Journal of Experimental Psychology: General
1988, Vol. 117, No. 4, 425–428

0096-3445/88/$00.75

The Complexity of Age × Complexity Functions: Comment on Charness and Campbell (1988)

Timothy A. Salthouse
Georgia Institute of Technology

In their recent article, Charness and Campbell (1988) described analyses of their data supporting what has come to be known as the Age × Complexity phenomenon. After briefly reviewing some of the history of this phenomenon and mentioning a potentially important implication, I discuss several limitations of the previous analyses. Finally, I argue that in order for the Age × Complexity phenomenon to be more than merely an empirical generalization, researchers must be sensitive to, and attempt to account for, both supraproportional and subproportional exceptions to the phenomenon.

The Charness and Campbell (1988) article made a number of important contributions to the literature on the acquisition of human skill and to that concerning adult age differences in cognitive functioning. At the risk of being accused of raising a minor objection about one course in an otherwise magnificent banquet, however, I would like to express my reservations concerning their treatment of what is referred to as the *Age × Complexity effect.* I first briefly review a little of the background of this age–complexity phenomenon, then discuss an important but often overlooked methodological implication, and finally describe what I perceive to be the weaknesses of current analyses of the phenomenon.

Background

Many authors have commented on the tendency for the absolute magnitude of adult age differences in a variety of perceptual–motor and cognitive tasks to increase as the hypothesized processing demands, or apparent complexity, of the task increased (e.g., Birren, 1956; Clay, 1957; Crowder, 1980; Welford, 1958). This Age × Complexity phenomenon was first expressed in the form of plots of the performance of older adults as a function of the performance of young adults by Brinley (1965). There are now numerous reports in which analyses of this type have been conducted on data of older adults (typically with average ages in the 60s) and data of young adults (generally with average ages in the early 20s). In both meta-analyses based on data collapsed across studies (e.g., Cerella, 1985; Cerella, Poon, & Williams, 1980; Hale, Myerson, & Wagstaff, 1987) and in analyses based on data from the same individuals (e.g., Brinley, 1965; Salthouse, 1978, 1985a, 1987, 1988), it has consistently been found that there is a systematic relationship between the reaction time performances of young and old adults. Most investigators have reported that the relationship is adequately described by a linear equation (i.e., the r^2 values generally exceed .9), although as Charness and Campbell (1988) pointed out, alternative relationships (e.g., power functions) also provide reasonable fits to much of the available data.

When comparisons are made between adults in their early 20s and adults in their mid 60s, the majority of the linear equations have yielded intercepts that are either slightly negative or very close to zero and slopes that typically range between about 1.2 and 2.0. Cerella and his colleagues (e.g., Cerella, 1985; Cerella & Fozard, 1984; Cerella et al., 1980) have suggested that the slopes are shallower for measures from tasks emphasizing sensory and motor processes than for measures reflecting central or cognitive processes. The lack of an objective operational basis for this distinction, however, in combination with the absence of statistical evaluations of the hypothesized slope differences, suggests that this claim should probably be considered speculative at the present time.

Charness and Campbell (1988) provided an example of this Age × Complexity phenomenon with several novel characteristics. The basic data for their analyses are 13 measures of different aspects of speeded performance from each of 48 adults. One unique feature of the Charness and Campbell approach is that reliability information is available for each of the measures, thus making it possible to evaluate the stability or consistency of each variable entering into the analyses. A second innovation introduced by Charness and Campbell is that task complexity is defined with respect to the average performance of all research participants rather than the performance of young individuals only. This procedure has the advantage of allowing complexity-performance equations to be computed for each research participant, thereby permitting the Age × Complexity phenomenon to be examined at the level of individual subjects. The major finding from their analyses was that the slopes of the individual complexity functions were positively correlated with chronological age (i.e., $r = .54$), indicating that with increased age successive increments in task complexity resulted in progressively larger increments in response time.

Implications

The fact that in the last decade many analyses have revealed considerable support for the Age × Complexity phenomenon has a number of intriguing implications. One of the most

Correspondence concerning this article should be addressed to Timothy A. Salthouse, School of Psychology, Georgia Institute of Technology, Atlanta, Georgia 30332.

important of these is that information-processing paradigms designed to isolate specific and independent stages or components of information processing may result in misleading inferences concerning the localization of age-related performance differences. The problem arises because what appear to be specific deficits, inferred on the basis of Age × Treatment interactions, may actually be reflections of a more general Age × Complexity phenomenon in which the absolute differences between adults of different ages increase whenever there is an increase in the overall complexity of the task (cf. Salthouse, 1978, 1985a).

As the evidence supporting the existence of the Age × Complexity phenomenon accumulates, therefore, there should also be an increase in reservations about the usefulness of "localization" procedures based on patterns of absolute age differences. Many of the analytical techniques of information-processing paradigms are still useful, particularly if the analyses reveal similar results in both absolute and relative measures (e.g., ratios, log-transformed values), but the Age × Complexity phenomenon clearly raises questions about the meaning of interactions previously assumed to be diagnostic of specific deficits.

Although most of the recent analyses have focused on measures of reaction time, a similar pattern of greater age differences at higher levels of task complexity has also been reported with measures of quality or accuracy of performance. The phenomenon may not be as easily detected with accuracy variables reflecting quality of performance because of restricted ranges of measurement (owing to measurement ceilings) and lack of comparability of accuracy units across different tasks. Nevertheless, several examples of Age × Complexity effects with accuracy measures are reviewed in Salthouse (1985b, pp. 183–190), and Brinley (1965) actually included accuracy measures in his original plots of the performance of older adults as a function of the performance of young adults.

To the extent that the Age × Complexity phenomenon occurs with both measures of time and accuracy it may reflect a general tendency for differences in the efficiency (speed) or effectiveness (probability of success) of elementary processes to accumulate as the number of repetitions of those processes increases with greater task complexity. Researchers might therefore be well-advised to consider as a null hypothesis the possibility that what appears to be evidence for a specific localized deficit may simply be a consequence of greater complexity of the overall task providing more opportunities for existing differences in elementary processes to be expressed.

Theoretical Interpretation

Although the Age × Complexity phenomenon with speeded measures appears to be fairly robust, and indeed might even be considered to represent one of the few empirical laws of human aging currently available, there is still little consensus concerning the reasons for this phenomenon. However, this is not to say that there are no hypotheses as to the factors contributing to this phenomenon. For example, several years ago I (1978) proposed a rather simple interpretation of the parameters of young–old complexity functions. My suggestion was that if the function had a slope of approximately 1.0 but an intercept greater than zero, then this would be consistent with a constant age difference that might be attributed to an age-related slowing in processes or components common to all tasks being compared. On the other hand, I reasoned that if the function had an intercept near zero and a slope greater than 1.0, then this would indicate that the absolute difference between the times of the young and old adults increased with the time of the young adults, a result that would be expected if nearly every process or component was subject to approximately the same proportional slowing. I also pointed out that this latter outcome would be consistent with a view espoused by Birren (e.g., 1956, 1965, 1974) in which he hypothesized that a major factor responsible for many age-related differences in cognition is a widespread, or generalized, slowing of information-processing operations.

The existence of numerous analyses confirming the finding that older adults are often slower than young adults by roughly the same proportion across a wide range of activities is clearly consistent with the Birren (1956, 1965, 1974) hypothesis, but there are at least two important deficiencies of the previous analyses. One weakness is that most of the earlier analyses have relied on an empirical, norm-referenced, assessment of complexity (i.e., indexed by the average response time of young adults or, as in the Charness & Campbell, 1988, article, of the entire sample of participants). Charness and Campbell pointed out that a number of theoretical assumptions are necessary in order to employ a theoretically derived complexity continuum, but the problem with the norm-referenced measures is that response time variations can occur for reasons unrelated to cognitive complexity (e.g., peripheral sensory–motor factors, discriminability, differential reliance on stored information, etc.). Only if complexity can be unambiguously related to the number of mental operations (e.g., by varying the number of repetitions of hypothesized processing components, as in Salthouse, 1988) can the Age × Complexity phenomenon be considered truly consistent with Birren's (e.g., 1974) generalized-slowing proposal.

A second limitation of most previous analyses of the Age × Complexity phenomenon, including those of Charness and Campbell (1988), is that exceptions to this phenomenon have often been ignored. That is, whereas previous researchers have quite naturally emphasized the range of results consistent with the Age × Complexity function, there appear to be a number of deviations from the proportionality phenomenon. To the extent that these exception patterns are systematic and replicable, they provide a basis for determining where, and how, interpretations of the proportional-slowing phenomenon must be refined. It is therefore desirable that exceptions to the phenomenon should receive at least as much attention as the evidence consistent with the phenomenon.

Two classes of exceptions to the Age × Complexity phenomenon can be identified: supraproportional and subproportional. Both are conveniently evident, although not explicitly recognized as such, in the Charness and Campbell (1988) data.

Supraproportional deviations are those in which the observed age differences are greater than that expected by the proportional slowing factor. Because results of this type are truly disproportional, one could presumably infer that the measures reflect processes that are differentially or selectively affected by increased age. In other words, even if a general slowing factor was operating, the fact that the slowing evident in these measures was more than what would be expected from a proportional slowing suggests that a separate explanation is required to account for the age-related effects evident in these measures. (It is important to note, however, that even though one might conclude that a specific deficit exists, it does not necessarily follow that the deficit is unrelated to the slower processing associated with increased age. It is possible, for example, that specific memory deficits emerge because of disparities between the time course of the loss of information and the speed of critical operations such as search, rehearsal, or retrieval; cf. Salthouse, 1985b.)

Supraproportional aging effects are evident in the Charness and Campbell (1988) data in the form of significant age differences in the ratios of the sum of the component durations to the squaring time. That is, expressing a contrast between two measures as ratios rather than as differences is in effect a proportional comparison, and the fact that greater age was associated with significantly lower ratios suggests that the relative discrepancy between the sum of the component durations and the duration of the integrated procedure increased with increased age. It therefore seems reasonable to infer that the processes represented by these ratios are disproportionately affected by increased age. The authors claimed that these ratios reflect the relative efficiency of subgoal access and memory management, but whatever the ratios represent, they appear to exhibit a sensitivity to age-related factors above and beyond any proportional factor. Another example of a supraproportional effect in the cognitive aging literature is the finding that older adults often have larger ratios of dual- to single-task reaction times in secondary task divided-attention paradigms (e.g., Madden, 1986; Salthouse & Saults, 1987).

Subproportional deviations from proportionality are those in which the observed age differences are smaller than those expected by the proportional slowing factor. Unlike supraproportional results, which appear to provide unequivocal evidence for the existence of a process that is impaired with increased age, subproportional age-related effects are subject to at least two quite different interpretations. That is, one interpretation of a finding that the difference between the times of older adults and those of young adults is less than proportional is that at least some perceptual–motor or cognitive processes are not susceptible to the proportional slowing. An alternative interpretation, however, is that the proportional slowing phenomenon still holds but that increased age is, for possibly unrelated reasons, associated with superior levels of coding or communication in the relevant processing structures. A fundamental ambiguity may therefore exist with subproportional results in that without additional information it is impossible to determine whether there are true exceptions to the proportional slowing, or whether proportional slowing always operates but that in certain circumstances increased age is associated with more redundant, or better optimized, processing structures that serve to compensate for the slower processing. Careful examination of subproportional results would likely prove quite rewarding because understanding why certain processes are apparently exempt from the proportional slowing, or how a proportional slowing might be masked by experience- or knowledge-based structural alterations, would undoubtedly help in explaining the Age × Complexity phenomenon and perhaps also other aspects of cognitive aging.

Although not contained in the present version of their 1988 article, in an earlier draft Charness and Campbell reported that the functions relating decision time to the magnitude of the multiplicand in the multiplication task were remarkably parallel for the three age groups. Because parallel functions indicate that the age differences remain constant in absolute, rather than proportional, terms, this finding is an example of a subproportional effect. A similar type of subproportionality has been reported in studies of semantic priming and lexical decision in which young and old adults have been found to exhibit similar priming benefits (e.g., Cerella & Fozard, 1984; Howard, Heisey, & Shaw, 1986; Rabinowitz, 1986). As noted already, however, without additional information it appears impossible to determine whether these results represent a genuine exception to the proportional slowing phenomenon or simply reflect the advantages of processing within highly overlearned or redundant structures.

Summary

To summarize, the basic message I would like to convey in this comment is that Age × Complexity functions are complex and by no means constitute in and of themselves an explanation for the age-related differences observed in measures of the speed or quality of performance. The consistency with which the times of older adults have been found to be proportional to those of young adults suggests that this is a robust phenomenon, and it may well lead to improved understanding of the nature of age-related differences in cognition. However, it seems unlikely that greater understanding will be achieved through reliance on theoretically ambiguous surrogate measures of complexity and selective reporting of only the results found to be consistent with the phenomenon, without examination of and attempts to account for the exceptions to that phenomenon.

References

Birren, J. E. (1956). The significance of age changes in speed of perception and psychomotor skills. In J. E. Anderson (Ed.), *Psychological aspects of aging* (pp. 97–104). Washington, DC: American Psychological Association.

Birren, J. E. (1965). Age changes in speed of behavior: Its central nature and physiological correlates. In A. T. Welford & J. E. Birren (Eds.), *Behavior, aging, and the nervous system* (pp. 191–216). Springfield, IL: Charles C Thomas.

Birren, J. E. (1974). Translations in gerontology—from lab to life: Psychophysiology and speed of response. *American Psychologist, 29*, 808–815.

Brinley, J. F. (1965). Cognitive sets, speed and accuracy of performance in the elderly. In A. T. Welford & J. E. Birren (Eds.), *Behavior, aging, and the nervous system* (pp. 114–149). Springfield, IL: Charles C Thomas.

Cerella, J. (1985). Information processing rates in the elderly. *Psychological Bulletin, 98*, 67–83.

Cerella, J., & Fozard, J. L. (1984). Lexical access and age. *Developmental Psychology, 20,* 235–243.

Cerella, J., Poon, L. W., & Williams, D. M. (1980). Age and the complexity hypothesis. In L. W. Poon (Ed.), *Aging in the 1980s* (pp. 332–340). Washington, DC: American Psychological Association.

Charness, N., & Campbell, J. I. D. (1988). Acquiring skill at mental calculation in adulthood: A task decomposition. *Journal of Experimental Psychology: General, 117,* 115–129.

Clay, H. M. (1957). The relationship between time, accuracy and age on similar tasks of varying complexity. *Gerontologia, 1,* 41–49.

Crowder, R. G. (1980). Echoic memory and the study of aging memory systems. In L. W. Poon, J. L. Fozard, L. S. Cermak, D. Arenberg, & L. W. Thompson (Eds.), *New directions in memory and aging* (pp. 181–204). Hillsdale, NJ: Erlbaum.

Hale, S., Myerson, J., & Wagstaff, D. (1987). General slowing of nonverbal information processing: Evidence for a power law. *Journal of Gerontology, 42,* 131–136.

Howard, D. V., Heisey, J. G., & Shaw, R. J. (1986). Aging and the priming of newly learned associations. *Developmental Psychology, 22,* 78–85.

Madden, D. J. (1986). Adult age differences in the attentional capacity demands of visual search. *Cognitive Development, 1,* 335–363.

Rabinowitz, J. C. (1986). Priming in episodic memory. *Journal of Gerontology, 41,* 204–213.

Salthouse, T. A. (1978). *Age and speed: The nature of the relationship.* Unpublished manuscript, Department of Psychology, University of Missouri, Columbia.

Salthouse, T. A. (1985a). Speed of behavior and its implications for cognition. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (pp. 400–426). New York: Van Nostrand Reinhold.

Salthouse, T. A. (1985b). *A theory of cognitive aging.* Amsterdam: North-Holland.

Salthouse, T. A. (1987). The role of representations in age differences in analogical reasoning. *Psychology and Aging, 2,* 357–362.

Salthouse, T. A. (1988). The role of processing resources in cognitive aging. In M. L. Howe & C. J. Brainerd (Eds.), *Cognitive development in adulthood* (pp. 185–239). New York: Springer-Verlag.

Salthouse, T. A., & Saults, J. S. (1987). Multiple spans in transcription typing. *Journal of Applied Psychology, 72,* 187–196.

Welford, A. T. (1958). *Ageing and human skill.* London: Oxford University Press.

Received January 26, 1988
Revision received March 21, 1988
Accepted March 22, 1988 ■

U.S. Postal Service
STATEMENT OF OWNERSHIP, MANAGEMENT AND CIRCULATION
Required by 39 U.S.C. 3685

1A. Title of Publication: Journal of Experimental Psychology: General
1B. Publication No.: 2 8 0 0 0 0
2. Date of Filing: 10/1/88
3. Frequency of Issue: Quarterly
3A. No. of Issues Published Annually: 4
3B. Annual Subscription Price: $18-Member $36-Indiv. $72-Inst.
4. Complete Mailing Address of Known Office of Publication: 1400 N Uhle Street, Arlington, VA 22201
5. Complete Mailing Address of the Headquarters of General Business Offices of the Publisher: 1200 17th Street, NW, Washington, DC 20036
6. Full Names and Complete Mailing Address of Publisher, Editor, and Managing Editor
Publisher: American Psychological Association, 1200 17th Street, NW, Washington, DC 20036
Editor: Sam Glucksberg, Dept. of Psychology, Princeton University, Princeton, NJ 08544
Managing Editor: Susan Knapp, 1400 N Uhle Street, Arlington, VA 22201

7. Owner

Full Name	Complete Mailing Address
American Psychological Association	1200 17th Street, NW Washington, DC 20036

8. Known Bondholders, Mortgagees, and Other Security Holders Owning or Holding 1 Percent or More of Total Amount of Bonds, Mortgages or Other Securities

Full Name	Complete Mailing Address
NONE	

9. For Completion by Nonprofit Organizations Authorized To Mail at Special Rates
(1) [X] Has Not Changed During Preceding 12 Months (2) [ ] Has Changed During Preceding 12 Months

10. Extent and Nature of Circulation	Average No. Copies Each Issue During Preceding 12 Months	Actual No. Copies of Single Issue Published Nearest to Filing Date
A. Total No. Copies (Net Press Run)	4,538	5,145
B. Paid and/or Requested Circulation 1. Sales through dealers and carriers, street vendors and counter sales	1,966	1,895
2. Mail Subscription (Paid and/or requested)	1,400	1,249
C. Total Paid and/or Requested Circulation (Sum of 10B1 and 10B2)	3,366	3,144
D. Free Distribution by Mail, Carrier or Other Means Samples, Complimentary, and Other Free Copies	111	122
E. Total Distribution (Sum of C and D)	3,477	3,266
F. Copies Not Distributed 1. Office use, left over, unaccounted, spoiled after printing	1,061	1,879
2. Return from News Agents	—	—
G. TOTAL (Sum of E, F1 and 2—should equal net press run shown in A)	4,538	5,145

11. I certify that the statements made by me above are correct and complete
Signature and Title of Editor, Publisher, Business Manager, or Owner: [illegible signature] Director, Publishing Services

PS Form 3526, Dec. 1981