In J.A. Joseph (Ed.), CENTRAL DETERMINANTS
OF AGE-RELATED DECLINES IN MOTOR FUNCTION.
New York: Annals of the New York Academy of
Sciences, Vol. 515.

Cognitive Aspects of Motor Functioning

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The focus of this article is on two sets of phenomena in which cognitive factors have been found to influence motor functioning and that have also been found to have important implications for the interpretation of the effects of aging on motor performance. The approach in each case will be to first discuss the general phenomenon and then to describe the effects of age on that phenomenon, together with an indication of the significance of those effects for research on aging.

It is important to begin by indicating the very restricted sense in which the term motor functioning will be used in this article. Because the phenomena to be discussed involve simple keypress responses, motor functioning will refer to the speed of executing finger depressions of response keys—or what is commonly known as manual reaction time. This is clearly an extremely limited form of motor functioning, but it has had a long history of investigation in psychology. In part, this is because many researchers have felt that an individual's reaction time somehow reflects the integrity of his or her central nervous system. Some theorists have even speculated that reaction time measures might be used to provide a culture-fair index of intelligence; indeed, a number of studies have reported statistically significant correlations between certain reaction time measures and scores on assorted intellectual tests. However, the concern in this article is not with manual reaction time as a measure of cognitive performance, but rather, as the title suggests, on how cognitive factors can influence this very simple type of motor functioning.

SPEED-ACCURACY TRADE-OFF

The first phenomenon to be discussed is what is known as the speed-accuracy trade-off. This is a rather esoteric term for what everyone has experienced in a great variety of activities, such as handwriting, typing, or automobile driving, in which one has control of the speed at which he or she performs, and where it is possible to evaluate the quality or accuracy of that performance. In situations such as these, there is often a point where the quality or accuracy of the performance begins to suffer if one attempts to perform faster. Because, from that point on, speed can be increased only at the cost of reduced accuracy, this phenomenon is referred to as the speed-accuracy trade-off.

The speed-accuracy trade-off phenomenon has been studied in the laboratory with a choice reaction time procedure in which the subject's task is to press one of several keys as rapidly as possible when the appropriate signal occurs. Typical instructions in this type of task are inherently ambiguous because the research subject is usually requested to respond as rapidly and accurately as possible; yet, these are actually contradictory goals when speed and accuracy are reciprocally related. It is therefore quite possible that the instructions are interpreted differently by different people—some individuals emphasize speed more than accuracy, while others emphasize accuracy more than speed.

Recognition of this possibility has led some researchers to advocate measurement of complete speed-accuracy trade-off functions, or what have been referred to as speed-accuracy operating characteristics. Two basic procedures have been employed to generate speed-accuracy operating characteristics, but, in both, the intention is to obtain paired values of speed and accuracy over a range of accuracy from near chance to near perfect levels. One procedure for generating speed-accuracy operating characteristics involves manipulations such as payoffs or instructions to induce people to respond at different levels of speed and accuracy in different sets of trials, and then to use the average speed and accuracy in each set of trials as data points comprising the speed-accuracy operating characteristic.

Another technique that has proven to be more efficient in generating speed-accuracy operating characteristics consists of inducing subjects to perform at many different levels of accuracy within a single set of trials (perhaps by specifying a new goal or criterion time before each trial). The resulting distribution of reaction times is then grouped into discrete time intervals, with the mean speed and accuracy for the trials in each interval used as the data points for the speed-accuracy operating characteristic.

Regardless of the procedure used, the resulting speed-accuracy operating characteristics generally look like the function illustrated in FIGURE 1. It is not yet known whether the function is best characterized by a linear, exponential, or some other form of equation, but it is clear that the optimum reaction time, which is what most researchers employing reaction time procedures are attempting to measure, corresponds to a very narrow region in the function. Moreover, while it is often possible to determine when reaction time is faster than the optimum point because accuracy is less than the maximum, it is much more difficult to determine whether reaction times at the maximum level of accuracy are truly at the optimum because accuracy asymptotes at the optimum point. It is for these reasons that some researchers have argued that reaction times by themselves are uninterpretable and that they must be placed in the context of a speed-accuracy operating characteristic in order to be meaningful.

The preceding argument concerning the importance of speed-accuracy operating characteristics has been generally accepted. However, it has just as generally been ignored because of the greater time and effort required to generate complete speed-accuracy operating characteristics when compared to that required to obtain a single average reaction time. The additional effort, though, may be particularly worthwhile in studies of aging because several interesting questions arise in connection with the effects of age on the speed-accuracy trade-offs. Two of the most important are: (1) do people of different ages perform at different speeds because they have distinct speed-accuracy operating characteristics, or are they simply operating at noncomparable positions along the same function?; (2) do people of different ages differ in the slopes of the speed-accuracy function such that there are differential rates of information acquisition across age groups?

Two studies have recently been reported in which age differences in speed-accuracy operating characteristics have been examined—one[1] employs the procedure with different instructions or incentives for speed as opposed to accuracy in different sets of trials, and the other[2] employs the procedure in which the reaction times within a single set of trials are partitioned into discrete intervals. The results from both studies were similar in suggesting that adults of different ages have distinct speed-accuracy operating characteristics, but that the slopes of the functions were relatively invariant between 20 and 70 years of age; that is, with increased age, the functions appear to shift uniformly

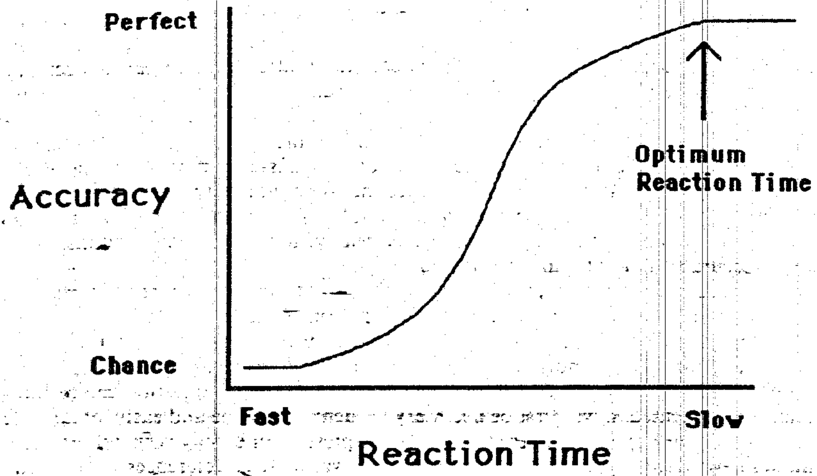

FIGURE 1. Idealized illustration of a speed-accuracy operating characteristic and the position of the optimum reaction time.

to the right such that reaction time is slowed by nearly a constant amount at each level of accuracy. These results thus suggest that age differences in speed do exist independent of the individual's particular emphasis on speed or accuracy, but that there is invariance across age in the rate at which accuracy increases per unit time. However, this latter conclusion should be considered quite tentative because the precision with which the slopes of the speed-accuracy operating characteristics have been assessed has not been great and, consequently, the power of the available comparisons is not known.

Another finding in some studies (e.g., references 1 and 3) is that older adults normally tend to operate with a higher accuracy bias than young adults. Many earlier investigators have made similar observations, but it was only with the advent of speed-accuracy operating characteristics that it became possible to establish that this effect was clearly distinct from the age differences in capacity for speeded responding. Therefore, as age increases, it appears that not only does the speed-accuracy operating characteristic shift to the right, but the region along the function at which one prefers to operate also moves from left to right.

The existence of the speed-accuracy trade-off phenomenon is an example of a cognitive influence on motor functioning because an individual's cognitive emphasis on speed or accuracy clearly affects the rate and quality of his or her motor performance. This particular cognitive aspect of motor functioning is important in research on aging for two reasons—one is methodological and the other is theoretical.

The methodological importance of the speed-accuracy trade-off phenomenon is derived from the realization that if speed and accuracy are reciprocally related, then it may be impossible to derive meaningful interpretations of results from adults of different ages based on only one of the measures. At the very least, ignoring accuracy when attempting to analyze time will greatly reduce the precision of measurement because there is no way of knowing whether or not individuals of different ages are operating at comparable positions in their respective speed-accuracy operating characteristics. In this respect, it may be very misleading to report reaction times in thousandths or even hundredths of a second when the possible variation across levels of accuracy could be on the order of tenths of a second. Regardless of the ostensible temporal resolution, the precision of reaction time measurement is directly dependent upon the accompanying level of accuracy and the specific parameters of the operating characteristic relating speed to accuracy. This methodological issue is particularly pertinent in research on aging because of the evidence that older adults typically operate with a greater emphasis on accuracy than young adults. This thus suggests that the true speeds of older adults may be underestimated relative to those of young adults unless speed-accuracy trade-offs are considered.

Speed-accuracy operating characteristics are also of substantive interest in research on aging because of a desire to determine the reasons for the apparent shift towards accuracy and away from speed with increased age. One possibility is that this accuracy bias is a concomitant of normal aging, but it could also be attributable to the greater experience associated with increased age. However, before this question can be thoroughly investigated, it will first be necessary to identify reliable and easily obtainable measures of the degree of accuracy bias. At the present time, only very indirect techniques have been employed for making this observation (e.g., references 1 and 3) and thus it has been difficult to subject it to systematic investigation.

ANTICIPATORY PROCESSING

The second example of a cognitive influence on motor functioning to be discussed concerns a phenomenon that can be termed anticipatory processing. In many motor tasks, there are severe limits on the rate of performance if one were to rely on strict serial processing in which all of the activity at one postulated stage or level must be completed before any activity can begin at a later stage or level. To illustrate, some estimates suggest that it requires about 100 milliseconds to register and detect a visual stimulus, 50 to 100 milliseconds to interpret the stimulus and decide which response to make, and about 50 milliseconds to execute the response. These estimates sum to a total of about 200 to 250 milliseconds for a choice reaction time, which is close to the value of average choice reaction time for practiced subjects at very high levels of accuracy. However, this figure implies that the maximum rate of repetitive responses should only be about 4 per second, which in the domain of typing would correspond to a rate of approximately 48 words per minute. Because many professional typists are considerably faster than this, it is interesting to ask how these apparently fundamental constraints on processing are circumvented to allow levels of typing performance much faster than that predicted on the basis of the analyses of choice reaction time.

Considerable research has revealed that a major factor contributing to the rapid performance of skilled typists is anticipatory processing; this means that the typists look beyond the immediate to-be-typed character and are often processing characters that are several in advance of the one for which the key is currently being pressed. The strongest support for this inference is derived from research in which the typing rate is measured when the number of characters simultaneously visible to the typist is systematically varied. The typing rate of nearly everyone slows down dramatically as the number of visible characters decreases. This culminates in the average interkey interval when only a single character is visible being virtually identical to that of choice reaction time. FIGURE 2 illustrates typical results with this manipulation.

In a number of recent studies (e.g., references 4–8), I have used this technique of

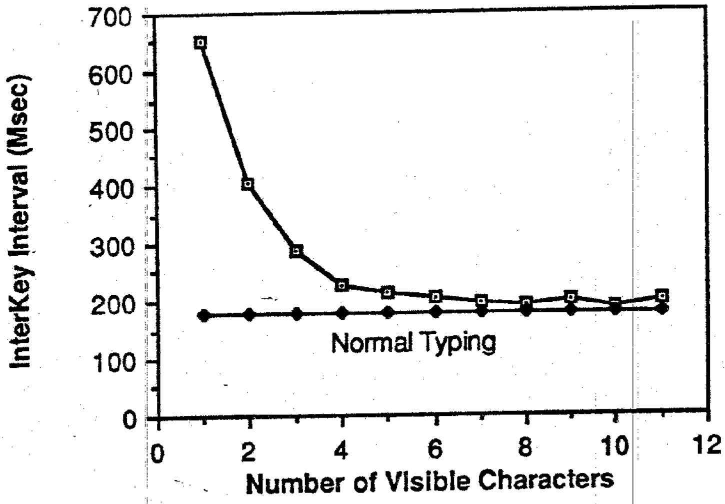

FIGURE 2. Median interkey interval as a function of the number of simultaneously visible characters.

varying the number of visible characters to determine the largest number at which typists exhibit substantial slowing of their typing relative to their rate with no restrictions on the number of visible characters. Because typists are impaired with this number of characters, it can be concluded that they rely upon more than this number in their normal typing. I have referred to this measure as the eye-hand span because it indicates the number of characters intervening between the focus of the eyes and the action of the hand. Across several studies involving slightly different procedures, typists averaging about 60 words per minute have been found to have average eye-hand spans ranging from about 3.4 to 4.9 characters.

The eye-hand span indicates when the typist begins processing a character in advance of the keystroke. Another technique that I have employed provides an estimate of when the typist finishes processing the character and becomes committed to the typing of that particular character. This commitment span is measured by requesting typists to type exactly what appears on a computer monitor and then intermittently changing one of the to-be-typed characters at various positions prior to the relevant keystroke. As FIGURE 3 illustrates, the probability of typing the replaced or second character decreases dramatically as the replacement occurs closer to the keystroke for that character. These results suggest that the typist becomes committed to a keystroke for the original character because he or she can no longer abort that preparation and execute the keystroke corresponding to the replaced character. An individual typist's commitment span can be identified by determining the number of characters in advance of the keystroke corresponding to a 0.5 probability of typing the replaced character. Results from several studies indicate that typists averaging about 60 words per minute have commitment spans ranging from about 2.8 to 3.0 characters.

FIGURE 4 summarizes the results from these two procedures. This manner of representing the results clearly suggests that skilled typists do not rely on strict serial

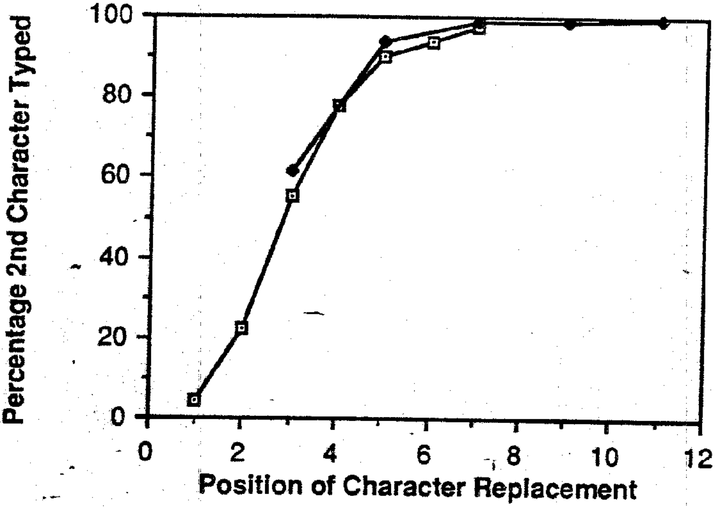

FIGURE 3. Probability of typing the replaced character as a function of the position of the replacement.

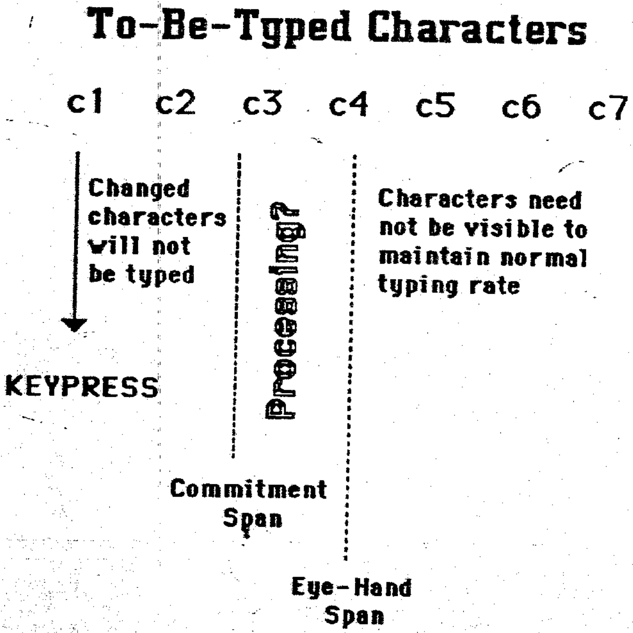

FIGURE 4. Summary illustration of the eye-hand span and commitment span measures of anticipatory processing in typing.

processing, but are instead beginning to process characters two to three in advance while executing the keystroke for a given character. Because these early phases of processing reflect an intricate coordination of perceptual and cognitive information, this anticipatory processing phenomenon is another instance in which cognitive factors influence motor functioning.

I have also examined the effects of age on these measures of anticipatory processing, but only in samples for which there was no correlation between age and average typing speed. Despite this equivalence in overall typing performance, the older typists were considerably slower than the younger typists in the speed of such basic motor processes as repetitive finger tapping and choice reaction time. Because these measures tend to be correlated with speed of typing in the general population, the older individuals would have been expected to be rather slow typists on the basis of their performance on these tasks. However, it was discovered that there were statistically significant positive correlations between age and both eye-hand span and commitment span, thus suggesting that the older typists may have compensated for their slower perceptual-motor processing capacity by expanding the extent of their anticipatory processing. In other words, the older typists apparently began and completed the initial phase of their processing of a character earlier than younger typists and were thus presumably not handicapped by their generally slower rate of perceptual-motor processing.

As with the speed-accuracy trade-off phenomenon, this anticipatory processing phenomenon has two implications for research on aging. The first is methodological and concerns the importance of ensuring that any groups to be compared are equivalent in amount of experience or level of skill. In my typing studies, it was found that the experienced typists, many of whom were older, seemed to employ larger degrees of anticipatory processing than the less experienced, and often younger, typists. Because of this difference in the manner in which the task is performed, levels of basic capacities may not impose the same type of constraints on performance among individuals with different amounts of experience. It is therefore very important that studies of the effects of age on motor functioning involve groups with comparable amounts of experience in the activities that are to be compared.

The second important implication of the anticipatory processing phenomenon is that it indicates that researchers should be very careful in attempting to extrapolate from performance on simple laboratory tasks to prediction of real-world competence. In many instances, performance on a laboratory-type task may have little relevance to functioning in naturally occurring activities, despite the apparent face validity of the tasks. To illustrate, choice reaction time is a valid predictor of typing skill and thus one would have expected the older individuals in the studies described to be poor typists because they tended to have slow reaction times. However, the older individuals had considerable experience as typists and they performed much better than predicted, apparently because they were relying upon cognitive factors (such as expanded anticipatory processing) as effective compensatory mechanisms. Therefore, if one is interested in evaluating the competence of experienced individuals in a reasonably complex motor activity, the performance observations should derive from that activity and not solely from simpler tasks that do not allow the operation of experientially mediated compensatory mechanisms.

To summarize, I have discussed two instances in which cognitive factors influence the level of motor function—one's cognitive emphasis on speed versus accuracy and one's degree of perceptual-cognitive anticipation in sequential activities like transcription typing. Both of these are potentially important to researchers interested in motor functioning because very misleading interpretations of motoric capacity could result if researchers fail to consider their impact. The evidence suggests that this is particularly true in comparisons involving individuals of different ages.

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DISCUSSION OF THE PAPER

UNIDENTIFIED DISCUSSANT: Have you looked at using nonsense types of words and, if you have, would this show some difference in terms of aging? I am wondering about whether or not the older subjects who are using lots of anticipatory processing are essentially chunking possibly more than the younger typists?

T. SALTHOUSE (*Georgia Institute of Technology, Atlanta, GA*): Yes, there are two ways that we looked at nonsense material. To begin with, we have to take into account the compensation that older typists might employ due to their greater familiarity with the English language, particularly, the sequential dependencies of different letters in the English language. Thus, we looked at both nonsense typing independent of this window manipulation and nonsense typing in the context of it. Our first way of doing this was by taking the same kinds of sentences and simply turning them around, which is very easy to do on the computer (you just start from the end of the array in memory and then go backwards; therefore, the people start with the period that ends the sentence and they end with the capital letter that normally begins the sentence). The advantage of this particular kind of nonsense typing is that it has the same letters, frequencies, spaces, and so forth, but it is completely devoid of meaning.

Another way, though, is to take randomly generated letters so that equal frequency is taken out as well. In both of those cases, the eye-hand spans are greatly reduced; they are shrunken, but you still get this same kind of phenomenon in that the typing rate slows down as you reduce the number of visible characters.

However, the problem is that we do not really know if that shrinking of the range is the cause for the age correlations to go down (which, in fact, they do). Thus, I am answering your question: the correlations between age and these eye-hand spans or anticipatory phenomena are about 0.5 with normal words, whereas they go down to about 0.2 or 0.3 with this nonsense material.

Moreover, though, we do not know whether the attenuation and the correlation are due to the eye-hand span shrinking for everybody. Therefore, the age effects may not be as noticeable, or people may just not be as sensitive to the frequencies differentially with age.

G. LOVELACE: Could you get around that by making the task easier, that is, not having a typing task just have a few buttons?

SALTHOUSE: That is not easier; typing is highly skilled. We did try to do that with number keys and having numbers up on the screen. Then, instead of working with the typewriter keypad, they work with a telephone keypad. However, after 20 sessions of this, the best of our subjects were not even approaching the novice levels of typing. Therefore, it would take an inordinate number of hours to do this.

LOVELACE: You talked about the number of items or characters producing smooth functions when it moves away from normal typing; it breaks off at about five or six items in advance. Now, to me, there is the magic number seven, plus or minus two, which again is a chunk kind of thing. I also wonder if talking in terms of items or characters is to ignore the psychological reality of lexical items; is it five or six because that is the average word length? Remember, they are working a word in advance.

SALTHOUSE: Yes. That is a possibility, but I think that there are a number of factors to argue against it. One is that we still do get these eye-hand spans with nonsense material. They are shrunken, but we still get maybe three to five characters instead of four to six (perhaps a little bit less than that with nonsense material).

The other factor is that when we use very constrained material (such as a study where we just use four-letter randomly arranged words with no semantic meaning because they are just randomly scrambled together) we still get eye-hand spans of about the same length. This argues against the average length of five due to semantic factors because we are still getting eye-hand spans in this same category. I also think that there is a little bit of contribution from the familiarity of meaningful units of words and the fact that they are picking those up in a glance. However, we still get the eye-hand spans with both nonsense material and with words constrained in length of shorter than average length.

A. T. WELFORD (*Aldeburgh, Suffolk, England*): In rapid repetitive movements, usually the dominant hand is a little bit faster than the nondominant hand. Have you separated in terms of your analysis as to which hand is being used and is there a difference in this situation?

SALTHOUSE: In typing, they are obviously using both hands. In the tapping that I used as one of the controls to see what the basic perceptual motor processes were, they either used one hand repetitively (which I balanced across left and right) or they used both hands in alternation. Exactly which one did you want to partial out?

WELFORD: My question is more in relation to those letters that are typed with the right hand and those letters that are typed with the left hand. Can one break up the anticipatory processing time and is it the same?

SALTHOUSE: Typing is very dependent upon hand alternation. Keystrokes are much, much faster if they were preceded by a keystroke on the opposite hand, presumably because there is more actual physical preparation for that next keystroke. Because of factors like this one, I did not try to partial it out.

WELFORD: Presumably, then, alternating fingers are quicker than one finger used repetitively.

SALTHOUSE: That is also true, but that varies with skill levels, as does this alternation effect.