Chapter 10

Ageing and skilled performance

Timothy A. Salthouse

What happens to skilled performance as we age? Are there reasons to expect cognitive skills to deteriorate as a function of increased age, and if so, are these expectations supported by empirical evidence? Is increased age in adulthood associated with reduced efficiency in the learning of new skills, and is age a factor in the ultimate level of proficiency that can be achieved in a cognitive skill? The present chapter addresses these questions, but the reader should be forewarned that few definitive answers are provided because the amount of relevant research is still quite limited. Nevertheless, some tentative conclusions will be offered on the basis of the available evidence, and considerable discussion will be devoted to the research procedures that seem likely to provide the most informative resolution of these issues. Also discussed in the chapter are the mutually beneficial contributions that can be expected from the joint investigation of ageing and skilled performance.

REVIEW OF RELEVANT RESEARCH

The first section of the chapter is devoted to a review of the literature on three topics concerned with the relationship between adult age and skilled performance. The initial topic is the effects of age on the elementary information processes that are often considered to represent the building blocks of cognition. Because the levels of these basic capacities presumably set limits on the ultimate proficiency of skills composed of those capacities, it is important to examine whether they vary systematically as a function of increased age in adulthood. To the extent that increased age is associated with declining levels of efficiency in elementary processes, one might expect that it

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would be difficult for older adults to achieve, or possibly even to maintain, proficient functioning in complex skills.

Examination of results relevant to the ease of acquiring new skills at different ages will be the second focus of this section. Important questions within this topic are whether older people can learn new skills as readily as young adults, and whether, regardless of the efficiency of their learning, they can ultimately achieve the same asymptotic level of proficiency.

The third topic in this section concerns the issue of whether adults of different ages utilize different mechanisms to achieve the same levels of skill. Of particular interest are situations in which one would expect older adults to have lower levels of efficiency in certain relevant component processes, but in which, perhaps because of selective sampling research participants, there is little or no relationship between age and overall degree of skill.

Elementary processes

A basic assumption underlying the information-processing approach to cognition is that there are a limited set of elementary or fundamental cognitive abilities that function as the building blocks of cognition. In fact, prominent cognitive psychologists such as Posner and McLeod (1982) have not only endorsed this position, but have suggested that the primary task of cognitive psychology is to determine how these cognitive primitives are combined to perform complex cognitive activities.

In support of this goal, a number of theorists have attempted to enumerate cognitive psychology's equivalent of chemistry's periodic table, with the elements referred to as elementary information processes (Chase, 1978; Newell and Simon, 1972), as elementary mental operations (Posner and McLeod, 1982), or as cognitive components (Sternberg, 1977; Sternberg and Gardner, 1983). Although certain processes tend to recur in many lists (e.g. discrimination, comparison, association), there is still little consensus on the exact composition of what are postulated to be fundamental cognitive abilities. Despite the lack of unanimity concerning the identity of these elementary processes, however, there seems to have been considerable tacit agreement that complex cognition is composed of, and consequently is at least partially dependent upon, these processes. A reasonable first step in the discussion of ageing and skilled performance is therefore to review the effects of age on the efficiency or effectiveness of processes that might be considered elementary or fundamental.

Comprehensive reviews documenting largely negative effects of ageing on relatively simple cognitive processes are available in numerous recent sources (Birren and Schaie, 1985; Kausler, 1982; Salthouse, 1982, 1985). Because data recently reported by Salthouse, Kausler, and Saults (1986, 1988) seem representative, they will be used to illustrate the major findings concerning the relationship between age and the efficiency or effectiveness of elementary cognitive processes.

The Salthouse *et al.* project involved the administration of similiar batteries of cognitive tests to two groups of 129 and 233 adults, respectively, ranging from 20 to 79 years of age. Most of the tests were designed to assess fairly basic cognitive abilities, and a test-retest procedure ensured that the assessments were all fairly reliable (i.e. estimated reliabilities of at least 0.6). Table 10.1 contains a brief description of several of the measures from the project, and the correlations between each measure and chronological age.

The first two variables are presumed to be indices of the speed with which the individual can execute elementary operations because the tasks were quite simple—involving a binary true/false decision—and most subjects had very high levels of accuracy. The verbal and spatial memory tasks were designed to assess the individual's capacity for temporarily retaining verbal or spatial information. Both tasks involved the presentation of seven target items, and performance averaged 5.35 verbal items correctly recalled and 3.76 spatial items correctly recalled, suggesting that in the average adult the passive storage capacity of verbal information may be somewhat greater than that of spatial information. The measure of paired-associates performance is assumed to reflect the efficiency with which the individual can form an association between two items. Performance in the geometric-analogies and series-completion tasks is hypothesized to reflect the individual's ability to infer or abstract the relationship that exists among familiar items. This is presumed to be a fundamental operation in most tasks involving inferential reasoning (e.g. Sternberg and Gardner, 1983). Finally, accuracy in the paper-folding task was hypothesized to represent the individual's effectiveness in carrying out mental transformations of spatial material. It should be noted that the performance measures reported for the last three tasks are all indices of accuracy; similar trends were also evident in measures of speed of performance despite the use of self-paced procedures and instructions emphasizing accuracy more than speed.

Inspection of the values in the first column of Table 10.1 reveals that increased age was associated ($p < 0.01$) with poorer performance on each of the measures that might be postulated to reflect basic information-processing capacities. As mentioned earlier, this pattern is typical of much of the literature on cognitive ageing. In fact, the median of the correlations reported in Table 10.1, (i.e. $r = -0.37$), is nearly identical to that (i.e. $r = -0.36$) computed from 54 correlations extracted from studies of memory, reasoning, and spatial abilities by Salthouse (1985, Tables 11.1, 12.1, and 13.1).

Given the substantial negative relationships frequently found to exist between age and measures of presumably basic cognitive processes, it seems reasonable to expect that older age would be a disadvantage in most complex skills. That is, if the constituent elements from which skilled performance is

Table 10.1. Summary results of the effects of age on elementary cognitive processes, data from Salthouse, Kausler and Saults (1988).

Age correlation	Measure	Task description
−0.55	Digit symbol speed (n = 362)	Rate of determining whether symbols and digits match according to a specified code
−0.36	Number comparison speed (n = 362)	Rate of determining whether two strings of digits are identical
−0.38	Verbal memory (n = 362)	Accuracy of recalling the identities of target letters from a matrix
−0.43	Spatial memory (n = 362)	Accuracy of recalling the locations of target letters from a matrix
−0.34	Paired associates (n = 362)	Accuracy of recalling the response word associated with a stimulus word (average of 2 trials)
−0.43	Geometric analogies (n = 233)	Accuracy of determining the truth or falsity of geometric analogies
−0.28	Series completion (n = 233)	Accuracy of extrapolating a numerical sequence
−0.28	Paper-folding (n = 129)	Accuracy of determining the outcome of a sequence of folds of a paper followed by punching of a hole

assembled are disintegrating, then it would presumably be impossible to achieve the same levels of proficiency in that skill at older ages. When evaluating this expectation against empirical evidence, however, it is important to distinguish between the acquisition of skilled performance on the one hand, and its continuation or maintenance on the other hand. These two issues are therefore considered separately in the following sections.

Efficiency of skill acquisition

Although the results summarized above concerning the negative relationship between age and measures of component processes suggest that older adults may be less efficient than young adults in the acquisition of cognitive skills, there is surprisingly little direct evidence in support of (or, it should be added, in opposition to) this expectation. It could be argued that the absence of well-documented increments in cognitive functioning with increased age, despite a generally positive correlation between age and experience, is indirect evidence that acquisition processes decline in efficiency across the adult years. However, this argument is not particularly compelling because alternative interpretations can be proposed to account for the failure to find age-related increases without assuming that there are age-related declines in the effectiveness or efficiency of acquisition processes. For example, although the total amount of experience may be positively correlated with adult age, it is possible that there is a gradual restriction with age in the diversity or variety of those experiences. Age-related improvements might not be expected under circumstances such as these because the additional experiences are primarily repetitions of earlier experiences, and not genuine opportunities for gaining new information. Another possible interpretation of the lack of convincing cases of age-related improvement in cognitive functioning is that the efficiency of acquisition processes might remain unchanged across the adult years, but there could be losses in previously acquired skills or knowledge such that there is no net change in overall proficiency. In other words, if the loss of old information occurs at a rate equal to or greater than the gain of new information, then there may be no net increment in level of cognitive functioning across the adult years despite invariant acquisition processes and the advantages of greater experience on the part of old individuals.

Because of the ambiguities of interpretation associated with this type of indirect argument, it is clearly preferable to base one's conclusions on an examination of the direct evidence concerning the effects of age on the efficiency of acquiring cognitive skills. Unfortunately the relevant literature is impoverished, and flawed in several important respects. For example, many of the studies purportedly investigating age differences in skill acquisition involved very small amounts of experience—rarely exceeding three hours with a given task—and thus cannot be considered as truly addressing the issue of skilled performance. The transition between novice and skilled levels of performance is not yet well defined, but it seems clear that considerably more than three hours is needed to reach interesting levels of skill on any moderately complex cognitive activity.

Another weakness of some studies that might have been considered relevant in the present context is that they examined adults from only a single age group, and thus provided no basis for determining whether or not there were age differences in the efficiency of acquisition processes. Much of the research conducted under the rubric of cognitive training (for reviews see Baltes and Willis, 1982; Willis, 1985) falls within this category in that the primary focus of the research was to demonstrate the existence of substantial cognitive 'plasticity' in older adults. However, the absence of groups of young adults receiving similar training severely restricts the usefulness of these studies for the purpose of evaluating the possibility that there were age differences in responsivity to training.

Several of the age-comparative studies involving moderate (at least 4 hours) amounts of experience have concerned perceptual-motor activities. For example, Salthouse and Somberg (1982) examined the improvements in performance of young and old adults in four perceptual-motor tasks across 50 one-hour experimental sessions. Measurement ceilings in several of the tasks precluded valid comparisons of acquisition efficiency with some performance measures. However, the practice effects in a reaction time task, after the first few sessions in which older adults improved more than young adults, were nearly parallel for young and old adults. This finding seems to suggest that young and old adults may not differ in the efficiency of acquiring, or optimizing, processes relevant to simple perceptual-motor performance. Moreover, because there is little indication in the data that the age differences were being attenuated with further practice, it also seems reasonable to infer that the two groups may never achieve the same asymptotic levels of performance on this type of task.

Some of the earliest, and still among the most impressive, studies of the effects of ageing on skill acquisition were reported by Thorndike, Bregman, Tilton, and Woodyard (1928). Although their volume, *Adult Learning*, summarized the results of many studies, two are particularly relevant in this context. Both studies involved 16 young adults (mean age = 22 years) and 16 middle-aged adults (mean age = 41 years), with one concerned with the activity of learning to write with their left hands (all individuals were right-handed), and the other with learning the artificial language Esperanto.

In the writing experiment the two groups started at nearly equivalent levels of speed and quality. Both groups improved a similar amount in the rated quality of their left-handed handwriting after 15 hours of practice, but the young adults made greater speed gains than did the middle-aged adults.

Esperanto was selected for the learning material in the other Thorndike *et* *al.* (1928) experiment because it represented a novel and complex intellectual task, and yet consisted of coherent and systematic material. The two groups of research participants were similar at the beginning of the study in measures of vocabulary, following printed directions, following oral directions, and paragraph comprehension. Both groups improved on all measures with 10 hours of classroom instruction and 10 hours of individual study. However, the magnitude of the performance improvement on the oral directions test was substantially smaller for the middle-aged adults than for the young adults.

Two recent, as yet unpublished, studies have also examined age effects in the acquisition of clearly cognitive tasks. One study, by Charness and Campbell (1987), compared 16 young (mean age = 24 years), 16 middle-aged (mean age = 41 years), and 16 old (mean age = 67 years) adults in the acquisition of a mental procedure to compute the squares of two-digit numbers. Although there were the expected age differences favouring young adults in most speeded measures, the three groups improved their speeds by nearly comparable amounts across four training sessions, and exhibited similar transfer to new problems. A particularly interesting aspect of this study was that measures of the speed of performing the components of the mental squaring procedure were obtained at both the beginning and the end of training. These measures allowed analyses of the ratios of the sum of the durations of the components in isolation to the mean time for the complete problems. To the extent that these ratios are less than 1.0, they can serve as an estimate of the amount of 'overhead', or added time needed to coordinate the components, required in the task. All groups increased their ratios with practice on the task, but the older adults had smaller ratios both before and after practice, suggesting that increased age may be associated with greater difficulty in the integration or coordination of component processes, independent of the efficiency of those processes.

The skill investigated in the second recent project, by Smith, Kliegl, and Baltes (1987), was serial word recall as mediated by a specially-trained mnemonic procedure. Four young adults (mean age 22.8 years) and 20 older adults (mean age 71.7 years) received mnemonic training either until they correctly recalled 32 out of 40 nouns, or until they had completed 26 individually-administered 90-minute training sessions. In virtually all measures of acquisition efficiency the young adults proved to be superior to the older adults. They achieved the criterion level of accuracy in fewer sessions (8.8 vs 17.0), with a smaller number of practice lists (19.3 vs 30.8), and with a smaller amount of total study time (188.0 minutes vs 381.8 minutes). The young adults also performed significantly better than the older adults in the final post-criterion assessment (39.8 vs 32.4 correct words out of 40) when the participants could determine the rate of item presentation.

The preceding summary suggests that the results from the existing studies of age effects in skill acquisition are somewhat contradictory. That is, with perceptual-motor skills, Salthouse and Somberg (1982) found nearly parallel improvements for young and old adults, while the young adults improved more than the middle-aged adults in the Thorndike *et al.* (1928) study of wrong-hand writing. In the case of cognitive skills, Charness and Campbell (1987) reported similar improvements in the speed of mental computation for adults of different ages, Smith *et al.* (1987) described results suggesting an advantage for young adults in the ease of acquiring a mnemonic skill, and Thorndike *et al.* (1928) reported a mixed pattern with middle-aged adults improving as much as young adults on three or four measures of Esperanto language proficiency. Because the amount of data is still so small, and because the activities that have been investigated are so different, it is probably premature to attempt a determination of the reasons for these discrepancies at this time. It is nevertheless interesting to note that the studies do seem consistent with respect to the absence of age differences in the amount of forgetting after a period without practice. That is, the performance declines across post-training intervals of 30 days (Charness and Campbell, 1987; Salthouse and Somberg, 1982) and 77 days (both Thorndike *et al.*, 1928 experiments) were found to be similar for all age groups investigated.

Mechanisms of skill maintenance

Because of the complex interrelations possible when one is attempting to examine the effects of age on both the efficiency of component processes and on the proficiency of a more global skill, it is frequently advantageous to investigate age effects on certain variables only after the age relations on other variables have been controlled in some manner. Depending upon which variables are controlled, one of two research strategies will result that can be used to address somewhat different questions related to the general issue of skill maintenance.

One strategy, termed Molar Equivalence–Molecular Decomposition by Salthouse (1984), consists of selecting individuals of different ages who are nearly equivalent in the proficiency of the molar skill, and then analysing the effects of age on the efficiency of the component processes presumed to contribute to that skill. This strategy therefore focuses on the question of whether people of different ages, when performing at comparable levels in a complex skill, place the same reliance on the efficiency of various component processes.

An alternative strategy results when people of different ages are equated in the efficiency of certain relevant component processes, and then age effects are examined in the proficiency of the molar skill. This strategy, which might be termed the Molar Analysis–Molecular Equivalence strategy, would presumably allow one to investigate the possibility that there are influences of age or experience in the effectiveness of integrating or coordinating one's cognitive processes. For example, the Charness and Campbell (1987) findings suggest that increased experience may result in greater optimization of the capacities one possesses, and that there is a loss with age in the ability efficiently to coordinate or utilize processing components, independent of the level of those components. This intriguing outcome could be subjected to verification and extension by systematic application of the Molar analysis–Molecular Equivalence strategy.

Unfortunately, while both analytic strategies seem likely to yield useful information, there has thus far been research only with the former strategy, and even that has been quite limited. This research will be reviewed, but it is first useful to examine how specific outcomes from the Molar Equivalence–Molecular Decomposition strategy might be interpreted. Of course, one cannot anticipate all outcomes that could possibly be observed, nor is it feasible to predict how individual investigators might choose to interpret their findings. It is nevertheless desirable to consider how specific outcome patterns from the Molar Equivalence–Molecular Decomposition strategy could provide insight into the mechanisms of skill maintenance across the adult years.

Perhaps the simplest outcome from equating adults on level of proficiency in a molar skill is that there will no longer be age-related declines on the measures of component efficiency. That is, adults of all ages may rely upon the same combination of component processes to achieve the molar skill such that different-aged individuals can be matched on molar proficiency only if they possess nearly identical levels of the relevant component processes. This would obviously be an interesting result, but it is likely to be ambiguous without further information about the reasons for the absence of expected age-related declines in the measures of component efficiency. That is, if the research literature suggests that there should be negative effects of increased age on the measures of component efficiency and yet there are no age-related effects on those measures in this sample, then the question naturally arises as to why this might be the case. One possibility is that the participants in the research sample were not representative of their age groups, with either the young individuals less select, or the older individuals more select, than their counterparts who have participated in the studies revealing that age is typically negatively related to efficiency of component processes. Obviously if the molar equivalence is achieved only by employing a biased sample of research participants in one or more age groups then the results from the procedure will not be very informative about the mechanisms responsible for the maintenance of skilled performance across adulthood.

An alternative, and in many respects much more interesting, possibility is that because of their extensive experience the older adults in the sample had maintained high levels of competency in relevant processes that normally decline in the absence of this experience. That is, while efficiency of component processes may typically decline with increased age in the general population, the greater experience on the part of the older individuals in the research sample may have been responsible both for the ability to equate individuals of different ages on molar proficiency, and for the maintenance of high competence levels on component processes that would have otherwise declined with age.

The preceding discussion reveals that a finding of no age-related declines in component processes when one is utilizing the Molar Equivalence–Molecular Decomposition procedure can be subject to substantially different interpretations. Unless there is a means of distinguishing between the biased-sample and the experience-mediated maintenance possibilities, therefore, a discovery that there are no age effects in measures of component efficiency, after ensuring that there is no relationship between age and proficiency of the molar skill, may remain ambiguous.

There also seem to be two distinctly different ways in which a Molar Equivalence–Molecular Decomposition outcome of age-related declines in component processes might be interpreted. One possibility is that as adults grow older they alter the manner in which they perform the molar activity such that decreases in the effectiveness of certain processes might be compensated for by increases in the effectiveness of other processes. Compensation of this type should be evident by the discovery that in at least some processes there are actually age-related increases that serve to offset or counteract the age-related decreases occurring in other relevant processes. Another somewhat technical implication of this view is that adults of different ages should have different regression weights in multiple regression equations attempting to predict molar performance from measures of molecular (and compensatory) processes. More specifically, as age increases among equally skilled adults the importance (weighting) of molecular processes should decrease, and that of compensatory processes should increase.

A second way in which declines in component efficiency without concomitant declines in molar competence might be interpreted is in terms of the encapsulation (e.g. Rybash, Hoyer, and Roodin, 1986) or compilation (e.g. Anderson, 1982) of the molar skill such that it is no longer dependent upon the efficiency of the molecular processes. This view can be elaborated by contrasting two metaphors of the molar skill. One metaphor is that of a building in which the structure will collapse if the materials from which it is constructed deteriorate. This is the perspective implied in the preceding discussion in that the skill would be expected to decline as the components lose their effectiveness because proficiency of the skill is always assumed to be dependent upon the current integrity of the constituent elements.

A second metaphor of the nature of skill is that of a computer program which is first assembled from subroutines, and then compiled into an efficient operational form. Because once in a compiled form the efficiency of the program will be independent of later changes in the efficiency of the subroutines, the program can be considered to have encapsulated an earlier level of functioning. In other words, variations in the effectiveness of what were once constituent parts of a program or skill may no longer influence the proficiency of the overall activity after it has been automated or compiled. From this perspective, therefore, compensation processes may not be necessary to achieve molar equivalence when molecular processes are declining because the important molecular-molar relation is not the current one, but rather that which existed at the time the skill became fully automated (or compiled, or encapsulated).

At least in principle, it seems possible to distinguish between the compensation and compilation interpretations on the basis of two criteria. One criterion is the presence or absence of a compensatory mechanism. That is, the existence of a process correlated with performance of the molar activity, but which increases rather than decreases with advancing age, is predicted from the compensation view but is not easily reconciled with the compilation interpretation. On the other hand, the compilation view seems to imply that the correlations between molecular efficiency and molar competence should decrease with increased skill because the important relationship occurs rather early in skill acquisition when the component processes are compiled to produce the automated version of the activity. A discovery that highly skilled individuals had smaller correlations between measures of component processes and proficiency of the molar skill than less skilled individuals might therefore be considered more consistent with the compilation interpretation than with the compensation interpretation.

Three activity domains have been investigated with the Molar Equivalence–Molecular Decomposition research strategy—bridge, chess, and typing. Unfortunately, research in the domain of bridge has been somewhat hampered by the lack of a valid measure of current level of skill. Charness (1979, 1983) has primarily relied upon an index derived from the total number of master points achieved by the player, and has also considered the player's score on a short bridge quiz. However, the former measure is based on the cumulative master points acquired throughout one's lifetime, and hence may not be an accurate reflection of current level of functioning. The psychometric properties of the bridge quiz are unknown, and it would be of dubious value if it is not reliable or has low validity for prediction of actual bridge performance. Moreover, the two measures do not always yield the same age patterns as the age correlations in the 1983 study were −0.06 with the (log transformed) master points index, and −0.40 with the measure of performance on the bridge quiz.

Although not viewed as such in these studies, it is possible to consider accuracy or quality of bridge bids as the measure of proficiency in the molar skill. There were no significant effects of age on these variables in either the Charness (1979) or Charness (1983) studies, and thus it can apparently be inferred that there was molar equivalence in bridge skill across age of the participants in these studies despite the ambiguous status of the other measures of molar skill.

The major finding in the 1979 study was that the older bridge players performed less accurately than the young bridge players in a task of recalling bridge hands. This memory process is presumably relevant to bridge because it was also reported that more skilled bridge players (i.e. those with more master points) were more accurate in the task than less skilled bridge players (i.e. those with fewer master points). Because the individuals in this sample exhibited fairly typical age-related declines in a relevant memory process, it can apparently be inferred that they did not achieve the same level of proficiency in the molar skill of bridge by maintaining high degrees of efficiency in all relevant components. It is not yet clear, however, whether the same level of bridge skill was achieved by age-related increases in one or more compensatory mechanisms, or by a decreased dependence upon the efficiency of component processes with increased skill.

Somewhat contradictory results were obtained with another suspected component of bridge skill concerned with the time to decide which bid to make in a given situation. In the Charness (1979) study this measure was negatively correlated with an index of skill (log master points), suggesting that it was relevant to the molar activity of bridge, but there were no effects of age, implying that the older players had maintained efficient (i.e. rapid) levels of performance. However, in the Charness (1983) study there were weak or non-existent relations between bidding time and skill, but highly significant positive relations between age and bidding time. In this latter study, therefore, the older players were slower in bidding time than the young players, but there was little evidence that this measure bears any relationship to overall skill in bridge. Different procedures in the two studies may have contributed to these discrepancies in results, but whether one concludes that bidding time is relevant to bridge skill and negatively related to age (1983 study), the results appear to be of only marginal interest to the issue of how adults of different ages are able to achieve nearly comparable levels of functioning in the molar activity of bridge.

Charness (1981a) was also responsible for utilizing, and first describing, the Molar Equivalence–Molecular Decomposition research strategy in the domain of chess. The criterion measure of skill in chess was the player's competitive rating, which is a non-cumulative index that increases or decreases as a function of one's performance against opponents of different skill levels. Molar equivalence was established by selecting the participants such that there was a very low correlation (i.e. $r = 0.085$) between age and chess rating, and this equivalence was confirmed by the absence of age effects on measures of the quality of move selected and the accuracy of evaluating game outcomes.

As was found in the bridge domain, older chess players were less accurate than young chess players in recalling meaningful configurations (in this case, positions of chess pieces during mid-game), even though skilled players were generally better than less skilled players in this task. Further analyses revealed that these memory differences were also evident in measures of recall organization in that older players utilized a greater number of smaller-sized chunks than did younger players.

Another finding in this study was that thc older players were faster than the young players in selecting an appropriate move from a displayed configuration. Charness (1981a) initially interpreted this result as suggesting that the older players engaged in a more efficient search than the young players, perhaps by greater selectivity of evaluations. However, later analyses (Charness 1981b) of the verbal protocols of the players produced when they were deciding which move to select suggested that the older players considered significantly fewer alternative moves than the young players. It is therefore not yet clear whcther the faster move selection on the part of older players represents search that is more efficient, search that is less extensive, or as Charness (1985) recently suggested, merely reflected a strategy difference in the sense that older players responded as soon as they found an acceptable move while younger players continued to search for better alternatives until the time limit was reached.

To summarize, the Charness studies suggest that, in the domains of both bridge and chess, older individuals are apparently able to achieve the same overall level of skill as young individuals despite experiencing typical age-related declines in skill-relevant aspects of memory functioning. While this pattern is inconsistent with both the maintained-abilities and the biased-sample interpretations, it is not yet possible to distinguish between the compensation and the compilation interpretations of these findings. No convincing evidence for an age-related increase in a compensatory mechanism was available in either domain, and the relatively small sample sizes precluded analyses of the magnitude of the molecular-molar correlations as a function of skill to determine whether, as expected from the compilation view, the relationship between component efficiency and level of molar performance declines with increasing skill.

Somewhat more definitive results were obtained in an application of the Molar Equivalence–Molecular Decomposition strategy in the domain of transcription typing by Salthouse (1984) and Salthouse and Saults (1987). (Also see Salthouse, 1987, in press, for further discussion of these studies.) Skill in typing was assessed by determining the individual's net (adjusted for errors) typing speed, and the samples of participants in each study were selected such that there were near-zero correlations between age and net typing speed.

Several measures of perceptual-motor speed were initially examined as potential molecular components in typing, and for each it was found that faster typists performed better than slower typists, but that older typists performed worse than younger typists. In other words, although there were no effects of age in overall typing speed, the older typists exhibited typical age-related declines in the speed of relevant perceptual-motor processes (e.g. finger tapping, choice reaction time, visual-manual transcription).

Investigation of several possible compensatory mechanisms eventually revealed that older typists appeared to have larger anticipation spans of to-be-typed characters than young typists. The span difference was most clearly demonstrated by determining the number of characters a typist needed to have visible in order to type at his or her normal rate (Salthouse, 1984), but it was also evident when the display was altered to determine when the typist no longer responded to switched characters (Salthouse and Saults, 1987). Because the older adults were actually superior to the young adults in the size of these measures of anticipatory processing, and because a greater span obviously minimizes the consequences of slower perceptual-motor processes in typing, these results seem to support the compensation interpretation of the maintenance of skill across adulthood.

Although there has not yet been much research examining how adults of different ages are able to achieve comparable levels of skill on cognitive tasks, the question has considerable theoretical significance, and the limited results that are available appear quite intriguing. It is thus desirable that more research of this type be conducted, examining a variety of different cognitive tasks and employing both the Molar Equivalence–Molecular Decomposition strategy and its converse, the Molar Analysis–Molecular Equivalence strategy.

INTERRELATIONS OF AGEING AND SKILL

This final section of the chapter consists of a discussion of how the joint study of ageing and skilled performance might result in improved understanding of each topic. For ease of communication the discussion is organized in terms of uni-directional relationships, but it should be recognized that this is simply for expository convenience and that the knowledge benefits are likely to be bi-directional, and highly interactive in nature.

Contributions of the study of ageing to the understanding of skill

Perhaps the major benefit of examining the joint effects of age and skill is that it might allow one to determine the minimum requirements needed to achieve skilled performance. That is, because older adults typically have lower levels of many relevant abilities than young adults, investigation of how older adults are able to achieve and maintain high levels of proficiency in different activities can be expected to yield valuable information about the basic nature of skill in those activities. Three specific examples of this type of contribution will be described, based on possible outcomes of studies designed to explore how age and experience interact in the production of skilled performance.

One potentially informative outcome would be a finding that young and old adults matched on the efficiency of all relevant component processes (i.e. the Molar Analysis–Molecular Equivalence Strategy) differed significantly in overall proficiency of the molar skill. Because the research participants were matched on the degree to which they performed on the components thought to be the elements of the molar skill, a finding of this type would imply that skilled performance is something more than the sum of its parts, and, in addition, that the something more was related to adult age. (It should be noted that the existence of age differences in the ratio of sum of component durations to complete problem time in the Charness and Campbell, 1987, study is also consistent with this interpretation.) The possibility that skilled performance consists of the efficient control and integration of processes, and not just the processes themselves, has been frequently discussed, but using the variable of age as a means of establishing the existence of this control or integration mechanism has apparently not yet been explored.

A second possible outcome from the simultaneous study of ageing and skilled performance that would probably contribute to greater knowledge about process of skill acquisition and skill maintenance is a result that adults of different ages who are matched on level of molar skill (i.e. the Molar Equivalence–Molecular Decomposition Strategy), also do not differ in the efficiency of relevant component processes. If such a finding were observed under circumstances where a selection bias in the sample could be ruled out, it might reasonably be inferred that practice or experience in the molar activity either remediates or maintains proficiency in the constituent processes of that activity. That is, because increased age is typically found to be associated with lower levels of functioning on the component processes, a discovery that otherwise representative adults matched on level of molar skill do not exhibit age effects on the relevant molecular measures would suggest that experience may retard or prevent age-related declines that would otherwise occur. Of course, the importance of this outcome is obviously related to how similar the assessment of molecular proficiency is to the molar skill. However, it would be interesting, and surprising from the perspective that capacities are relatively stable characteristics of an individual's information-processing system, to discover that continued performance of a complex activity leads to alterations in the efficiency or effectiveness of presumably fundamental information processes.

The third outcome from research on ageing and skill that could prove informative about the nature and composition of skilled performance is the compensation pattern discussed earlier in which age-related declines in certain molecular components are apparently compensated for by age-related improvements in other components. This type of exchange, in which decreases in the efficiency of some processes seem to be offset by increases in other processes in order to maintain the same overall level of molar skill, would indicate that there is considerable flexibility in how a given degree of molar proficiency can be achieved. Determination of the limits of component substitutability and the conditions leading to particular patterns of compensation would obviously require systematic investigation, but this might be most feasible in the study of adults who are striving to maintain their high levels of performance in activities where they are experiencing declines in the efficiency of component processes.

Contributions of the study of skilled performance to the understanding of ageing

There seem to be at least two ways in which knowledge about the nature of skill might lead to improved understanding of processes of ageing. One concerns possible parallels between skill or expertise and ageing because the tendency for age and experience to be positively correlated suggests that older adults are likely to be more skilled than young adults in the ability domains in which they have specialized. Of course, experience is only a necessary and not a sufficient condition for the development of extreme skill or expertise, but it nevertheless seems reasonable to expect that highly skilled individuals and very experienced older individuals will have numerous characteristics in common. In particular, the study of skill may indicate the breadth of the specialized competence acquired as one develops expertise. Information of this type should be very helpful in understanding the range of abilities in which one might anticipate that high levels of competence could be maintained with continued experience in later adulthood.

Knowledge about skill, and specifically the consequences for skill of prolonged periods without practice, would also be very relevant for one of the dominant theoretical perspectives in the area of cognitive ageing. This position, sometimes referred to as the disuse theory, postulates that age-related declines in many types of cognitive functioning are attributable to older adults having less current experience than young adults with activities similar to those being tested. Empirical evidence for this interpretation is currently mixed (e.g. for reviews see Salthouse, 1985, in press), but the study of skilled performance may provide some of the most directly relevent evidence. That is, if age-related differences in cognitive functioning are attributable to the same mechanisms responsible for proficiency losses in a skill that has not been exercised, then the differences between young and old adults in a given activity should be qualitatively similar to those between performers in that domain who were once equally skilled but now differ with respect to whether or not the skill has been recently exercised.

SUMMARY

Perhaps the major conclusion to be reached from this chapter is that substantial gaps exist between what we would like to know and what we do know about the interrelationships of ageing and skilled performance. For example, despite frequent speculation, there is still little evidence establishing whether skilled activities that are continuously exercised are less susceptible to negative ageing effects than are unfamiliar or novel activities. Furthermore, even if the evidence were consistent in suggesting that there were smaller effects of ageing on skilled activities, it would still not be known whether this is attributable to the influence of ageing being restricted to novel activities, or to increased age being associated with greater amounts of experience with the relevant activities. It is clear, however, that there are substantial age-related decreases in the efficiency or effectiveness of measures that might be considered to reflect the building blocks of cognition. By capitalizing on this fact in the designs of one's research it appears possible to determine not only the answers to the questions posed above, but also to obtain much additional information about the nature of both ageing and skill, and how they interrelate with one another.

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