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Reaction Time, Age, and Cognitive Ability: Longitudinal Findings from Age 16 to 63 Years in Representative Population Samples

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ABSTRACT

Reaction time variables are used widely in studies of human cognitive ageing and in research on the information processing foundations of psychometric intelligence. The research is largely based on biased population samples. In the present study, large (500+), representative samples of the population of the West of Scotland were tested at ages 16, 36 and 56 years on simple and choice reaction time. Participants were re-tested eight years later, at which time they also took the Paced Auditory Serial Addition Test (PASAT). We report simple and choice reaction time means and their variabilities, their stability across 8 years, and their correlations with the PASAT. Simple and choice reaction times become slower and more variable with age. Women from age 36 to 63 show more variability in choice reaction times than men, an effect which remains after controlling for mean reaction time. Reaction time differences largely account for age differences, but not sex differences, in PASAT scores.

INTRODUCTION

Simple and choice reaction times have been used by psychologists since the beginnings of experimental psychology and the study of individual differences in cognition (Donders, 1868). In the late 19th century, Galton employed reaction time in his anthropometric laboratory as a putative element of higher cognitive functions (see Johnson et al., 1985). Cattell (1890; Galton, 1890) included reaction time in his historic proposal for the very

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first battery of 'Mental Tests'. Reaction times are theoretically prominent in the field of cognitive gerontology for at least two reasons.

First, there is interest in age-related changes in the processing of information. Madden (2001) emphasised the special place of speed of processing in aging research, because "speed is often viewed not only as a behavioural measure but also as a fundamental property of the central nervous system" (p. 288).

Second, age-related variance in reaction time indices might account for sizeable portions of the variance in more complex cognitive functions (Madden, 2001; Salthouse, 1991, 1996).

To date, there are no representative, population-based studies of age changes in reaction times as applied to these two key issues in cognitive ageing. Here we firstly describe cross-sectional and longitudinal age-related changes in mean simple and choice reaction times and their variabilities. Secondly, we examine whether reaction time indices account for any age-related variance in a psychometric ability test. The samples we examine are broadly representative of the underlying Scottish population and they are sequential narrow age cohorts examined longitudinally.

Age and changes in reaction times

Summary of existing findings

In cross-sectional studies, mean reaction times slow as adults grow older (e.g. Era, Jokela, & Heikkinen, 1986; Fozard et al., 1994; Huppert & Whittington, 1993; and see the reviews in Madden, 2001, and Salthouse, 1985). Fozard et al. (1994) provided a brief guide to this research, indicating that the age-related slowing in reaction times is well established, but that there is dispute as to whether there is a consistent pattern of sex differences as reaction times change with age. One purpose of the present report is to add novel, population-representative reaction time findings to those few studies that have provided both longitudinal and cross-sectional data, which are now described.

The Bonn Longitudinal Study of Aging reported cross-sectional and longitudinal effects on choice reaction times (Mathey, 1976), but with only 24-34 men and women in the final wave of testing. Employing an unusual reaction time procedure, they found that the older group (aged 70-80) had, on average, slower reaction times than the younger group (aged 60-70). The only notable longitudinal slowing was between the last two visits. The same cross-sectional and longitudinal pattern was seen with the standard deviations of reaction times. Male participants showed better psychomotor performance than females. In small subsamples of the Duke Longitudinal Studies, decision time decreased with age, and movement time increased (Maddox & Douglass, 1985; Siegler, 1985). Maddox & Douglass (1985) used decision times to address change of intraindividual (inconsistency) and interindividual (diversity) variance with age and stability of individual differences. They concluded from a small sample that, “Intraindividual variability of reaction time showed no clear pattern of change through time” (p. 321) and that mean reaction times and their standard deviations showed non-significant changes over 5 waves of testing. Age-related changes in reaction time inconsistency and diversity are examined in the present study.

The UK’s Health and Lifestyle Survey (HALS) collected simple and four-choice reaction times from people aged 18 to 75+ twice, seven years apart (Huppert & Whittington, 1993). Only descriptive data were given. Cross-sectional data indicated that simple reaction times are relatively similar from age 18 to 45-54, with subsequent slowing in both males and females to 75+. Longitudinal data showed improvements in simple reaction times for participants up to about age 34, but slowing for participants 65 and over. Cross-sectional data on choice reaction times showed slowing from the mid-thirties to 75+. Longitudinal data showed stability of mean choice reaction times to about 45-54 with accelerated slowing after that. There was a slight male advantage on simple reaction time and a very small advantage for four-choice reaction time.

The Baltimore Longitudinal Study of Aging (BLSA) examined disjunctive and simple reaction times prospectively (Fozard et al., 1994). The sample belonged to the “upper-middle socio-economic level” (p. 180). Cross-sectional data indicated a slowing rate for simple reaction time of about 0.5 ms/year, and for disjunctive reaction time of 1.6 ms/year. Within-participant variance increased with age for simple and disjunctive reaction times, the latter was especially marked after age 60-70 years. Men tended to be faster than women on both reaction time tasks at all ages. Longitudinal data showed age-related slowing of simple and disjunctive reaction times; the effects of age, sex (faster reactions in men) and visit were all significant.

The importance of intraindividual variability

Mean reaction times are the principal measures from the studies described above, but there is an increasing interest in intraindividual variability of reaction times ($RTSD_i$) in cognitive aging (Hultsch & MacDonald, in press). Anstey (1999) found that $RTSD_i$ correlated with age at similar levels to mean RT, and that lung function, vibration sense and grip strength contributed variance to $RTSD_i$. She recommended that $RTSD_i$ become a more prominent outcome measure in cognitive aging research. $RTSD_i$ represents what Hultsch, MacDonald, and Dixon (2002) called inconsistency, one of three types of variability in cognitive performance related to aging. They found that inconsistency in non-verbal reaction time increased with age, and accounted for substantial and unique variance (10-20% after controlling for the intraindividual mean reaction time) in tests of episodic and working memory, perceptual speed, and crystallised ability. $RTSD_i$ was a relatively stable person characteristic across time and tasks, and they argued that it is "substantively important" (p. 113), and likely to reflect the influence of stable, endogenous neural mechanisms. They also found that $RTSD_i$ had some unique predictive power in dementia (Hultsch, MacDonald, Hunter, Levy-Bencheton, & Strauss, 2000) and chronic fatigue syndrome (Fuentes, Hunter, Strauss, & Hultsch, 2001). Rabbitt, Osman, Moore, and Stollery (2001) found that $RTSD_i$ increased with age and accounted for much of the between-session variability in performance and in the age-related variance in culture fair intelligence scores. Rabbitt et al. suggested that it is a moot point whether reaction time mean or $RTSD_i$ is the better indicator of some primitive performance characteristic.

In summary, there is imperfect knowledge about the cross-sectional and longitudinal associations between age and simple and more complex reaction times. To date, samples rarely represent the underlying population and are frequently small; devices and experimental procedures vary; simple and choice reaction times are not always available; means and intraindividual variabilities are not always collected; stability of individual differences is rarely reported; and the results with respect to sex differences are equivocal. Nevertheless, there is a general acknowledgement that reaction time data are potentially valuable indicators of processing efficiency in people of different ages. More adequate, representative data are needed.

Reaction time, cognitive tests and the processing speed hypothesis of cognitive aging

Reaction times and cognitive test scores

There are significant correlations between psychometric tests of cognitive abilities and indices derived from reaction time procedures. This has long interested researchers in intelligence differences, because it was thought to bolster the search for the cognitive processing elements that might underlie individual differences in psychometric intelligence (Wissler, 1901; Peak & Boring, 1926; Beck, 1933; Roth, 1964; Eysenck, 1967; Jensen & Munro, 1979; Jensen, 1987; Neubauer, 1997; Neubauer et al., 1997; Roberts & Stankov, 1999). Deary (2000, chapter 6) provided a critical review of this research. Significant associations between psychometric intelligence and reaction time indices (means and variabilities) occur at all ages, not just in old age. The effect sizes are typically small, with correlations often around -.2 (people with better psychometric test scores generally have faster and less variable reaction times). However, these effect sizes are probably underestimates, because many samples of participants consist of college and university students whose range of cognitive ability is attenuated. Our previous report on a large (N = 900) representative sample of the Scottish population (the oldest of the three cohorts in the present study) found the correlation between general psychometric intelligence and simple and choice reaction times to be greater than -.3 and -.4, respectively (Deary, Der, & Ford, 2001). Otherwise, the association between reaction times and psychometric ability test scores is rarely studied in representative population samples.

The processing speed hypothesis of cognitive aging

Reaction times slow with age, and they correlate with scores on tests of higher cognitive functions many of which also deteriorate with age. The age-related changes in reaction times account for a substantial proportion of the age-related variance in higher cognitive functions (e.g., Deary, 2000, chapter 8; Madden, 2001; Salthouse, 1996, 2000; Sliwinski & Buschke, 1999). These higher cognitive functions are often those assessed by psychometric tests of intellectual functions such as reasoning, memory, spatial ability and so forth. Thus, a parsimonious theory of cognitive ageing is that 'speed of processing' is a core ability that ages, and that changes in processing speed contribute to the age-related changes in heterogeneous cognitive tasks (Salthouse, 1996; Hertzog & Bleckley, 2001). Reaction time is commonly used to assess speed of information processing in this context. It is, therefore, important to know not only the changes in reaction times that occur with age, but also to assess the degree to which they account for age-related changes in other cognitive abilities.

One limitation of these findings is that they are mostly based upon cross-sectional samples with a wide range of ages. Hofer and Sliwinski (2001) showed that such samples exaggerate the interdependence of processes that change with age. Sliwinski and Buschke (1999) found less evidence for processing speed's accounting for age-related changes in other mental abilities in longitudinal analyses (where it accounted for 7-29% of the variance) than in cross-sectional studies (70-100% of the variance). Hofer and Sliwinski recommended longitudinal examinations of a sequence of narrow age cohorts as an optimal design for examining shared ageing effects on cognitive processes. This is the design employed in the present study.

The present study

The present study examines how reaction times age, and studies the relationship of reaction times to cognitive ability differences. The principal strengths of the present study are: representative samples of the population; large samples at a number of ages from 16 to the mid-60s; simple and four choice reaction times and their variabilities collected using standard procedures and on the same devices in all participants on all occasions; and eight year longitudinal data on all samples. Thus, we examine, in cross-sectional and longitudinal analyses, the changes with age in simple and choice reaction times, and their variabilities (intraindividual and interindividual), across the entire young adult age range. In longitudinal analyses we report the stability of these measures across eight years from age 16 to 24, 36 to 44, and 56 to 63. We report the correlations between reaction time variables and psychometric test (PASAT) scores at these same ages. We examine whether reaction time variables account for the age-related variance in PASAT scores. The samples are sufficiently large to allow separate accounts of these results in men and women; to date, the evidence about sex differences in reaction time changes with age is equivocal.

METHOD

Participants

The samples are drawn from the West of Scotland Twenty-07 Study. This is a population-based, longitudinal cohort study that aims to investigate the processes by which socially structured health inequalities are created and maintained. Full details of the design and sampling have been described elsewhere (Ford et al., 1994; Macintyre et al., 1989). Briefly, the study involved a two-stage random sample of the population of the Central Clydeside Conurbation, a large urban area in the West of Scotland centred on Glasgow City. The sample contains three age cohorts who were aged around 16, 36 and 56 at first interview. Participants undertook simple- and 4-choice reaction time tasks at Wave 1 and Wave 3. They performed the Paced Auditory Serial Addition Test (PASAT) at Wave 3. Wave 2 did not collect any reaction time or other cognitive data. Wave 1 data were collected by fieldworkers between 1987 and 1988. Wave 3 data were collected between 1995 and 1996. Analyses of reaction times are based on those participants who provided reaction time data at both Wave 1 and Wave 3. Analyses involving the PASAT are further restricted to those deemed to have performed the task satisfactorily. Details of sample attrition, with reference to reasons for dropping out and reaction time means, are provided in Appendix Tables A1 and A2, respectively.

At Wave 1, Cohort 1 had the following range of ages (with the numbers of participants at each age in parentheses): 15 (171), 16 (373). At Wave 3 for Cohort 1 the ages (numbers) were as follows: 23 (19), 24 (391), 25 (130), 26 (4). At Wave 1, the ages (numbers) for Cohort 2 were as follows: 31 (1), 33 (3), 34 (10), 35 (74), 36 (515), 37 (85), 38 (18), 39 (4), 40 (3), 41 (2). At Wave 3 for Cohort 2 the ages (numbers) were as follows: 39 (1), 41 (1), 42 (7), 43 (13), 44 (355), 45 (276), 46 (48), 47 (7), 48 (3), 49 (3), 50 (1). At Wave 1, the ages (numbers) for Cohort 3 were as follows: 54 (1), 55 (124), 56 (403), 57 (137), 58 (8). At Wave 3 for Cohort 3 the ages (numbers) were as follows: 62 (11), 63 (331), 64 (276), 65 (53), 66 (2). Therefore, within each cohort, and at each wave within each cohort, almost all of the participants fall within a very narrow range of ages.

The numbers of participants from each wave of each cohort that were drawn from different occupational groups are shown in Table 1. They are classified according to the UK Registrar General's standard six-fold classification of occupations that ranges from (I) professional occupations to (V) unskilled manual occupations (OPCS, 1980). Allocation of each participant to a given class was based upon the occupational status of the head of the household. For each cohort at Wave 1 the numbers in each occupational group are compared (Table 1) with the Samples of Anonymised Records (SARs; Der, 1998). The SARs are individual and household data drawn from the UK's 1991 census. They offer information about local areas in the UK and thus enable us to compare the samples tested here with information about the population from which they were drawn. Table 1 shows that Wave 1 of all three cohorts provides participant samples with a good match to the relevant population characteristics. The Twenty-07 study in general, and the samples analysed here in particular, have little bias in terms of gender or socioeconomic status (Der, 1998). The Kolmogorov-Smirnov test is non-significant, whether men and women are examined separately or combined, when comparing each age cohort separately with the corresponding SAR distribution. Table A1 shows the numbers of participants at the outset of the study and the attrition between Wave 1 and Wave 3 by age and gender. Table A2 shows simple and choice reaction time means for people who did and did not return for Wave 3; only those participants with fewer than five errors on the choice reaction time task are included. With only one exception (female simple reaction time in the middle cohort) the dropouts are slower than the returners. The difference between returners and dropouts for the oldest cohort is larger than the younger two groups. Therefore, the main impact of attrition will be an underestimation of the effect of age on reaction time slowing.

TABLE 1. Social class characteristics of the participants (percentages, with actual numbers in parentheses) in each cohort and wave of the West of Scotland Twenty-07 study and figures for the relevant underlying Scottish population compared with each cohort at Wave 1 (SARs = Sample of Anonymised Records)

Social class	SAR	Cohort 1, Wave 1 (age 16)		SAR	Cohort 2, Wave 1 (age 36)		SAR	Cohort 3, Wave 1 (age 56)	
		Men	Women		Men	Women		Men	Women
I	4.2	11.0 (28)	7.3 (21)	5.8	8.7 (27)	7.7 (31)	5.4	5.0 (15)	8.8 (33)
II	24.4	19.6 (50)	21.8 (63)	28.6	27.4 (85)	24.2 (98)	21.9	24.8 (74)	21.6 (81)
IIIn	15.3	16.1 (41)	14.2 (41)	13.8	14.5 (45)	15.8 (64)	11.0	9.4 (28)	21.1 (79)
IIIm	32.1	33.3 (85)	37.4 (108)	31.8	35.5 (110)	31.9 (129)	32.7	39.9 (119)	27.5 (103)
IV	14.3	13.3 (34)	12.1 (35)	12.0	8.4 (26)	12.1 (49)	23.0	15.8 (47)	13.6 (51)
V	9.7	5.9 (15)	6.6 (19)	8.0	3.5 (11)	3.0 (12)	6.0	5.0 (15)	7.5 (28)
Missing		0.8 (2)	0.7 (2)		1.9 (6)	5.4 (22)		0 (0)	0 (0)

Measures

Reaction times

Reaction time was measured using a portable device, originally designed for the UK Health and Lifestyle Survey (Cox, Huppert, & Whichelow, 1993). This has a high-contrast LCD display screen at the top with five response keys arranged below in a shallow arc (see Deary, Der, & Ford, 2001 for an illustration). The keys are labelled 1, 2, 0, 3, 4 from left to right. For simple reaction time, the respondent rests the second (index) finger of their preferred hand on the central '0' key and is instructed to press it as quickly as possible after a zero appears in the display. No digit other than a 0 appears during the simple reaction time task. There are 8 practice trials and 20 test trials. The mean and standard deviation of the test trials were recorded in milliseconds. For four-choice reaction time, the respondent rests the second (index) and third (middle) finger of each hand on the keys labelled 1, 2, 3, 4, and presses the corresponding key when one of the four digits appears in the display. There are 8 practice trials and 40 test trials. In the test trials, the digits 1 to 4 each appear 10 times in a randomised order. Mean reaction time and the standard deviation of reaction time are recorded separately for correct and incorrect responses as well as the number of errors. The time interval between a response and the display of the next digit varied randomly between 1 and 3 seconds for both simple and four-choice reaction times. Total time for testing reaction times was between 10 and 15 min. The results of the individual trials are not stored by the device.

Paced Auditory Serial Addition Test (PASAT)

The PASAT task involves participants' listening to an audio tape on which a voice reads a list of numbers between 1 and 9. Participants add these numbers according to the following rule: 'add the first number to the second number and give the answer, add the second number to the third number and give the answer, add the third number to the fourth number and give the answer', and so forth. There are two parts to the test. At first, numbers are read at a rate of one every four seconds (the easier condition), and then at one number per two seconds (the harder condition). In each of the two parts there are 31 numbers, giving a possible maximum score of 30 for each. The PASAT task was designed as a test of attention and concentration to detect mild cognitive decrements after closed head injury. In fact, the PASAT task has high correlations with psychometric tests of general intelligence (Crawford, Obonsawin, & Allan, 1998; Deary, Langan, Hepburn, & Frier, 1991; Egan, 1988). More specifically, PASAT performance loads on the general cognitive factor and highly on the working memory aspect of psychometric test performance (Crawford, Obonsawin, & Allan). The PASAT task is often used explicitly to assess working memory performance (Diehr, Heaton, Miller, & Grant, 1998; Fisk & Archibald, 2001).

The PASAT instructions to the interviewers made provision for them to stop the audio tape and repeat the instructions if the respondent had become “seriously muddled” during the task. We have excluded from analysis all cases where the tape was stopped or the interviewer recorded that the task was not performed properly. Stopping of the tape accounts for 80% of those excluded. From the interviewers’ notes it is clear that the majority of the remaining 20% also had difficulty with the task. PASAT was tested at Wave 3 only.

Statistical analyses

Reaction time parameters were analysed using general linear modelling on SPSS 10.1. Cohort and sex were between-subject variables and wave of testing was a repeated measure. Stability of reaction time parameters over the 8 year period between Wave 1 and Wave 3, and correlations between reaction time parameters and scores on the PASAT were computed using Pearson’s correlation coefficient. Only those participants with four or fewer errors in the choice reaction time test (i.e. those who responded correctly on 90% or more trials) were included in the analyses. No further exclusions were made based on reaction times.

RESULTS

Reaction time changes with age

Simple reaction time mean

Simple reaction time showed some slowing from Cohort 1 to 2, but there was a larger slowing from Cohort 2 to 3 (Table 2 and Figure 1a). In addition, the oldest cohort showed a larger longitudinal increase in reaction time from Wave 1 to 3. The significant effects for simple reaction time were: cohort, $F(2,1919) = 113.5$, $p < .001$, $\text{eta}^2 = .11$; wave, $F(1,1919) = 40.6$, $p < .001$, $\text{eta}^2 = .02$; and wave by cohort interaction, $F(2,1919) = 5.7$, $p = .003$, $\text{eta}^2 = .006$. All three pairwise comparisons among cohorts were significant at $p < .001$.

Choice reaction time mean

The age 16 cohort had shorter choice reaction times than those age 36, who were faster than those age 56 (Table 2 and Figure 1d). The youngest cohort had shorter mean choice reaction times at Wave 3 (eight year follow up), the middle cohort had very similar results across the 8 year span, and the oldest cohort had slower choice reaction times. The cohort and wave patterns and means were very similar for men and women (Figure 1d). The effect size of cohort was large, $F(2,1922) = 697.6$, $p < .001$, $\text{eta}^2 = .42$; and the wave by

TABLE 2. Reaction time (choice and simple) means (SD) and intraindividual standard deviations (SD) for three cohorts (age 16, 36 and 56 years) tested at Wave 1 and at 8-year follow-up (Wave 3) of the West of Scotland Twenty-07 study†

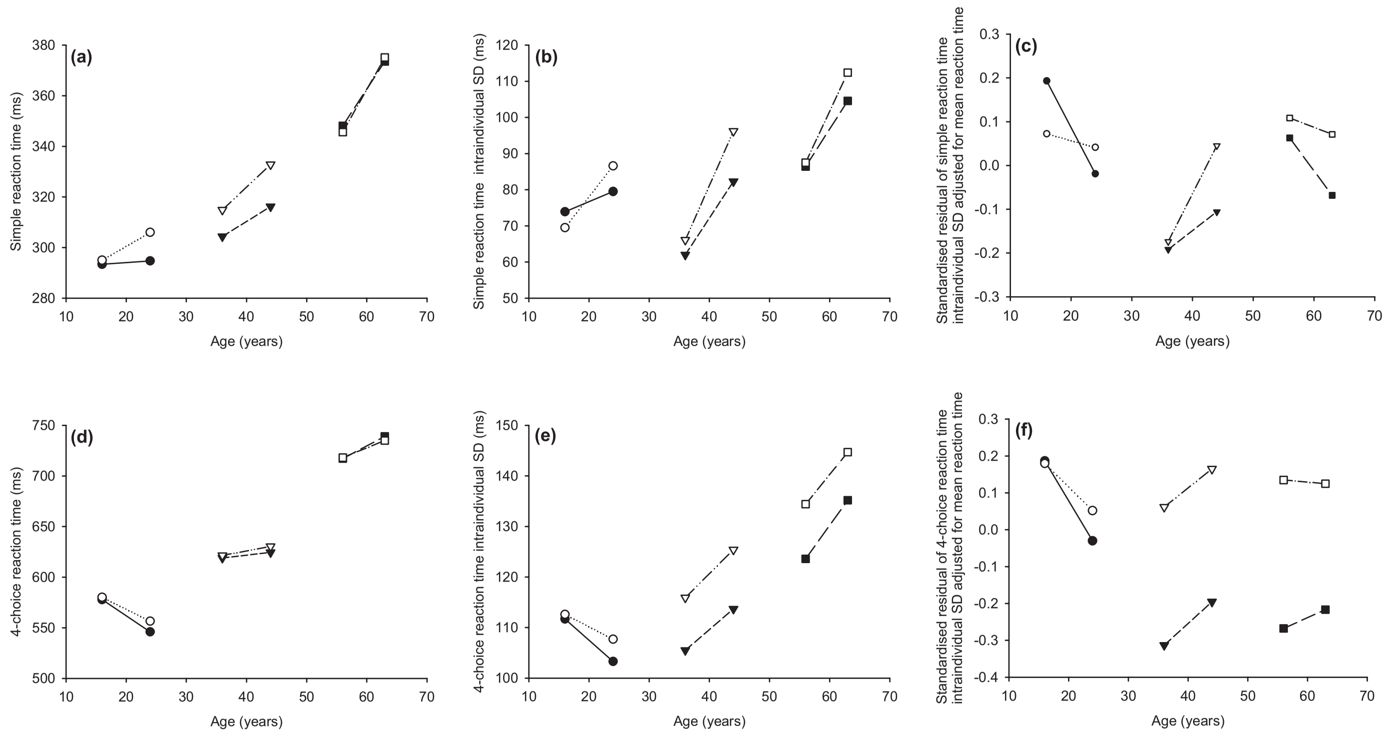
	Cohort 1, Wave 1 (age 16)		Cohort 1, Wave 3 (age 24)		Cohort 2, Wave 1 (age 36)		Cohort 2, Wave 3 (age 44)		Cohort 3, Wave 1 (age 56)		Cohort 3, Wave 3 (age 63)	
	Men N = 254-255	Women N = 288-289	Men N = 254-255	Women N = 288-289	Men N = 307-310	Women N = 402-404	Men N = 307-310	Women N = 402-404	Men N = 296-298	Women N = 374	Men N = 296-298	Women N = 374
Choice RT mean (SD)	577.8 (68.4)	580.1 (65.6)	546.0 (69.3)	556.5 (72.4)	618.9 (78.5)	621.5 (83.9)	624.5 (84.8)	630.3 (92.0)	717.2 (90.5)	718.1 (101.8)	739.1 (103.6)	735.0 (104.9)
Simple RT mean (SD)	293.4 (72.8)	295.0 (56.4)	294.7 (77.9)	306.0 (73.0)	304.4 (75.4)	314.9 (79.2)	316.2 (89.8)	332.8 (95.4)	348.1 (108.6)	345.6 (101.0)	373.5 (124.0)	375.1 (125.7)
Choice RT SD (SD)	111.7 (29.5)	112.6 (30.5)	103.3 (28.7)	107.7 (29.1)	105.5 (27.1)	115.9 (29.8)	113.7 (32.4)	125.4 (33.7)	123.6 (30.9)	134.4 (34.5)	135.2 (35.8)	144.7 (39.1)
Choice RT adj. SD (SD)*	0.1868 (0.946)	0.1795 (0.840)	-0.0298 (0.852)	0.0520 (0.826)	-0.3130 (0.916)	0.0616 (0.916)	-0.1954 (0.924)	0.1650 (0.992)	-0.2676 (1.046)	0.1349 (1.152)	-0.2166 (1.017)	0.1379 (1.194)
Simple RT SD (SD)	73.9 (49.5)	69.5 (40.8)	79.5 (53.4)	86.6 (57.5)	62.0 (36.0)	66.1 (40.6)	82.3 (55.5)	96.2 (61.4)	86.4 (55.3)	87.5 (62.2)	104.6 (72.4)	112.4 (72.6)
Simple RT adj. SD (SD)*	0.1930 (0.980)	0.0723 (0.858)	-0.0190 (0.834)	0.0413 (0.908)	-0.1918 (0.675)	-0.1739 (0.824)	-0.1059 (0.894)	0.0453 (0.984)	0.0630 (1.164)	0.1085 (1.284)	-0.0683 (1.110)	0.0711 (1.166)

Note. Numbers are in milliseconds, except *.

*Standardised residuals (mean = 0; SD = 1) in which reaction time standard deviations are adjusted for the appropriate reaction time means.

†Slight differences in subgroup Ns reflect occasional instances where some individual variables were unavailable.

Figure 1. Reaction time findings for three cohorts (age 16, 36 and 56 years) tested at Wave 1 and at 8-year follow-up (Wave 3) of the West of Scotland Twenty-07 study. Closed symbols = men; open symbols = women. Panels are: (a) simple reaction time means (ms); (b) simple reaction time intraindividual standard deviations (ms); (c) simple reaction time intraindividual standard deviations adjusted for simple reaction time mean (standardised scores; mean = 0, SD = 1); (d) four-choice reaction time means (ms); (e) four-choice reaction time intraindividual standard deviations for three cohorts (ms); (f) four-choice reaction time intraindividual standard deviations adjusted for choice reaction time means (standardised scores; mean = 0, SD = 1).



cohort interaction more modest, $F(2,1922) = 52.7$, $p < .001$, eta^2 = .05. All three pairwise comparisons among cohorts were significant at $p < .001$.

Simple reaction time intraindividual standard deviation

The oldest cohort was the most variable, women were generally more variable, and intraindividual variability in simple reaction time tended to rise at Wave 3 (Table 2 and Figure 1b). There were significant main effects of: cohort, $F(2,1916) = 51.4$, $p < .001$, eta^2 = .05; sex, $F(1,1916) = 6.4$, $p = .01$, eta^2 = .003; and wave, $F(1,1916) = 129.4$, $p < .001$, eta^2 = .06. There were two significant interactions: wave by cohort, $F(2,1916) = 5.6$, $p = .004$, eta^2 = .006; and wave by sex, $F(1,1916) = 7.5$, $p = .006$, eta^2 = .004. All of the effect sizes were small to modest. In post-hoc *t* tests the only significant sex difference was in the middle cohort at Wave 3 ($p = .002$).

Simple reaction time intraindividual standard deviation adjusted for simple reaction time mean

Simple reaction time mean and intraindividual standard deviation were positively correlated. For example, in the whole sample, including all three cohorts and both sexes, at Wave 1, $r(1926) = .58$, $p < .001$, and at Wave 3, $r(1928) = .58$, $p < .001$. Simple reaction time intraindividual standard deviation was adjusted for simple reaction time mean by linear regression and saving the standardised residuals. This was done separately for each wave and the analyses in the previous paragraph were repeated using these residuals as the dependent variable. There were significant differences among the cohorts in the adjusted intraindividual variability of simple reaction time (Table 2 and Figure 1c), $F(2,1916) = 10.9$, $p < .001$, eta^2 = .01. Pairwise comparisons showed that the middle cohort had significantly lower values than the other two cohorts, $p < .05$, but the comparison between the youngest and oldest cohorts was non-significant. There was no significant main effect of sex. There was no significant main effect of wave. There was a significant wave by cohort interaction, $F(2,1916) = 8.1$, $p < .001$, eta^2 = .008. There was a significant wave by sex interaction, $F(1,1916) = 4.9$, $p = .03$, eta^2 = .003. In post-hoc *t* tests the only significant sex difference was in the middle cohort at Wave 3 ($p = .03$). There was no significant cohort by sex interaction, or wave by cohort by sex interaction.

Choice reaction time intraindividual standard deviation

There were significant differences among the cohorts in the intraindividual variability of choice reaction time (Table 2 and Figure 1e), $F(2,1923) = 161.9$, $p < .001$, eta^2 = .14. All three pairwise comparisons among cohorts were significant at $p < .001$. There was a main effect of sex, with women being more variable in all cohorts at both waves, $F(1,1923) = 43.0$, $p < .001$, eta^2 = .02.

There was a significant main effect of wave, $F(1,1923) = 26.6$, $p < .001$, eta^2 =.01, and a significant wave by cohort interaction, $F(2,1923) = 38.7$, $p < .001$, eta^2 = .04, with the youngest cohort becoming on average less variable across 8 years and the oldest cohort more variable. There was also a small effect of cohort by sex interaction, $F(2,1923) = 4.5$, $p = .01$, eta^2 = .005. Post-hoc testing (*t* tests) showed no significant sex differences in the youngest cohort, though there was a trend (p =.07) at Wave 3. Men were less variable in the middle and oldest cohorts at Waves 1 and 3, with all comparisons $p < .001$.

Choice reaction time intraindividual standard deviation adjusted for choice reaction time mean

Choice reaction time mean and intraindividual standard deviation were positively correlated. For example, in the whole sample, including all three cohorts and both sexes, at Wave 1, $r(1929) = .55$, $p < .001$, and at Wave 3, $r(1930) = .61$, $p < .001$. Choice reaction time intraindividual standard deviation was adjusted for choice reaction time mean by linear regression and saving the standardised residuals. This was done separately for each wave and the analyses in the previous paragraph were repeated using these residuals as the dependent variable. There were significant differences among the cohorts in the adjusted intraindividual variability of choice reaction time (Table 2 and Figure 1f), $F(2,1921) = 8.3$, $p < .001$, eta^2 = .009. Pairwise comparisons between the youngest and the other two cohorts were significant at $p < .05$, but the comparison between the older two cohorts was non-significant. There was a main effect of sex, $F(1,1921) = 53.7$, $p < .001$, eta^2 = .03. There was no significant main effect of wave, or wave by sex interaction. There was a significant wave by cohort interaction, $F(2,1921) = 8.4$, $p < .001$, eta^2 = .009. There was a significant cohort by sex interaction, $F(2,1921) = 9.1$, $p < .001$, eta^2 = .009. There was no significant wave by cohort by sex interaction. Post-hoc testing (*t* tests) showed no significant sex differences in the youngest cohort. Men were less variable in the middle and oldest cohorts at Waves 1 and 3, with all comparisons $p < .001$.

Age-related diversity in reaction time indices

Interindividual variability, also known as diversity (Hale, Myerson, Smith, & Poon, 1988; Hultsch and MacDonald, in press) is shown in Table 2 as the standard deviation of each reaction time measure (given in parentheses). There are signs of increasing diversity with age for each measure and these were tested for significance using Levene's test for equality of variances. Table 3 gives the *p* values for these comparisons. There was increased diversity in simple and choice reaction time means among women from the youngest to the oldest cohorts. Among men the youngest and middle cohorts did not differ significantly (except on choice reaction time at Wave 3), but all other pairwise comparisons were significant.

TABLE 3. Comparison of between-cohort differences in diversity. Cells contain p values*

	Cohort 1 vs 2, Wave 1		Cohort 1 vs 2, Wave 3		Cohort 1 vs 3, Wave 1		Cohort 1 vs 3, Wave 3		Cohort 2 vs 3, Wave 1		Cohort 2 vs 3, Wave 3	
	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women
Simple RT mean	.117	<.001	.139	.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Simple RT SD	.002	.640	.958	.115	.046	<.001	.001	<.001	<.001	<.001	.001	.006
Choice RT mean	.364	.035	.049	.004	<.001	<.001	<.001	<.001	.009	.001	<.001	.007
Choice RT SD	.068	.635	.270	.011	.948	.026	.001	<.001	.077	.003	.035	.012
Simple RT adj. SD**	.005	.578	.640	.136	.015	<.001	.002	<.001	<.001	<.001	.007	<.001
Choice RT adj. SD**	.666	.828	.319	.001	.258	<.001	.010	<.001	.102	<.001	.092	<.001

Note. *Levene's test for equality of variances.

**Standardised residuals (mean = 0; SD = 1) in which reaction time standard deviations are adjusted for the appropriate reaction time means.

Comparisons of diversity of intraindividual variability in simple and choice reaction times showed few differences between the youngest and middle cohorts, but there were significant differences when the youngest and middle groups were compared with the oldest. These differences were generally sustained when the intraindividual variability was adjusted for the mean reaction time. An exception to this pattern was among male cohorts in the choice reaction time task, where there was less evidence of increasingly diverse intraindividual variability with age, especially after correcting for the mean reaction time.

Stability of reaction time indices across 8 years

The stability of choice reaction time mean scores across eight year periods at different points in the lifespan is highly consistent, with all but one of the coefficients falling in the narrow range between .51 and .63 (Table 4). The exception is the somewhat lower stability in young men between the ages of 16 and 24 (r = .38). The stability coefficients (Pearson's r) for simple reaction time means fell in the range .20 to .43, with most being in the .3s. Stability coefficients for choice reaction time intraindividual variability showed a similar range of modest effect sizes. The lowest stability coefficients were found for simple reaction time intraindividual variability, which ranged from .04 to .25. There were no obvious differences in stability coefficients among the three cohorts or between the sexes.

Analyses with Paced Auditory Serial Addition Test scores

Correlations with reaction time variables

Since these analyses are based on those participants who completed the PASAT satisfactorily, the samples are somewhat more restrictive than for

TABLE 4. Stability coefficients (Pearson's r) of reaction time (choice and simple) means and intraindividual standard deviations (SD) for three cohorts (age 16, 36 and 56 years) tested at Wave 1 and at 8-year follow-up (Wave 3) of the West of Scotland Twenty-07 study*

	Cohort 1 (age 16)		Cohort 2 (age 36)		Cohort 3 (age 56)	
	Men N = 254-255	Women N= 288-289	Men N = 307-310	Women N = 402-404	Men N = 296-298	Women N = 374
Choice RT mean	.38	.51	.57	.58	.55	.63
Simple RT mean	.34	.31	.43	.38	.20	.31
Choice RT intraindividual SD	.25	.36	.39	.37	.41	.27
Simple RT intraindividual SD	.12	.10	.25	.13	.04	.23

*Slight differences in subgroup Ns reflect occasional instances where some individual variables were unavailable.

the previous analyses in this report. The numbers of each sex in each cohort for these analyses are set out in the Appendix Table A3, which may be compared with Table 2 in the main body of the paper. The largest loss of participants is from the older cohort, for whom a smaller proportion satisfactorily completed the task.

The correlations between PASAT scores and choice reaction time means for the three cohorts (broken down by sex and wave) range from -.19 to -.42 (Table 5). There is a tendency toward a slightly higher correlation among women, otherwise coefficients are similar in the different cohorts and waves. The lack of any effect of wave on coefficient size is notable, because PASAT performance was assessed at Wave 3 and not at Wave 1. The correlations between PASAT scores and simple reaction time means are lower, between -.09 and -.26. Again, those with higher PASAT scores have, on average, faster reaction times. The coefficients are low for the middle cohort. People with higher PASAT scores tend to have less variable choice reaction times, with the correlations ranging from -.04 to -.31. Low coefficients occur in the first wave of the oldest cohort. Correlations between PASAT scores and intraindividual variability in simple reaction times range from -.01 to -.24. There were only very low correlations between PASAT scores and numbers of errors made on the choice reaction time task.

Effect of age, sex and reaction time on PASAT scores

PASAT was administered at Wave 3 only. The raw PASAT scores for men and women in the three age cohorts are shown in Table 6. There was a significant effect of cohort on PASAT scores $F(2,1245) = 23.0$, $p < .001$, $\text{eta}^2 = .036$. Pairwise comparisons showed that the youngest and middle cohorts both scored significantly higher than the oldest cohort ($p < .001$). There was a significant effect of sex on PASAT scores, $F(1,1245) = 8.8$, $p < .001$, $\text{eta}^2 = .007$. Men scored higher than women at the two younger cohorts, although there was no significant cohort by sex interaction. PASAT scores were controlled for choice reaction time mean and intraindividual variability using linear regression and the analyses were repeated (Table 6). The effect of cohort was no longer significant, $F(2,1245) = 2.9$, $p = .06$, $\text{eta}^2 = .005$. The effect of sex remained significant, $F(1,1245) = 6.0$, $p = .01$, $\text{eta}^2 = .005$. The reduction in the cohort effect's eta^2 from .036 to .005 after controlling for reaction time variables represents a removal of 86% of the age-related variance from the PASAT score. Thus, controlling for speed of processing removes most of the age-related variance in PASAT performance, but not the sex-related variance.

TABLE 5. Correlations between reaction time parameters and scores on the PASAT test for the three cohorts of the West of Scotland Twenty-07 study*

	Cohort 1, Wave 1 (age 16)		Cohort 1, Wave 3 (age 24)		Cohort 2,Wave 1 (age 36)		Cohort 2, Wave 3 (age 44)		Cohort 3, Wave 1 (age 56)		Cohort 3, Wave 3 (age 63)	
	Men N = 200-201	Women N = 216-217	Men N = 201	Women N = 216-217	Men N = 219-221	Women N = 266-267	Men N = 219-221	Women N = 266-267	Men N = 177	Women N = 168	Men N = 177	Women N = 168
Choice RT mean	–.38	–.42	–.19	–.36	–.27	–.34	–.20	–.28	–.23	–.41	–.33	–.35
Simple RT mean	–.26	–.19	–.21	–.21	–.09	–.12	–.06	–.09	–.15	–.20	–.22	–.17
Choice RT SD	–.30	–.25	–.17	–.31	–.25	–.25	–.09	–.28	–.04	–.10	–.22	–.20
Simple RT SD	–.16	–.19	–.21	–.16	–.12	–.16	–.01	–.01	–.07	–.10	–.24	–.06
Choice RT errors	.05	.03	.02	.03	.06	–.07	.11	.01	–.04	.05	.05	–.04

*Slight differences in subgroup Ns reflect occasional instances where some individual variables were unavailable.

TABLE 6. Mean (SD) age and sex effects on paced auditory serial addition test (PASAT) scores before and after controlling for choice reaction time mean and variability

		PASAT score	Standardised PASAT score[a]
Women	Cohort 1 (N = 217)	44.8 (8.5)	−.187 (.963)
	Cohort 2 (N = 267)	44.1 (9.1)	−.036 (1.050)
	Cohort 3 (N = 168)	42.0 (8.7)	.021 (.987)
Men	Cohort 1 (N = 201)	47.0 (8.0)	.025 (.949)
	Cohort 2 (N = 221)	46.5 (8.0)	.193 (.961)
	Cohort 3 (N = 177)	41.9 (8.6)	−.004 (1.040)

[a]Controlling for choice reaction time mean and variability.

DISCUSSION

The data and results presented here address reaction times as applied to two theoretical issues: the age-related changes in reaction times (and any sex differences), and the processing speed hypothesis of cognitive ageing. Whereas researchers in these areas commonly use reaction time measures, none typically has data on normal samples of the population. In that respect, with their large numbers, the spread across the young adult age range, and the close matching to the relevant Scottish population for socio-economic background, the present data are useful. They offer a picture of simple and choice reaction times’ mean and variability changes and stability, and their correlations with a mental test score that relates to working memory, across most of the young adult lifespan.

Age, sex and reaction time means

The principal findings of the present study were as follows. For simple and choice reaction time there was cross-sectional slowing from the 30s and 20s, respectively. In the case of simple reaction time the cross-sectional and longitudinal data indicated steady slowing from the 30s. Choice reaction time improved in men and women from late adolescence to the early 20s.

These findings support those found in the UK’s Health and Lifestyle Study (HALS; Huppert & Whittington, 1993) and the Baltimore Longitudinal Study of Aging (BLSA; Fozard et al., 1994), which are the other studies with large samples and age ranges across the normal adult lifespan. We found relatively few sex differences in these variables, with the exception of slower choice reaction time in women compared to men in the middle cohort. Both the BLSA and the HALS found evidence of males’ being faster, though the advantage for males in the more representative HALS study was not large. In the BLSA males were recruited many years earlier and in larger numbers than women.

Sex, age and intra- and inter-individual variability in reaction time

The principal findings of the present study were as follows. Intraindividual variability in choice reaction time increased steadily from the mid-30s to the mid-60s. Women were consistently more variable than men at these ages. We are not aware of this clear result being reported previously. The effect of age, but not of sex, on intraindividual variability in choice reaction time was largely removed when adjusted for mean choice reaction time. There was an increase in the intraindividual variability in simple reaction time at the oldest ages studied here. Again the effect of age was largely removed after adjusting for mean reaction time. However, the effect of the ajdustment appears to differ between choice and simple reaction time. From Figures 1c and 1f the effect on choice reaction time appears to be primarily a change of scale, whereas for simple reaction time, comparing Figures 1b and 1e, the shape of the relationship is changed. This might imply that the relationship between the mean and intraindividual variability is different for the two tasks, which would warrant further investigation

Between-subjects variability—diversity—was also examined. Overall, the results indicated increasing diversity of reaction time indices after middle age, with a partial exception for men on the intraindividual variability of choice reaction time.

The BLSA (Fozard et al., 1994) found increased intraindividual variability of reaction time responses with age, though the much smaller Bonn (Mathey, 1976) and Duke (Maddox & Douglass, 1985) studies did not. The present study's results complement data from the Victoria Longitudinal study of over 446 older, relatively healthy people who were tested longitudinally on four reaction time tasks and several cognitive domains (MacDonald, Hultsch, & Dixon, 2003). Intraindividual variability was greater in their older participants and increased across six years, it (adjusted for mean performance) accounted for a substantial amount of the variance in cognitive change across the six-year interval, and increasing intraindividual variability was associated with greater decline in several cognitive domains.

The present representative population data on age changes and sex differences in intraindividual variability are potentially important, given this growing evidence that reaction variability constitutes a cognitive index that is of interest in itself (Anstey, 1999; Hultsch & MacDonald, in press; Hultsch, MacDonald, & Dixon, 2002), and might provide as fundamental a measure as mean reaction time (Rabbitt et al., 2001). However, a key implication of the present results is that sex and age-related differences in intraindividual variability in choice reaction time might have different origins and implications.

Controlling intraindividual variability in choice reaction time for mean reaction time abolished most of the age differences, but moderately large (about 0.4 standard deviation difference) and consistent sex differences remained, especially in the middle and oldest cohorts. It is possible that some of this effect might be due to hormonal changes. Sex steroids have protective effects on the central nervous system, including the hippocampus (Goodman, Bruce, Cheng, & Mattson, 1996; Norbury et al., 2003; Wolf, 2003). However, the existence of the difference at age 36, and possibly earlier, makes an explanation in terms of post-menopausal sex hormone changes untenable. Moreover, there are inconsistent reports of any deleterious effect of low endogenous estrogen on women in middle to early old age (Portin et al., 1999). Meta-analyses and reviews find that results of observational studies and randomised controlled trials are inconsistent with regard to whether there is cognitive enhancement as a result of estradiol replacement (Hogervorst, Yaffe, Richards, & Huppert, 2002; Maki & Hogervorst, 2003; Wolf, 2003). Studies of these types tend not to examine intraindividual variability as an outcome variable.

The difference between men and women in intraindividual variability in reaction time might be related to general adult sex differences in the brain actions of estrogens. Estrogens and the other steroid hormones have receptors in the brain. Estrogens' effects differ in male and female brains, either as a result of the brain's sexual differentiation or as a result of circulating hormone levels (McEwen, 2001). Estrogens affect areas of the brain related to memory and other aspects of information processing, including the hippocampus and the ascending cholinergic, serotonergic, noradrenergic and dopaminergic neurons (McEwen, 2001). These systems have been suggested as regulators of signal-to-noise ratio and variability in information processing, and dopamine function specifically was hypothesised to affect age-related variability in cognitive performance (Li, Lindenberger, & Sikstrom, 2001). The organisation of the basal forebrain cholinergic system is sexually dimorphic. It is affected in Alzheimer's disease and it can be pharmacologically manipulated to alter cognitive function in healthy individuals (Freo, Pizzolato, Dam, Ori, & Battistin, 2002). Estrogen receptors are also found in the cingulate cortex, which is concerned with attentional mechanisms (McEwen, 2001). Sex hormones and their effects on the brain, therefore, offer a testable hypothetical mechanism for sex differences in the intraindividual variability in reaction time. If we had found consistent sex differences in intraindividual variability at all ages, that might implicate sexually dimorphic brain differentiation as a cause. There was less difference in intraindividual variability at the earliest ages tested here, when the subjects, though mostly post-pubertal, had fewer years for adult sex hormone concentrations to affect their brains. Therefore, the cause of the sex difference might be due to brain effects of sex hormones found after puberty.

Hultsch and MacDonald (2004) referred to the study of inconsistency in cognitive performance as a "frontier of research". They enumerated theoretical reasons and empirical findings that accumulate to a strong case for focussing on intraindividual variability in human cognitive development and aging. The frontier characteristic is emphasised by the necessarily speculative comments on mechanisms we have provided. Given that the area is still immature, it is worth commenting on the increasingly common tendency to adjust for mean reaction time when examining intraindividual variability. The two indices are moderately to highly correlated. However, the brain mechanisms that subserve individual differences in these indices are not known. If it were discovered that the neural underpinnings of intraindividual variability were causally prior to reaction time mean—a possibility argued by Hultsch and MacDonald (2004)—then it would be rational to control mean for intraindividual variability and not the reverse. Until more is known about causal mechanisms of these two indices we recommend the presentation and analysis of unadjusted as well as adjusted intraindividual variability.

Reaction time stability

Data on the stability of reaction time indices' differences add considerably to data provided by the Duke study (Maddox & Douglass, 1985). It is shown that these indices differ markedly in their stabilities across time, and that these different stabilities are largely consistent across the adult age range. Mean choice reaction time provides the most stable index across the 8 year span. However, these stability data are limited by our not having, and therefore not being able to disattenuate for, short-term test-retest reliability estimates of the reaction time indices.

Reaction time procedures

The present study adds valuable data on age and sex differences in reaction time by using standard procedures for assessing simple and choice reaction times and their intraindividual differences. The choice reaction time procedure resembles Hick's (1952) device, with fewer response choices. Other longitudinal studies of reaction times employed procedures that were much less standard, either because the main aim of the study was not to assess reaction times (Fozard et al., 1994) or because a stressful procedure was used (Mathey, 1976). The study which used the same device as the one described here did not report statistical analyses and did not report response variability (Huppert & Whittington, 1993). The device used in the Duke studies (Maddox & Douglass, 1985; Siegler, 1985) separated overall reaction time into decision and movement times, a procedure that might be associated with strategies that could undermine the validity of the decision-movement partitioning (Deary, 2000, chapter 6; Nettelbeck, 1998; Smith & Carew, 1987). One such strategy is to lift the finger off the home button before deciding which response to make. This shortens the decision time and adds some extra time to what is meant to be movement time only.

Reaction times and the PASAT

We found consistent evidence of significant correlations between reaction time and PASAT performance. Significant associations between reaction times and mental ability test scores were reported in the Bonn study (Mathey, 1976). We confirmed Salthouse's (1996) finding that reaction time differences account for most of the age-related variance in higher-level mental tasks. However, reaction time did not eliminate sex differences in the PASAT task; males in the two younger cohorts achieved higher scores.

Limitations of the study

The present study has a number of limitations. As with all longitudinal studies, there was attrition. To quantify any effect of this, we analysed the Wave 1 cognitive differences between people who did and did not return for Wave 3 testing. Where there were significant interactions between returning to Wave 3 (yes or no, a between subjects factor) and age cohort or sex, as appropriate, we constructed specific contrasts to estimate and test the implied biases. These suggest that the age-related changes over the 40 years which separates the youngest and oldest cohorts are underestimated by 29 and 40 ms for men and women, respectively, on simple reaction time mean, and by 36 and 54 ms, respectively, for men and women on choice RT mean. The gender difference in simple reaction time variability is not evident at Wave 1, and there is no suggestion of bias in the gender difference in choice reaction time variability.

Another limitation is that the PASAT task represents only one of a number of mental tests with which it would be interesting to correlate reaction times. Nevertheless, there are ample data to suggest that PASAT assesses important aspects of psychometric intelligence. It especially taps working memory that is very closely linked to general intelligence.

Another aspect of PASAT is that it is a relatively complex task. We took the conservative decision to exclude from analysis any data where the proper procedure was not strictly adhered to. This tended disproportionately to eliminate people from the older cohort, and those who remained had, on average, faster reaction times. The analyses of the effect of age on PASAT test scores are, therefore, underestimates. However, it was clear that PASAT performance did correlate with reaction time parameters across the lifespan, and even with reaction time measures taken 8 years earlier.

A further limitation is that stability and other correlations here are not corrected for the short-term reliability of the reaction time measures. The similarity of the correlations of reaction time measures with the PASAT test across waves (Table 5), the lower correlations with intraindividual SDs, and the proportionality of the correlations between Tables 4 (stability) and 5 (validity to PASAT) suggests that individual differences over the 8 years are highly stable, but that the modest reliabilities generate modest test-retest correlations.

CONCLUSION

The present study provides previously-unavailable, representative data on ageing and various aspects of reaction time, a measure which has been dubbed “an important index of functional age” (Mathey, 1976) and which is otherwise employed widely as a key measure in cognitive studies of human development and ageing. Slowing and increased variability in late life are confirmed for simple and choice reaction time, with interesting patterns from the teens to early mid-life. Marked and consistent sex differences were noted in intraindividual variability of choice reaction time from the 30s to the 60s. Reaction time acounted for much of the age effect on PASAT scores, but not the sex differences.

AUTHOR NOTE

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APPENDIX

TABLE A1. Attrition between Wave 1 and Wave 3 (8-year follow-up) of the West of Scotland Twenty-07 study in terms of reasons for non-completion

	Age cohort											
	Age 16				Age 36				Age 56			
	Male		Female		Male		Female		Male		Female	
Wave 3 contact	N	%	N	%	N	%	N	%	N	%	N	%
Completed Wave 3	318	66.0	358	67.9	331	74.5	423	78.2	323	68.1	399	70.2
Dead	3	0.6	2	0.4	10	2.3	7	1.3	57	12.0	41	7.2
Moved	52	10.8	57	10.8	37	8.3	32	5.9	16	3.4	20	3.5
Non contact	39	8.1	31	5.9	32	7.2	21	3.9	10	2.1	8	1.4
Refused	50	10.4	58	11.0	27	6.1	51	9.4	65	13.7	97	17.1
Other	20	4.1	21	4.0	7	1.6	7	1.3	3	0.6	3	0.5
Total	482	100	527	100	444	100	541	100	474	99.9	568	99.9

TABLE A2. Attrition between Wave 1 and Wave 3 (8-year follow-up) of the West of Scotland Twenty-07 study in terms of reaction time means*

	Age cohort											
	Age 16				Age 36				Age 56			
	Male		Female		Male		Female		Male		Female	
	ms	N	ms	N	ms	N	ms	N	ms	N	ms	N
Simple RT mean of those completing Wave 3	293.3	258	295.8	294	304.3	317	314.9	405	348.3	306	345.9	385
Simple RT mean of those not completing Wave 3	303.5	129	319.7	126	317.3	89	301.3	98	384.5	126	409.3	136
Choice RT mean of those completing Wave 3	577.6	257	581.3	293	617.3	318	621.5	407	717.6	307	716.6	386
Choice RT mean of those not completing Wave 3	593.5	128	586.7	125	647.4	89	630.2	98	769.5	126	775.8	136

**Note*. Participants are included only if they met the performance criterion of fewer than five errors in the choice reaction time task. Therefore, the numbers differ from Table A1.

TABLE A3. Participants for whom the PASAT test was administered successfully. Reaction time (choice and simple) means (SD) and intraindividual standard deviations (SD) for three cohorts (age 15, 35 and 55 years) tested at Wave 1 and at 8-year follow-up (Wave 3) of the West of Scotland Twenty-07 study (numbers are milliseconds)*

	Cohort 1, Wave 1 (age 16)		Cohort 1, Wave 3 (age 24)		Cohort 2, Wave 1 (age 36)		Cohort 2, Wave 3 (age 44)		Cohort 3, Wave 1 (age 56)		Cohort 3, Wave 3 (age 63)	
	Men N = 200-201	Women N = 216-217	Men N = 200-201	Women N = 216-217	Men N = 220-222	Women N = 267-272	Men N = 220-222	Women N = 267-272	Men N = 177-178	Women N = 168-172	Men N = 177-178	Women N = 168-172
Choice RT	576.0	576.2	542.6	552.4	613.0	613.7	614.6	618.8	703.8	704.6	718.1	713.6
mean (SD)	(69.3)	(62.5)	(69.6)	(72.0)	(69.8)	(78.3)	(79.5)	(80.2)	(85.0)	(97.8)	(91.8)	(103.9)
Simple RT	295.3	295.7	294.9	302.8	303.5	308.8	312.6	318.8	340.2	344.7	355.0	357.9
mean (SD)	(77.7)	(56.1)	(80.0)	(72.7)	(67.8)	(70.4)	(87.5)	(83.5)	(101.8)	(101.8)	(112.3)	(119.2)
Choice RT	111.0	111.5	101.7	106.7	103.4	113.1	109.8	121.7	119.9	130.2	131.6	138.8
SD (SD)	(29.1)	(31.0)	(27.5)	(27.2)	(26.3)	(29.1)	(28.0)	(30.5)	(28.0)	(33.5)	(33.9)	(36.1)
Simple RT	74.7	69.0	79.3	82.6	61.7	64.3	77.6	91.2	81.0	81.9	93.1	101.0
SD (SD)	(51.4)	(40.8)	(56.0)	(51.0)	(36.8)	(35.5)	(48.5)	(55.1)	(50.4)	(49.6)	(57.0)	(62.5)

*Slight differences in subgroup Ns reflect occasional instances where some individual variables were unavailable.