external stimuli, rather it is guided by internal representations of goals and the means to achieve them. Cognitive (or executive) control refers to such mechanisms of top-down regulation of perception, action, and thought (Miller & Cohen, 2001). Aging-induced difficulties in implementing control mechanisms differ widely by task, context, and person. When tasks are clearly structured and distracting stimuli are absent, demands on cognitive control tend to be low, and adult age differences tend to be small. Conversely, when multiple tasks need to be coordinated, when tasks conflict with perceptual input (e.g., when top-down and bottom-up activation are discordant), or both, demands on cognitive control are high, and adult age differences tend to be large. Typical examples for situations that impose high demands on cognitive control include multitasking (Mayr, Kliegl, & Krampe, 1996), the selection and shifting between tasks under conditions of high stimulus ambiguity (Kray & Lindenberger, 2000), and the suppression of strong stimulus-driven action tendencies (Salthouse & Meinz, 1995).

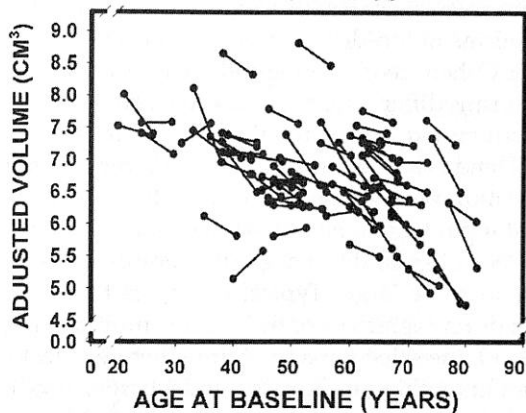
### LATERAL PREFRONTAL CORTEX



### PRIMARY VISUAL CORTEX



### HIPPOCAMPUS



### Working Memory

Similar to the notion of cognitive control, working memory denotes the ability to preserve information in one or more short-term stores while transforming the same or some other information (Just, Carpenter, & Keller, 1996). Working memory clearly serves an important function for cognitive control because it allows individuals to coordinate various goals when working on complex or multiple tasks. One way to study adult age differences in working memory is to vary the relative importance of temporary storage and processing (i.e., information transformation) demands within or across tasks. Generally, this research has demonstrated that negative age differences during adulthood are more pronounced when demands on processing are increased (Mayr et al., 1996). In other words, age differences are especially pronounced for tasks that put high demands on the simultaneous coordination of various pieces of incoming information, stored information, or both. Differential susceptibility to coordinative demands may also help explain why lifespan age differences in marker tests of fluid intelligence such as Raven's matrices tend to persist even when participants are given unlimited amounts of time to solve the items.

The prefrontal cortex plays a central role in cognitive control and working memory (Miller & Cohen, 2001). The behavioral evidence on particularly pronounced adult age differences in cognitive control is matched by evidence suggesting that the prefrontal cortex and the functionally connected basal ganglia show greater and earlier signs of decline than most other areas of the brain. In a comprehensive review of the neuroanatomical literature, Raz (2000) reported average cross-sectional reductions in brain weight and volume of about 2% per decade during adulthood, which were more pronounced for anterior parts of the brain. Figure 16.2 shows results from a recent longitudinal study that reinforced these findings (Raz et al., 2005). It depicts longitudinal declines in adjusted volumes of the lateral prefrontal and primary visual cortices, as well as of the hippocampus. Clearly, decrease in the prefrontal cortex is more pronounced than in the hippocampus and, especially, more pronounced than in the visual cortex, in which decrease is virtually absent.

### Binding

Closely related to losses in cognitive control efficiency and working memory, growing evidence suggests that binding mechanisms are

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FIGURE 16.2. Longitudinal changes in volumes of the lateral prefrontal cortex, primary visual cortex, and hippocampus as a function of baseline age. (Adapted from Raz, N., Lindenberger, U., Rodrigue, K. M., Kennedy, K. M., Head, D., Williamson, A., et al. (2005). Regional brain changes in aging healthy adults: General trends, individual differences, and modifiers. *Cerebral Cortex*, by permission of Oxford University Press.)



disproportionately impaired in old age. Binding serves to associate elements during perception, working memory, and memory (e.g., Murre, Wolters, & Raffone, in press). Synchronous and co-active binding mechanisms structure perceptual input and are at the basis of working memory. Interactive binding allows highly specific interpretations to become active during encoding and enables cue-driven selective activation of memory items during recall. Associative binding allows for long-term storage. Murre et al. (in press) argued that a cascade of binding mechanisms may be imagined at different levels, in which bound episodes, scenes, events, and entities reflect the structure of experience.

Various binding mechanisms decline during adulthood and old age (e.g., Chalfonte & Johnson, 1996; Craik, in press; Li, Naveh-Benjamin, & Lindenberger, 2005). For example, when young and older adults study pairs of words, age-based decrements are more pronounced for recognition of pairs than for recognition of individual words (Naveh-Benjamin, 2000). Similarly, adult age differences in episodic memory performance increase as a function of between-list similarity, probably reflecting older adults' disproportionate deficits in binding memory items with their encoding contexts (Kliegl & Lindenberger, 1993). Importantly, age changes in binding extend to operations that link incoming information to preexisting schemas and knowledge structures (e.g., Craik, 1983, in press).

According to Murre et al. (in press), human versatility in coping with continuously changing environments and demands reflects the brain's capacity to store coherent patterns of input and output in long-term memory, and its capacity to control the processing of input by selecting and maintaining task-relevant information in working memory. Thus, the various time scales of binding continuously interact: what is transiently bound in working memory partly determines what is temporarily and eventually permanently bound in long-term memory, and what is permanently bound biases transient binding in working memory. With advancing adult age, this intricate interplay of binding processes operating at different time scales and resolutions during perception, encoding, memory consolidation, and retrieval becomes ever more fragile and error prone. New bindings are less easily established, and previous binding events are less easily reinstated by appropriate cues.

The notions of cognitive control, working memory, and binding overlap in content and scope. For instance, working memory serves a function in cognitive control, and synchronous binding mechanisms probably form the basis of working memory. Taken together, the presence of pronounced age-related decrements in these functions and mechanisms underscore the potential utility of IHET in old age. In a situation in which top-down control and binding mechanisms deteriorate, IHET offers the opportunity to help individuals organize their behavior through the external provision of task-relevant cues and information.



## Sensory and Motor Functioning

### *Vision*

Vision declines with age (e.g., Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994; Marsiske et al., 1999; cf. Hawthorn, 2000, for a review focused on implications for assistive technology). During middle adulthood, many individuals start to notice problems with adjusting focus for near vision. Likewise, visual acuity, the ability to see details, begins to decline. Furthermore, declines in contrast sensitivity and reduced sensitivity to color are noted. With advancing age, adults also become more susceptible to glare and adapt more slowly to shifts in brightness. Over and above continued decline in visual acuity, visual field reductions emerge during early old age (e.g., after age 60). Thus, relative to young adults, peripheral stimuli need to be presented for longer times, with greater contrast, or moved toward the center of the visual field to be detected. Age-related decline in vision extends beyond the peripheral stages of perception, for example, the ability to identify figures embedded into other figures and the capacity to recognize fragmented objects deteriorate as well (Salthouse & Prill, 1988).

### *Hearing*

Based on World Health Organization criteria, about 20% of individuals ages 40 to 50 years have some form of hearing impairment. This percentage increases to 75% (Marsiske et al., 1999; cf. Hawthorn, 2000) for adults ages 70 to 80 years. Tone detection is generally impaired, with sounds at high pitch being affected earlier and more strongly than others. Older adults often miss sounds that peak at frequencies over 2,500 Hz. Although this finding is well established, technical appliances often use high-pitch sounds to alert their users. For example, telephone bells and smoke alarms often have intensity peaks around 4,000 Hz. In many languages, consonants are high pitched, which results in parts of speech being unavailable to the older listener. Estimates suggest that most individuals older than 80 years of age miss about 25% of the words in a conversation, having to guess or infer their meaning (Feldman & Reger, 1967). Aggravated by concomitant declines in selective attention, background noise is an ubiquitous problem for older individuals.

### *Posture and Gait*

The high prevalence of falls in the elderly population is the most dramatic symptom for the increasing difficulties of aging individuals to avoid maladaptive postural sway while standing or walking (Marsiske et al., 1999). The maintenance of postural stability while standing or walking requires the continuous coordination and integration of visual, proprioceptive, and vestibular sensory information in several areas of the brain, including the

cerebellum, brainstem, basal ganglia, and sensorimotor cortex (Woollacott & Jensen, 1996), as well as the execution of balancing movements by the limb and trunk muscles, which receive impulses from the spinal cord and peripheral nerves. Normal aging appears to negatively affect all stages of the postural control system, resulting in less reliable sensory information, less accurate integration, and less effective postural control (Brown & Woollacott, 1998).

### **Interactions Between Sensory/Sensorimotor and Cognitive Aging**

A growing body of literature has explored the hypothesis that sensory and sensorimotor performance of older adults should be compromised more than that of younger adults when cognitive demands are increased relative to a baseline condition. Such a result would be consistent with the idea that sensory and sensorimotor systems are increasingly in need of control and supervision as we age. In general, the available evidence supports this view (for a summary, see Li & Lindenberger, 2002). In addition to revealing more peripheral changes in sensory and motor domains, age-comparative analyses have demonstrated that cognitive control processes contribute to age differences in maintaining a stable upright stance (Teasdale et al., 1992). Studies in the domain of walking report similar results (e.g., Li, Lindenberger, Freund, & Baltes, 2001; Lindenberger, Marsiske, & Baltes, 2000).

To examine the effects of cognitive load on sensory processing, Sekuler, Bennett, and Mamelak (2000) assessed adults ages 15 to 84 years on a measure of peripheral visual processing, the useful field-of-view test. The useful field of view was tested either alone or concurrently with a centrally presented letter identification task. Whereas performance on the central task showed little effect of divided attention, error rates on the useful field-of-view test increased disproportionately when the central letter identification task was performed concurrently. This finding suggests that older adults' diminished useful field of view primarily reflects age-associated decrements in cognitive (e.g., attentional) resources.

Other studies have examined interactions between cognitive load and sensorimotor performance rather than sensory performance. Again, the general expectation was that cognitive load would hinder balance or locomotion in older adults more than in young adults. Research from the fields of kinesiology and rehabilitation medicine adopted the dual task paradigm from cognitive psychology to examine how specific aspects of walking (Chen et al., 1996) or balance control (Brown, Shumway-Cook, & Woollacott, 1999) are compromised by adding a concurrent cognitive task. For example, Brown et al. (1999) tested balance recovery by measuring center of mass before and after perturbations on a moving platform. Under dual task conditions, participants engaged in a concurrent counting

backward task. Whereas young and older adults demonstrated similar counting speeds before perturbations, older adults were differentially slowed in counting speed during the recovery period.

In the field of cognitive aging, a growing interest in the relationship between cognitive and sensorimotor aging has prompted sensorimotor dual task research that emphasizes cognitive issues such as reduced attentional capacity (Lindenberger et al., 2000). In contrast to earlier studies, this literature has also examined more complex cognitive tasks such as walking while talking (Kemper, Herman, & Lian, 2003) or walking while memorizing words using mental imagery (Li, Lindenberger et al., 2001; Lindenberger et al., 2000).

In the walking and memorizing study carried out by Lindenberger et al. (2000), young and older adults were trained to perform a memorizing task while walking quickly and accurately. On several measures of memory and walking, older adults showed a greater drop in performance under dual task conditions than young adults. Li, Lindenberger et al. (2001) replicated and extended these results by incorporating more extensive training of each task and individualized manipulations of task difficulty. Older adults were able to maintain high levels of walking performance but showed significant effects of divided attention in the cognitive domain. In addition to demonstrating a strong relationship between cognitive and sensorimotor ability, the findings also relate to the issue of task priority because older adults appeared to be protecting walking performance at the expense of cognitive performance.

Cross-sectional correlational evidence extending into very old age is also suggestive of connections among cognitive, sensory, and sensorimotor aging (see Li & Lindenberger, 2002, for review). Associations across domains appear to increase with age (Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994). To the extent that mean age trends and interindividual differences around mean age trends reflect similar mechanisms, these findings suggest that at least some of the mechanisms underlying age changes in sensory and intellectual abilities are functionally and perhaps causally related. Recent longitudinal analyses of sensory and intellectual changes in old and very old age lend more direct support to this interpretation (Ghisletta & Lindenberger, 2004).

## CO-CONSTRUCTING ENVIRONMENTAL SUPPORT IN OLD AGE

### **Strategies for Human Engineering Technologies in Old Age: A Preliminary Resumé**

Two broad classes of change processes are occurring simultaneously in the course of later adulthood and old age, probably in part for related reasons. First, the functional integrity and automaticity of sensory and motor

systems is deteriorating, with the important consequence that sensory and motor aspects of behavior are increasingly in need of cognitive resources. Second, cognitive resources such as executive control operations, working memory, and binding mechanisms also decline with advancing age. In combination, these two classes of changes result in increasing demands on decreasing resources, and constitute the quandary of behavioral aging (e.g., Lindenberger et al., 2000). A key purpose of assistive technology in old age is to attenuate the adverse effects of this quandary on development in later adulthood, old age, and very old age. Evidently, progress toward this goal requires the integrated consideration of sensory, motor, and cognitive changes. Specifically, designers of human engineering technology need to be aware of the reciprocal and increasingly tight interactions among motor, sensory, and cognitive aspects of behavior with advancing age.

Initially, we specified three criteria for evaluating the effectiveness of human engineering technologies in old age (Fig. 16.1). Net resource release (marginal resource gain) prescribes that the resource costs associated with the use of human engineering technologies must be lower than the resource release produced by other changes in task characteristics. Person specificity mandates that human engineering technologies ought to adapt themselves to the knowledge structure, habits, and preferences of the individual user. It also underscores that the criteria needed to judge the effectiveness of human engineering technologies should not be restricted to objective measures within the target domain but need to include subjective criteria, as well as the total life space of the individual. Third, the notion of proximal versus distal frames of evaluation helps remind us that a critical assessment of human engineering technologies requires attention to both short- and long-term effects.

With these three criteria in mind, and after having defined the quandary of behavioral aging in terms of increasing demands on decreasing cognitive resources, we are now in a position to formulate strategies for the effective implementation of human engineering technologies in old age. Emphasizing either the sensory/sensorimotor or the cognitive constituents of the quandary, two complementary and interconnected strategies come to mind. The first strategy approaches the quandary from the sensory/sensorimotor side: it attempts to free up cognitive resources by reducing the cognitive demands of sensory or sensorimotor aspects of performance. The second strategy attempts to provide individuals with adaptive external cuing structures that directly alleviate the effects of reduced cognitive control, working memory, and binding capabilities on cognitive performance. To be effective, the latter strategy needs to incorporate knowledge about the structure of the task, the task environment, and the person into an artifact that supports goal-oriented action in an adaptive and flexible manner.

The sensory/sensorimotor strategy, which aims at reducing cognitive resource demands by facilitating sensory and sensorimotor aspects of behavior, is generally less difficult to implement than the cognitive strategy. Therefore, past design recommendations have favored this approach (e.g., Hawthorn, 2000). Typical examples include the reduction of background noise, or glare-free, high-contrast, and well-lit workplaces. Assistive technology of this kind is often consistent with task-appropriate environments in general, and does not mandate any person- or task-specific adaptive capabilities. Other forms of human engineering technology targeting our sensory and bodily functions, such as glasses or canes, are person specific but, once adopted, require relatively little flexibility within persons (unless long-term changes in bodily functions need to be accommodated).

Note, however, that assistive technology aimed at our senses also can be quite complicated. For instance, many older adults experience the use of hearing aids with various nonautomated amplification modes for different auditory environments as cumbersome. In our terminology, the marginal resource gain of these aids is negative because the potential gain (i.e., less attention-demanding hearing) is outweighed by the resource demands associated with the operation of the aid. More recent hearing aids automatically adapt their amplification strategy to the auditory scene and are more likely to result in a net release of cognitive resources.

### **Enhancing Cognition by Providing Sensorimotor Support: Sample Case of Spatial Navigation**

Attempts at enhancing cognition by providing basic forms of sensory or sensorimotor support that require little cognitive investment can be surprisingly effective. A recent example from our own laboratory illustrates this claim. Lövdén, Schellenbach, Grossman-Hutter, Krüger, and Lindenberger (2005) projected virtual, maze-like museums in front of a treadmill. Young and older men were asked to perform a way-finding task in each of these virtual museums while walking on the treadmill. The task was to navigate from the entrance of the museum to its bistro twice in a row without error (i.e., without taking wrong turns at intersections). In the sensorimotor support condition, participants were allowed to hold on to a handrail. In the no support condition, participants were asked to walk freely on the treadmill. Young adults' navigation performance was not affected by walking support. However, in line with the predictions, older adults showed better navigation learning when holding on to the handrail (Fig. 16.3). It took older adults considerably less time and less walking distance to learn their way through a virtual museum when gait control was aided by handrail support.

These results indicate that supporting stability of gait in old age can have a beneficial effect on spatial navigation performance and demonstrate, once

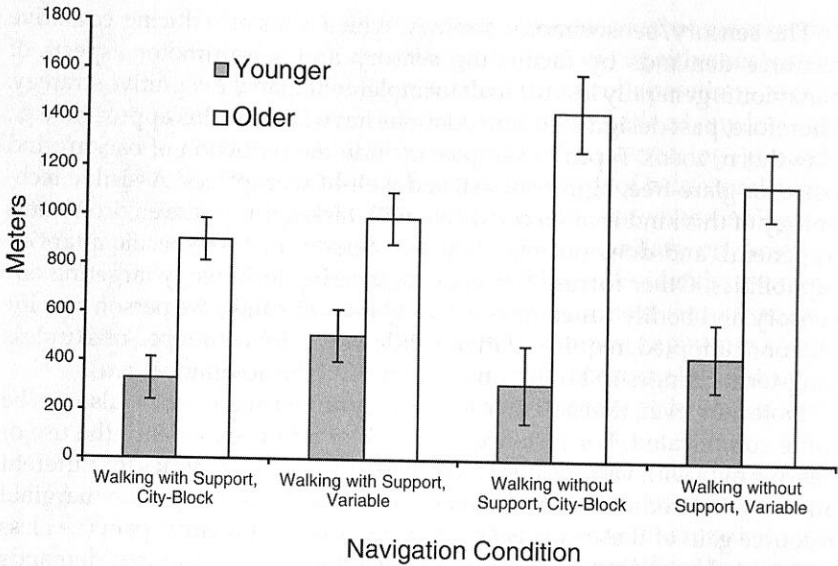


FIGURE 16.3. Adult age differences in way finding (spatial navigation) are modulated by sensorimotor demands. Bars display the mean distance covered to criterion ( $\pm$  standard error) as a function of age group (young vs. older adults), topography of the virtual environment (variable vs. city block), and walking demand (with or without support). (Adapted from Lövdén et al., 2005.)

again, the close connection between sensorimotor and cognitive aspects of behavior in old age. In older adults, support for walking not only improves postural control, but also frees up attentional resources that can then be invested into navigation-related processing. Based on this close coupling between sensorimotor and spatial aspects of locomotion, we predict that spatial navigation support should increase walking stability among older adults.

### Intelligent Human Engineering Technology as Adaptive and Personalized Cuing Structures

We now turn to the second assistive strategy, which aims at reducing cognitive resource demands through genuinely cognitive rather than sensory or sensorimotor intervention. Here, we highlight research on expertise (Krampe & Baltes, 2003), particularly research on skilled memory performance (e.g., Ericsson, 1985; Mäntylä, 1986).

IHET sometimes invokes the impression that elderly users, and IHET users in general, are expected to adapt their ways of thinking and acting to technological requirements. We want to propagate the opposite position. In line with the SOC model of successful lifespan development, we



conceive of older individuals as experts in leading their lives and pursuing their personal goals, and as people who own a rich behavioral repertoire and body of knowledge in accordance with their preferences, habits, and specializations. As “experts about themselves,” aging individuals possess exquisite knowledge, both implicit and explicit, about the ways in which their actions are organized in time and space. At the same time, due to decrements in cognitive control, working memory, and binding mechanisms, they experience difficulties in implementing their own knowledge in the course of action, especially under difficult conditions and in declarative manners – when they are tired, when distracting goals are present, when multiple goals are pursued simultaneously, when integration across different levels of generality or contexts is required, and when their sensory and sensorimotor systems are taxed and in need of additional attention. According to our interpretation, the key purpose of IHET in such instances is to act as an external cuing structure that keeps older individuals on the track of their own goal-directed actions.

### **Mnemonic Devices and Expert Knowledge**

Knowledge about the effectiveness of cuing structures in supporting goal-directed action is not new. In psychological research, cuing structures have been studied extensively in the context of exceptional memory performance (e.g., Ericsson, 1985). This work therefore provides a good point of departure for exploring the role of cuing structures in IHET design. Mnemonic devices always contain a series of overlearned cues, or “pegs.” In one particular mnemonic strategy, the Method of Loci (Bower, 1970), these pegs or cues consist of an invariant sequence of well-known locations. When memorizing a series of items, one associates each to-be-learned item with one element of the cuing structure. In the Method of Loci, one forms interactive images or thoughts that connect each of the to-be-learned items with one of the locations from the landmark sequence. At retrieval, the cuing structure (e.g., the locations) prompts the retrieval of newly learned items in serial order. As this example illustrates, a mnemonic device acts as a cuing structure during encoding and recall by integrating new information to a knowledge base in long-term memory.

Of course, cues as organizers of action and thought are not confined to mnemonic devices. Rather, the invention of mnemonic devices, which dates back to Ancient Greece and Rome, speaks to the power of cuing structures as organizers of thought and action, which in turn reflects the ubiquitous interplay of various binding mechanisms in learning and memory (Murre et al., in press). Thus, any well-organized body of knowledge simultaneously constitutes a cuing structure (Ericsson, 1985). For this reason, individuals inevitably show superior memory performance in their domains of expertise, whether it is bridge (e.g.,



Charness, 1979) or an area of professional specialization (Krampe & Balthes, 2003).

### **Determinants of Cue Effectiveness: Compatibility and Distinctiveness**

What determines the effectiveness with which cues facilitate access to goal-relevant information? Two aspects, compatibility and distinctiveness, are central (e.g., Mäntylä, 1986). Cues are said to be compatible when they contain or point to attributes that are functionally related to the task-relevant memory episode or action tendency. For instance, a stop signal effectively cues the action of stopping one's car because it has been firmly associated with this action during prior learning episodes. Note that this cue is likely to be compatible for all individuals whose learning history includes driving experience. However, the compatibility of other cues may vary widely from person to person because the corresponding learning histories are less uniform. Conceptually, the notion of cue compatibility is consistent with the principle of encoding specificity (Tulving & Thompson, 1973).

In addition to being compatible, cues should also be distinctive; that is, they should activate the specific action required without co-activating a large number of competing actions. Again, cue distinctiveness may not be invariant across persons and contexts (e.g., Hunt & Einstein, 1981). Depending on context and knowledge, cues that are distinct for one person may be ambiguous for another. The recent proliferation of ring tones speaks to the speed with which distinctiveness of cues can be gained (and lost).

When individuals generate their own cues, either explicitly or as implicit residues of successful behavior and action, these cues are likely to match their knowledge, habits, and preferences. Such cues should therefore show superior compatibility and distinctiveness compared with cues generated by other people. Mäntylä (1986) tested this hypothesis by asking college students to define their own retrieval cues by generating properties or features for each to-be-remembered word presented at the encoding phase. In his second experiment, one group of participants generated, on 3 consecutive days, one property to a total of 504 words. A second study group generated three properties to each word. During unexpected recall tests administered repeatedly at different retention intervals (immediate, 1 day, 2 days, and 7 days), participants in these two groups were given both their own properties and those generated by someone else as retrieval cues. In addition, participants in a no study condition were not presented with the to-be-remembered items. Instead, they were given 504 single properties or sets of three properties that the participants in the study condition had previously generated and were asked to generate the study words based on these properties.

The outcome of this experiment was quite spectacular. Self-generated properties presented as cues resulted in exceptionally high levels of recall. For instance, after 7 days, participants recalled on average 327 of the 504 words when given three self-generated properties as cues; immediately after study, they recalled 459 of the 504 words. Also, self-generated retrieval cues were far more effective than those generated by someone else. The difference in immediate recall between self-generated properties and properties generated by others was more than 35% when three properties were presented, and nearly 50% when only one property was presented as a cue.

The data also showed that participants were more likely to forget self-generated retrieval cues than those generated by someone else. Mean recall performance decreased as a function of retention interval by approximately 30% when the participants were presented with their own properties. When someone else's properties were presented as cues, a smaller decrease in performance was observed. These data indicate that self-generated properties are powerful cues but that their effectiveness depends on contextual factors. Finally, when one or three properties were presented as cues without any preceding study phase, the mean proportions of correctly generated target words were 5% and 17% for one and three properties, respectively. Thus, the high degrees of recall obtained in the self-generated cue conditions clearly resulted from retention and not from any general cuing power of the properties per se.

In subsequent studies, it was found that self-generated cues also boost recall performance in older adults (Bäckman & Mäntylä, 1988); however, the effect was less pronounced than in young adults. The observed age difference probably reflects age-based increments in intraperson context variability, less idiosyncratic processing of older adults at encoding, and less efficient binding mechanisms (Bäckman & Mäntylä, 1988; cf. Craik, *in press*; Li & Lindenberger, 1999; Li et al., 2005). Still, when compared with other forms of cuing, self-generated cues are extraordinarily effective in late adulthood and old age.

To summarize, effective cues are compatible and distinct. Self-generated cues excel on both dimensions and permit exceptionally high levels of recall performance. By analogy, compatibility and distinctiveness of expertise-related cues (e.g., chessboard configurations) are predictably high in experts because their personalized knowledge system is consistent with the rules and history of the expertise domain (e.g., chess).

### **Toward the Design of Person-Oriented Assistive Technology**

Older adults have difficulties in accessing, and operating with, details, but they show less or no decline when processing general or gist-like information, probably due to impaired binding mechanisms. In addition, executive processes that help regulate and coordinate goal-directed action also

function less reliably, and the ability to simultaneously process and retain events in working memory is reduced. In this situation, a key purpose of IHET is to provide an adaptive cuing structure. This structure orients the aging individual in time and space by providing prompts that connect properties in the environment to the action goals of the individual. Cues are helpful when they prompt the appropriate action at the right point in time. Relevant research on memory functioning indicates that compatibility and distinctiveness contribute to cue efficiency, and that self-generated cues excel in both regards.

In agreement with these considerations, IHET designers are asked to adapt the properties of assistive devices to aging individuals' needs and competencies (e.g., Charness & Schaie, 2003). To approximate this goal, some systems require explicit input and manual reprogramming from the user of the assistive device (e.g., LoPresti et al., 2004). This, in turn, greatly reduces the net cognitive resource release assisted with the operation of such devices, at least during the initial phases of IHET customizing.

However, adapting IHET to the individual user can also be accomplished in a different, technologically more demanding but psychologically more promising manner. Put simply, the assistive device or the instrumented environment itself, rather than the user, can be charged with the task of learning the user's habits and preferences. Work on several systems of this kind is in progress (e.g., Kautz et al., 2004). For example, a wide range of sensors, such as GPS and motion detectors, can monitor aspects of an individual's location and environment (e.g., ubiquitous computing; cf. Patterson et al., 2003). Based on pattern recognition and machine learning algorithms, IHET extracts the individual's patterns of behavior and deviations from the individual's normal daily routines. It assists the user by prompting for action and providing action-relevant information, and further customizes its cuing structure in response to the user's reactions.

We envision the functioning of IHET as a multilayered, ontogenetically adaptive process of individualization. Initially, when knowledge about the individual user is absent, IHET will operate on the basis of a default model (e.g., the "average user"). Explicit offline information about the user's cognitive, sensory, and sensorimotor abilities, as well as his or her preferences and habits, may be entered to modify these default parameters. More important, however, is an extended period of "acculturation" that permits IHET to learn the regularities and contingencies that permeate the life of the individual user.

### **Individualized IHET: An Imaginary Case Study**

To render our vision of individualized IHET more concrete, we end this chapter with an illustrative and admittedly fictitious case study. Ms. Miller, a 90-year-old widow, lives in her own apartment in a small town in Europe.

Her core family consists of two daughters and their families. Ms. Miller is mentally fit and physically healthy, and has no intention of giving up her apartment; being able to live in her own home matters much to her. On the occasion of her ninetieth birthday, she receives a handheld electronic device from one of her daughters. At first sight, the device looks like a mobile phone and, in fact, can be used as such. Ms. Miller has been using mobile phones for several years, and she immediately starts using the handheld for this purpose, taking it with her on all errands.

In addition to serving as a mobile phone, the new handheld also has other capabilities: it is equipped with GPS, a large and well-lit short message service display, a piezoelectric movement sensor, an infrared receiver/transmitter, and, most important, with machine learning capabilities. At home, it is electronically connected to the stationary telephone, and registers all incoming and outgoing calls.

Initially, Ms. Miller does not make active use of these additional functions; for her, the device is just a new and somewhat clumsy mobile phone. However, most of these additional functions are operating from the very first day. Due to its machine learning capabilities, the handheld is extracting regularities in Ms. Miller's life. For instance, it will register (1) that Ms. Miller calls the younger of her daughters about every other day in the afternoon; (2) that she calls the other daughter each day early in the morning; (3) that she walks to the cemetery once a week to visit the grave of her late husband; (4) that she goes to the hairdresser every Saturday morning; (5) that she goes to church every Sunday morning; (6) that she receives a phone call from one of her two granddaughters living in another European country every other month; and (7) that she moves the device before 9 AM every day.

With advancing age, Ms. Miller's cognitive abilities eventually begin to decline. At age 94, she tends to forget planned actions and is more easily distracted than before. In this situation, the handheld slowly begins to assume its role as a personalized cuing device that assists Ms. Miller with her everyday activities. At first, Ms. Miller is somewhat annoyed by the messages from the handheld that remind her of things she may want to do by making remarks such as "Good time to call your daughter Anna!" or "What about the hairdresser?" However, she eventually gets used to these kinds of prompts. She also notices that her relatives are impressed by her persisting independence and competence. The device continues to take notice of enduring changes in daily routines and adapts to them. For instance, the visit to the cemetery is now taking place every other week.

Ms. Miller has also begun to make use of the shopping aid component of the device. Before leaving her apartment for shopping, she sits down at the kitchen table, and registers her shopping items on the handheld with a voice key. She then goes to the shopping mall equipped with infrared

sensors matching those of the handheld device. The sensors make contact with Ms. Miller's handheld, register her shopping list, and suggest a shopping route, navigating Ms. Miller through the mall from shop to shop by giving directions on the display of her handheld. When Ms. Miller has reached a shop, the handheld prompts her with the shopping items that are available at this location. If an item is sold out, the handheld redirects Ms. Miller to another store in the mall that may also carry that item and reconfigures the shopping route accordingly. In this manner, the handheld keeps track of the shopping list and navigates Ms. Miller through the mall until all her shopping needs are satisfied.

One morning, Ms. Miller feels sick and is not able to get out of bed. At 9:00 AM, the piezoelectric sensor notes that the handheld has not yet been moved and starts ringing. Ms. Miller cannot respond because the handheld is too far away. At 9:20 AM, the handheld automatically calls the hospital, and an ambulance arrives in time to provide medical treatment.<sup>1</sup>

## CONCLUSION AND OUTLOOK

In this chapter, we critically examined human engineering technologies from the perspective of lifespan theory and biocultural co-constructivism. Our aim was neither to review the latest technological developments nor to provide descriptions of relevant hardware and software (but see Kautz et al., 2004; LoPresti et al., 2004; Patterson et al., 2003). Instead, we wanted to propose genuinely psychological guidelines that provide a conceptual foundation for the development of assisted technology in old age. In our judgment, such a psychological foundation is badly needed. Perhaps the most palpable desiderata of IHET design reflect insufficient attention to psychological laws and findings rather than technological shortcomings. For example, based on the theoretical framework presented in this chapter, we predict that individuals suffering from dementia will profit most if IHET is introduced into their lives prior to, rather than after, the onset of the disease.

Our evaluation of human engineering technology in old age was based on lifespan theory (Baltes et al., 2006); findings about age-associated decrements in sensory, motor, and cognitive functions; and general laws of learning, memory, and expert performance. Informed by the SOC model of successful lifespan development, we established three criteria for IHET design: net resource release, person specificity, and proximal versus distal frames of evaluation (Fig. 16.1). We argued that IHET design needs to consider determinants of cue effectiveness, the increasing need of sensory

All technological components described in this imaginary case study, including the shopping assistant (Krüger et al., 2004), are available. However, to the best of our knowledge, a device of this kind has not yet been developed.

and sensorimotor functions for cognitive control, and the idiosyncratic habits and preferences of aging individuals.

In future research on IHET, the issue of proximal versus distal evaluation merits special attention. The initial operation of a new assistive device may impose additional resource demands, thereby violating the criterion of net resource release. After a few weeks, most elements of skill involved in using the device may have become automatized, and the resource balance may eventually become positive. However, after a few years, chronic net resource release may induce reactive resource depletion because certain skills and abilities that would have been practiced and trained without the device have not been used anymore. In short, too much technological assistance may be harmful. Finding the right balance between "environmental support" and "self-initiated processing" (Craik, 1983, in press) to arrive at support that adaptively avoids undershooting the maximum manageable difficulty will become a central element for the design and evaluation of IHET. For instance, spatial navigation aids may have positive effects on individuals' way-finding success. However, to the extent that the use of such aids installs route learning strategies and disuse of cognitive processes involved in spatial integration, long-term and transfer effects may be negative. In light of mind-tickling findings relating increased size of the brain structures (posterior hippocampus) functionally involved in spatial integration to exposure to environments with high demands on navigational skill (London taxi drivers; Maguire et al., 2000), one might predict that disuse induced by technological interventions could negatively affect the human brain. In other words, just as the specific needs of the growing population of aging individuals impose demands on society in general, and engineers and industry in particular, to construct supportive environments, these environments may eventually reshape the architecture of the aging brain.

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