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Adult age and the speed-accuracy trade-off

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Three experiments were conducted to investigate the possibility that previously reported age differences in speed of performance were caused by older subjects placing more emphasis on accuracy than younger subjects. The speculation that older subjects generally have a greater emphasis on accuracy was confirmed, but only in one of the experiments was the complete age difference in speed found to be attributable to an age difference in accuracy. It was concluded that although a speed-accuracy trade-off cannot account for all age differences in speed, the greater bias towards accuracy in older subjects and the problems associated with interpreting traditional reaction time make it advisable that future researchers in this area employ procedures that allow an empirical determination of the relationship between speed and accuracy.

1. Introduction

As the elderly segment of the population has grown larger, the amount of research concerned with determining the performance limitations associated with old age has also increased. Among the age-related performance differences that have been discovered, perhaps the most well-documented are the age changes in speed of performance. Older adults have been found to be substantially slower than younger adults in almost all tasks that emphasize rapid performance (*e.g.* Botwinick 1973, Welford 1977).

Despite the generality of the slowing with-age phenomenon, at the present time there is no satisfactory explanation to account for the negative relationship between decision speed and adult age. One interesting speculation discussed by several investigators (e.g. Birren 1964, Botwinick 1973, Davies 1968, and Fozard Carr 1972, Rabbitt 1968, Welford 1977) is that at least part of the slower performance of older adults might be attributable to the older individuals placing a greater emphasis on accuracy than younger individuals. The existence of speed-accuracy trade-off in reaction time tasks is well-established (*e.g.* Pachella 1974, Pew 1969, Wickelgren 1977, Wood and Jennings 1976), and thus it is possible that age differences in the preference for accuracy could account for the age differences in speed. The experiments described in this report were designed to investigate this speed-accuracy trade-off interpretation of the age differences in speed in a choice reaction time task.

In attempting to investigate performance speed independent of one's preference for accuracy, speed-accuracy operating characteristics (*e.g.* Pew 1969) will be determined for each individual in each age group. Several recent authors (*e.g.* Lappin and Disch 1972, Pachella 1974, Wickelgren 1977, Wood and Jennings 1976) have argued that these speed-accuracy operating characteristics are to be preferred over traditional reaction time measures because they are free of the problems that complicate the interpretation of these measures. Perhaps the most widely recognized of these problems at the current time is that because errors and reaction time are often reciprocally related, an increase in reaction time might be produced by a decrease in error rate, or vice versa. However, a problem of interpretation also exists when all subjects perform at 100% accuracy. Here the ambiguity arises because unless the subject is induced to perform at less-than-perfect levels of accuracy, there is no way to determine whether the time in which the subject performs the task is truly the minimum time required since there are an infinite number of times in which the task can be performed at perfect accuracy. There is even an interpretation problem when both the error rate and the reaction time are greater in one group or condition than another. The difficulty in this case is that precise quantitative comparisons are impossible when the exact relationship between reaction time and error rate is not known and only ordinal level information can be extracted from the reaction time data.

In view of these problems of interpretation with traditional reaction time experiments, it might be claimed that despite the large amount of apparently relevant evidence, it is still not known whether adults of different ages differ in their capacity to respond rapidly since none of the previous experiments has compared the speed-accuracy operating characteristics of subjects of different ages. Such a comparison is attempted in the present experiments.

Speed-accuracy trade-offs will be produced by requesting subjects to perform a reaction time task at several different levels of accuracy and speed. The relationship between speed and accuracy will be summarized by the parameters of the linear regression equation that is found to provide the most accurate description of the data according to a least squares procedure. The primary dependent variables in the experiment will therefore be the intercept, slope, and correlation parameters from the linear regression equation and not the traditional measures of reaction time and error rate.

2. Experiment 1

2.1. *Method*

2.1.1. *Subjects:* Ten males and ten females in each of three age groups (ages 17 to 30 y, 31 to 60 y, and 61 to 75 y) served as experimental subjects.

All subjects claimed to be in good health. They were from a variety of educational and economic backgrounds, with most of the young and middle-aged subjects recruited from the local state employment office, and the old subjects recruited from senior citizen groups and retirement organizations.

2.1.2. *Apparatus:* The stimuli were presented as two sets of four lamps located to the left and right below a red warning lamp. Microswitches with labels SAME and DIFFERENT located above them served as the response keys.

A *Hunter Model 1520 electronic clock* was used to measure reaction time to the nearest ms. *Hunter Interval Timers* were used to control the 1·0 s durations of the warning signal and the reaction stimuli and the 1·5 s foreperiod interval between the warning signal and the reaction stimulus.

2.1.3. *Procedure:* The subjects were instructed that on all trials in the experiment they should press the button on the right if the pattern of lighted lamps on the right was the same as the pattern of lighted lamps on the left, and they should press the button on the left if the two patterns were different. They were further informed that the sequence of 48 trials in each block involved an equal, but randomly distributed, mixture of 'same' trials and 'different' trials. Four independent sequences were constructed to provide a different sequence for each block. The order of the sequences was varied across subjects within each age group. Both time and accuracy feedback were provided vocally after each trial throughout the experiment.

At the end of the first block of trials the subject's modal reaction time was determined to the nearest 100 ms. This value served as the deadline time on the second block of trials. The subject was told that he should now try to increase his speed such that all of his responses were faster than this deadline. As an incentive, he was to receive \$0·02 for every response faster than this deadline, but to insure that he paid some attention to accuracy he was to be penalized \$0·01 for every incorrect response. To make certain that the subject understood the consequences of various strategies, the payoff contingencies for different outcomes were described.

The third and fourth blocks of trials had deadlines 150 and 350 ms faster than the deadline of the second block with bonuses for fast responses of \$0·04 and \$0·06, respectively.

The total bonuses averaged \$3·88, \$3·71, and \$3·59 for the young, middle-aged, and old groups: values that were not significantly different (*i.e.*, $F(2,57) < 1 \cdot 0$).

2.2. *Results and discussion*

The mean reaction times for the 144 trials in blocks 2, 3, and 4 for the three age groups were: young = 572 ms, middle-aged = 654 ms, and old = 745 ms. The values of accuracy in percent correct were: young = 71, middle-aged = 75, and old = 80. The directions of the two variables are thus consistent with a speed-accuracy trade-off explanation of the age difference in reaction time-older subjects are slower but more accurate than younger subjects.

Least squares linear regression equations between reaction time and accuracy across blocks 2, 3 and 4 were computed for each subject with five alternative accuracy measures: P(C)–the traditional measure of percent correct; d′–the signal detection theory measure of sensitivity: $(d')^2$–a measure postulated to be directly related to time by Taylor, Lindsay and Forbes (1967); log odds correct to incorrect–the measure of accuracy favoured by Pew (1969) and Swensson (1972); and Ht–the information theory measure of amount of information transmitted. The proportion of variance in reaction time accounted for by the linear equation with each accuracy measure is displayed in table 1.

Table 1. Proportion of variance (*r*) accounted for in linear regression equations with five measures of accuracy

Age Group	Measure				
	P(C)	d′	$(d')^2$	log odds	Ht
Young (N = 20)	0·822	0·843	0·858	0·831	0·809
Middle-Aged (N = 20)	0·903	0·856	0·806	0·885	0·859
Old (N = 20)	0·821	0·778	0·768	0·808	0·804

It is interesting to note that all accuracy measures appear to provide reasonably good fits to the data, and that if anything, the P(C) measure accounts for somewhat more of the variance than the other measures. Because the P(C) measure is the most familiar and the one least dependent upon theoretical assumptions, it will be used throughout the remainder of this report.

The age-group means of the correlation, intercept and slope values from the least squares linear regression equations relating accuracy in P(C) to reaction time in ms are displayed in table 2. *Analyses of variance* revealed no age, sex, or age × sex effects on any measure (i.e., $F(2,45) < 2{\cdot}01$).

Table 2. Linear regression parameters for the three age groups in experiment 1.

Age Group	Correlation	Slope	P(C) Intercept
Young (N=20)	0·897	0·074	28·134
Middle-Aged (N=20)	0·949	0·083	23·412
Old (N=20)	0·831	0·070	32·280

The relatively high correlations in table 2 indicate that the linear regression equations provide a fairly good fit to the data, and that subjects are generally trading speed for accuracy in a roughly linear fashion. Morever, the absence of any age effects in the magnitudes of the correlations suggests that the subjects in all groups were equally capable of making this trade between speed and accuracy. Since this study is the first to have attempted comparisons of speed-accuracy operating characteristics across groups of subjects, the discovery that the speed-accuracy trade-off procedures can be used successfully in unsophisticated subjects tested for only a very short period of time is an important finding.

One possible reason for the failure to find any significant effects with the intercept and slope measures is that the measures might be extremely variable because they are in part compensatory. This is, precisely the same performance point could be achieved by a combination of a large intercept and a small slope as by a combination of a small intercept and a large slope. An observation consistent with this interpretation is that the correlations between the intercept and slope measures were $-0{\cdot}95$ for the young subjects, $-0{\cdot}87$ for the middle-aged subjects, and $-0{\cdot}97$ for the old subjects. The large dependency between the two measures makes it unreasonable to expect that separate analyses of each measure will provide meaningful results. What seems to be needed is a single performance measure that reflects aspects of both the intercept and slope measures.

One such measure, employed by Pachella (1974) and Jennings *et al.* (1976), involves using the intercept and slope parameters to predict the level of accuracy that would result at a specified rate of speed. This measure was used in the current study with speeds corresponding to reaction times of 500 and 700 ms, values well within the range of reaction times for all age groups. Predicted levels of accuracy were determined for each subject and were analyzed in an *analysis of variance* with age (3 levels), sex (2 levels), and speed (500 ms and 700 ms) as factors. The speed factor was highly significant (*i.e.*, $F(1,99) = 86{\cdot}97$, $p < 0{\cdot}0001$), confirming that accuracy was greater with longer reaction times. The only other significant factor was the interaction of age and sex (*i.e.*, $F(2,99) = 8{\cdot}01$, $p < 0{\cdot}001$), indicating that older females were less accurate than older males but that males and females in the other age groups did not differ.

The absence of a significant age effect or a significant age × speed interaction effect is illustrated in figure 1 where the mean speed-accuracy operating characteristics, obtained by averaging the predicted accuracy values at 500 and 700 ms, have been

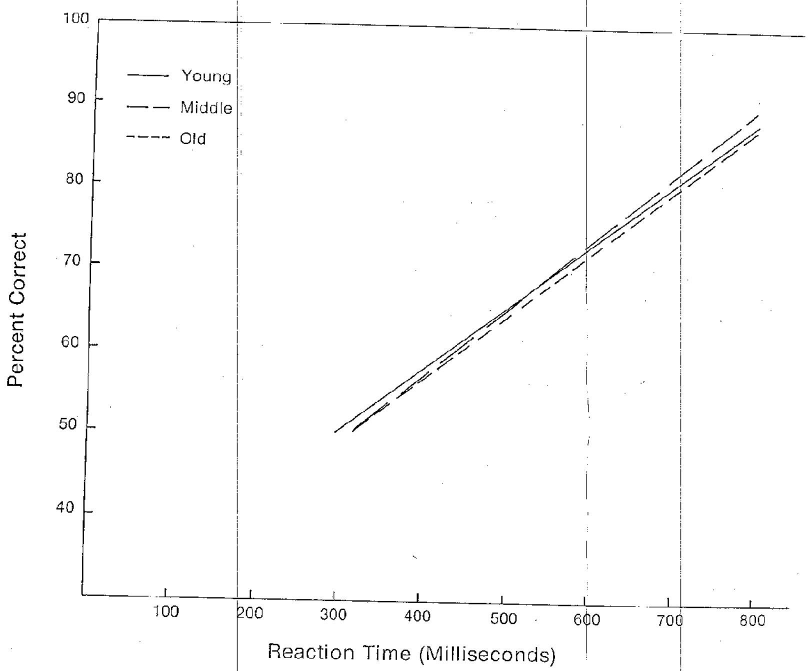

Figure 1. Predicted speed-accuracy operating characteristics for the three groups of subjects in experiment 1.

plotted for each age group. The virtually identical functions for the three age groups indicate that no age differences in speed or accuracy are evident when the comparisons are made at a fixed level of the other variable.

3. Experiment 2

The possibility that age differences in speed of performance might be an artifact of age differences in the relative emphasis on accuracy is such a potentially important result that it was considered desirable to attempt to replicate this finding. The current experiment was designed to attempt such a replication with the same task employed in the previous experiment, but with several procedural changes. One change involved the testing of subjects from only the extreme age groups since these were the groups of major interest. Another change consisted of giving the subjects very little practice before the experimental series, and then counterbalancing the order of the three speed-accuracy conditions across six blocks for each subject. The final change involved paying all subjects at the same base rate and using the same criterion times for all subjects regardless of their initial level of performance.

3.1. *Method*

3.1.1. *Subjects:* Ten males and ten females in each of two age groups served as experimental subjects. The young (range 18 to 25 y) subjects were all college students, and the old (range 63 to 78 y) subjects were recruited from senior citizen groups and retirement organizations. All subjects reported themselves to be in good to excellent health. None had participated in the previous experiment.

3.1.2. *Apparatus:* The apparatus was identical to that described in Experiment 1.

3.1.3. *Procedure:* After the first 12 trials, which served as practice, the subjects received six blocks of 24 trials each with the following deadline times: 1000 ms, 700 ms, 400 ms, 400 ms, 700 ms, and 1000 ms. The penalty for an error was −\$0·01 in all conditions, but the bonus for a response faster than the deadline was increased from \$0·02 for the 1000 ms condition, to \$0·04 for the 700 ms condition, and finally to \$0·06 for the 400 ms condition. As might be expected with these deadlines, the young subjects earned more bonus pay than the old subjects (*i.e.*, \$3·93 vs. \$2·21, $F(1,36)=30{\cdot}29$, $p<0{\cdot}001$).

3.2. *Results and discussion*

The mean reaction times for the 144 trials in blocks 2 through 7 were 569 ms for the young subjects and 768 ms for the old subjects. The accuracy values were 75% and 76%, respectively, suggesting that in this experiment age differences in accuracy will not be able to account for the age differences in speed.

Table 3. Linear regression parameters for the two age groups in experiment 2.

Age Group	Correlation	Slope	P(C) Intercept
Young (N=20)	0·821	0·083	28·926
Old (N=20)	0·689	0·047	41·105

The age group means of the correlation, intercept, and slope parameters from the least squares equations with P(C) as the accuracy measure are displayed in table 3. *Analyses of variance* revealed a significant age effect on the slope measure (*i.e.*, $F(1, 27)=19{\cdot}75$, $p<0{\cdot}001$), and a significant age × sex interaction on both the slope measure (*i.e.*, $F(1,27)=12{\cdot}57$, $p<0{\cdot}005$) and the intercept measure (*i.e.*, $F(1,27)=8{\cdot}40$, $p<0{\cdot}01$). The direction of the effects were for young subjects to have steeper slopes than old subjects, and for young males to have smaller intercepts and greater slopes than young females, but for old males to have greater intercepts and smaller slopes than old females.

As in the previous experiment, the correlations between the intercept and slope measures were large and negative (*i.e.*, −0·94 for the young subjects and −0·96 for the old subjects), and thus analyses of the predicted accuracy values were conducted to combine the two parameters into a single performance measure. The predicted values of accuracy at 500 ms and 700 ms were determined for each subject and entered into an *analysis of variance* with age, sex, and speed as factors. The statistically significant results, and the direction of the effects, were as follows: age (young more accurate than old)—$F(1,63)=33{\cdot}54, p<0{\cdot}0001$; sex (males more accurate than females)—$F(1,63)=9{\cdot}42$, $p<0{\cdot}005$; speed (700 ms more accurate than 500 ms)—$F(1,63)=64{\cdot}31$, $p<0{\cdot}0001$; and age × speed (the young exhibiting a greater increase in accuracy from 500 ms to 700 ms than the old)—$F(1,63)=4{\cdot}93$, $p<0{\cdot}05$.

The mean speed-accuracy operating characteristics, derived from the predicted accuracy levels at 500 and 700 ms, are displayed in figure 2. These results quite clearly indicate a substantial difference between the two groups of subjects. The figure

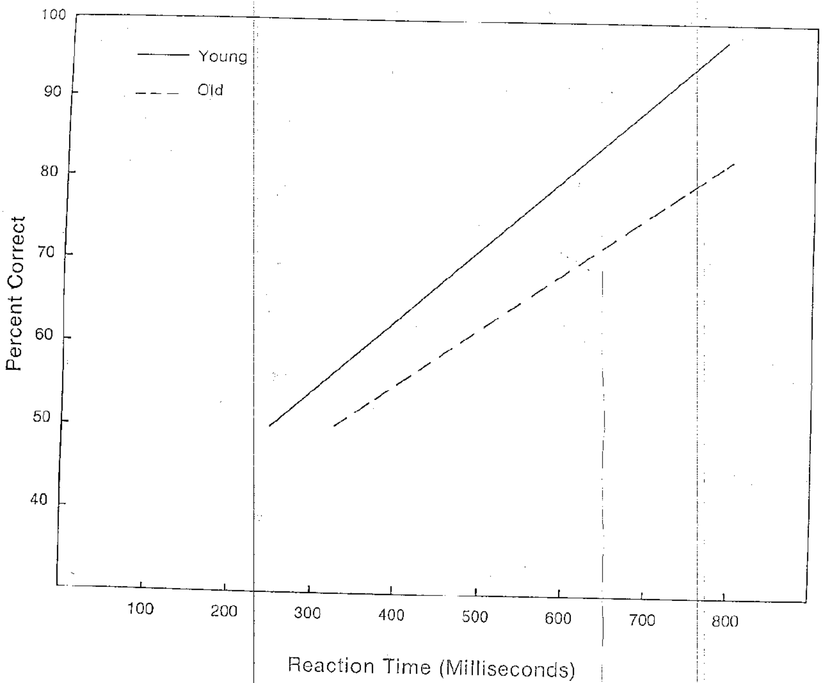

Figure 2. Predicted speed-accuracy operating characteristics for the two groups of subjects in experiment 2.

suggests, and the statistical tests confirm, that young subjects are considerably more accurate than the old subjects at moderate to slow reaction times.

The age differences in the speed-accuracy operating characteristics displayed in figure 2 are in striking contrast to the complete absence of such differences in the experiment 1 results illustrated in figure 1. Two possibilities were considered to account for the discrepancy in the results of the two experiments. One concerned the manner in which the response deadlines, which influenced the amount of bonus pay, were determined in each experiment. The deadlines were determined individually in experiment 1, and thus the young and old subjects had to reduce their reaction times by the same amount in order to meet their deadlines and receive a comparable amount of bonus pay. In experiment 2, however, the deadlines were the same for all subjects and therefore if the old subjects were slower initially, they would have to reduce their reaction times by a greater amount than the young subjects in order to receive the same amount of bonus pay. It is possible that the greater demands upon the older subjects led them to perceive the task as unattainable and, as a consequence, led to decreased motivation to perform the task. As a test of this hypothesis, 10 additional old females were tested under exactly the same procedures as those described in experiment 2, but with deadlines of 1250, 950, and 650 ms instead of 1000, 700, and 400 ms. These deadlines were selected to allow the bonus pay of the old subjects to approximate that of the young subjects in experiment 2, thus presumably equating the perceived demands of the task across age groups. The predicted accuracy levels of these 10 equal-bonus old subjects were nearly identical to the 10 lower-bonus old females from experiment 2 (*i.e.*, 60·7% *vs.* 60·9% at 500 ms and 72·1% *vs* 72·4% at 700 ms), thereby suggesting that the difference in results between experiments 1 and 2 is not attributable to an age × experiment interaction in perceived task demand.

The second possibility considered for the different pattern of results obtained in the two experiments was that one of the experiments involved an unusual sample of either young or old subjects. This hypothesis was examined by comparing the performance of the four groups of subjects (*i.e.*, the young and old groups from the two experiments) on the first 12 practice trials in each experiment (*i.e.*, the only trials that were precisely comparable across experiments). The mean reaction times for the first 12 trials were: 1034 ms for the young subjects of experiment 1, 834 ms for the young subjects of experiment 2, 1242 ms for the old subject of experiment 1, and 1221 ms for the old subjects of experiment 2. Although the extremely large variability in the data prevented the age × experiment interaction in an *analysis of variance* from reaching an acceptable level of significance (*i.e.*, $F(2,75) = 3{\cdot}64$, $0{\cdot}05 < p < 0{\cdot}10$), it definitely appears that the two old groups of subjects were roughly equivalent, but that the young subjects of experiment 2 were much faster than the young subjects of experiment 1. Indeed, separate analyses revealed a significant difference between young groups (*i.e.*, $F(1,36) = 10{\cdot}35$, $p < 0{\cdot}01$) but no significant difference between old groups (*i.e.*, $F(1,36) < 1{\cdot}0$). Since these performance differences were evident in the first 12 trials, before the experimental manipulations went into effect, this finding provides indirect evidence that procedural differences between the experiments were not responsible for the result discrepancy.

The question immediately arises as to why there should be such a large difference in the performance of the two young samples of subjects. The samples differed in two important respects—when they were tested and where they were recruited. The subjects of experiment 1 were tested in the summer and were recruited primarily from the state employment office while the subjects of experiment 2 were tested during the academic semester and were recruited from the student population at a selective private university. It is possible that either or both of these sampling characteristics could be responsible for the observed differences as at least two studies have reported season of testing effects (e.g. Ellis *et al.* 1975; Kosslyn 1975), and it is conceivable that perceptual-motor performance is linked to variables such as social or economic class, or even intelligence.

A third experiment was conducted under very similar procedures to determine whether age differences would be apparent in two new samples of subjects recruited from community newspaper advertisements during the spring season. The task was somewhat different and thus direct comparisons among experiments are not possible, but the general results (see figure 3) were much like those of experiment 2. The only significant effects in this experiment, with 12 females in each age group, were an age difference ($p < 0{\cdot}0001$) and a speed difference ($p < 0{\cdot}0001$) in predicted accuracy level. These results thus suggest that the sample of young subjects in experiment 1 was atypical, and that under most circumstances age differences are evident in speed-accuracy operating characteristics.

The discrepancy in the results of experiments 1 and 2 therefore seems to be attributable to a sampling difference. For some reason, perhaps related to the season of testing or to unknown subject characteristics, the young subjects of experiment 1 responded approximately 200 ms slower than the young subjects of experiment 2. It is important to note, however, that in both experiments the young subjects were at least 200 ms faster than the old subjects in the first 12 practice trials. Thus both experiments exhibit a typical age difference in the traditional measure of reaction time, but only in

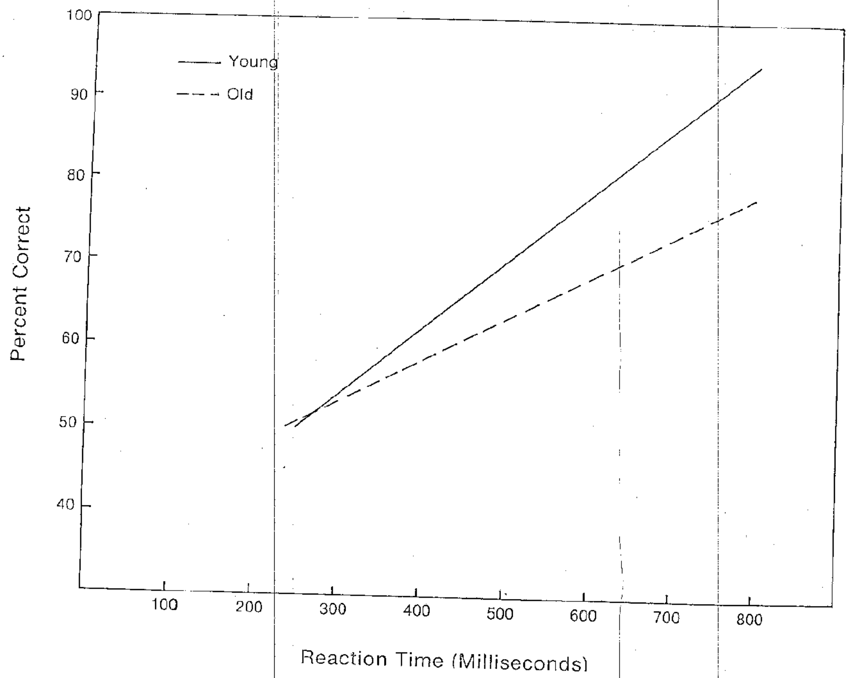

Figure 3. Predicted speed-accuracy operating characteristics for the two groups of subjects in experiment 3.

the first experiment was this difference found to be completely attributable to a speed-accuracy trade-off.

A rough estimate of the amount of bias towards accuracy in each age group in the first two experiments can be determined by contrasting the reaction time on the initial 12 trials with the predicted reaction time at 100% accuracy. This estimate is only approximate since it confounds the variables of accuracy and practice (although there was no indication of differential practice effects in different age groups), but it does provide an indication of the extent to which the subject was performing near his optimal level (*i.e.*, the predicted reaction time at 100% accuracy) in the initial 12 trials. The mean values of these 'deviations from optimality' were 111 ms for the 20 young subjects of experiment 1, 234 ms for the 20 old subjects of experiment 1, 43 ms for the 20 young subjects of experiment 2, and 166 ms for the 20 old subjects of experiment 2. An *analysis of variance* revealed that the age factor (*i.e.*, $F(1,76)=7{\cdot}26$, $p<0{\cdot}01$) was significant but the experiment factor (*i.e.*, $F(1,76)=2{\cdot}23$, $p>0{\cdot}05$) and the age × experiment interaction (*i.e.*, $F(1,76)<1{\cdot}0$) were not. Both experiments are therefore consistent in the finding that older subjects are slower relative to their predicted optimum speed than younger subjects. One interpretation of this result is that the older subjects are more concerned about committing a mistake than younger subjects and hence prefer to operate at slower speeds when errors are less likely.

4. General discussion

The major conclusion from this series of experiments is that while a greater emphasis on accuracy as opposed to speed is definitely a factor contributing to the slower performance of older adults, it probably cannot account for all of the age differences in speed of performance. A speed-accuracy trade-off did seem to be responsible for all of the age differences observed in experiment 1, but sizeable age differences remained after the elimination of differential accuracy biases in experiments 2, and 3.

The differences observed across experiments serve to emphasize the importance of sample specification in ageing research. Apparently researchers must now be as careful in describing the characteristics of the young subject group as the old subject group, despite a general absence of knowledge about which descriptor variables are the most relevant ones. It seems virtually certain that sample differences are responsible for some of the inconsistent results in the ageing literature and yet it is only when sensitive strategy-independent performance measures such as those of the current experiments are employed that one can rule out other explanations for discrepant results. In this regard it is important to note that if present experiments had been concerned solely with the traditional measure of reaction time there would have been no inconsistency apparent since the older subjects were substantially slower than the younger subjects in each experiment.

Although it appears that the speed-accuracy trade-off procedures can make only a limited substantive contribution to the understanding of age differences in performance speed, the methodological contribution of these procedures seems unlimited. Speed-accuracy operating characteristics share none of the interpretation problems discussed earlier that are associated with traditional reaction time measures, and the discovery in the current experiments that speed-accuracy operating characteristics can be obtained in naive unpracticed subjects makes the procedures plausible for research on individual differences. It is highly recommended that subsequent research attempting to assess the relative contribution of different factors to the age difference in speed utilize speed-accuracy trade-off procedures if it is desired to obtain quantitative, and not merely qualitative, results.

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Les trois expériences rapportées dans cet article, se proposaient de vérifier si les différences entre les vitesses des performances attribuables à l'âge n'étaient pas dues au fait que les sujets âgés attachent plus d'importance à la précision que les sujets jeunes.

Cette hypothèse a été confirmée; mais dans une expérience seulement la différence entre les vitesses attribuable à l'âge pouvait être mis au compte d'une différence dans la précision variable avec l'âge. On en conclut qu'une transfert rapidité-précision ne peut pas rendre compte de toutes les différences entre la rapidité pour les différents groupes d'âge. Mais il y a lieu de tenir compte de la tendance des sujets âgés vers une précision plus grande. Les recherches futures dans ce domaine devraient s'efforcer à utiliser des techniques permettant de mieux cerner la liaison rapidité-précision.

Zur Überprüfung der Möglichkeit, ob früher dargestellte Unterschiede in der Arbeitsgeschwindigkeit in Abhängigkeit vom Alter dadurch verursacht werden, daß ältere Versuchspersonen mehr Wert auf Genauigkeit legen als jüngere, wurden drei Versuche durchgeführt. Die Vermutung, daß ältere Personen im allgemeinen die Genauigkeit betonen, wurde bestätigt. Der gesamte Altersunterschied konnte aber nur in einem Versuch einer unterschiedlichen Genauigkeit in Abhängigkeit vom Alter zugeordnet werden. Daraus wurde geschlossen, daß, obwohl ein Geschwindigkeits-Genauigkeits-Ausgleich nicht alle Geschwindigkeitsunterschiede in Abhängigkeit vom Alter erklären kann, die größeren Abweichungen in Richtung der Genauigkeit bei älteren Personen und die Probleme, die mit der Interpretation der traditionellen Reaktionszeit verbunden sind, es ratsam erscheinen lassen, daß Forscher auf diesem Gebiet in der Zukunft Verfahren anwenden, die eine empirische Bestimmung der Beziehung zwischen Geschwindigkeit und Genauigkeit erlauben.

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