Comorbidity and Its Impact on Disability

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RECOGNITION OF DISABILITY AS A CENTRAL CONCEPT of health and wellbeing is growing, and survey questions on physical and social functioning are being developed for general population surveys and for evaluation and monitoring of patients with specific chronic diseases.

Older people often have several chronic conditions simultaneously (comorbidity). Presence of comorbidity complicates the question of how specific diseases lead to disability. In clinical research, investigators often solve the problem by limiting their samples to patients who have just one disease, such as arthritis. By contrast, social and epidemiological researchers usually opt for broader samples and then statistically estimate the net effect a disease (or several) has on disability. The first approach is tidy but bypasses the real world's complexity. The second approach permits a direct look at comorbidity and its role in causing disability. Yet even here, analyses that statistically control for chronic conditions but view them as confounding variables rather than important substantive ones sidestep the topic.

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Despite the importance and commonness of comorbidity, government health statistics rarely tell us about it, focusing instead on prevalence rates of specific diseases taken one at a time. This provides no sound clues about the numbers or combinations of conditions that older people have. A recent report on people aged 60 and older helps remedy this situation (Guralnik et al. 1989).

The current impetus to study comorbidity comes especially from gerontology researchers, who cannot escape the matter in their analyses of disability, health behavior, and mortality. Fundamental research questions are: How does the total number of accumulated diseases and impairments, or particular conditions and combinations of them, influence physical and social functioning? Do diseases work independently of each other in their consequences or, more plausibly, interact synergistically to propel disability?

This article uses the 1984 Supplement on Aging (SOA) (Fitti and Kovar 1987) to study how the total number of chronic conditions, 13 specific conditions, and pairs of those conditions affect physical and social disability. The term "disability impact" refers to the net effect a condition has on presence or level of disability. We address four questions:

1. Does disability rise linearly with the number of chronic conditions a person has? Or is the relationship exponential, or asymptotic?
2. Do specific diseases and impairments have a disability impact consonant with their prevalence? In other words, are the most common diseases also the most disabling ones for community dwellers?
3. Once chronic conditions are controlled, do sociodemographic characteristics (age, gender, race) have any remaining impact on disability? If so, what do these effects suggest about physiological or cultural propellers of disability?
4. Do certain pairs of conditions have unusually large effects on disability, pushing it much more than the solo (main) effects of the two component diseases? This is an issue of synergism among chronic conditions: statistically, it involves interaction effects.

This article offers for the first time some answers for the community-dwelling population. (It uses the same data set as Guralnik et al. [1989] in a more comprehensive analytic manner and for all persons

aged 55 and older.) Its contribution is limited in several ways by the data set, and we want to note them at the outset:

First, the SOA data are cross-sectional, so causation can only be implied and not demonstrated. We are interested in causation—how chronic conditions influence disability—and interpretations often take that perspective. This is reasonable (the likelihood that chronic conditions cause disability is larger than the reverse) but not conclusive (the possibility that disability may sometimes bring people to physicians and thereby enhance the chance of diagnosis, and the possibility that some dysfunctions do increase disease vulnerability, must be mentioned).

Second, our answers to "How disabling are various chronic conditions?" are limited to community-dwelling persons. Highly disabling conditions do indeed force people to move to institutions, and this affects (presumably decreases) prevalence rates and estimated impact among community dwellers. The SOA data can answer "How disabling are chronic conditions for current community residents?" They cannot answer "How disabling are certain chronic conditions on people?" since the impact for institutional residents is not in their scope. Most likely, the relative standing of conditions—which ones are most disabling, and least disabling—is stable whether the sample is community dwellers or all persons. (We argue that differential mortality for conditions is not relevant for this analysis: Questions about disability pertain to living persons, not dead ones. So, birth-cohort members who have died by a certain age do not need to be considered; they are legitimately out of scope.)

Third, the conditions recorded in SOA have crossed a threshold of personal or medical awareness and are willingly reported. Conditions that are asymptomatic or nondiagnosed may be absent, and also those held secret. The first issue (awareness) is handled by the interview's very inclusive, probing approach for querying chronic conditions and subsequent painstaking review of that information. Presence of proxy interviews (10 percent) is pertinent, since proxies may not know all of the sample person's conditions. (In the SOA, proxies report lower average numbers of chronic conditions for sample persons than self-respondents do, within each age group.) The second issue (willingness) has no solution in this or most other surveys.

Fourth, our analysis of specific conditions is limited to 13. Some important ones are excluded, such as chronic obstructive pulmonary diseases and Alzheimer's disease. (The SOA has a question about Alz-

heimer's disease, but our medical advisor suggested it be excluded from analysis due to high reporting error.) We can estimate relative importance just for our list of 13 conditions and can only regret the absence of others that interest readers.

These limitations draw in the scope of answers to "How disabling are chronic conditions?" But when scope is properly defined—"How disabling are certain reported chronic conditions for community residents?"—the data set is appropriate, and advantageous due to its size and national span.

Background

The scientific literature on comorbidity is small to date. It has three themes: frequency of comorbidity in populations, consequences of comorbidity, and theories about disease co-occurrence.

1. Clinicians have published reports on their common finding of multiple conditions among elderly patients (Howell 1963; Wilson, Lawson, and Brass 1962; Zeman 1962). More scientific interest is represented in Chappell's (1981) study of chronic conditions in three groups of elderly people: Most correlations among conditions are positive but rather low (.15–.50), and age is positively associated with number of conditions. A different result comes from analysis of Cornell Medical Index (CMI) scores, which are counts of physical and psychological symptoms: No evidence of increasing symptoms with age is found by Denney, Kole, and Matarazzo (1965). They suggest that personal interpretations of health are highly variable and a dominant factor in CMI responses.

Rates of specific comorbidities for the United States population are published in LaPlante (1988, table 10 [not age-specific]). Only combinations within the same body system could be estimated due to the data-set structure. Focusing just on conditions that limit people, other tables show degree of limitation for various conditions alone and in pairs (tables 11–13). (In using tables 11–13, note carefully that only conditions that limit people are considered, but combinations across body systems are reported there.) Upward trends in multiple chronic disabling conditions in the 1970s are discussed in Rice and LaPlante (1988).

2. There is strong scientific interest now in how comorbidity affects disability, psychological status, institutionalization, and death. Several studies have considered people with a target disease, and how additional diseases increase poor outcomes: Kaplan and Feinstein (1974) found that diabetics with severe comorbidity (an index) had higher 5-year fatality rates than those with moderate or none, and that coexisting vascular conditions increased fatality more than nonvascular ones. Comorbidity also elevates disability and mortality for women with breast cancer (Satariano, Ragheb, and Dupuis 1989). Finally, as comorbidity increases, physicians' approval of surgical procedures for gastrointestinal indications decreases (Kahn et al. 1988).

In the population-survey setting, the work on disability outcomes is called the "epidemiology of disability." At issue are risk factors for disability rather than for disease. Analysis can occur in a sample of persons with a target disease—thus P(disability/disease), or a broader one—thus P(disability) for a variety of disease predictors. Studies with population-based data are now few, but bound to increase. As an example, in Alameda County initial comorbidity is associated with subsequent depression and mortality, and also with subsequent development of more conditions (Seeman et al. 1989). The predictive effects are especially strong for persons with 3 or more conditions at the outset. Our analysis fits into this niche of the scientific literature, by asking how comorbidity affects disability in a national sample of adults.

3. Recommendations for theoretical work on comorbidity, either in the form of case-classification schemes or formal models of disease interactions, are voiced in Feinstein (1970), Manton (1985), and Satariano (1985). Work on multiple causes of death in the past decade (Israel, Rosenberg, and Curtin 1986; Manton and Stallard 1984) has also given a boost to interest in multiple causes of illness among living persons.

Data Set and Variables

The Supplement on Aging (SOA) is accompanied by the 1984 National Health Interview Survey (NHIS). It is based on a national probability sample of civilian noninstitutional persons aged 55 and older, who were asked extensive questions about chronic conditions and physical

and social disabilities (Fitti and Kovar 1987). A total of 16,148 completed interviews are available for analysis.

In the results reported here, data are weighted to compensate for disproportionate sampling and response. Our rates and regression effects are estimates for the national population. No adjustments are made for sample clustering; the consequence is smaller variance estimates than are actually true for the population. We accommodate this in a nonformal manner at many points by using conservative levels of statistical significance ($P \leq .01$, $\leq .001$). Standard regression procedures of OSIRIS IV that incorporate case weights are used. All results reported here are based on one-stage, rather than hierarchical, models.

Comorbidity

We study comorbidity in three ways: by the simple count of chronic conditions a person has, by the presence of 13 specific diseases and impairments, and by the presence of pairs of those specific conditions.

The counts are based on condition records, which contain details about chronic conditions mentioned at any point in the entire interview process (including the core NHIS preceding the SOA). The details entered on condition records are evaluated by a team of professional medical coders. Each record is assigned an ICD (International Classification of Diseases) code, i.e., a diagnosis code. Our variable is the total number of condition records for a person. (Thus, it encompasses all conditions reported, not just the 13 titles to be named below.) The average number of chronic conditions for the SOA sample is 2.68 (table 1).

The specific conditions all have public health importance due to their known high prevalence or high mortality rates. The titles include selected diseases and sensory impairments (table 1). All respondents were asked directly if they had experienced each one in the past year (or now/ever [note c in table 1]). A *yes* response generated a condition record, which was later ICD-coded. We base our analysis on that final point, the span of ICD codes used by the National Center for Health Statistics in its published prevalence rates for each condition (note b in table 1). (See also technical appendix , item 1. Note that in the Guralnik et al. [1989] report mentioned earlier, the authors use the *yes/no* items rather than ICD-coded titles.) For readers new to this survey, ICD codes are assigned conservatively. To code disease *X* usually re-

TABLE 1
Prevalence of Chronic Conditions and Levels of Disability
(U.S. civilian noninstitutional pop., aged 55+)

Conditions	
No. of chronic conditions ($\bar{x}$ = 2.68)[a]	
0	16.4%
1	20.5
2-3	33.7
4-5	17.3
6-7	7.8
8-10	3.6
11+	0.7
Percentage with chronic conditions:[b,c]	
Arthritis	43.7
High blood pressure (HBP)	40.3
Hearing impairment	28.1
Vision disease (= cataract, glaucoma, disease of retina)	15.0
Ischemic heart disease (IHD)	12.1
Visual impairment	11.0
Other circulatory system condition (= phlebitis, varicose veins)	10.2
Diabetes	8.9
Atherosclerosis	7.5
Cancer (= all except nonmelanoma skin)	7.5
Cerebrovascular disease (CVD)	4.7
Osteoporosis	2.7
Fracture of hip (FxHip)	2.4
Physical disability	
Difficulty walking (0 = none to 3 = unable) ($\bar{x}$ = 0.23)	
None	85.5
Some	7.8
A lot	5.0
Unable	1.7
No. of physical limitations ($\bar{x}$ = 1.81)	
0	51.2
1-2	19.7
3-4	11.8
5-6	9.6
7-10	7.7
Social disability	
No. of ADLs with difficulty ($\bar{x}$ = 0.23)[d]	
0	88.9
1	5.3
2-3	3.9
4-5	1.9

continued

TABLE 1 (Continued)

Social disability (continued)	
No. of ADLs unable ($\bar{x}$ = 0.05)	
0	97.4
1	1.3
2–3	0.7
4–5	0.6
No. of IADLs with difficulty ($\bar{x}$ = 0.24)[d]	
0	89.4
1	4.5
2–3	3.9
4–5	2.2
No. of IADLs unable ($\bar{x}$ = 0.14)	
0	94.1
1	2.6
2–3	2.0
4–5	1.3
Activity limitation status (0 = no to 3 = unable) ($\bar{x}$ = 0.70)[e]	
No limitation	65.1
Limited in secondary activities only	11.0
Limited in kind/amount of major activity	12.9
Unable to perform major activity	11.0

Source: Supplement on Aging, 1984 National Health Interview Survey (NHIS). All data are weighted to adjust for sample stratification.

[a] Count of condition records.

[b] ICD-9 (adapted to NHIS) codes are: arthritis (711.b,0,9,712.b,8,9,714–716,720.0,721), high blood pressure (401–405), hearing impairment (X05–X09) (includes deaf in one or both ears), vision disease (361,362.b,1–9,365,366), ischemic heart disease (410–414,429.6), visual impairment (X00–X03) (includes blind in one or both eyes), other circulatory system conditions (451,454), diabetes (250), atherosclerosis (440), cancer (140–172,174–208), cerebrovascular disease (430–435,437), osteoporosis (733.0). *b* means blank. When only 3 digits are shown, all decimal values are included. *X* refers to NHIS impairment code classification. Fracture of hip is coded from the *yes/no* question rather than condition records.

[c] The time periods queried for the conditions vary: now (hearing impairment, vision disease, visual impairment), past 12 months (arthritis, other circulatory, diabetes), ever (HBP, IHD, atherosclerosis, cancer, CVD, osteoporosis, fix hip).

[d] For each activity queried, the response "doesn't do for reasons besides health" is assumed to be "no difficulty" and is scored 0.

[e] Activity limitation status is based on questions in the core NHIS. (1) For ages 55–69, major activity is job or housework, whichever was usual role in past year. Current ability to perform this is asked. People who say their main activity is retired/school/something else are asked about job ability. For all persons, if no difficulty with main activity: they are asked about difficulty in other secondary activities. (2) For ages 70+, two general questions about assistance with ADL/IADL are asked in core NHIS. If no difficulty in either, people are asked about difficulties in any activities due to health. Response categories shown here are: no limitation, difficulty in just activities other than ADL/IADL, assistance for IADL(s) only, assistance for any ADL(s).

quires (a) physician diagnosis (as reported by respondent) or (b) nondiagnosed conditions named as *X* by the respondent where all further details corroborate that name.

Arthritis is the most prevalent condition (43.7 percent), followed closely by high blood pressure (40.3 percent). Hearing and vision conditions rank next. Least common for persons aged 55 and older are osteoporosis (2.7 percent) and fracture of hip (2.4 percent). (Age/sex-specific rates are available on request.)

The pairs are the 78 possible combinations of the 13 conditions. In our regression models, coexistence of two conditions (ICD-coded) in a person scores 1; else 0. Over 20 percent (21.1 percent) of community dwellers aged 55 and older have both arthritis and high blood pressure (HBP) (table 2). Fifteen percent (14.7 percent) have both arthritis and

TABLE 2
The Twenty Leading Pairs of Chronic Conditions
(U.S. civilian noninstitutional pop., aged 55+)

Rank	Pair	Percentage with pair of chronic conditions
1	Arthritis, HBP	21.1%
2	Arthritis, HearImp	14.7
3	HBP, HearImp	12.6
4	Arthritis, VisDis	8.6
5	HBP, VisDis	7.5
6	HBP, IHD	6.8
7	Arthritis, VisImp	6.3
8	Arthritis, IHD	6.2
9	Arthritis, Other Circ	6.2
10	HearImp, VisDis	6.0
11	HBP, VisImp	5.8
12	HBP, Diabetes	5.4
13	HearImp, VisImp	5.0
14	HBP, Other Circ	4.9
15	Arthritis, Diabetes	4.8
16	HearImp, IHD	4.8
17	HBP, Atherosclerosis	4.7
18	Arthritis, Atherosclerosis	4.6
19	VisDis, VisImp	4.2
20	HearImp, Atherosclerosis	3.7

hearing impairment, and 12.6 percent have HBP and hearing impairment. Not surprisingly, the most common pairs tend to involve the most common conditions: The top 10 pairs all derive from the top 7 solos; the top 20 from the top 9. Four low-prevalence conditions (cancer, CVD, osteoporosis, fracture of hip) do not show up at all in the top 20 pairs.

Physical Disability

Respondents were asked about difficulty in gross mobility (walking, getting outside). In addition, they were asked about difficulty doing 10 specific physical functions: walking 1/4 mile, walking up 10 steps without resting, standing 2 hours, sitting 2 hours, stooping/crouching/kneeling, reaching up over head, reaching out, using fingers to grasp/handle, lifting/carrying 25 pounds, lifting/carrying 10 pounds. For each *yes*, they were asked the degree of difficulty (some, a lot, unable).

Social Disability

Respondents were asked about difficulty "because of a health or physical problem" in performing 5 personal care tasks (bathing/showering, dressing, eating, getting in/out of bed or chair, using the toilet) and 5 household management tasks (preparing own meals, shopping for personal items, managing own money, using the telephone, doing light housework). The first group are commonly called basic activities of daily living (ADL); the second, instrumental activities of daily living (IADL). For each *yes*, respondents were asked about degree of difficulty and about dependence (viz., assistance from another person). Finally, there is a global question about role limitation (ability to perform one's usual main activity [job or housework for persons aged 55 to 69, activities of daily living for those aged 70 and older]).

From these physical and social disability items, we derive 7 dependent variables: walking difficulty (gross mobility), number of physical limitations (any degree), number of ADLs with difficulty (any degree), number of ADLs unable, number of IADLs with difficulty (any degree), number of IADLs unable, and role limitations. Each is an important indicator of disability. Our results will usually scan across the 7 variables, but readers interested in a particular indicator can locate its results in the technical appendix, item 6.

All the items portray difficulty rather than dependence. This is because our interest is in how chronic problems affect physical and social capabilities; thus, the epidemiology of disability. By contrast, analyses of dependence lead to conclusions about long-term care needs for community-dwelling people—not a purpose of this article.

Most people (85.5 percent) have no difficulty walking due to a health problem (table 1). But limitations in other motions and in strength are common: Almost one-half (48.8 percent) of the population aged 55 and older have one or more limitations, and 17.3 percent have five or more. Few community-dwelling people (11.1 percent) have difficulty in doing ADLs, and very few are unable to do them alone (1+ unable; 2.6 percent). Though IADL activities require more complex and integrated abilities than ADLs—so people are likely to encounter IADL problems sooner, the percentage with difficulty (10.6 percent) is similar to ADLs. More people are unable to perform IADLs (5.9 percent) than ADLs. In sum, the overall picture is of low levels of disability in the community-dwelling population.

Further details about variables are in the technical appendix, item 2.

We now turn to the analysis. Results are discussed in four sections, one for each question posed in the Introduction.

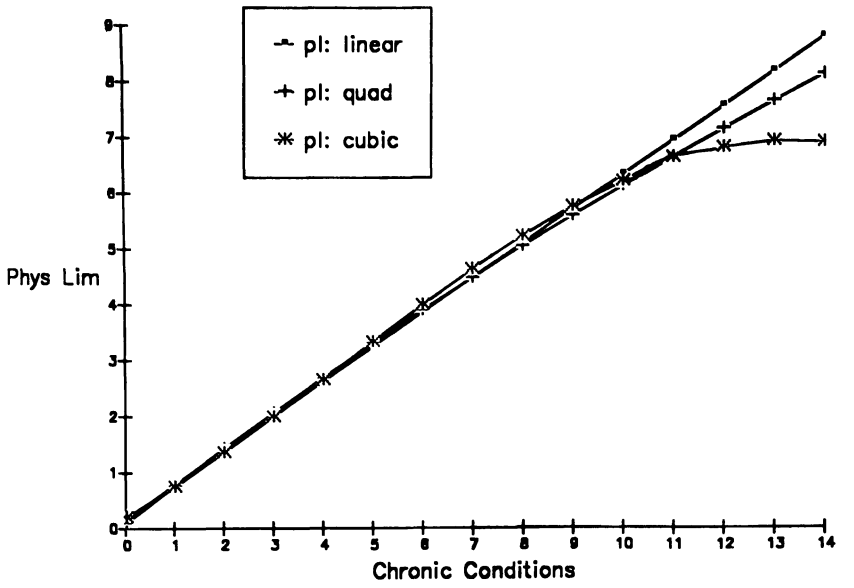
Linear or Nonlinear Increases in Disability

To analyze the pattern of disability increments with worsening health, we chose 3 of the disability variables: physical limitations, difficult ADLs, and difficult IADLs.

Beginning with one-way analysis of variance of observed disability (Y) by number of chronic conditions (X): Disability rises monotonically with number of chronic conditions (some exceptions when sample size <20).

Is the monotonic increase strictly linear, or is it some other functional form? To locate the form, we estimated a variety of models (technical appendix, item 3). A quadratic OLS (ordinary least squares) model proved best: $Y = f[\text{Age, Gender, Race, CC, CC}^2]$ where CC means number of chronic conditions. Figure 1 shows this quadratic model, with its kindred linear and cubic models.

What do we conclude? (1) Worsening health gives very rapid propulsion to disability. The pace is slowed only at high numbers (almost im-



A. Physical Limitations Coefficients and R^2:

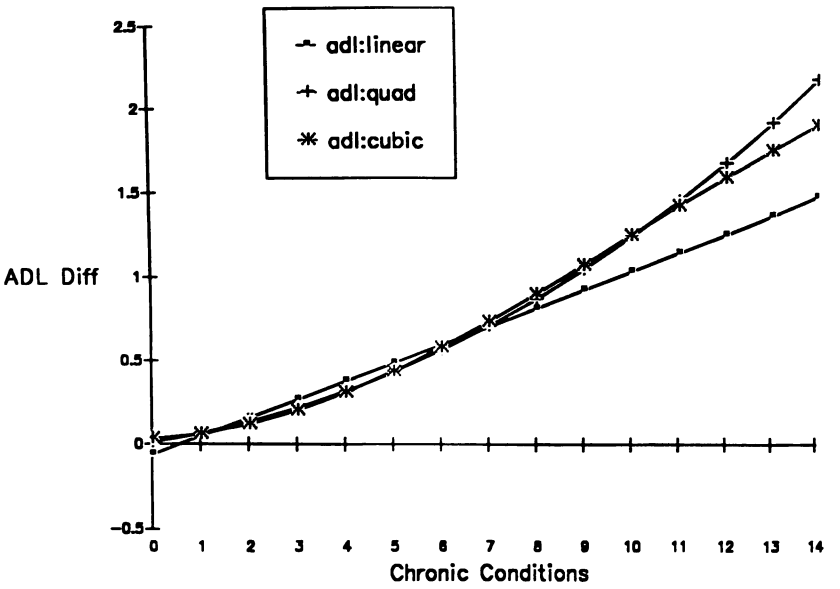
	CC	CC^2	CC^3	R^2
L	.614	–	–	.383
Q	.676	−.007	–	.384
C	.509	.037	−.003	.386

Inflection point for C: 4.4.

FIG. 1. Rise in disability with increasing number of chronic conditions for three disability items.

Models: OLS Linear: Y = f[Age, Gender, Race, No chron. cond. (CC)]; OLS Quadratic: Y = f[A, G, R, CC, CC^2]; OLS Cubic: Y = f[A, G, R, CC, CC^2, CC^3]. (*Figure continued on next two pages.*)

plausibly high) of chronic conditions. The slowing is gentle for ADLs and IADLs; that is, social disability still continues to rise markedly for very ill people. It is sharper for functional limitations; that is, there is an upper (average) limit for community dwellers around 6.5 to 7.0 (out of 10). (2) Even when very ill, people seldom reach extreme levels of disability. Note that the final disability levels predicted for $X = 14$ are still well below each item's maximum. (3) Morbidity predicts physical disability better than social disability (see R^2). This is repeated at many points in our entire analysis. It reflects something theoretically sound: Diseases have their readiest manifestation in physical functioning. Social disabilities are less proximate and are subject to more buffers inserted by medicine, personal efforts, and environment change



B. Difficult ADLs Coefficients and R^2:

	CC	CC^2	CC^3	R^2
L	.110	–	–	.134
Q	.046	.008	–	.140
C	.011	.017	−.001	.141

Inflection point for C: 9.6.

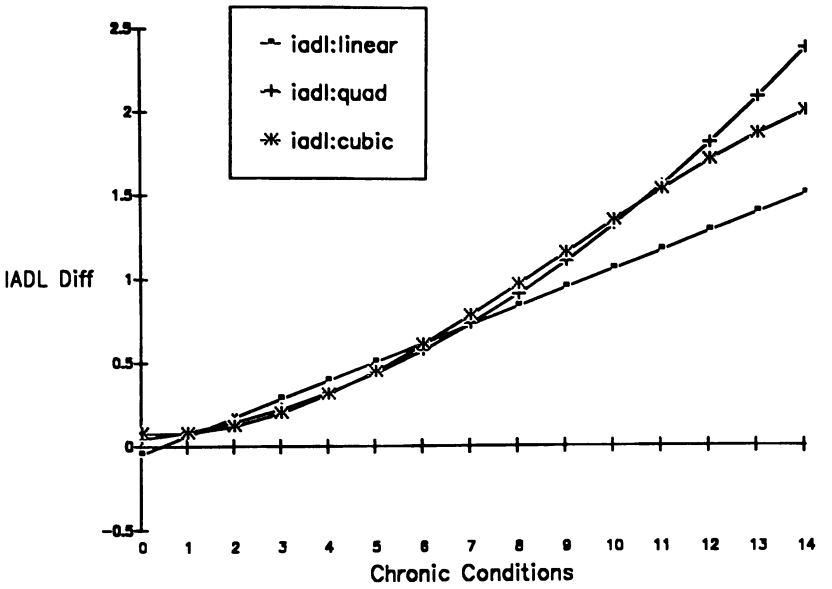
FIG. 1. (Continued).

(figure 2). Stated another way, people do their best to get around physical dysfunctions in order to accomplish social tasks.

Prevalence and Disability Impact

Having examined the overall relation between chronic conditions and disability, we now ask: "Which specific chronic conditions are most limiting?" This question can be construed two ways: "Which conditions cause the largest numbers or percentages of people in the population to be limited?" or "Which conditions are most likely to cause limitations among those ill?"

The first question is about overall limitation rates: for example, number of limiting [type X] conditions per 1,000 population. These



C. Difficult IADLs Coefficients and R^2:

	CC	CC^2	CC^3	R^2
L	.110	–	–	.162
Q	.029	.010	–	.172
C	−.023	.024	−.001	.176

Inflection point for C: 9.0.

FIG. 1. (Continued).

aggregate rates are actually a function of two components: a condition's prevalence and its disability impact. National statistics on disability typically provide such rates. Arthritis produces the highest overall limitation rates for middle-aged and older women, and heart diseases for men of those ages (Verbrugge 1987, 1989), but one cannot tell how much the high rank of these diseases is due to prevalence versus impact. The second question is explicitly about disability impact. This is the probability or level of disability among people with a given condition (Verbrugge 1989; herein called limiting potential instead of disability impact). One way to measure it is by comparing disability of persons who have a given condition to those who do not. This article is interested in disability impact not of just one condition, but 13, so we can compare their relative importance.

A model with 3 sociodemographic predictors (age, gender, race) and

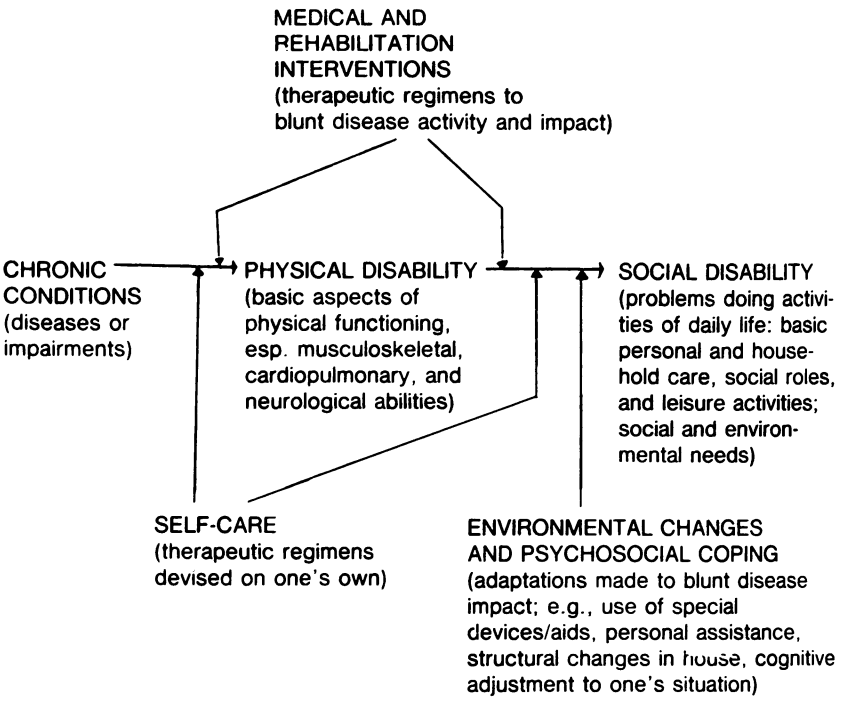


FIG. 2. A sociomedical view of disability.

Note: Readers familiar with the International Classification of Impairments, Disabilities, and Handicaps (ICIDH) (World Health Organization 1980) will see some of its features and not others here. Our figure deletes the ICIDH impairment concept (because it refers to something different than our text) and the handicap concept. It splits the disability concept into two components, physical and social, with a claim about causal sequence. Lastly, our figure adds the buffers that are so important in real-world experience of disability.

the 13 conditions (each represented as a separate X, scored 0 for absence and 1 for presence) was estimated for each disability item:

$$\text{Solos model: } Y = f[\text{Age, Gender, Race, 13 solos}].$$

Because the main (solo) effect of each condition is estimated here, we call this the solos model. (Age in single years, $\bar{x} = 67.1$; gender [male = 0, female = 1], 43.5 percent, 56.5 percent; race [0 = white, 1 = nonwhite], 90.1 percent, 9.9 percent.) This model estimates the disability impact of each condition when present (versus absent); we want to compare the magnitude of impact for the 13 conditions.

The results indicate that regression coefficients (b) are virtually all positive in sign and statistically significant ($P \leq .05$). Older age, female

gender, nonwhite race, and presence of each condition are associated with higher disability.

Regression coefficients in each equation were ranked to identify predictors with the most and least impact (table 3). (We also ranked standardized coefficients (beta) but decided that the unstandardized ones (b) are more interpretable, since they indicate concretely how much disability changes from absence to presence of a disease.)

Cerebrovascular disease (CVD) has the highest disability impact of the 13 conditions. It stands out decisively from all others with average rank of 1.1 for impact. Fracture of hip (Fx Hip) ranks second overall, with average rank 1.9. A tier of three conditions with quite-high impact follows: visual impairment (4.0), osteoporosis (4.4), and athero-

TABLE 3
The Relative Impact of Conditions and Demographic Items on Disability
(solos model: $Y = f$[Age, Gender, Race, 13 solos])

	Rank of regression coefficient (b)[a]								
Y: Predictor	Walking	Phys. Lim.	Diff. ADL	Unable ADL	Diff. IADL	Unable IADL	Role Lim.	Average rank of b	Overall rank
CVD	2	1	1	1	1	1	1	1.1	1
Fracture of hip	1	2	2	2	2	2	2	1.9	2
Visual impairment	4	5	4	5	3	3	4	4.0	3
Osteoporosis	3	4	3	3	5	6	7	4.4	4
Atherosclerosis	5	7	5	4	4	4	5	4.9	5
Diabetes	6	8	6	7	8	9	6	7.1	6
Race	10	8	12	8	7	7	10	9.0	7
IHD	8	6	9	14	13	11	3	9.1	8
Arthritis	7	3	7	15	14	12	8	9.4	9
Age (10 yr.)	9	15	11	6	6	5	16	9.0	10
Cancer	13	13	8	9	9	8	9	9.9	11
Other circulatory	11	10	10	11	16	15	14	12.4	12
Gender	16	12	14	12	10	10	15	12.7	13
Hearing impair.	12	11	13	16	11	16	11	12.9	14
HBP	15	14	16	10	15	13	12	13.6	15
Vision disease	14	16	15	13	12	14	13	13.9	16

[a] Biggest unstandardized regression coefficient ranks 1; smallest ranks 16.

sclerosis (4.9). Moderate impact comes from diabetes, ischemic heart disease (IHD), arthritis, and cancer (7.1 to 9.9). Conditions least likely to propel disability are other circulatory system conditions, hearing impairment, high blood pressure (HBP), and vision disease (average ranks 12.4 or greater).

(We estimated the solos model within four age groups and found the same rankings, with minor exceptions. Thus, the relative impact of the 13 conditions on disability is invariant by age.)

Looking along a row, note that a condition tends to have very consistent ranks across the dependent variables. This means a particular condition's (relative) importance for prompting physical and social disabilities is about the same.

There are two telling exceptions: (1) Ischemic heart disease has high impact on role activities and moderate impact on physical functions, but low impact on ADLs and IADLs. We suspect this reflects physicians' strong caution to heart patients to avoid physical and emotional stress. Patients comply and cut down on their physical and role activities, and thereby report disability; but they experience little trouble in basic activities of living. In short, as phrased by a reviewer of this article, cardiovascular disease (with the exception of stroke) is not well-correlated with personal care and household management problems. (2) Arthritis has high impact on physical functions (reaching, stooping, etc.), but otherwise moderate or low impact. This is a close reflection of the disease process; arthritis causes pain, stiffness, and restricted range of motion in hands, knees, hips, spine, and occasionally other sites. The most immediate and likely consequence is problems in basic motions, strength, and endurance. Sometimes but not always, these lead to problems in large-scale social tasks. In short, arthritis is a disease of the musculoskeletal system, and it leaves its signature there readily; it is less likely to penetrate social activities.

Table 4 presents a comparison of condition prevalence with disability impact. A simple powerful result emerges: High prevalence conditions tend to have low impact among community-dwelling persons (see HBP, hearing impairment, vision disease), whereas low prevalence ones have very high impact (CVD, osteoporosis, fracture of hip).

Arthritis is an anomaly, with very high prevalence matched to moderate impact. It is now obvious why arthritis stands at the top in overall limitation rates—a function of its high frequency joined with middle (not low) impact.

Our list of 13 conditions scarcely covers the territory of human dis-

TABLE 4
Comparing the Prevalence and Disability Impact of Chronic Conditions

Condition	Rank for prevalence	Rank for impact[a]
Arthritis	1	8
HBP	2	12
Hearing impairment	3	11
Vision disease	4	13
IHD	5	7
Visual impairment	6	3
Other circulatory	7	10
Diabetes	8	6
Atherosclerosis	9	5
Cancer	10	9
CVD	11	1
Osteoporosis	12	4
Fracture of hip	13	2

[a] Overall rank based on solos model (table 3), ignoring controls. Thus, ranks here range from 1 to 13 for the conditions.

ease and impairment. Inevitably, the titles in any list of conditions with "public health importance" are chosen for high frequency or impact. There is no way around that in this data set or many others. What we learn from this particular list is that prevalence and disability impact tend to be genuinely separable features in real life. One simply does not find conditions with simultaneously high prevalence and impact. Thus, public health opinions and policies about "critical" diseases (for quality of life among community dwellers) are very diverse, depending on which aspect is considered.

Remnant Effects of Age, Gender, and Race

To compare the importance of morbidity and sociodemographic variables, a model with just the three controls was estimated:

Baseline Model: $Y = f[\text{Age, Gender, Race}]$

It was compared with the solos model for size of R^2, and how coefficients for age, gender, and race change from baseline to solos models.

The results indicate the following: (1) The baseline model shows the maximal contribution of age, gender, and race; R^2s range from .012 to .079. The solos model increases R^2s three to fourfold: they range from .053 to .228. This signals the relatively small importance of the sociodemographic factors even "at their best." (2) More information comes from the coefficients and their ranks in the solos model. Initial (baseline) age effects on disability drop over 50 percent when morbidity is controlled, and age ends up at rank 10 (table 3). Initial gender and race effects are both smaller than those for age. They are scarcely affected by inclusion of morbidity (a surprise, given the sizable differences in health by gender and race), and they take ranks 13 and 7 respectively in the solos model. Net effects for race match or exceed those of age.

In sum, the initial positive effects of age on disability largely reflect age differences in condition prevalence, rather than hidden frailty or other "intrinsic aging" factors. For gender, women have slightly higher disability levels than men, both initially and after morbidity is controlled. (The female excess is sizable for one item: physical limitations. Long-standing differences in physical strength probably account for this.) Race stays important for most items, with higher disability among nonwhites. The question arises, are there possibly lifelong differences in physical capabilities or cultural opportunities to explain these remaining race effects in mid and late life?

Synergy in Pairs of Chronic Conditions

We have shown how specific conditions influence disability on their own, or "solo." Now, we ask if certain combinations of conditions give special propulsion to disability beyond what we would expect from the solo (main) effects. We assess the special (interaction) effects that all 78 pairs formed from the 13 conditions have on disability.

Prevalence

We begin with an interesting analytic issue about prevalence of pairs that is unrelated to synergism:

Do pairs occur at a frequency that might be expected by chance alone, or more often than that? Observed frequencies of pairs were compared to expected frequencies based on an independence model, by the kappa statistic. Most (69 of 78) pairs occur near chance levels, and kappas are small (.00–.10) (see technical appendix, item 4).

But 9 pairs appear notably more often than chance (table 5):

1. In some instances, this reflects shared pathogenesis: 3 pairs are combinations of circulatory conditions: 1 combines vision disease and vision impairment (impairment has many sources, disease is one of them).

2. In other instances, similar etiology or similar predisposing characteristics are relevant: The association of arthritis and HBP can stem from a shared risk factor (overweight) or from biological aspects of gender (both diseases are more common for women: the specific risk factors may differ but occur among women more than men). Similarly, the overlap of osteoporosis and HBP may have a sex-linked basis.

3. Lastly, biological aging processes—diverse but working in parallel—may account for the 2 combinations of circulatory with visual problems, and the 1 of hearing and vision problems.

TABLE 5
Pairs That Occur Notably Beyond Chance Level (kappa > .10)

Pair	Observed prevalence	Expected prevalance	Kappa[a]
IHD, Atherosclerosis	3.2%	0.6%	.26
VisDis, VisImp	4.2	1.6	.23
Atherosclerosis, CVD	1.3	0.4	.16
Arthritis, HBP	21.1	17.6	.14
VisImp, Atherosclerosis	2.0	0.8	.13
VisImp, CVD	1.4	0.5	.12
IHD, CVD	1.5	0.6	.12
HearImp, VisImp	5.0	3.1	.11
HBP, Osteoporosis	0.3	0.1	.11

[a] Kappa measures the degree of observed co-occurrence beyond that expected from an independence model ($X_1 \times X_2$). Range of positive kappa is 0.0 for chance level to 1.0 for perfect overlap (see also technical appendix, item 4). Of 78 pairs, 76 have positive kappas; 2 have slightly negative ones (occur less often than chance).

Disability Impact

When two conditions co-occur in a person, are there special effects (especially, exacerbating ones) for disability? Which pairs have special effects? We explored this by extending the solos model.

Single Pair Model. Regressions were run for each Y, looking at every pair one by one.

Single Pair Model: $Y = f$ [Age, Gender, Race, 13 solos, 1 pair].

This was a screening step to locate significant pairs ($P \leq .001$, or ***).

Altogether, 546 single pair models (78 pairs × 7 Ys) were estimated. The included pair was significant at a minimal level ($P \leq .05$) in 40 percent ($n = 221$) of the models; more stringent levels still yielded 26 percent ($P \leq .01$, $n = 141$) and 16 percent ($P \leq .001$, $n = 88$). Significant pairs were well distributed across the disability variables.

Each particular pair had 7 opportunities to manifest its importance. Table 6, top panel, shows how well the highest-prevalence and lowest-prevalence pairs performed. The bottom panel picks out pairs that were significant most often; common titles in these frequent-impact pairs are CVD, atherosclerosis, fracture of hip, and osteoporosis. More broadly, the most common titles found in the 88 ($P \leq .001$) significant pairs are CVD, atherosclerosis, IHD, and fracture of hip (data not shown). Clinicians may be especially interested in the specific pairs named in table 6, bottom panel. Nonclinical readers may instead remember the 5 titles; when they occur with another chronic problem, synergistic effects on disability often happen.

Table 7 presents a summary of the analytic results in a very compact manner (readers are encouraged to read the text here before perusing it). The top panel shows how many pairs reached significance zero times, once, twice, etc. Earlier, we ranked each pair for prevalence (1–78; table 2). Taking the collection of pairs with zero significant effects, we computed their average prevalence rank; similarly for the other collections. A striking fact emerges: Often-significant pairs (4–5 times) tend to have low prevalence in the population; sometimes-significant pairs (1–3) have highest prevalence; and never-significant pairs (0) are a broad mix of prevalence. The bottom panel presents this another way: High prevalence pairs (ranks 1–20) typically have moderate impact; middle prevalence pairs (21–40) tend to be least powerful;

TABLE 6
Comparing the Prevalence and Disability Impact of Pairs

Pair	High prevalance: Rank for prevalence	High prevalance: Count for impact[a]	Pair	Low prevalance: Rank for prevalence	Low prevalance: Count for impact
1. How often the highest prevalence and lowest prevalence pairs have significant effects on disability:					
Arth, HBP	1	2	VisImp, FxHip	64	2
Arth, HearImp	2	3	IHD, Osteo	65	3
HBP, HearImp	3	0	Athero, Osteo	66	4
Arth, VisDis	4	3	Oth Circ, Osteo	67	0
HBP, VisDis.	5	1	Cancer, CVD	68	2
HBP, IHD	6	0	Athero, FxHip	69	4
Arth, VisImp	7	3	IHD, FxHip	70	4
Arth, IHD	8	2	Oth Circ, FxHip	71	0
Arth, Oth Circ	9	1	Cancer, Osteo	72	0
HearImp, VisDis	10	1	Cancer, FxHip	73	0
HBP, VisImp	11	2	FxHip, Osteo	74	5
HBP, Diab	12	0	Diab, Osteo	75	0
HearImp, VisImp	13	2	Diab, FxHip	76	2
HBP, Oth Circ	14	4	CVD, Osteo	77	4
HearImp, IHD	15	1	CVD, FxHip	78	5

2. Which pairs are most-often significant and their prevalence ( ):[b]

	$P \leq .01$	$P \leq .001$
Significant in 5 regressions:	CVD, FxHip (78) FxHip, Osteo (74) VisImp, Osteo (62) Athero, Ca (58) CVD, Diabetes (57) Athero, CVD (48)	CVD, FxHip (78) CVD, Diabetes (57)
Significant in 4 regressions:	CVD, Osteo (77) IHD, FxHip (70) Athero, FxHip (69) Athero, Osteo (66) IHD, Ca (52) HearImp, CVD (37) HBP, Oth Circ (14)	CVD, Osteo (77) Osteo, FxHip (74) Athero, FxHip (69) VisImp, Osteo (62) IHD, Ca (52)

[a] Results are based on single pair model: $Y = f$[Age, Gender, Race, 13 solos, 1 pair]. Impact is the number of regression coefficients (of 7 possible) with $P \leq .01$.
[b] No pairs are significant in 6 or 7 regressions.

TABLE 7
Disability Impact of Pairs
single pair model: $Y = f$[Age, Gender, Race, 13 solos, 1 pair][a]

Pair has this number of significant effects on disability	No. of such pairs		Average prevalence rank of such pairs	
	$P \leq .01$	$P \leq .001$	$P \leq .01$	$P \leq .001$
0	27	40	41.1	37.8
1	12	11	34.2	30.3
2	9	13	33.9	34.5
3	17	7	29.1	46.1
4	7	5	55.0	66.4
5	6	2	62.5	67.5
6	0	0	—	—
7	0	0	—	—
Total	78	78		

Pair has prevalence rank in this range	No. of such pairs	Average no. of times (in 7) pair is SIG	
		$P \leq .01$	$P \leq .001$
1–10 (high prevalence)	10	1.6	0.7
11–20	10	1.9	1.1
21–30	10	1.4	0.8
31–40	10	1.4	0.5
41–50	10	1.7	1.0
51–60	10	1.9	1.3
61–70	10	2.4	1.9
71–78 (low prevalence)	8	2.0	1.9
Total	78		

Note: Low rank means high prevalence for the pair. High rank means low prevalence. (Text describes how to read this table.)
[a] Results are based on 546 regressions (78 equations for 7 Y's). Top panel organizes pairs by how often they produce statistically significant effects. Bottom panel organizes them by prevalence.

and rare pairs (61–78) have highest average impact. The pattern is clearest for $P \leq .01$. (More details about "powerful pairs" are in the technical appendix, item 5.)

Summing up, disability impact is generated especially often by some low-prevalence pairs, and moderately often by high-prevalence ones.

This relation between pairs' prevalence and impact is more complex than we found for the solo titles (there, it was inverse).

Significant Pairs Model. Based on the model above, we prepared the best model for each dependent variable. Only highly significant pairs ($P \leq .001$, $n = 88$ instances in single pair regressions) were retained for further scrutiny. Each disability variable was regressed on the sociodemographic items, 13 solos, and its own significant pairs:

> Significant Pairs Model: $Y = f$[Age, Gender, Race, 13 solos, *** pairs].

Though competing together now, most pairs still remained significant at $P \leq .05$ (89 percent, $n = 78$): one-half stayed highly significant ($P \leq .001$, 54 percent, $n = 47$).

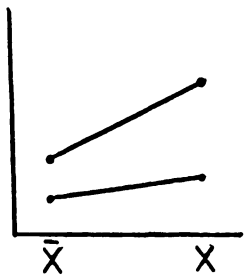
Six basic patterns of interaction effects appear for the 88 pairs. We describe them below. Pairs propel disability in patterns I, II(a,b), and VI; they diminish disability in III; they have no effect in IV and V. We also portray the patterns visually (figure 3). In the figure, disability is on the Y axis, one condition title is placed on the X axis, and the second condition title is a covariate. Pairs that belong to each pattern are listed in the figure.

Most common is an exacerbating pattern (I) with positive (+) significant effects for two solo titles and their joint pair. Of the 88 pairs, 33 fit this pattern. Visually, we see two rising, diverging lines. CVD and FxHip are most responsible for exacerbating effects. After them, three other conditions are often exacerbators when paired with other health problems: atherosclerosis, visual impairment, and diabetes.

The Nascent pattern (II) has just one solo title significant (+ or −), but the pair is significant ($n = 26$). The model is denoted as IIa for + solo effect, IIb for − solo effect. Figure 3 shows a flat line, plus a rising or else falling one. Cancer and osteoporosis often have nascent effects, being nonsignificant on their own but prompting disability in conjunction with other conditions.

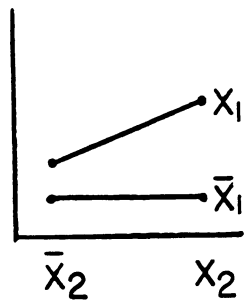
The damping pattern (III) has positive significant effects for the solos, but a negative significant effect for the pair ($n = 15$). This means the presence of both conditions leads to lower than expected disability. Visually, this is a rising line and another one that starts above and typically approaches it. Damping effects are most often associated with CVD and IHD. This seems odd at the outset (and con-

Type I. Exacerbating: SIG/+, SIG/+, SIG/+



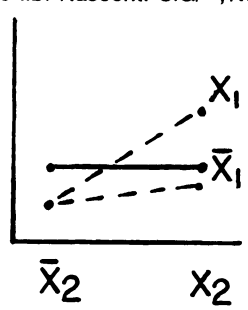
Pairs:
5: CVD, FxHip
4: Athero, FxHip
3: CVD, Diab
2: VisImp, Hear; VisImp, Osteo; VisImp, Arth; Diab, OthCirc; CVD, Athero; CVD, Osteo; FxHip, Osteo
1: VisImp, HBP; Hear, Athero; Diab, IHD; Diab, FxHip; Athero, Arth; Athero, Ca; FxHip, Arth

Type IIa. Nascent: SIG/+, NS, SIG/+



Pairs (first title is SIG solo):
2: CVD, Diab; IHD, Ca; Athero, Osteo; Athero, Ca; FxHip, Osteo
1: VisImp, VisDis; VisImp, Diab; VisImp, Osteo; Arth, VisDis; Athero, Hear; Arth, IHD; Ca, IHD; CVD, Osteo; CVD, Ca; FxHip, Diab

Type IIb. Nascent: SIG/−, NS, SIG/+



Pairs (first title is SIG solo):
1: VisDis, Diab; Diab, VisDis; IHD, VisImp; VisDis, Arth; IHD, Diab; IHD, Ca

FIG. 3. Patterns of pair effects. Types of interactions are identified by significance/sign of X_1, X_2, X_1X_2.

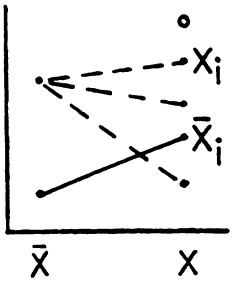
For example: SIG/+, SIG/+, SIG/+.

On the left: The pure form, or pattern, of each Type is drawn. For Types IIa, IIb, V, the nonsignificant solo (X_2) is shown on the abscissa and the significant one (X_1) is the covariate. For other Types, the two X's can take either position. Absence is denoted by a bar over the X, and presence by plain X.

On the right: pairs that fit the Type are stated, and the number of times (of 7 possible) they do so (88 pairs [$P \leq .001$] are studied. All but 5 fit the patterns shown here).

(*Figure continued on facing page.*)

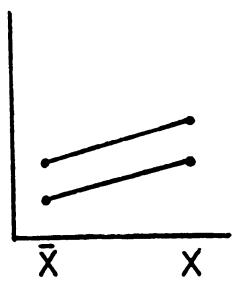
Type III. Damping: SIG/+, SIG/+, SIG/−



Pairs:
3: IHD, Athero
2: IHD, CVD; CVD, Arth
1: VisImp, IHD; VisImp, Arth; VisDis, CVD; Hear, IHD; IHD, FxHip; HBP, FxHip; CVD, Athero; CVD, Ca

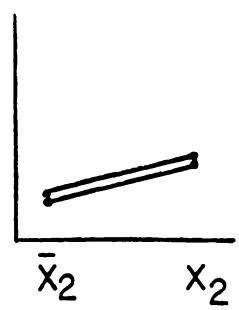
∘ - X_1 value for additive model

Type IV. Solos Only: SIG/+, SIG/+, NS



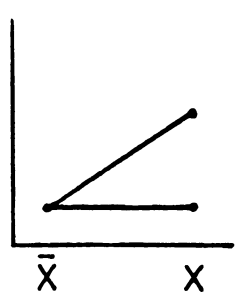
Pairs:
1: IHD, FxHip; CVD, OthCirc; Athero, Osteo; Athero, Arth

Type V. One Solo: SIG/+, NS, NS



Pairs (first title is SIG solo):
1: IHD, Osteo; CVD, Osteo

Type VI. Pair Only: NS, NS, SIG/+



Pairs:
1: VisImp, Osteo; Diab, OthCirc; HBP, OthCirc

FIG. 3. (Continued).

tradictory for CVD: cf. pattern I). For pairs involving two circulatory conditions, the damping appears largely for physical limitations. The reason may lie in pathology: The pair encodes the same underlying pathology, so adding their solo effects overestimates impact; this causes a negative interaction. For pairs of CVD/IHD with a noncirculatory condition, the effects are mostly on role limitation. The reason may lie in treatment: CVD and IHD patients cut back sharply in their social roles, sometimes more than the disease "intrinsically" requires; the negative interaction adjusts for this in the comorbid situation.

The solos only pattern (IV) has positive significant effects from the two solo titles, but in this competitive milieu the pair has become nonsignificant ($n = 4$). This is recorded in rising parallel lines.

The one solo pattern (V) shows impact from just one title; the other solo and the pair are nonsignificant ($n = 2$). This is recorded in one rising line, or two very close parallel lines rising together.

In the pair only pattern (VI), two conditions affect disability only when occurring together and not on their own ($n = 3$). Visually, two lines are joined at one end, then one rises while the other stays flat.

(Five pairs do not fit these types; all involve unusual negative signs and are not easily interpretable.)

The main results for each specific disability variable are discussed in the technical appendix, item 6. A table showing the regression coefficients for the solos models and significant pairs models is available on request.

Discussion and Conclusion

How does the multiplicity of conditions a person has (comorbidity) influence disability? Our analysis yields these key results:

1. As the number of chronic conditions increases, disability rises rapidly, almost exponentially. But at very high counts, it ceases to rise so fast. In other words, for most people who have just a few chronic problems, an additional problem greatly propels disability. For the few people who are extremely ill, an additional problem no longer pushes disability as much.

2. Chronic conditions most important for aging policy and geriatric medicine tend to have either (a) high prevalence and low (occasionally

moderate) disability impact or (b) low prevalence and high impact. For example, arthritis is the leading chronic condition for middle-aged and older persons, but it has modest impact compared to CVD, osteoporosis, and fracture of hip, all much less common. This disjunction between prevalence and impact means that the aggregate level of disability in the community-dwelling population has very diverse sources, to which the sheer frequency of some diseases and the high impact of others both contribute.

3. Health problems are the main driver of disability, and sociodemographic characteristics have only small additional effects. Initial age effects almost vanish when morbidity is controlled; thus, a person's age is not nearly so important for disability as what chronic problems she/he has. Women continue to have slightly higher disability levels than men, and nonwhites higher disability than whites, even when morbidity is controlled.

4. When conditions co-occur, they do not always have special, or synergistic, impact. We find it in 88 of 546, or 16 percent, of the single pair models. Thus, most of the time, there is no special penalty from having two conditions simultaneously.

But the instances of significant synergism are revealing; our common sense notion of synergism is to expect that having a pair of conditions will exacerbate disability (the exacerbating pattern). Yet, only 38 percent (33 of 88) of the significant pairs examined work this way. Two other patterns exist in which the pair propels disability: nascent, where one condition has no effect on its own but does in conjunction with another (30 percent); and pair only, where two conditions have impact only when they co-occur (3 percent). Overall, this means that 71 percent of the significant pair effects show a special disability "penalty."

There is one other common pattern, but it works in the opposite direction: damping, where solo effects are diminished when the two diseases co-occur (17 percent). The remaining 12 percent have other minor patterns.

5. The most powerful pairs (determined by their frequency of significant impact) are: CVD with FxHip, diabetes, or osteoporosis; FxHip with osteoporosis or atherosclerosis; visual impairment with osteoporosis; and IHD with cancer. When these pairs exist in a person, they often give extra propulsion to disability.

The conditions most often involved in synergistic effects are CVD, atherosclerosis, osteoporosis, fracture of hip, and IHD. Pairs of circu-

latory conditions sometimes act in exacerbating fashion, sometimes damping, and we gave possible reasons for both situations. The conditions least often involved are HBP, hearing impairment, and other circulatory conditions; they operate mostly through main effects.

6. Pairs do not have a disability impact consonant with their prevalence. Low-prevalence pairs go two ways: Most do not have impact, but a few among them have frequent strong impact. High-prevalence pairs typically have impact with moderate frequency.

Stated differently, when synergism occurs it typically stems from uncommon pairs—two low-prevalence conditions that already have large solo effects. Our analysis using the total condition count also shows synergism in the nonlinear rise for disability as health worsens. The count contains, in a hidden manner, specific pairs and other multiples with exacerbating effects.

Why stop this analysis at pairs? There are probably certain triplets and larger clusters of conditions that have powerful effects on disability. We began analysis of triplets, but prevalence rates are so low for the vast majority that their statistical effects would be unreliable. The issue of how to screen clusters of conditions for comorbidity effects is a difficult one, and most data sets are not large enough to provide much information. We welcome suggestions on an efficient strategy for such work.

Geriatricians are well aware that older people tend to have several chronic problems, and not just limited to physical but including mental, emotional, and social ones (Minaker and Rowe 1985; Rowe 1985; Rowe and Besdine 1982). They recognize the debilitating impact of multiple conditions on activities and wellbeing, and they are trained to take a holistic approach toward their clients. This professional stance is slowly making its way into health research as well. Which clusters of problems pose special threat beyond their independent effects? Which have no such pernicious effects when co-occurring? How does the sheer volume of morbidity affect overall robustness and functioning? These are questions worthy of specific attention in both population-based and patient-based (target disease) surveys. Research on comorbidity will not only buttress what physicians now know by experience, but will also pinpoint in a quantitative manner (a) combinations of conditions that pose especially great risks and (b) population groups in which comorbidity has elevated impact. Such scientific knowledge can contribute directly to patient evaluation and care in clinical practice.

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Technical Appendix

1. In preliminary analyses, we asked how often the direct questions and the condition records matched. (1) Were *yes* responses always associated with a condition record for the same ICD-coded disease? Overlap of *yes* responses with relevant condition records is very high for 12 of the conditions. The exception is fracture of hip, where a *yes* could easily "map" to numerous ICD codes depending on current/past status. For that condition, we use the *yes/no* question in our analysis rather than condition records. (2) How often does a condition record exist even when someone said *no* to the direct question? This could happen if the condition was elicited by questions elsewhere in the interview, but not the direct *yes/no* question. Such occurrences are few. (Details of these analyses are available on request.)

2. We present these further details about disability variables: (1) Gross Mobility. In the SOA questionnaire, the two items on gross mobility sit in the ADL section. They are not routinely considered ADLs by researchers. Conceptually, they are physical rather than social disability, and we treat them as the former. In our analyses, walking is the gross mobility item; it is not drawn from the physical function items. (2) ADL and IADL. The difficulty question for ADL is prefaced by: "By yourself and without using special equipment, how much difficulty . . . ?" For IADL, it is: "By yourself, how much difficulty . . . ?" The dependence question for both ADL and IADL is: "Do you receive help from another person in [activity]?"

In the SOA, the IADL section included a question about doing heavy housework. It produces such high disability rates compared to the other 5 items, we chose to exclude it. The housework item with lower physical demand (light housework) is included in our analysis.

The two unable variables are components of the more-inclusive difficulty ones. Unable and any difficulty are both important perspectives, and we chose to analyze both. The unable variables are very skewed, so we treat results for them with circumspection.

3. Three families of models were explored: (1) ordinary least squares (OLS) models; (2) inverse regression models in which the dependent and independent variables are multiplied by $1/X$; and (3) pseudo-logit models in which the disability variable Y is transformed to an S-shaped logistic curve by $\log[(Y + k)/(MAX-(Y + k))]$, where k is a small constant for people with zero conditions and MAX is a number slightly larger than the top value of $Y + k$. In the inverse models, values of $X = 0$ were handled by adding 0.1 to all X. For all families, four regressions were computed: (a) baseline with just the sociodemographic variables (age, gender, race), (b) linear with X ($1/X$ for inverse) and the controls, (c) a quadratic extension of the linear, and (d) a cubic extension of the quadratic. (The specific equations are available on request.) For the inverse and pseudo-logit models, predicted values were transformed back to original scale for purposes of computing R^2 values.

What do these models mean? The linear, quadratic, and cubic forms allow different degrees of curvature (none for linear, and a variety of options for quadratic and cubic). THe linear form claims that every addition of a chronic condition has the same incremental effect on disability. The quadratic and cubic show larger, or smaller, increases depending on their signs. The families offer different contexts for curvature. Specifically, the inverse family is estimated for statistical purposes to accommodate heterogeneous variance of Y. The pseudo-logit family has a strong theoretical rationale; it forces an S-shaped curve (degree varies for linear, quadratic, cubic). If the S-shaped curve fits the data, it means that disability rises slowly at first, then rapidly, then tapers off for very ill people.

We examine values of X from 0–14; higher values have 10 or fewer cases.

The results: Values of R^2 for the OLS family are shown in figure 1. (Other criteria for fit are available, but this is simplest and readily understood by a general audience.) The basic linear model offers a good fit, but it is always improved by the quadratic. The cubic offers additional small gains. (For the social disability items, disability has a tendency to rise at an exponential rate with a slight slowdown (via cubic) at high numbers of chronic conditions. For physical limitations, disability rises at a slightly declining exponential rate, and this slowing is furthered by the cubic.) The pseudo-logit model repeats these results, although its S-shaped curves provide lower R^2 values than OLS. The

inverse regression model provides more precise estimates of disability at high values of X, but never reaches the R^2 levels of comparable OLS models.

For all families, the R^2 increments from linear to quadratic, and from quadratic to cubic, models are statistically significant ($P \leq .001$) though numerically tiny in most instances. The cubic coefficients are extremely small and based on "thin" data at high values of X; they are probably unstable from one data set to another.

4. Guralnik et al. (1989) also report some differences between observed and expected rates for pairs. Ratios using observed and expected rates have good descriptive utility (there are some in our table 5), but kappa is a better research measure of nonindependence. Its range is 0 to 1.00, with 0 representing chance agreement and 1.00 perfect agreement (Fleiss 1973). By standardizing degree-beyond-chance to the 0–1 range, it permits comparisons of pairs whose prevalence differs greatly.

5. In the pairs analysis, impact is operationalized by frequency of significant pairs, not by size of their coefficients. This is, we think, a good exploratory approach in the situation of multiple dependent variables and many instances of nonsignificant effects. It differs from the approach we use for solo titles; there, statistical significance is almost universal, so we use coefficient size as the criterion of importance.

6. Results of the significant pairs model for each disability item are summarized here:

Walking difficulty is increased by virtually all the solo conditions (esp. CVD and FxHip). There are 11 significant pair effects, most of them exacerbating (Type I, $n = 9$). The strongest exacerbation comes from: CVD,FxHip; FxHip,Diab; VisImp,Osteo. One pair-only pattern appears: HBP and OthCirc have no impact on their own, but together they do increase walking difficulty.

Physical limitations rise in the presence of every solo condition (esp. CVD and FxHip). Comorbidities have little effect here, with only 6 pair effects present (2 exacerbating, 4 damping, the latter involving CVD and IHD).

ADL difficulty rises due to most conditions (esp. CVD and FxHip). Comorbidity is important, usually via exacerbating effects ($n = 10$); esp. CVD,FxHip; FxHip,Osteo). IHD has 2 nascent effects: its solo effect has become nonsignificant in the model, but its impact is restored within several pairs.

Only a few conditions prompt severe difficulties in personal care, or

unable ADl, on their own. But a sizable number of pair effects occur: Most are mascent (n = 9) stemming from "restored" effects for diabetes, osteoporosis, and cancer. The skewness of this variable provides a poor fit and some unstable effects for solos, whose impact then becomes expressed in pairs.

A limited number of conditions increase IADL difficulty: CVD is strongest. But comorbidity takes great importances as a propeller of IADL disability. Fourteen pairs are significant (6 exacerbating, 6 nascent). The strongest exacerbating effects are for CVD,Osteo and CVD, FxHip. The nascent effects are due to diabetes and cancer.

Similar to these results, just 8 conditions have main effects for unable IADL (exp. CVD and FxHip). There are 14 significant pairs (3 exacerbating, 8 nascent with osteoporosis and cancer having emergent effects).

Finally, role limitations increase strongly in the presence of any condition (exp. CVD, FxHip, IHD). Comorbidity has importance via damping effects. Most of the damping pairs involve CVD or IHD. As noted earlier, we think their solo effects are inflated and the pair effects restore a more natural picture of disease impact on disability.

In sum, walking has the simplest results: Each condition increases walking trouble, and coexistence of conditions exacerbates the situation further. This profile appears also for the ADL items, with some nascent pair effects as well. It continues for IADL items but with weaker solo effects and more nascent ones for pairs. In striking contrast is the profile for physical and role limitations. Here, solos have very strong effects and pairs act to damp them. The dampers are probably due to shared etiology (for physical limitations) and to medical treatment effects (for role limitation).