The Berlin Aging Study

Aging from 70 to 100

Edited by

PAUL B. BALTES

KARL ULRICH MAYER

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Sensory Systems in Old Age

Michael Marsiske, Julia Delius, Ineke Maas, Ulman Lindenberger, Hans Scherer, and Clemens Tesch-Römer

In this chapter, three sensory systems (hearing, vision, and balance/gait) are examined. We begin with a descriptive overview of individual differences and age difference patterns in sensory functioning. The pattern of how individual differences in sensory acuity might be related to performance in other psychological and behavioral domains is examined. We reveal a strong, negative pattern of age differences in all three senses studied. These negative age trends have implications for the classification of sensory impairment rates: Although participants in their 70s have levels of sensory acuity that might be classified, on average, as slightly or mildly impaired, by their 90s most participants evince levels that might be classified as moderately to severely impaired, not only in one but in multiple modalities. We also report prevalence rates for the use of commonly occurring compensatory devices and procedures (e.g., hearing aids, glasses, cataract operations). We report the following findings with regard to the relationship of sensory functioning to other domains of psychological and behavioral performance (e.g., intellectual functioning, basic and expanded everyday competence, personality characteristics, well-being, social network size):

(1) Relationships exist between all three sensory domains and the selected outcome domains. The relationships with intellectual functioning and everyday competence are particularly strong.
(2) In all domains studied, the sensory variables can explain or mediate virtually all of the age-related variance in those domains; that is, after statistically controlling for sensory performance, there is essentially no unique effect of chronological age.
(3) For the most part, the effects of sensory variables seem to be additive, rather than interactive, throughout the age range from 70 to over 100 years.

1 Introduction

This chapter reports findings from the Berlin Aging Study (BASE) regarding individual differences in sensory functioning among old and very old persons. The consequences of age-related differences in sensory capabilities for performance in a variety of functional domains are also examined. By considering "functional" consequences of sensory aging, we ask the question of what individuals do, or how they perform, on selected outcome variables in the context of their levels of sensory performance. We focus on three senses: hearing, vision, and balance/gait.

The central importance of effective sensory functioning as a necessary precondition for interaction with the environment is indisputable. Although it may be possible to com-

pensate for some sensory losses, or to function effectively following limited impairments in one or more senses (Whitbourne, 1985), age-associated sensory losses must be thought of as a risk factor restricting effective participation in the everyday world. Since late life is thought of as a time of multiple impairments (see Steinhagen-Thiessen & Borchelt, Chapter 5 in this volume), cumulative risk resulting from losses in more than one sense may have particular importance as a potential source for losses in *other* domains of functioning.

Theoretically, this chapter draws upon the conceptual underpinnings of BASE (discussed in detail in P. B. Baltes et al., Chapter 1; Mayer et al., Chapter 18), particularly the notions of aging as a systemic phenomenon, and differential aging. By viewing *aging as a systemic phenomenon*, we focus on the integration of functioning across systems, and the fact that age-associated changes in some subsystems may have implications for functioning in other systems. One version of this perspective is the "cascade hypothesis" (Birren, 1964), in which the effects of aging losses in some systems seem to have "domino-like" effects for other systems. Sensory performance is a basic domain of functioning. In this domain we can see the most fundamental level of the organism's interaction with its environment. One important question is whether losses in sensory functioning "drive" losses in other, more complex functional domains. It is important to note, however, that the cross-sectional, correlational nature of BASE does not permit us to evaluate the causal status of sensory variables.

Another question embedded in the systemic aging view is whether the "sensory compensation" effect reported earlier in life (e.g., blind persons might hear better or have better tactile sense; Neville, 1990; Rauschecker, 1995) breaks down in later life. Are losses in one sense made up for by stability or gains in other senses? Or are they matched by losses in other senses?

Differential aging, as outlined in detail in Chapter 7 by Smith and Baltes, considers the ways in which the aging process might vary between individuals. A differential perspective might hypothesize, therefore, that the experience of aging may differ for persons with and without severe sensory losses.

To explore late-life sensory functioning and its relations to other domains, this chapter is organized around two major questions. First, we consider, descriptively, the distribution of hearing, vision, and balance/gait functioning in old and very old age, trying to place our findings within the context of other studies, and to illustrate what such losses imply. Second, we also explore the associations of sensory functioning with other domains of performance, and consider what such relationships might mean from systemic and differential perspectives.

2   Descriptive Findings

This section is organized into three parts, each with the aim of describing elements of sensory functioning in BASE participants. First, we consider the distribution of sensory performance in hearing, vision, and balance/gait, focusing on the pattern of age-related individual differences. Second, we explore the implications of these age-related patterns for the classification of sensory impairments (in hearing and vision, where such classification criteria exist). Third, we briefly examine the use of assistive devices and procedures (e.g., hearing aids, glasses, cataract operations) in BASE participants.

Figure 13.1. a) Participants' visual acuity in Snellen decimals by age decade and gender. b) Distribution of binocular distance vision by age.
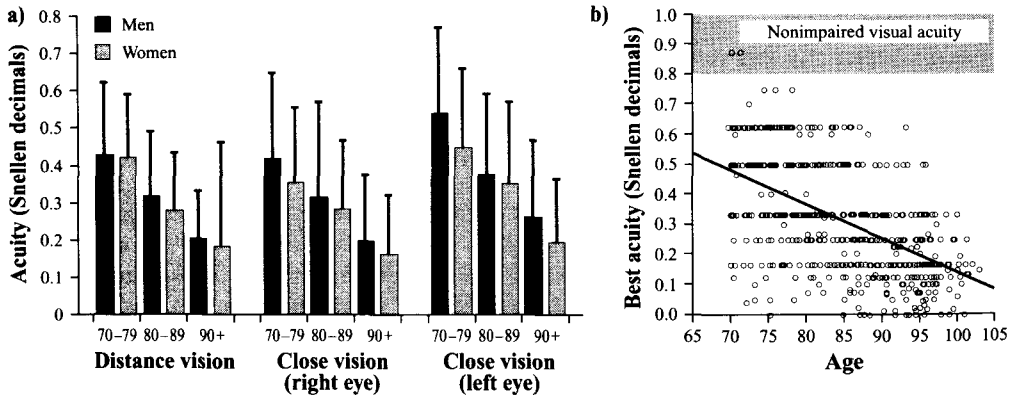
Note. Distance vision was tested for both eyes together, and close vision was tested for right and left eye separately.

2.1   Mean-Level Patterns and Individual Differences

2.1.1   Age Differences in Vision

Within BASE, visual acuity[1] was assessed using standard optometric (clinical) procedures (see also Borchelt & Steinhagen-Thiessen, 1992; Lindenberger & Baltes, 1994; Steinhagen-Thiessen & Borchelt, 1993). It is important to point out that, for the measurement of all senses, process-oriented psychophysical measurements were not available. Close vision was assessed separately for the left and right eyes using a Snellen reading chart presented at an individually determined reading distance (typically about 25 cm); distance vision was assessed binocularly with a Snellen chart 2.5 m away (with greater distances used for persons performing at ceiling under standard assessment). All vision measurements were obtained without and with correction (i.e., participants' glasses, when available). Measurements were taken in Snellen decimal units, where a value of 1.0 is taken to indicate normal (20/20) vision, as normed in younger adults (see below for discussion of thresholds). Over 90% of BASE participants wore glasses, and some analyses in this chapter are based on the *better* performance values (so as to rule out those cases where poor visual correction was clearly a contributor to poor vision).

Figure 13.1a shows the distribution of visual acuity by age and gender within BASE; each additional decade of life was associated with significantly lower visual performance, and women performed significantly more poorly than men. It is important to note that the apparent gender difference may be a spurious consequence of gender-specific selection effects (see Fig. 2.5, Lindenberger et al., Chapter 2), although there is convergent

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[1] In the following, it is always stated whether visual acuity was measured with or without correction (i.e., participants' glasses). Generally, "vision" encompasses several aspects of visual functioning. In BASE, only acuity was examined. Thus, other functions such as the visual field and color vision are not discussed.

evidence in the geriatric literature that women report a higher rate of visual impairment (e.g., Schmack, 1989).

Figure 13.1b shows the distribution of individual differences in corrected distance vision with age using a scatterplot. The shaded area represents nonimpaired vision as normed in younger adults (Snellen decimal of 0.8 or greater). As the figure shows, not only did very few of the BASE participants meet this criterion for "normal" vision, but there was also a strong trend toward lower performance with advancing age. At the highest ages, most participants were concentrated at the lowest end of the vision distribution; at the youngest ages, most participants were performing closer to (but below) the range of normal vision.

How do the BASE findings regarding visual acuity compare with the results of other studies? A number of cross-sectional and longitudinal investigations of visual aging have documented substantial age-associated losses in vision (for comprehensive reviews, see Fozard, 1990; Kline & Schieber, 1985; Schieber, 1992). Everyday observation suggests that reading glasses become a normative acquisition in midlife; indeed, the epidemiological data suggest that preferred reading distances vary from 10 cm in 20-year-olds to 40 cm in 50-year-olds due to reduced accommodation ability (Bennett & Eklund, 1983a).

Cross-sectional estimates of distance visual acuity show substantial decline after age 50 (Pitts, 1982); visual acuity poorer than 20/50 in the better eye has been reported to occur in about 10% of those aged 60 to 69 years, and in 25–35% of those over age 80 (Anderson & Palmore, 1974; Branch, Horowitz, & Carr, 1989).

In comparison to other studies, the level of visual acuity in BASE participants seems to be substantially lower than that reported in other studies. One reason for this difference may be that other published prevalence estimates of visual impairment actually underestimate true rates of impairment; essentially no studies have studied subjects over 80 years of age as systematically as BASE. Moreover, since most studies of older adults exclude institutionalized individuals, published disability prevalence rates may be further underestimated. At the same time, it must be recalled that BASE participants were tested in their own home and institutional environments. Although this meant that vision was assessed under relatively naturalistic conditions, it was not possible to control the level of target illumination and glare as well as has been done in some other studies. This could have contributed to lower performance levels (Fozard, 1990).

2.1.2 Age Differences in Hearing

In BASE, auditory acuity was assessed with a Bosch ST-20–1 pure-tone audiometer, using headphones. This precluded analysis of corrected versus uncorrected hearing since hearing aids could not be comfortably or securely worn with these headphones. Decibel thresholds were assessed for eight different frequencies, in the following order: 1.0, 2.0, 3.0, 4.0, 6.0, 8.0, 0.5, 0.25 kHz. Testing was started with the ear reported as "better" by participants (the right ear when subjects did not know). Figure 13.2 shows the obtained age-by-gender-by-frequency distribution.

To summarize the results of an analysis of variance on these data, there were significant main effects of age, and frequency, and significant interaction effects included gender by frequency, age by frequency, and age by gender by frequency ($p < .01$). The data suggest that women had lower hearing thresholds (better hearing) than men in frequencies above 0.50 kHz at all ages, and that increasing age was associated with increases in hearing thresholds (i.e., worse hearing). At the lowest frequency (0.25 kHz), men actu-

Figure 13.2. Participants' auditory thresholds, averaged over both ears, by age decade and gender.
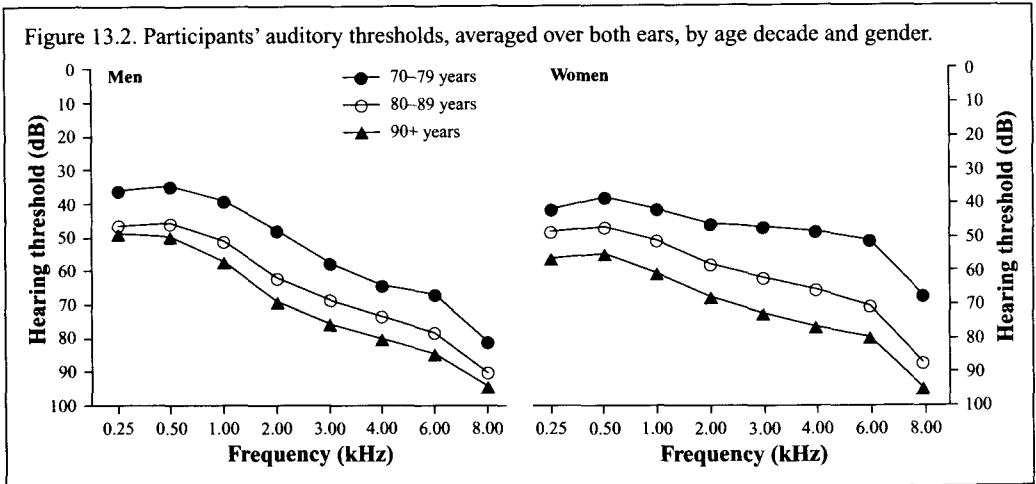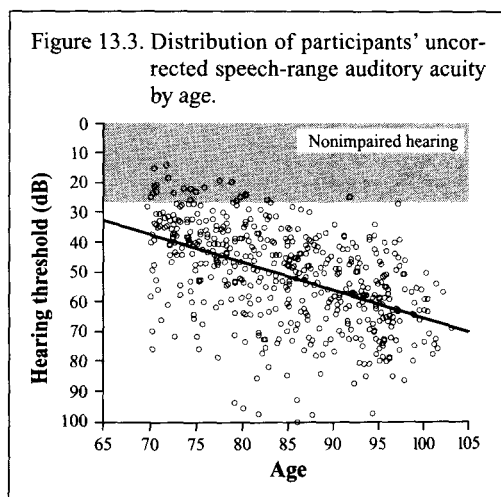

ally had lower thresholds than women, a result that is consistent with work reported by Corso (1963), Jerger, Chmiel, Stack, and Spretnjak (1993), Pearson et al. (1995), and others. At the same time, there was some narrowing of the gender gap, particularly at higher ages and at higher frequencies. Consequently, the average shapes of the hearing curves, across frequencies, differed by age and gender.

Figure 13.3 displays the variation of uncorrected speech-range auditory acuity (i.e., at 0.5, 1.0, and 2.0 kHz) with age. The shaded area, which runs across the scatterplot, shows normal hearing (normed in younger adults) at speech-range hearing frequencies. Very few participants were performing within this normal range, and most of these persons were at the younger end of the age range. Indeed, with advancing age, there seems to be a shift in both the lowest and highest volumes needed to hear speech-range tones: In the 70s, no one required a tone to be presented at greater than 80 dB; in contrast, in the 80s and 90s, some individuals required tones to be even louder. And while some participants in their 70s could hear tones between 10 and 30 dB, in the 90s virtually no one could hear tones at less than 30 dB.

As with vision, mean levels of auditory acuity are lower in the heterogeneous BASE sample than in many other studies. Two explanations seem likely. First, published prevalence estimates for individuals over 65 may again seriously underestimate the prevalence of hearing loss in the oldest old. Second, the testing of participants in their natural environments means that surrounding noise during the hearing assessment was not as well controlled in BASE as in some other studies, thus raising hearing thresholds to a certain degree.

Despite these caveats, the BASE data reflect patterns that have been widely reported in the research literature. It has been reported that symmetrical (affecting both ears) loss of hearing for high-frequency sounds sets in quite early in life (20+ years), increasing at differing rates (for a review, see Olsho, Harkins, & Lenhardt, 1985; Willott, 1991). This leads to a typical pattern of hearing loss: the higher the frequency, the more severe the hearing loss. Clinically significant hearing loss (defined as 30 dB below the normal 0–15 dB hearing level)[2] is observed in about 30% of men over 65 (e.g., Bess, Lichten-

Figure 13.3. Distribution of participants' uncorrected speech-range auditory acuity by age.

stein, Logan, Burger, & Nelson, 1989). Indeed, as Corbin and Eastwood (1986) have noted, hearing loss in the range of 25–35 dB within speech-range frequencies, and 45–50 dB at high frequencies, is considered "normal" for 80-year-olds, although these would constitute clinically significant hearing loss for 40-year-olds. It is also important to note that pure-tone audiometry may underestimate functional hearing impairments in the everyday world. Age-related limitations in speech comprehension, for example, are often more serious than the audiometrically measured pure-tone thresholds in the range of speech frequencies (0.5–2.0 kHz) indicate (for review, see Working Group on Speech Understanding and Aging, 1988). Aging is also associated with an increase in problems like tinnitus and functional deficits, including slowing of signal processing, and limitations in comprehension of distorted speech (e.g., via telephone; Bess et al., 1989).

2.1.3   Age Differences in Balance/Gait

Many reviews of altered sensory functioning in late life do not include balance/gait (but see Corso, 1981), since it is typically not counted as one of the "big five" senses (hearing, vision, taste, touch, and smell).[3] Balance/gait is a "higher order" sense, since the maintenance of orientation in space requires integration of information from many other sensory input channels; coherent ocular, vestibular, proprioceptive, and acoustic information, as well as motor coordination, are necessary for the sensation of stable balance/gait (for review, see Mhoon, 1990). Indeed, many studies have reported that sensory losses, especially in vision, are an important precursor of balance/gait problems (Lord, Clark, & Webster, 1991; Manchester, Woollacott, Zederbauer-Hylton, & Marin, 1989).

[2] Different criteria for classification of hearing impairments are used in the literature. According to the World Health Organization (WHO, 1980) a hearing threshold of 0–15 dB is "normal." Impairments of more than 25 dB are termed as mild. The problems associated with setting such criteria are discussed in more depth below.

[3] Although we emphasize sensory functioning throughout this chapter, it is important to underscore that balance/gait also has a motoric component. Where balance/gait is seen to have a unique predictive effect on other variables (below), it may be that this unique variance is primarily motoric.

Figure 13.4. Participants' performance in balance/gait tests by age decade and gender. a) Number of steps taken to turn 360° quickly. b) Romberg trial (see text for details); degree of sway measured on a six-point scale.
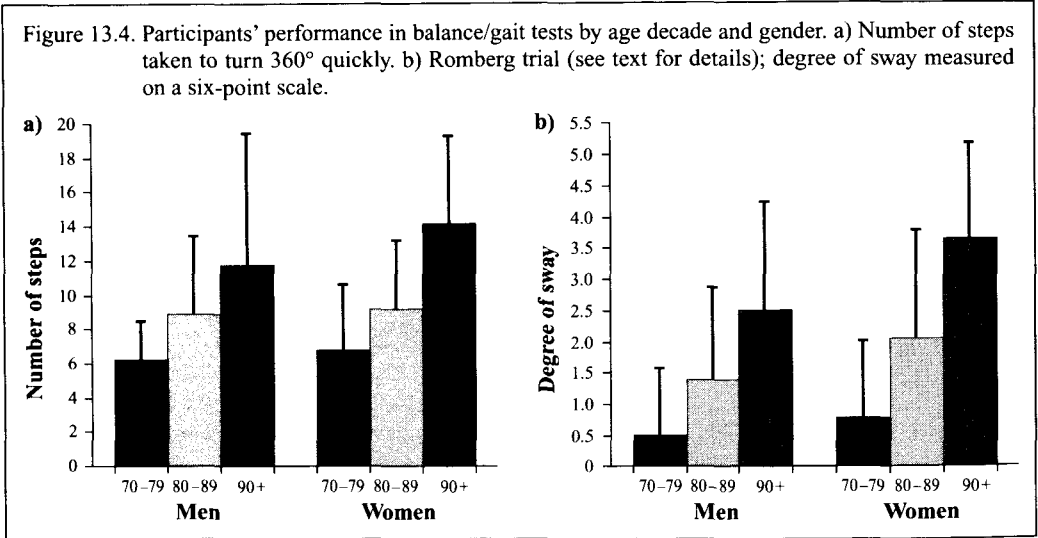

Much of the research on balance/gait problems has been conducted within the context of research on the prevalence, predictors, and prevention of falls in older adults. Estimates suggest that as many as one-third to one-half of adults over the age of 65 years fall each year (Exton-Smith, 1977; Gryfe, Amies, & Ashley, 1977; Horak, Shupert, & Mirka, 1989; Isaacs, 1985). Survey data also suggest that increasing proportions of adults report subjective difficulties with maintaining equilibrium after age 65 (Gerson, Jarjoura, & McCord, 1989; Ödkvist, Malmberg, & Möller, 1989). According to one review of various investigations, about 60% of women and 30% of men over 65 report attacks of dizziness (Haid, 1993).

Within BASE, a clinical assessment approach derived from Tinetti (1986) was used (for additional details, see M. M. Baltes, Mayr, Borchelt, Maas, & Wilms, 1993; Borchelt & Steinhagen-Thiessen, 1992; Lindenberger & Baltes, 1994; Steinhagen-Thiessen & Borchelt, 1993). In this chapter, we focus on two measures:

(1) For the *Romberg trial*, participants were required to stand with arms extended forward, palms up, eyes closed, and legs together for about one minute. Degree of sway was scored on a six-point scale by physicians in the BASE medical data collection sessions (see Steinhagen-Thiessen & Borchelt, Chapter 5).

(2) For the *360° turn*, participants were asked to turn their body by 360° as quickly and as safely as possible; the number of steps taken was recorded by the medical observers.

Figure 13.4 shows the age and gender distribution of the two balance/gait assessments in BASE. For both measures, as with hearing and vision, there were significant main effects of age and gender ($p < .01$). Increased age was associated with greater difficulty (more sway, more steps), and women performed more poorly than men. Figure 13.5 displays the distribution of postural sway in the Romberg trial. In this task, we see individu-

Figure 13.5. Distribution of participants' performance in Romberg trial by age.
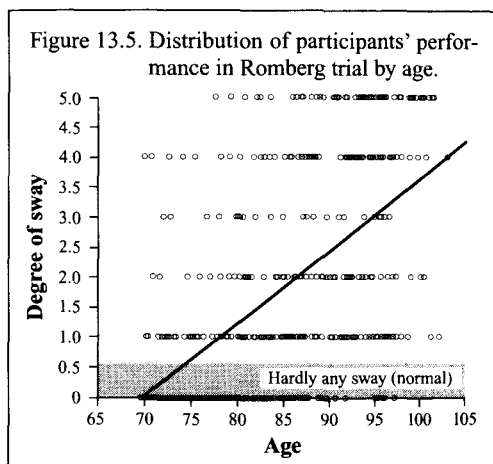
als who demonstrated no sway across the full age range studied, although, as the plot densities show, the proportion of individuals who showed the highest levels of sway (4) and who could not perform the task (5) became increasingly larger at higher ages.

2.2   Patterns of Sensory Impairment

What are the implications of these mean and individual difference trends for rates of sensory impairment? Although the estimation of impairment rates is not without problems,[4] we provide estimates for two reasons. First, since much of the research literature on the aging of sensory systems provides estimates of impairment rates, provision of these data here facilitate comparability with other studies. Second, by obtaining information about the proportion of individuals at different levels of functioning within particular age groups, one gains a more concrete understanding of the range of individual performance capabilities among old and very old adults. We present impairment rates for vision and hearing only (i.e., not for balance/gait), since well-agreed-upon impairment criteria for the clinical balance/gait measures discussed in this chapter are not yet available. For further discussion of these measures in connection with disability and impairments of mobility, see Chapter 5 by Steinhagen-Thiessen and Borchelt.

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[4] It is important to clarify several issues about the impairment classifications in this chapter. First, all systems of impairment classification are essentially arbitrary, and potentially dangerous, because there may be a range of individual competencies at a particular level of auditory or visual acuity, and individuals may have different ways of compensating for impairments. Second, rates of impairment will vary as a function of the classification system used. Third, the impairment classifications discussed below are not specifically normed for older adults. Thus, given normal age-associated losses in hearing and vision, these impairment criteria will lead to the identification of disproportionately more "impaired" older adults than in younger age groups. Fourth, these rates do not speak to remediated versus unremediated impairments, or to the putative origins of such impairments (it is not being suggested, for example, that these impairment rates are indicative of primary or intrinsic aging phenomena, or that they do not include age-related effects on vision and hearing that result from cumulative environment risk and injury, medication, acoustic or optical trauma, etc.).

Although the classification of impairment is somewhat arbitrary (rates of impairment are dependent on the classification system used), we draw upon the World Health Organization (WHO, 1980) "International classification of impairments, disabilities, and handicaps." This system has the benefit of being widely used, and of differentiating several levels of impairment.

For vision, we consider four levels of impairment, focusing here on distance vision averaged across both eyes (WHO, 1980). *No visual impairment* consists of visual acuity at a Snellen decimal of 0.8 or better. *Slight visual impairment* exists for Snellen decimals between 0.8 and 0.3. *Moderate low vision* refers to visual acuity at Snellen decimals between 0.3 and 0.12. *Severe low vision to blindness* includes all individuals with distance visual acuity that is less than 0.12.

For hearing, we also consider four levels of impairment, averaged across both ears. Individuals with *no impairment* are those with hearing in the speech-range frequencies (0.5, 1.0, and 2.0 kHz) between 0 and 25 dB. *Mild impairment* describes speech-range hearing between 26 and 40 dB. *Moderate impairment* refers to speech-range hearing between 41 and 55 dB. All other individuals (with hearing thresholds in the three frequencies that are 56 dB or higher) are classified as having *moderately severe to profound hearing loss*.

In Table 13.1, the resulting impairment rates are shown for three age decades (70–79, 80–89, 90+ years). We report weighted data that correct for the oversampling of men and the very old and, in turn, provide estimated prevalence rates for the West Berlin population of persons aged 70 and above. The weighting procedure, its conceptual basis, and interpretative implications are discussed in detail in Chapter 1 by P. B. Baltes et al.

The impairment patterns reflect the age-patterns in vision already discussed. As Table 13.1 shows for vision, at all ages represented in BASE, very few elderly West Berliners had distance vision that would be classified as "nonimpaired" (as normed in younger adults). However, about 80% of 70- to 79-year-olds showed only slight impairment. In contrast, almost half of 80- to 89-year-olds had moderately low vision. By the age of 90 and above, slightly more than half had moderately low vision, and between one-quarter and one-third had severely impaired vision or blindness.

Table 13.1 also shows impairment rates for hearing in speech-range frequencies. The picture is similar to that obtained with distance vision. At all ages, less than 10% had "normal" hearing (as normed in younger adults). Half of 70- to 79-year-olds were only mildly hearing impaired. Two-thirds of 80- to 89-year-olds were equally divided between moderate and moderately severe hearing impairment. By the age of 90 and above, fully two-thirds of the population had moderately severe hearing impairment or worse.

The picture that emerges then from these data is one of very high prevalence of sensory impairment with advancing age. At the highest ages, nearly everyone in this sample showed some clinically significant loss in hearing or vision.

As suggested above, most prevalence estimates for vision loss and hearing loss in older adults (e.g., Davis, 1983) have been lower, but few studies have included as heterogeneous a subject group as BASE, both in terms of age and residence conditions. Moreover, many studies have not tested older adults in their everyday contexts.

Of course, the examination of impairment separately by modality obscures one of the hallmarks of late life: multimorbidity (e.g., Fries, 1990; cf. Steinhagen-Thiessen & Borchelt, Chapter 5; Borchelt et al, Chapter 15). It has been argued that late life is a time

Table 13.1. *Rates of impairment (in %) in vision and hearing by age*

Distance vision (in Snellen decimals)

	Impairment[a]			
Age group	None (≥ 0.8)	Slight (0.3–0.8)	Moderate (0.12–0.3)	Severe (< 0.12)
All subjects	0.5	63.2	29.3	7.0
70–79	0.7	79.6	16.3	3.4
80–89	0.0	48.2	44.0	7.8
90+	0.0	19.8	47.3	32.9

Hearing (thresholds in speech-range frequencies)

	Impairment[a]			
Age group	None (0–25 dB)	Mild (26–40 dB)	Moderate (41–55 dB)	Moderately severe (> 55 dB)
All subjects	5.1	33.5	35.8	25.6
70–79	8.4	42.4	35.7	13.4
80–89	1.5	25.7	37.5	35.2
90+	0.3	6.8	24.2	68.6

[a]Degrees of impairment defined following WHO, 1980.

of particular risk because of the many losses and challenges that must be confronted (e.g., P. B. Baltes & Baltes, 1990). Indeed, in just the two domains of hearing and vision, as the correlations between these domains would suggest (presented below), there is evidence that multiple impairment is common in the age range studied.

One-fourth of the population of old people in West Berlin was classified as having at least moderate impairment in both modalities (i.e., moderate uncorrected hearing impairment in speech-range frequencies and moderately low corrected distance vision). When impairment in either sense (hearing, vision, or both) was considered, 68% were adjudged as having an impairment. Breaking these percentages down by age decade, among 70- to 79-year-olds, 10% were classified as having impairment in both senses, and 53% in at least one sense. For the 80- to 89-year-olds, 39% were impaired in both senses, and 85% were impaired in at least one. Finally, for persons aged 90 and above, 73% were classified as impaired in both senses, and 99% were impaired in either hearing or vision. Thus, sensory disability rates, particularly multiple impairments, were very common. Among the oldest individuals, impairment in both hearing and vision seems to become an essentially universal phenomenon.

Statistically, these cross classifications of hearing and vision impairments suggest a high correlation between vision and hearing in this sample. At the same time, there is no hearing-by-vision interaction in these values; the co-occurrence is not more or less frequent than would be expected from their joint probabilities alone. It is striking to note

Table 13.2. *Relationships among age and aggregated hearing, vision, and balance/gait performances*

	Age	Hearing	Vision	Balance/gait
Age	1.00	—	—	—
Hearing	-0.57	1.00	—	—
Vision	-0.56	0.43	1.00	—
Balance/gait	-0.64	0.45	0.49	1.00

what a high proportion of individuals experience multiple impairments at the oldest ages. Table 13.2 illustrates the bivariate Pearson product-moment correlations between hearing, vision, balance/gait, and chronological age in the BASE sample. It shows that the three senses share about 25% of their variance, and each sense is commonly and strongly related to chronological age.

2.3 Physiological and Pathological Conditions in Hearing and Vision

Thus far, we have emphasized the patterns of normal sensory aging. One of the strengths of the BASE data set, however, is the availability of a rich amount of clinical data taken from medical examinations of BASE participants. In this section, we briefly consider evidence concerning the occurrence of pathological conditions affecting the visual and auditory system in the BASE sample. It is important to clarify, however, that diagnostic information comes from the participants' medical history, and does not have the same degree of diagnostic validity as the opthalmologic and otologic examinations included in some studies.

With regard to pathological conditions, the BASE data strongly support previous findings that diagnosable visual pathologies become increasingly normative with advancing age. Indeed, when all visual diagnoses were considered (including nonspecific, age-related diagnoses like presbyopia), 452 participants (88%) had a classifiable visual impairment. When only specific conditions (like cataracts, glaucoma, retinal damage) were considered, a relatively high number of subjects (241, 47%) were still adjudged as having a pathological condition. Major visual conditions included glaucoma and cataracts, but simple diagnoses of poor vision were also very common.

BASE physician interviews with study participants about auditory conditions (as with vision) revealed a wide variety, and fairly high prevalence, of self-reported auditory impairments. In contrast to vision, however, substantially fewer participants had a specific auditory diagnosis. Although 477 (92%) had some diagnosed auditory problem, many of these included such general, age-related phenomena as "sensorineural hearing loss." When only specific diagnoses were considered (like otorrhoea, otalgia, tinnitus, eardrum perforations), 71 subjects (14%) had a diagnosed condition of the auditory system. In contrast to vision, relatively few specific conditions seemed to be implicated in age-associated hearing loss.

2.4   Use of Compensatory Assistive Devices and Procedures for Hearing and Vision

Having provided basic information regarding the patterns of sensory aging, impairment rates, and pathological conditions in BASE, we turn our focus to an area of interest for many gerontologists: that is, the extent to which these sensory losses can be effectively compensated for (Corso, 1984). In this section,[5] we briefly consider the reported availability of hearing aids and corrective lenses, noting again that these data come from participants' medical history. We also examine the proportion of participants reporting at least one surgery for the removal of cataracts. It is important to note, however, that these data do not speak to the question of whether corrective auditory and visual devices and procedures are appropriately prescribed, or how often they are used. This is an important issue, since there is evidence that many older adults may not have the best correction available. Reinstein et al. (1993), for example, reported that 34% of older adults have an immediately improvable refraction problem in vision which is typically not corrected.

Despite the high prevalence of hearing loss, only 83 participants (16%) reported having at least one hearing aid. With regard to glasses, corrected close vision (i.e., reading glasses) was available for 494 (96%) participants, and distance glasses were available for 388 (75%) participants. Fifty-eight (11%) participants reported having at least one surgery for the removal of a cataract in the last 30 years. Many of these participants reported having multiple surgeries (either for both eyes, or repeated operations on one eye). Most of the reported cataract operations were performed in the four or five years before BASE participation, although a small number of operations (less than 10%) took place at least 10 years before the study. However, none predated 1970.

One interesting finding is that the availability of glasses may not only improve mean-level visual acuity, but it may also increase visual performance variability. Without glasses, most participants were grouped around the lowest level of functioning. With glasses, they were distributed over a wider range of functioning. Figure 13.6 provides a more detailed exploration of the range of visual performance in *close vision* (averaged over left and right eyes). Several points are interesting to note. First, since Snellen decimals lower than 0.3 are typically taken as an indicator of poor vision (WHO, 1980), the substantial majority of study participants had *uncorrected* close vision that was well below levels which would indicate impairment. The right-hand panel in Figure 13.6 also shows the positive effects of visual correction, as well as the limits to visual correctability. Clearly, glasses improve average close visual acuity (although the mean is still below a level classifiable as impaired), but they seem to be differentially efficient in correcting participants' vision, thus leading to greater variability in visual acuity. These results are consistent with the notion that different aging mechanisms (peripheral, central, and pathological processes) affect vision, and that these can be remedied to varying extents by lenses.

[5] Although walking aids are mobility rather than balance aids, we should point out that more than one-quarter of the West Berliners aged 70 and above used such aids. Table 5.7 in Chapter 5 (Steinhagen-Thiessen & Borchelt) shows that more than 20% used a cane, and 2–5% used other aids.

Figure 13.6. Corrected vision (right) is characterized by more variability and a higher level of performance than uncorrected vision (left). Nevertheless, most participants fall below a criterion of close vision impairment, even when wearing glasses.
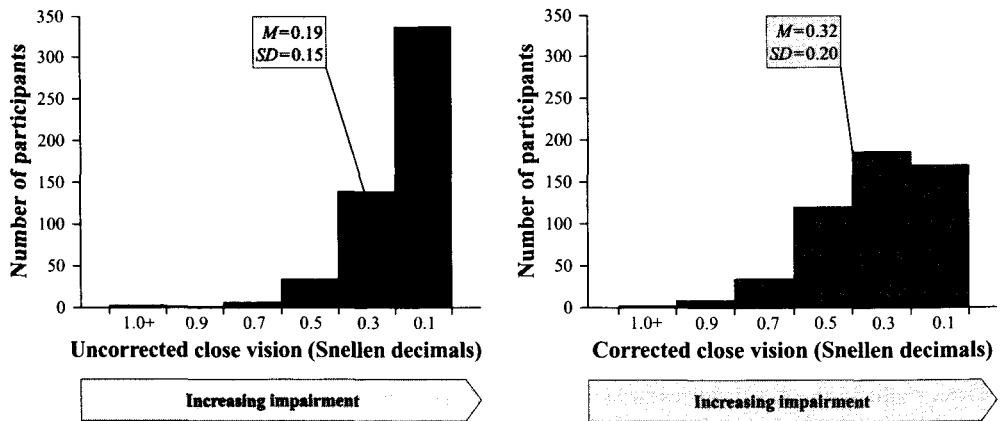
3   Correlates of Sensory Functioning

Having demonstrated strong, negative trends in hearing, vision, and balance/gait with advanced age, we turn now to questions of differential aging, and aging as a systemic process. Can sensory variables account for individual differences (both age-related and otherwise) in late life? Is there any evidence that the processes underlying sensory aging are related to a broader process that cuts across multiple domains?

The literature on the relationship between sensory functioning and potential outcome variables is voluminous, and goes beyond the scope of the present chapter. The data suggest that in late life, sensory functioning (hearing, vision, and balance/gait) is a significant predictor of numerous outcome variables including *intellectual functioning* (see Lindenberger & Baltes, 1994, for a review; see also Teasdale et al., 1992), *basic functional competence and leisure participation* (e.g., M. M. Baltes, Wilms, Horgas, & Little, 1998; Branch et al., 1989; Laforge, Spector, & Sternberg, 1992), *social relationships* (e.g., Corso, 1987; Gilhome Herbst, 1983), as well as *aspects of the self* (including well-being; e.g., Bess et al., 1989). These possible outcome variables reflect constructs of substantial interest in the gerontological and adult developmental literature.

To investigate the relationship between hearing, vision, and balance/gait and selected outcome variables within BASE, we created aggregate scores reflecting:

(1) *intellectual functioning*: an aggregate of the five primary intellectual abilities assessed within BASE (see Smith & Baltes, Chapter 7; Lindenberger & Reischies, Chapter 12);

(2) *basic functional competence*: number of self-rated limitations in Activities of Daily Living and Instrumental Activities of Daily Living (ADL/IADL; Lawton & Brody, 1969; Mahoney & Barthel, 1965; see also Steinhagen-Thiessen & Borchelt, Chapter 5; M. M. Baltes et al., Chapter 14);

Table 13.3. *Bivariate correlations between sensory functioning and selected outcome variables*

	Age	Hearing	Vision	Balance/gait
Cognitive-motoric domains				
Intellectual functioning	-.57	.51	.56	.56
	(-.60)	(.56)	(.73)	(.71)
Basic functional competence	-.53	.38	.47	.66
	(-.57)	(.43)	(.60)	(.83)
Expanded competence	-.58	.44	.53	.57
	(-.76)	(.63)	(.86)	(.89)
Self and personality				
Positive openness	-.26	.26	.28	.30
	(-.31)	(.34)	(.43)	(.43)
Anxiety/loneliness	.13	-.14	-.20	-.24
	(.08)	(-.16)	(-.23)	(-.30)
Overall well-being	-.12	.12	.17	.29
	(-.23)	(.22)	(.35)	(.49)
Social relationships				
Social network size	-.34	.25	.29	.33
	(-.34)	(.26)	(.37)	(.39)

Note. Values in parentheses represent correlations between latent constructs disattenuated for measurement error.

(3) *expanded competence*: discretionary activity participation; aggregate of time spent in non-ADL/IADL activities on a typical day, and activity participation in the last year (see M. M. Baltes et al., Chapter 14);

(4) *positive openness*: an aggregate of positive affect, extraversion, and openness to experience (Clark & Watson, 1991; Watson & Clark, 1984; see Smith & Baltes, Chapter 7);

(5) *anxiety/loneliness*: an aggregate of neuroticism, negative affect, and emotional loneliness (cf. Smith & Baltes, Chapter 7);

(6) *overall well-being*: the global score from the Philadelphia Geriatric Center Morale Scale (PGCMS; Lawton, 1975; see Smith et al., Chapter 17); and

(7) *social network size*: (number of very close, close, and less close persons mentioned in the individual's social network (Kahn & Antonucci, 1980; see Smith & Baltes, Chapter 7; Wagner et al., Chapter 10).

Table 13.3 presents the intercorrelations of age, hearing, vision, and balance/gait with each of these outcome variables. The results suggest at least two broad generalizations: First, the relationship between each of the sensory variables and our selected outcome variables tended to be of a similar order of magnitude as the relationship between age and these outcomes. (The exceptions are discussed below.) Second, the outcome domains varied substantially in the magnitude of their relationships with both age and sensory functioning. Variable domains reflecting cognitive-motoric functioning (intellectual

Table 13.4. *Hierarchical communality analyses for the prediction of selected outcome variables: Unique and shared variance percentages*

	Cognitive-motoric domains			Self and personality			Social relation-ships
	1	2	3	4	5	6	7
Total variance explained	47.5	47.3	44.6	12.7	7.4	9.9	14.6
Unique age	1.8	1.3	5.3	0.0	8.5	12.2	6.1
Unique hearing	5.4	0.1	1.3	7.7	1.5	0.3	1.1
Unique vision	10.5	2.8	7.3	10.5	14.7	5.0	6.0
Unique balance/gait	7.2	30.0	9.0	13.9	42.4	67.0	9.7
Shared among sensory functions only	9.4	20.5	6.6	13.1	18.1	13.8	6.0
Shared between sensory functions and age	65.7	45.3	70.5	54.8	14.8	1.7	71.1
Sum	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Note. Column headings: (1) intellectual functioning; (2) basic competence; (3) expanded competence; (4) positive openness; (5) anxiety/loneliness; (6) well-being; (7) social network size.

functioning, basic and expanded functional competence) were relatively strongly related to both age and sensory functioning, whereas the other variable domains showed substantially less relationship to either age or sensory functioning (e.g., positive openness, social network size, well-being).

Table 13.4 shows how well hearing, vision, and balance/gait together accounted for the age-related variance in each of these outcome domains, using the framework of hierarchical regression. The table shows the unique and shared variance components attributable to hearing, vision, balance/gait, and age. A general summary is that sensory functioning not only seemed to account for all or most of the age-related variance in each domain (even where there was only a relatively small proportion of age-related variance), but it typically accounted for a small proportion of unique variance beyond age. While this was generally true, the magnitude of age-related variance (and thus, the magnitude of sensory effects) was substantially larger in the cognitive-motoric behavioral domains of intellectual functioning, basic functional competence, and expanded competence. The largest component of explained variance in most outcomes (intelligence, positive openness, expanded competence, and social network size) could be explained by a complex aggregate of variance *shared* by age and sensory functioning. In the two other domains (anxiety/loneliness, well-being), the largest component of explained variance was attributable to the unique effect of balance/gait, and the second largest component was variance shared by the sensorimotor domains that was independent of age. In these domains, sensorimotor functioning (especially balance/gait) *exceeded* the predictive power of chronological age.

For two variables, expanded competence and well-being, there was a small but significant residual effect of age. The meaning of this residual variance differed substantially for the two domains. For expanded competence, even after controlling for sensorimotor functioning, increased age was associated with lower levels of activity participation.

In contrast, after controlling for sensory functioning, the residual effect of age became *positive* for well-being (it had a weak, negative bivariate correlation with age: $r = -.12$; see Fig. 17.2 in Smith et al., Chapter 17). In other words, sensory functioning (and not age per se) seems to constitute a risk factor for well-being. The positive residual effect of chronological age may reflect the operation of self-regulatory processes, which adjust levels of aspiration and well-being upward to compensate for the negative effects of biological losses (cf. Staudinger et al., Chapter 11; Smith et al., Chapter 17). Of course, this explanation of the positive residual effect of age on well-being is speculative and needs to be confirmed using longitudinal data.

The power of the sensory relationships with the cognitive-motoric domains, and their ability to explain or mediate most age-related variance in many constructs, is striking. Based on the assumption that the predictive power of sensory and sensorimotor functioning is lower in earlier phases of adult life, this could mean that age-correlated biological factors, which are clearly manifested in sensory functioning, become more important in old age (thus indicating "predictive discontinuity"; P. B. Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1997; Lindenberger, Marsiske, & Baltes, 1998). However, in the BASE data there were no indications to show increasing importance of sensory functioning with increasing age. There is one exception in that there *was* a significant, unique age-by-balance/gait interaction, after controlling for sensory predictor main effects, in expanded competence ($F(1, 510) = 8.98, p < .001$) – in other words, at higher ages, the effects of balance/gait on leisure participation become increasingly negative (see M. M. Baltes et al., Chapter 14). Results from a study with samples of younger adults indicate that the predictive power of sensory and sensorimotor performance for intellectual functioning clearly increases across the adult age range (P. B. Baltes & Lindenberger, 1997).

Are these sensory predictors simply additive in their effects, or is there "multiple jeopardy" from having impairments in more than one sense? To address this question, we asked whether (in addition to the strong main effects observed in this study) interaction effects among any two, or all three, of the senses might account for additional unique variance in our outcome domains (after controlling for age, balance/gait, hearing, and vision). Only one particular combination of modalities (vision and balance/gait) had a small but significant positive interaction effect that affected social network size ($p < .01$) and expanded competence: Thus, persons with impairments in both senses showed disproportionately lower levels of leisure participation and lower social network sizes.[6]

4   Discussion

In this chapter, we have pursued two goals. First, we provided a descriptive account of sensory functioning in three domains: hearing, vision, and balance/gait. The re-

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[6] Note that the statistical power for detecting interactions among normally distributed variables is low (McClelland & Judd, 1993).

sults of this descriptive analysis lend strong support to the notion that sensory impairment and loss become increasingly common in the final decades of life, and that there is substantial multimorbidity in sensory functioning. As mentioned in the introduction, these concurrent impairments of different sensory systems may mean that the sensory compensation observed at younger ages (Neville, 1990; Rauschecker, 1995) is no longer possible in old age.

The second goal of the chapter was to investigate possible outcomes of age-associated individual differences in sensory functioning. We selected a broad array of outcome constructs of interest to behavioral and medical scientists. Although the magnitude of relationships between these outcome variables and sensory functioning varied substantially (with cognitive-motoric outcome domains showing the greatest relationships), sensory-sensorimotor functioning accounted for all or most of the age-related variance in each construct. In addition, the unique effects of sensory variables (separately or together) were generally larger than the unique effects of chronological age on each outcome domain.

We began this chapter with a mention of two underlying theoretical underpinnings of BASE: aging as a systemic phenomenon and differential aging. With regard to the differential aging question, we believe that this chapter has persuasively shown that individual differences in a variety of domains of functioning are (sometimes quite strongly) related to individual differences in sensory performance. As we shall discuss in detail below, it is not possible to assign *causal* status to sensory functioning in these data, but it does highlight the practical value of using sensory variables as screening constructs for the identification of individuals "at risk" in a variety of other psychological and behavioral domains. With regard to aging as a systemic phenomenon, we underscore the point that sensory variables account for most of the *age-related* individual differences in the psychological and behavioral domains we examined.

In the cognitive aging literature, many investigators (e.g., Hertzog, 1989; Lindenberger, Mayr, & Kliegl, 1993; Salthouse, 1991) have shown that measures of perceptual speed can mediate, or account for, age-related individual differences in more complex cognitive domains (e.g., reasoning, spatial performance), although much of this research has considered adults younger than BASE participants. From such data, these theorists have argued that one plausible scenario for the aging of the cognitive system is that aging exerts its effects most directly on the speed of intellectual functioning, and that all other cognitive changes may result from this fundamental age effect (e.g., Salthouse, 1994). By extension, the results of this study could similarly be used to support a view of sensory variables as the most direct "recipients" of the effects of aging – reflecting fundamental, underlying aging phenomena in the central nervous system (see Corso, 1981; Era, 1987). As we suggest below, this view of sensory variables does not necessarily mean that sensory aging has as its consequence aging in other domains, but only that sensory aging serves as a useful index of basic aging processes which cut across functional domains (i.e., aging as a systemic phenomenon; P. B. Baltes & Lindenberger, 1997).

Why might sensory functioning (e.g., hearing, vision, and balance/gait) serve as such a powerful predictor? Two broad categories of explanation have been proposed by Lindenberger and Baltes (1998; see also P. B. Baltes & Lindenberger, 1997): *direct effects* (which they discussed mostly in terms of "sensory deprivation" in their work on intelligence), and *common effects* (called the "common cause" hypothesis in their work). The

common-effect idea suggests that if "aging" affects outcome X, and "aging" also affects sensory functioning, then the association between sensory functioning and X emerges because of their common causation by "aging." Of course, at its most basic level, the common-effect idea refers to age-associated biological (anatomical or physiological) changes in the brain. There is a rich body of literature about these basic processes (see Corso, 1981, for a detailed discussion), which we cannot discuss in depth. However, it is striking that age-associated changes in sensory performance are frequently linked to neuronal causes (Fozard, 1990). In this context it is important to note that *general* somatic health does not seem to constitute the common underlying feature of relationships between sensory functioning and outcomes. Subjective health was correlated .07, .16, and .26 with hearing, vision, and balance/gait, respectively, and the number of clinically significant diagnoses (Steinhagen-Thiessen & Borchelt, Chapter 5) was correlated -.12, .15, and -.24 with the respective sensory modalities.

A more causal role for sensory functioning is embedded in the direct-effect notion. Of course, it is important to restate that the causal status of sensory functioning cannot be evaluated on the basis of our cross-sectional, correlational data. The direct effect idea assumes that sensory functioning constitutes such a basic ability that effective functioning in a variety of other domains *presupposes* effective sensory capabilities. If one cannot see/hear/remain stable, one cannot do things that require these sensory capabilities (e.g., read, write, interact socially). In this view, sensory functioning is taken to be particularly sensitive to the effects of aging (as we have suggested above), and aging losses in sensory functioning "drag" other functions (which depend on intact senses) with them. This is a version of the "cascade" hypothesis (Birren, 1964), which can be modified to suggest that losses in sensory functioning might *initiate* (i.e., be the most proximal antecedent for) subsequent losses in other domains. Sensory effects can be extremely direct, in the form of *performance effects* (see also Bennett & Eklund, 1983b). Here, the physical inability to perceive implies an inability to perform other tasks.[7]

A second mechanism of sensory effects may be *sensory deprivation*. In this view, loss of sensory inputs leads to active and passive withdrawal from participation in other activities.[8] In addition to the long-standing potential mental health effects of such deprivation (Hebb, 1954), long-term consequences could include reduced intellectual stimulation and practice, as well as social isolation. A third mechanism of sensory effects may be *resource reallocation*, which P. B. Baltes and Lindenberger (1997) have discussed in terms of the attentional costs of sensory loss for intellectual functioning. With regard to intellectual functioning, the argument suggests that losses in sensory functioning mean that more attention must be paid (i.e., more attentional resource must be allocated) to perceiving and interpreting inputs. This increased demand on attentional resources (perhaps combined with other normal age-associated reductions in attentional capacity) may leave less attentional resource for other tasks. In the intellectual and cognitive domain, this attentional

[7] However, in this case, the explanation seems unlikely for two reasons (Lindenberger & Baltes, 1998). First, the correlations between vision and hearing, and the 14 tests of the cognitive test battery were more or less independent of the level of sensory demand during the test. Second, this hypothesis is not able to explain the strong connection between intellectual functioning and balance/gait.

[8] Of course, sensory deprivation effects may not be mutually exclusive of the neurophysiological and anatomical effects we have suggested, and might be a key component of the "common cause" idea. Sensory deprivation could itself contribute to processes of neuronal atrophy (Kaas, 1995).

hypothesis leads to the prediction that persons with sensory impairments will perform less well on cognitive tasks, because they are in a natural situation of divided attention.

In principle, the attentional argument can be extended to other domains of functioning. Social relationships, self-care activities, and even indices of mental health might be expected to suffer if individuals are increasingly attending to, and preoccupied with, their sensory functioning. More precisely stated, in the domain of self and personality, one might expect that impaired sensory functioning could serve as a "personal marker" or cue to the fact that one is growing older. When the awareness of one's experience of aging losses can no longer be denied, negative consequences for well-being might be expected (e.g., Brandtstädter & Greve, 1994; see also Smith et al., Chapter 17). There is further evidence for this "personal marker of aging" idea in the correlational data reported in this chapter. For both anxiety/loneliness and overall well-being, it is the unique effects of sensory functioning and not chronological age that explain the largest proportion of variance (in Chapter 17, Smith et al. offer an interesting perspective on what the underlying processes might be). Smith, Borchelt, and Steinhagen-Thiessen (1992) also present interesting qualitative data to suggest that the self-definitions of persons with severe sensory losses may differ substantially from their age peers. How older adults restructure their sense of self and well-being in the face of sensory impairment is an important question for future research.

Some additional amplification is needed regarding the finding that some variables such as intelligence, basic functional competence, and expanded competence show much stronger relationships to sensory functioning than others. As a general statement, *performance* domains (domains in which individuals actually engage in behaviors) seem to be more affected by sensory aging than *self-evaluation* domains. Colloquially, interaction with the external world may be more compromised by lost sensory capabilities than interaction with the "internal" world. Future research must consider the phenomenology of sensory losses in more detail. Are older persons less "bothered" by hearing and vision losses than theoretically expected because of social cognitive processes like downward social comparisons with age peers (i.e., they compare themselves with those who are worse off)? Are there thresholds beyond which sensory losses are more likely to have negative effects on mental health, self-evaluation, and well-being? Do losses in some modalities lead to more negative consequences than losses in others (cf. Rott & Wahl, 1993; Tesch-Römer & Nowak, 1995)? The relatively weak association between social relationships and sensory functioning also merits further study. Are long-term and close emotional relationships more resistant to sensory losses than more peripheral friendships and acquaintanceships (Antonucci, 1990; Carstensen, 1993)?

The most interesting result of this chapter has been to show strong sensory relationships with a broad array of outcome variables. These findings support a growing body of literature documenting substantial associations between hearing, vision, and/or balance/gait, and cognitive functioning (Anstey, Lord, & Williams, 1997; P. B. Baltes & Lindenberger, 1997; Granick, Kleban, & Weiss, 1976; Lindenberger & Baltes, 1997; Maylor & Wing, 1996; Salthouse, Hancock, Meinz, & Hambrick, 1996; Teasdale, Bard, LaRue, & Fleury, 1993; see also Marsiske, Klumb, & Baltes, 1997, for a detailed consideration of relationships between sensory functioning and activity). Regarding the rich multidisciplinary data set of BASE, we have only "scratched the surface": A large body of constructs remains to be explored in terms of its relationship to sensory functioning, particularly from the underexplored (in this chapter) psychiatric and medical domains.

Although data that precisely address questions of physiological and psychophysical aging, detailed sensory examinations, or occupational history of exposure to particular environmental sensory risks are not available, the detailed life-history and medical data from BASE also hold promise for investigating some potential antecedents for late-life individual differences in sensory performance.

We have tried to provide new evidence, from an older and more heterogeneous sample than has typically been used in sensory research, that (a) sensory systems are subject to a strong age-related decrease of performance, and (b) that sensory performances can be used as powerful indicators of effects of aging in other domains (in the sense of systemic aging phenomena). Indeed, at least for cognitive-motoric domains, the sensory variables in this chapter seem to be among the best predictors of individual, and particularly age-associated, differences in late life.

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