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Reaction time and intelligence: comparing associations based on two response modes

Abstract

People who score highly on intelligence tests also tend to have faster and less variable reaction times. Effect size estimates for the reaction time-intelligence association are larger in samples that are more representative of the population. However, such samples have often been tested on a reaction time device that requires reading a number and processing its association with a specific response location (Cox, Huppert, & Whichelow, 1993). Here, we use this device and another reaction time device (Dykiert et al., 2010) that is similar, except that the responses require less processing; subjects simply press a button that is adjacent to the stimulus light. We focus on the possibility that lights as stimuli require less higher-order cognitive engagement than numbers, and then test whether parameters from these two tasks are highly correlated and similarly associated with age and higher cognitive abilities. Both tasks measured Simple and Choice reaction times and their intra-individual variation across trials. The parameters of the two tasks were very highly correlated and parameters from both tasks were similarly associated with age, social factors, and differences in higher cognitive abilities. The respective choice reaction time parameters from either task accounted for much of the age- and higher cognitive ability- associations of the other task’s parameters. These findings are important in establishing that the effect sizes of higher cognitive ability associations with processing speed measures may be found when the processing demands are minimal.

Reaction time has been used in the study of psychology since the nineteenth century (Cattell, 1890; Galton 1890). Today, many types of reaction time task exist and are used in a variety of contexts and measured for their associations with various factors and in response to many manipulations. For example, using some examples from our own work, reaction times slow and become more variable with age (Deary & Der, 2005a; Der and Deary, 2006; Dykiert, Der, Starr, & Deary, 2012), correlate with measures of general fluid intelligence (Deary, Der, & Ford, 2001), and are associated with survival (Deary & Der, 2005b; Shipley, Der, Taylor, & Deary, 2006). In addition, reaction times are often used as an index of processing speed, which is seen by some as a fundamental factor in the age-related decline in various cognitive functions (Madden, 2001; Salthouse, 1996). Reaction times are also used in a number of other areas of study including medical research, psychopharmacology and experimental psychology (e.g., Strachan, Deary, Ewing, Ferguson, Young & Frier, 2001). In a large, age-homogeneous sample of people aged about 73 years, we found that processing speed—principally formed from reaction time parameters—wholly mediated the association between brain white matter integrity and general intelligence (Penke, Maniega, Bastin, Hernandez, Murray et al., 2012).

Reaction times are therefore a widespread, important and informative tool in the study of cognitive ability in psychology and other disciplines. It is important that the various reaction time tasks in use are valid and comparable with one another. Simple and choice reaction times are two useful indices used in many studies (e.g. Deary & Der, 2005a, 2005b; Der & Deary, 2006; Shipley et al., 2006; Dykiert et al., 2012). Simple reaction time refers to the time taken to respond to a single stimulus, whereas choice reaction time refers to the time taken to make the correct response to one of a number of possible stimuli. With respect to choice reaction time, there can be a problem in comparing studies, in so far as the response modes can differ substantially between devices. We previously found this in attempting to compare age effects on reaction time parameters (Deary & Der, 2005a; Dykiert at al., 2012). Here, we principally address reaction time's associations with higher cognitive abilities.

The long history of studies that explore the associations of reaction times with psychometric intelligence test scores was motivated by an attempt to find something more fundamental about nervous system performance that might account for some of the variation in higher-level cognitive efficiency (Deary, 2000). Finding that relatively simple, possibly more tractable, reaction time indices were significantly associated with cognitive test scores contributed to refuting the suggestion that the latter were largely based on successful enculturation; and reaction time-intelligence associations seemed to offer hope that some of the variance in intelligence might be understood in simpler terms. We previously noted that such associations tended to be small in effect size (Deary, 2000, chapter 6). However, a large proportion of studies had included student samples, with likely attenuation of effect sizes. When a large population-representative sample of middle-aged people was studied, the effect size for the association between choice reaction time and intelligence was -.49 (Deary, Der, & Ford, 2001); people who scored better on the brief Alice Heim 4 Test of General Intelligence Part 1 tended to have faster choice reaction times.

Before we accept this effect size, it is worth considering the response mode of the reaction time device that was used (Cox, Huppert, & Whichelow, 1993; Deary, Der, & Ford, 2001). The device is represented in Figure 1. Simple reaction time responses involve placing a finger lightly on the 0 button and pressing down as soon as a 0 appears on the liquid crystal display window. Choice reaction time responses involve placing the two index and middle fingers lightly on the buttons numbered 1 to

4, waiting to see which of the numbers 1, 2, 3, or 4 appears in the liquid crystal display window, and pressing the appropriate button as quickly as possible thereafter. This is arguably a more complex cognitive task than is desired in a reaction time task: the subject must process the number, translate the number into a relative position with respect to the four buttons, and then choose the appropriate button to press. It is possible, therefore, that this could be measuring individual differences in cognitive aspects of the process—the processing and translating to response position of the number—and this might explain this device’s relatively high correlation with intelligence (and perhaps age) by comparison with other devices. The main possibility focussed upon here is that location-based lights as stimuli require less higher-order cognitive engagement than numbers.

The present study had the following aims. First, we devised a task that was as similar in structure and response demands as possible to the original numbers-based reaction time device (Cox, Huppert, & Whichelow, 1993), but that replaced the need to process numbers and link them to a location with a much more straightforward stimulus-response contingency using lights and their locations. Second, we compared the associations between the two reaction time indices provided by the new and old tests. Third, we compared the two reaction time devices’ indices’ correlations with higher-level cognitive ability test scores and age. Fourth, we tested whether the reaction time indices from one reaction time device could account for the other device’s indices’ correlations with age and higher cognitive ability.

Method

Participants

We tested 150 participants. Fifty were young adults aged between 18 and 25 years (mean = 20.5, SD = 2.6), fifty were middle-aged adults aged between 45 and 60 (mean = 53.7, SD = 4.9), and fifty were older adults aged between 61 and 80 (mean = 69.1, SD = 6.2). The large majority of participants in the young adult group aged 18-25 were students from the University of Edinburgh. Some of the older participants in this group were non-student residents from the City of Edinburgh. Participants in the middle-aged and older adult groups were residents from the city of Edinburgh. Some of these participants were recruited via a university volunteer database, and others via advertising around the city. None of the participants in the two older groups were students. The students received course credit for their participation and all other adults were paid a small honorarium for taking part. These are the same subjects who were used to test and validate the computer-based Deary-Liewald reaction time test (Deary, Liewald, & Nissan, 2011). Here, we use the cognitive test scores and numbers-based reaction time test data that were used in that publication. Their data from the lights-based reaction time device have not been published previously.

Cognitive ability tests

Participants were tested on three higher-level cognitive measures: the Digit-Symbol Coding subtest of the Wechsler Adult Intelligence Scale III (Wechsler, 1997); the Matrix Reasoning subtest of the Wechsler Abbreviated Scale of Intelligence (Psychological Corporation, 1999); and the Wechsler Test of Adult Reading (WTAR) (Psychological Corporation, 2001). Digit-Symbol Coding was included as a paper-and-pencil test of processing speed, Matrix Reasoning as a fluid-type (age-sensitive) cognitive test of abstract reasoning, and WTAR as a test of crystallised-type (ageinsensitive) cognitive ability assessing vocabulary via pronunciation. The tests were applied according to instructions in the tests' manuals.

Reaction time tasks

Two reaction time tasks were used. These will be referred to as the Numbers reaction time box and the Lights reaction time box. Simple Reaction Time (SRT) and four-Choice Reaction Time (CRT) means and standard deviations were measured for each participant on both tasks. In the SRT, participants had to press a button in response to a single stimulus. In the CRT, there were four stimuli and participants had to press a button that corresponded to the correct response. For both reaction time tasks, the SRT involved eight practice trials and twenty test trials. The CRT for both tasks involved eight practice trials and forty test trials. Subjects undertook a third reaction time task, reported by Deary et al. (2011), but it is not reported further here.

Numbers reaction time box. The Numbers reaction time box was a rectangular, stand-alone box, originally designed for the UK Health and Lifestyle Survey (Cox, Huppert, & Whichelow, 1993; Figure 1). Data collected from it in large population-based studies have provided the associations with ageing, correlations with intelligence, and associations with mortality that were summarised in the Introduction. On its top surface, there is a liquid crystal display (LCD) screen and 5 response buttons, each with a number written above it. The buttons are arranged underneath the LCD screen in a gentle curve to fit the natural position of the participant's fingers. From left to right, the buttons are labelled with the numbers 1, 2, 0, 3, 4 (Figure 1). The stimulus for response is the appearance of a number on the LCD screen. Subjects are asked to respond as quickly as possible when a number appears. A number remains on the screen until participants make a response, after which it disappears and another number appears shortly after. The inter-stimulus interval ranges between 1 and 3 seconds and is randomised within these boundaries.

For the SRT, only the number 0 appears on the screen. Participants are instructed gently to rest the index finger of their preferred hand on the button labelled 0, and told that they will only be using this button. For the CRT, one of the numbers 1, 2, 3 or 4 appears on the screen. Participants are instructed gently to rest the index and middle fingers of their left hand on the buttons labelled 1 and 2, and the index and middle fingers of their right hand on the buttons labelled 3 and 4, and to press the button which corresponded to the number that appeared on the screen. For the SRT, the box records mean and standard deviation of response times. For the CRT, the box records the number of errors and the means and standard deviations of response times for correct and incorrect responses. The Numbers box does not record individual trial data.

Lights reaction time box. The Lights reaction time box is a rectangular, stand-alone box, designed by author IJD and constructed by Eagle Designs (Edinburgh, UK). The stimulus-response contingencies are not novel in reaction time work, but the main thing to note was the overall similarity of this device and the Numbers device. The sole study in which the Lights device was used previously was on the effect of high altitude on reaction times (Dykiert et al., 2010). On its top surface, there is a liquid crystal display (LCD) screen and 4 response buttons, arranged in a horizontal line below the screen. The LCD screen is for the tester’s use only and contains no stimulus information. Two of the buttons are positioned slightly to the left of the centre and two are positioned slightly to the right. Each button has a corresponding red light-emitting diode (LED) which is situated just above the button (Figure 2). The distance between the two furthest-apart lights is 6 cm, and the visual angle between these lights is 9.8 degrees, based on an approximated distance of 35 cm between a subject's eyes and the stimuli. In each trial a single LED is lit and participants are asked to respond as quickly as they can by pressing the button which is adjacent to the illuminated LED. The LED remains lit until a response is made, after which it is switched off and another LED is lit shortly after. The time interval between each response and when the next LED lit up ranges between 1 and 3 seconds.

For the SRT, the only LED in operation is the one on the far right (Figure 2). Participants are instructed to rest the index finger of their preferred hand over the button on the far right and told that they will be using only this button for the test. For the CRT, all four lights are used. Participants are instructed to rest the index and middle fingers of their left hand on the buttons to the left, and the index and middle fingers of their right hand on the buttons to the right, and to press the button which corresponds to the LED that lights up. The box records the response times for each response and whether these responses were correct or wrong. For the SRT, the box calculates mean and standard deviation of response times. For the CRT, the box calculates the number of correct and incorrect responses, and the means and standard deviations of response times for correct and incorrect responses.

Procedure

Participants first completed a short social and demographic questionnaire which asked questions about their age, gender, education (number of years in full-time education), and occupation (the SOC2000, based on the UK's standard classification of occupations; Rose & Pevalin, 2003). The younger group was asked about their parents' occupations. They then completed the tasks in the following order: Reaction Time Task (a), Matrix Reasoning, Reaction Time Task (b), WTAR, Digit-Symbol

Coding, Reaction Time Task (c). Note that there are three reaction time tasks and that one is not reported here. The order in which the different reaction time tasks were completed was varied equally among the participants.

Results

Background and Cognitive Measures

Table 1 describes the Means (SD) and Table 2 describes the Frequencies for the background measures, cognitive measures and the reaction time results for the total sample and for the three age groups. The mean (SD) number of years in full time education was 15.1 (2.9). There was a significant difference between the age groups with regard to the Standard Occupational Classification (SOC2000; $\chi^2[12, N = 150] = 24.46$, $p < .009$; see Table 2). One-way ANOVAs with a between subjects factor of age (3 levels: Young, Middle-aged and Old) revealed a significant effect of age on the WTAR ($F[2,147] = 13.05$, $p < 0.01$, $\eta^2 = .15$), the Matrix Reasoning test ($F[2,147)] = 33.73$, $p < 0.01$, $\eta^2 = .32$), and the Digit-Symbol Coding test ($F[2,147] = 22.73$, $p < 0.01$, $\eta^2 = .24$). Younger adults scored higher on the Matrix Reasoning and Digit-Symbol Coding tests, and lower on the WTAR, than the middle-aged and older adults. There was no difference between the middle-aged and old groups in any of these tests (see Table 1). The full correlation matrix for these variables is shown in Table 3. Most notable are the strong inverse correlations between age and Matrix Reasoning and Digit-Symbol Coding tests, and a substantial positive correlation between age and WTAR.

Reaction Time Tasks

Comparison of the two reaction time tasks. With regard to the SRT measures, repeated measures t-tests revealed that there was no difference between the Numbers task and the Lights task with regard to mean response times or SD of response times. With regard to the CRT measures, mean response time was substantially slower for the Numbers task (555.8 ms) than the Lights Box (412.6 ms) [t(149) = 32.16, $p < .01$, Cohen's $d = 1.6$]. The mean SD of response times was higher for the Numbers task (108.2 ms) than the Lights task (73.8 ms) [t(149) = 14.54, $p < .01$]. The mean number of errors made with the Numbers task (2.5) was higher than the Lights Box (1.7) [t(149) = 2.96, $p < .01$]. Not all reaction time parameters were normally distributed, so we repeated comparisons between the different measures of the Lights and Numbers tasks using the Wilcoxon non-parametric test. The size of the samples in all comparisons was 150 for the Lights Task and 150 for the Numbers Task. There were no significant differences for Simple RT Mean or SD. There were significant differences for Choice RT Mean (W = 0.00, Z = -10.62, p <.001), SD (W = 389.00, Z = -9.85, p <.001) and number of errors (W = 1669.50, Z = -2.61, p =.009).

The correlations between the reaction time measures are shown in Table 4. With regard to the Simple Reaction Time (SRT) tasks, there was a large, significant positive correlation between the mean response times of the Numbers task and the Lights task (r = .68). There was a significant positive correlation between the Standard Deviations (SD) of response times of the Numbers task and the Lights task (r = .26). The correlations of the means and SDs within both reaction time tasks were also all significant.

With regard to the Choice Reaction Time (CRT) tasks, there was a very large, significant positive correlation between the mean response times of the Numbers task and the Lights task (r = .81). There was a large significant positive correlation between the standard deviations (SD) of response times for the Numbers task and the Lights task (r = .57). The correlations of the means and SD within each task were also large and significant: Numbers task (r = .78); Lights task (r = .84). Faster participants were less variable. There was a significant positive correlation between the number of errors made in the Numbers task and the Lights task (r = .19). There were few errors overall. The number of errors and mean response times within each task were slightly negatively correlated: Numbers task (r = -.25); Lights task (r = -.23).

Not all reaction time parameters are perfectly normally distributed, especially errors for which even transformations will not achieve a normal distribution. Therefore, the above correlations were all re-run using the non-parametric Spearman's ρ coefficient. The results are shown in parentheses below the Pearson correlations in Table 4. These differ very little from the Pearson *r* coefficients, and show that the Pearson coefficients have not led to any over-estimation of effect sizes.

Reaction time correlations with age and higher cognitive abilities. Table 5 shows the correlations between the background and cognitive variables with the two reaction time tasks. Age correlated significantly with all of the reaction time measures apart from the number of errors made in the Lights task CRT. Older people were slower and more variable. Education correlate non-significantly with all reaction time measures except mean SRT from the Lights task. People in more professional occupations (SOC2000) had faster and less variable CRT in both tasks, and faster SRT in the Numbers task. For the cognitive measures (WTAR, Matrix Reasoning, and Digit-Symbol Coding), we report both raw and gender- and age-adjusted correlations, because of these measures' different correlations with age (see Tables 3 and 5). The WTAR showed near-to-zero raw correlations with reaction time indices. When gender- and age-adjusted, there were significant negative correlations with CRT Mean and SD in both the Numbers and Lights tasks, and with SRT Mean and SD in the Lights task. Matrix Reasoning was substantially negatively correlated with nearly all of the SRT and CRT variables. When age (and gender) was controlled, the effect sizes in the Lights task were reduced and many of the correlations were not significant in the Numbers task. Digit-Symbol Coding correlated negatively with the majority of reaction time measures, except errors, and nearly all of these persisted, though reduced in effect size, when age (and gender) was controlled. Importantly for the present study, the choice reaction time means and SDs from the two devices were correlated at very similar levels with Matrix Reasoning and with Digit-Symbol coding.

The above Results were repeated using the non-parametric Spearman's ρ coefficient, for the reasons that were given above. The results are given in Appendix Table 1. They are very similar to those obtained with the Pearson correlation analyses.

It is likely that the cognitive test-reaction time correlations are attenuated because of restriction of range in our samples: people who take part in such studies generally have higher mean cognitive ability scores and less variance than the population from which they are drawn. To examine this, we compared the Matrix Reasoning SD of each of our age-samples with those from age-matched Wechsler normative data (Wisdom, Mignogna, & Collins, 2012). This revealed that our young, middle-aged, and older samples' SDs were, respectively, 80%, 90% and 53% of the population SDs. We re-calculated the correlations between the CRT means of the Lights and Numbers devices with Matrix Reasoning after correcting for these restrictions of range, using Thorndike's case 2 correction method described in Wiberg and Sundström (2009). The disattenuated coefficients are shown in Table 6 alongside the raw coefficients. As expected, because theirs is the greatest range restriction, the largest increment is found in the older sample.

Similarity of the correlations between the two devices' reaction time parameters with age and higher cognitive abilities are necessary but not sufficient to establish that these correlations are due to the shared rather than the unique processes that the reaction time procedures involve. Therefore, we examined how much attenuation would take place if the correlation between a reaction time parameter and age or higher cognitive ability was adjusted for the equivalent reaction time parameter from the other device. For this analysis we used only CRT mean and SD, as these are the most reliable variables and have the highest correlations with age and intelligence in past research. The metric of attenuation used is the reduction in shared variance (the correlation squared) after adjustment, not the reduction in the raw correlation. Table 5 shows the results. With respect to correlations with age, that of the Lights task CRT mean is reduced by 91% after adjustment by Numbers task CRT mean. The reverse attenuation is 62%, and the respective attenuations when the CRT SD measures are used are 45% and 68%. Given that the reliability of none of the measures used in these analyses is perfect, these attenuations are large. The attenuations of the associations with higher cognitive abilities are also large (Table 5), with the Matrix Reasoning and Digit-Symbol Coding correlations often falling from large to small or almost small effect sizes. These results suggest that the age- and higher cognitive ability- associations with CRT means and SDs are largely due to processing differences shared by the two reaction time tasks. Note, also, that there remain significant associations between Lights task CRT mean and SD and WTAR and Digit-Symbol Coding, even after the adjustments for age, gender and the equivalent parameter from the Numbers RT task.

Discussion

We designed and constructed a reaction time device for comparison with a widely-used and well-validated device described as the Numbers reaction time box (Deary, Der, & Ford, 2001). The Lights reaction time box we constructed was highly similar, except that it used the position of lights as the response stimuli, which took away the number-processing element of the other device. We aimed to test whether the strong correlations with age and intelligence that have been obtained with the Numbers reaction time box were caused by its choice reaction time procedure's requiring higher-level cognitive processing. The simple reaction time means and SDs from the Lights and Numbers devices were very similar. However, the choice reaction time means and SDs were both considerably larger in the Numbers versus the Lights device. The Lights task's choice reaction time mean was almost 150ms less than that obtained from the numbers device, an effect size (Cohen's *d*) of 1.6. This is as expected if the Numbers box involved additional stages of cognitive processing. The small difference between devices in the number of errors might be because it is easier to confuse a number with another number and its spatial location, than with a light which is shown directly at its designated response location.

The important (with respect to age and intelligence) parameters of the Lights task were very highly correlated with the same parameters of the Numbers box. Both tasks were similarly associated with age, social factors, and the three psychometric cognitive tests. Faster and less variable reaction times were associated with being younger, being in more professional occupations, and with scoring higher on tests of abstract reasoning and processing speed. As such, the comparison between the Lights task and the Numbers task provides support for the Lights task as a valid and reliable reaction time task. The large attenuation of either RT device's CRT parameters' correlations with age and psychometric cognitive tests suggests that the source of these correlations is mostly in processing differences common to the two tasks. Especially, we note that the correlations between the CRT mean and age and Matrix Reasoning and Digit-Symbol Coding often fall from large to small or almost small effect sizes. However, the fact that there are some significant small associations between Lights task CRT mean and SD and WTAR and Digit-Symbol Coding even after the equivalent parameter from the Numbers RT task was controlled for means that there is some unique contribution to these cognitive task performances from the Lights task.

More importantly, in the Lights device that produces much lower choice reaction times, and which involves obviously simpler processing demands, the key associations with abstract reasoning and the Digit Symbol text suggest that the relatively large effect estimates for intelligence-choice reaction time associations obtained using the Numbers device (Deary, Der, & Ford, 2001) are not a result of the Numbers device's requiring complex processing prior to pressing the response button. Instead, it appears that the individual differences captured by the Numbers device are substiantially retained in the simpler Lights reaction time device. Jensen (especially in Jensen, 1987; also in Jensen, 1998; and as discussed in Deary, 2003) stressed that it is important to pay attention to the changes in parameters—SDs as well as means—between different tests of information processing. Thus, the increases in SD and mean from the Lights to the Numbers device indicate that there are extra processing stages in the Numbers task. However, the individual differences in these stages do not appear to account for much of the age or higher cognitive ability variation that is shared with choice reaction time variance. We also draw readers' attention to our previous paper, using this same subject sample, that found strong associations between the Numbers reaction time task and a computerised task that has similar stimulus-response contingencies to those used in the Lights task in the present report (Deary, Liewald, & Nissan, 2011).

None of the reaction time parameters used in the present study has perfect reliability—and, of course, neither do the cognitive tests—and so it is useful to be reminded of the relative reliabilities of the parameters in assessing the correlations found here. For the Numbers task, in a previous study, we found almost-period-free test-retest reliability (Spearman's ρ) as follows: SRT mean = .67; SRT SD = .20; CRT mean = .92; CRT SD = .73 (Deary & Der, 2005c). Therefore the correlations, especially those with SRT SD, could not be expected to have reached beyond modest effect sizes.

The correlations we found between reaction time and higher cognitive ability test scores were somewhat lower than those reported by Deary, Der and Ford (2001). This is partly due to two factors. The first is that our present samples were somewhat restricted in ability range by comparison with the sample in Deary et al., which was fully representative of its background population. Disattenuation of the coefficients in the present study led to at least the older sample's coefficients approximating those of Deary et al. However, that study used the Alice Heim 4 test, which is almost certainly a more reliable and broad test of general cognitive ability than Matrix Reasoning and therefore likely to be more strongly correlated with reaction time.

Strengths of the present study include: the careful assembly of a reaction time device that shared as many physical and response characteristics as possible with the comparison device (Numbers; Cox, Huppert, & Whichelow, 1993); and demographically and cognitively well-characterised samples of young, middle-aged and older people. The individual age group samples were modest in size, though the overall sample size was moderately large. The Numbers device did not retain individual trial data, which means that any extreme responses would not be excluded, and that means were used as an individual’s score. It would have been ideal to be able to exclude any outlying responses, and also to take account more fully of the reaction time distributions. However, it was important that the present study was conducted using the procedures and parameters of the Numbers task that have produced so much age- and intelligence- relevant findings, and that the Lights task was similarly set-up and used. The likely effect of not having individual trial data is the addition of some noise to the reaction time parameters, and some lowering of effect sizes. Despite that, the results were clear and cross-device effect sizes were large.

In the present study we argued that the Lights device is less complex than the Numbers procedure, and that relations with the Lights device may be less influenced by requirements associated with processing and translation. Although this appears to be reasonable, there are other differences between the two devices, and the role of translation or other processing requirements could be investigated in future research much more directly within any one device. For example, instructions across conditions could be varied, as in research on stimulus-response compatibility effects. Our largely in-principle arguments about the involvement of theoretical processes involved in the tasks would be helped in future research with more direct, experimentally-manipulated comparisons in which nearly everything is the same except for a critical manipulation.

There will continue to be discussion about why people differ in intelligence and what reaction time can tell us about those differences. The present study at least eliminates some higher-level cognitive confounders from the results obtained from the device that has, to date, provided the strongest evidence for that association.

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Table 1

Means and Standard Deviations (SD) for Background, Cognitive and Reaction Time Task Measures

Variable	Age								
	18-25		45-60		61-80		Total		ANOVA
	N	*Mean (SD)*	*N*	*Mean (SD)*	*N*	*Mean (SD)*	*N*	*Mean (SD)*	*p*
Age (years)	50	20.5 (2.6)	50	53.7 (4.9) [a]	50	69.1 (6.2) [b c]	150	47.7 (20.9)	<.001
Education (years)	50	14.8 (2.3)	50	15.5 (3.2)	50	14.9 (3.2)	150	15.1 (2.9)	.37
WTAR (no. correct)	50	41.5 (4.2)	50	45.1 (6.5) [a]	50	46.4 (4.0) [b]	150	44.3 (5.4)	<.001
Matrix Reasoning (raw score)	50	28.4 (3.6)	50	23.2 (4.3) [a]	50	22.4 (3.9) [b]	150	24.6 (4.7)	<.001
Digit-Symbol Coding (raw score)	50	85.0 (13.7)	50	72.1 (13.6) [a]	50	67.3 (13.4) [b]	150	74.8 (15.4)	<.001
LS mean (ms)	50	230.8 (31.2)	50	276.2 (50.3) [a]	50	270.7 (47.7) [b]	150	259.2 (48.1)	<.001
LS SD (ms)	50	42.3 (17.8)	50	58.1 (25.0) [a]	50	55.4 (18.5) [b]	150	51.9 (21.7)	<.001
LC mean (ms)	50	334.7 (45.2)	50	432.9 (57.1) [a]	50	470.1 (78.5) [b c]	150	412.6 (84.0)	<.001
LC SD (ms)	50	52.9 (15.5)	50	75.4 (18.9) [a]	50	93.1 (26.5) [b c]	150	73.8 (26.4)	<.001
LC Errors (trials)	50	1.9 (2.1)	50	1.5 (3.1)	50	1.7 (1.9)	150	1.7 (2.4)	.71
NS mean (ms)	50	230.2 (17.5)	50	269.1 (30.4) [a]	50	267.7 (45.2) [b]	150	255.7 (37.5)	<.001
NS SD (ms)	50	40.8 (15.2)	50	54.0 (23.1) [a]	50	54.2 (23.1) [b]	150	49.7 (21.6)	.001
NC mean (ms)	50	459.4 (42.5)	50	581.2 (66.3) [a]	50	626.8 (63.0) [b c]	150	555.8 (91.5)	<.001
NC SD (ms)	50	80.8 (20.0)	50	115.5 (28.3) [a]	50	128.2 (33.4) [b c*]	150	108.2 (34.2)	<.001
NC Errors (trials)	50	3.6 (3.4)	50	1.6 (2.1) [a]	50	2.2 (2.6) [b*]	150	2.5 (2.8)	.001

[a] = significant difference between age groups 18-25 and 45-60 at 0.01 level
[b] = significant difference between age groups 18-25 and 61-80 at 0.01 level
[c] = significant difference between age groups 45-60 and 61-80 at 0.01 level
[*] = significant at 0.05 level.
Key: WTAR=Wechsler Test of Adult Reading; LS=Lights Box, Simple Reaction Time task; LC=Lights Box, Choice Reaction Time task; NS=Numbers Box, Simple Reaction Time task; NC= Numbers Box, Choice Reaction Time task; Errors=Percentage of incorrect responses.

Table 2

Frequencies, Percentages and Non-Parametric Tests for Gender, Handedness and Occupational Classification

Variable	Age				
	18-25	45-60	61-80	Total	Non-Parametric tests
	N (%)	*N (%)*	*N (%)*	*N (%)*	*p*
Gender					
Male	24 (48)	17 (34)	17 (34)	58 (39)	.25 [a]
Female	26 (52)	33 (66)	33 (66)	92 (61)	
Handedness					
Right	46 (92)	46 (92)	45 (90)	137 (91)	.92 [b]
Left	4 (8)	4 (8)	5 (10)	13 (9)	
SOC2000*					
1	20 (40)	10 (20)	6 (12)	36 (24)	.009 [c]
2	23 (46)	17 (34)	27 (54)	67 (45)	
3	2 (4)	9 (18)	8 (16)	19 (13)	
4	4 (8)	7 (14)	7 (14)	18 (12)	
5	0 (0)	1 (2)	0 (0)	1 (1)	
6	1 (2)	4 (8)	2 (4)	7 (5)	
7	0 (0)	2 (4)	0 (0)	2 (1)	
8	0 (0)	0 (0)	0 (0)	0 (0)	
9	0 (0)	0 (0)	0 (0)	0 (0)	

* = Standard Occupational Classification 2000: 1=Managers and senior officials, 2=Professional occupations, 3=Associate professional and technical occupations, 4=Administrative and secretarial occupations, 5=Skilled trades occupations, 6=Personal service occupations, 7=Sales and customer service occupations, 8=Process, plant and machine operatives, 9=Elementary occupation
[a] = Chi squared test
[b] = Exact test
[c] = Monte Carlo test: based on 10000 sampled tables with starting seed 2000000

Table 3

Pearson correlations Among Background and Cognitive Measures

	2	3	4	5	6
1. Age	.08	.25**	.40**	-.57**	-.53**
2. Education	—	-.25**	.50**	.30**	.05
3. SOC2000[a]		—	-.08	-.29**	-.21**
4. WTAR[b]			—	.10	-.18*
5. Matrix Reasoning				—	.42**
6. Digit-Symbol Coding					—

**=Correlation is significant at the 0.01 level
*=Correlation is significant at the 0.05 level
[a] = Standard Occupational Classification 2000
[b] =Wechsler Test of Adult Reading

Table 4

Pearson *r* correlations (Spearman's in parentheses) Among the Measures of the Simple and Choice Reaction Time Tasks for the Lights Task and Numbers Task

	2	3	4	5	6	7	8	9	10
1. LS Mean	.55** (.64**)	.54** (.58**)	.40** (.45**)	-.20* (-.21*)	**.68**** (**.68****)	.28** (.26**)	.52** (.52**)	.34** (.38**)	-.19* (-.27**)
2. LS SD	—	.41** (.42**)	.35** (.40**)	-.05 (-.02)	.39** (.41**)	**.26**** (**.24****)	.38** (.38**)	.32** (.37**)	-.07 (-.11)
3. LC Mean		—	.84** (.83**)	-.23** (-.20*)	.56** (.58**)	.36** (.38**)	**.81**** (**.82****)	.60** (.63**)	-.30** (-.31**)
4. LC SD			—	-.10 (-.05)	.38** (.42**)	.33** (.33**)	.70** (.72**)	**.57**** (**.62****)	-.21** (-.20*)
5. LC Errors				—	-.26** (-.29**)	-.15 (-.23**)	-.16 (-.13)	-.07 (-.03)	**.19*** (**.15**)
6. NS Mean					—	.56** (.59**)	.54** (.56**)	.32** (.34**)	-.19* (-.26**)
7. NS SD						—	.33** (.34**)	.26** (.29**)	-.12 (-.18*)
8. NC Mean							—	.78** (.82**)	-.25** (-.23**)
9. NC SD								—	-.15 (-.16)
10. NC Errors									—

Note:
**=Correlation is significant at the 0.01 level
*=Correlation is significant at the 0.05 level
Correlations between the same parameters in the two reaction time tests are shown in bold.
Correlations reported are for the full sample (N = 150)

Key: LS=Lights Box, Simple Reaction Time task; LC=Lights Box, Choice Reaction Time task; NS= Numbers Box, Simple Reaction Time task; NC= Numbers Box, Choice Reaction Time task; Errors=Percentage of incorrect responses

Table 5

Correlations Between Background and Cognitive Variables and the Measures of the Simple and Choice Reaction Time Tasks for the Lights Task and Numbers Task

		LS Mean	LS SD	LC Mean	LC SD	LC Errors	NS Mean	NS SD	NC Mean	NC SD	NC Errors
Age [a]	Full Sample	.37**	.27**	.70**	.66**	-.02	.43**	.30**	.76**	.58**	-.26*
	(RT Adjusted[c])	(.11)	(.21*)	(.21**)	(.49**)	(.03)	(.27**)	(.25**)	(.47**)	(.33**)	(-.26**)
	(% Attenuation[d])			*91*	*45*				*62*	*68*	
Education [a]		-.18*	-.11	-.12	-.06	-.01	-.04	-.02	-.11	-.09	-.06
SOC2000 [b]		.15	.04	.35**	.30**	-.13	.27**	.16	.37**	.32**	-.08
WTAR [a]	Full Sample	-.04	-.11	.08	.10	.45	.10	.08	.11	.05	-.06
	(RT Adjusted[c])	(-.15)	(-.13)	(-.02)	(.08)	(.06)	(.17*)	(.11)	(.09)	(-.01)	(-.07)
	(% Attenuation[d])			*94*	*36*				*33*	*96*	
	(Age & Gender Adjusted)	(-.20*)	(-.23**)	(-.30**)	(-.24**)	(.06)	(-.08)	(-.05)	(-.32**)	(-.23**)	(.06)
	(Age, Gender & RT Adjusted[c])	(-.20*)	(-.23**)	(-.15*)	(-.18*)	(.04)	(.06)	(-.00)	(-.18*)	(-.17*)	(.05)
	(% Attenuation[d])			*75*	*44*				*68*	*45*	
Matrix Reasoning [a]	Full Sample	-.49**	-.33**	-.55**	-.45**	-.01	-.35**	-.18*	-.56**	-.38**	.19*
	(RT-Adjusted[c])	(-.37**)	(-.29**)	(-.19*)	(-.31**)	(-.04)	(-.03)	(-.11)	(-.24**)	(-.17*)	(.20*)
	(% Attenuation[d])			*88*	*53*				*82*	*80*	
	(Age & Gender Adjusted)	(-.39**)	(-.22**)	(-.26**)	(-.13)	(-.02)	(-.15)	(-.01)	(-.24**)	(-.08)	(.05)
	(Age, Gender & RT Adjusted[c])	(-.38**)	(-.23**)	(-.15)	(-.11)	(-.03)	(.12)	(.03)	(-.11)	(-.05)	(.06)
	(% Attenuation[d])			*67*	*28*				*79*	*61*	
Digit-Symbol Coding [a]	Full Sample	-.32**	-.32**	-.59**	-.56**	.19	-.41**	-.37**	-.62**	-.46**	.15
	(RT-Adjusted[c])	(-.06)	(-.25**)	(-.19*)	(-.41**)	(-.01)	(-.28**)	(-.31**)	(-.30**)	(-.21*)	(.15)
	(% Attenuation[d])			*90*	*46*				*77*	*79*	
	(Age & Gender Adjusted)	(-.23**)	(-.27**)	(-.38**)	(-.35**)	(.02)	(-.28**)	(-.27**)	(-.42**)	(-.27**)	(-.01)
	(Age, Gender & RT Adjusted[c])	(-.07)	(-.23**)	(-.18*)	(-.29**)	(.02)	(-.19*)	(-.23**)	(-.25**)	(-.18*)	(-.01)
	(% Attenuation[d])			*78*	*31*				*65*	*56*	

Note: **=Correlation is significant at the 0.01 level
*=Correlation is significant at the 0.05 level
[a]=Pearson's *r* Correlations (see Appenix 2 for Spearman's correlations)
[b]=Spearman's ρ Correlations

[c] 'RT Adjusted' correlations adjust for the corresponding reaction time measure from the other reaction time device; e.g. the RT Adjusted correlation between Age & LS Mean adjusts for the effect of NS Mean; the RT Adjusted correlation between Age & NC Mean adjusts for the effect of LC Mean, etc.
[d] '% Attenuation' refers to the percentage of change in variance between the two correlations immediately above in the table, i.e. the percentage of change in variance when adjusted for reaction time performance in the same parameter from the other reaction time task. For method, see main text.

Key: SOC2000=Standard Occupational Classification 2000; WTAR=Wechsler Test of Adult Reading; LS=Lights Box, Simple Reaction Time task; LC=Lights Box, Choice Reaction Time task; NS= Numbers Box, Simple Reaction Time task; NC= Numbers Box, Choice Reaction Time task; Errors=Percentage of incorrect responses, RT=Reaction Time.

Table 6

Raw and Disattenuated Correlations between Matrix Reasoning and Choice Reaction Time Means for the Lights and Numbers Tasks within different age-groups

Age Group	LC Mean		NC Mean	
	Raw *r* [a]	Disattenuated *r* [b]	Raw *r* [a]	Disattenuated *r* [b]
18-25	-0.27	-0.33	-0.18	-0.22
45-60	-0.23	-0.26	-0.3	-0.33
61-80	-0.34	-0.57	-0.23	-0.41

[a] 'Raw *r*' refers to correlations for the raw sample data.
[b] 'Disattenuated *r*' refers to correlations corrected for restriction in ability range on Matrix Reasoning. We used Thorndike's case 2 correction method described in Wiberg and Sundström (2009), comparing Matrix Reasoning SDs of each of our age-samples with those from age-matched Wechsler normative data (Wisdom, Mignogna, & Collins, 2012).

Key: LC=Lights Box, Choice Reaction Time task; NC= Numbers Box, Choice Reaction Time task

Appendix Table 1

Spearman's ρ correlations Between Background and Cognitive Variables and the Measures of the Simple and Choice Reaction Time Tasks for the Lights Task and Numbers Task, for Comparison with Pearson's *r* Correlations in Table 5 of Main Article

	LS Mean	LS SD	LC Mean	LC SD	LC Errors	NS Mean	NS SD	NC Mean	NC SD	NC Errors
Age	.36**	.27**	.70**	.66**	.00	.41**	.31**	.74**	.58**	-.20*
Education	-.12	-.09	-.10	-.04	.06	-.01	.04	-.09	-.06	-.10
SOC2000	.15	.04	.35**	.30**	-.13	.27**	.16	.37**	.32**	-.08
WTAR	.15	.04	.35**	.30**	-.13	.27**	.16	.37**	.32**	-.08
Matrix Reasoning	-.48**	-.35**	-.54**	-.44**	.02	-.41**	-.20*	-.57**	-.43**	.12
Digit-Symbol Coding	-.35**	-.32**	-.61**	-.59**	.02	-.42**	-.38**	-.60**	-.49**	.18*

Note: **=Correlation is significant at the 0.01 level
*=Correlation is significant at the 0.05 level
Correlations reported are for the full sample only

Key: SOC2000=Standard Occupational Classification 2000; WTAR=Wechsler Test of Adult Reading; LS=Lights Box, Simple Reaction Time task; LC=Lights Box, Choice Reaction Time task; NS= Numbers Box, Simple Reaction Time task; NC= Numbers Box, Choice Reaction Time task; Errors=Percentage of incorrect responses.

Figure 1

Illustration of the top surface of the Numbers Reaction Time Box.

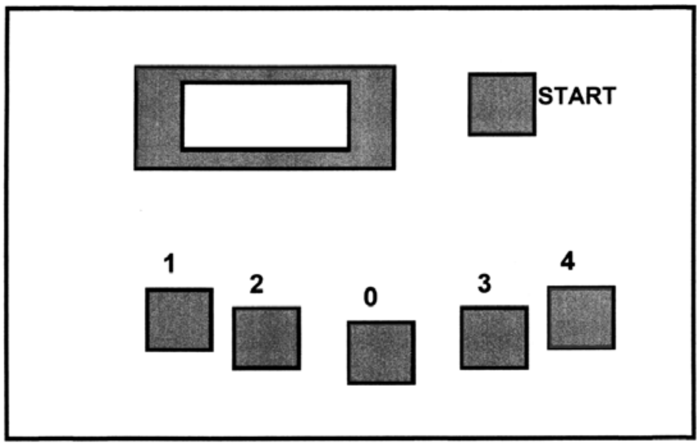

Figure 2

Illustration of the top surface of the Lights Reaction Time Box.