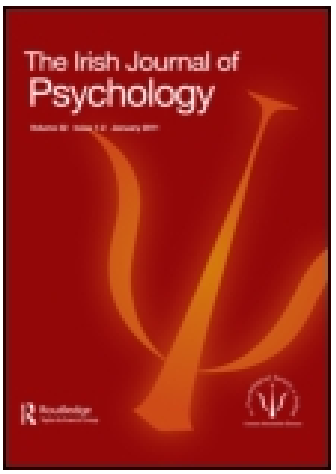

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Reaction Times, Movement Times and Intelligence Among Irish Nine Year Olds

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Reaction Times, Movement Times and Intelligence Among Irish Nine Year Olds

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Nine year old children (n=191) were tested for 12 reaction time parameters measuring simple, choice and odd-man-out reaction times, movement times and variabilities, and were also tested on 12 intelligence tests measuring major reasoning, verbal and visuospatial primary abilities. The results showed that reaction times, movement times and variabilities were all correlated with psychometric intelligence. Factor analysis suggested that reaction time tasks can be broken down into three factors of movement time, reaction time and odd-man-out reaction time.

During the last few years there has been a good deal of interest in the relationship between reaction times and intelligence as measured by conventional intelligence tests. A number of studies have claimed that reaction times correlate with intelligence tests at a magnitude of around .1 to .5, (e.g., Jensen, 1982, 1987; Vernon, 1983). It has further been argued that reaction time (RT) provides a measure of the neurological efficiency of the brain, or what can be termed 'biological' intelligence (Jensen, 1982; Eysenck, 1982). The theory proposed by Jensen (1982) is that reaction times are a function of the speed of neural processing. This is itself a function of neural oscillation, that is, it is proposed that if neural cells fire more quickly the subject can handle more information and react faster. This also determines performance on intelligence tests and accounts for the correlation between reaction time and intelligence. Eysenck (1982) has advanced an alternative theory to the effect that the accuracy of neural transmission is the crucial component underlying individual differences in reaction times. Accuracy of neural transmission would

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also enter into the ability to solve the problems in intelligence tests, and this would give rise to the positive correlations between reaction times and intelligence.

In these studies five parameters of reaction times have been measured. These are (i) movement time (MT); (ii) simple reaction time involving response to a single light; (iii) complex reaction times involving responses to several lights; (iv) reaction times in the more complex odd-man-out (OMO) task of Frearson and Eysenck (1986), involving the identification of the most distant of three lights; and (v) the variability of the reaction times in a set of trials, generally measured by the standard deviation of the reaction times. In general it has been found that RTs in the more complex tasks have higher correlations with intelligence than MTs or RTs in more simple tasks (Jensen, 1987). There are also some studies showing that the variability of reaction times is more highly correlated with intelligence than the mean speed of reaction, a finding which has led some commentators to infer that consistency of attention may be an important variable responsible for the correlations between reaction times and intelligence (Jensen, 1987; Mackintosh, 1986).

The present study involved the collection of further data on the relationship between reaction times and intelligence with the aim of advancing knowledge in this area in two directions. Firstly, most studies have been carried out on university students (Jensen, 1987; Vernon, 1983), young adults (Frearson & Eysenck, 1986) or secondary school children (Jensen & Munro, 1979). There have been few studies of representative samples covering the whole ability range of primary school children, who constitute the subjects in the present investigation. The first objective was, therefore, to determine whether the relationships obtained among selected groups of adolescents and adults in North America are also present among primary school children in Ireland. Secondly, in most of the previous studies, reaction time tests have been administered with a single intelligence test, generally Raven's Progressive Matrices (Frearson & Eysenck, 1986; Jenson & Munro, 1974). In the present study the reaction time tests were administered together with a battery of standard intelligence tests. This would permit the factor analysis of the entire set of tests to determine whether the various reaction time parameters and intelligence tests are all loaded on a general factor — normally identified with general intelligence, or Spearman's g — as well as whether the reaction time parameters can be analysed into independent primary factors, and if so whether some of these may be identifiable with some of the established primary mental abilities.

METHOD

Subjects

The subjects comprised 95 boys and 96 girls aged between 9.00 and 9.11 years who were pupils from country primary schools in the Irish Republic. All the children in the selected schools in this age range were tested.

Materials and procedure

The cognitive tests were selected to represent the major primary abilities listed by Ekstrom, French, Harman and Dermen (1976). These primary abilities are listed below, together with the test used for measuring them.

1. *Verbal comprehension.* Mill Hill Vocabulary Test.
2. *Reasoning.* Raven's Standard Progressive Matrices.
3. *Verbal closure.* 20 anagram problems were given consisting of 3 and 4 letter words which had to be rearranged to make words (time allowed: 2 min).
4. *Number.* The Primary Mental Abilities Addition Test consisting of 20 addition sums (Thurstone, 1963).
5. *Long term memory.* A short story was read to the children prior to the administration of the Primary Mental Abilities Addition Test. The story was read aloud by the tester and the children followed the story from a copy printed in the test booklets. They were asked to try to remember as much about the story as possible. When the Primary Mental Abilities Addition Test had been completed the children were given a multiple-choice test about the story. Twelve questions were asked and in each case the subjects were required to choose the correct answer from a number of alternatives.
6. *Ideational fluency.* The subjects were asked to write the names of as many animals as they could think of (time allowed: 2 min).
7. *Space relations.* The Primary Mental Ability Space Relations Test (Thurstone, 1963).
8. *Flexibility of closure.* Hidden Patterns Test; the subjects were presented with 120 small diagrams and were asked to indicate whether or not each of the diagrams contained a given pattern.
9. *Perceptual speed.* The Primary Mental Abilities Test (Thurstone, 1963).
10. *Associative memory.* The subjects were asked to study and try to remember a list of 10 Christian and surnames (time allowed: 1 min). The correct surnames were provided in the answer booklets and the subjects were asked to insert the correct Christian name from memory (time allowed: 2 min).
11. *Word fluency.* Word Endings Test; the subjects were asked to write as many words as they could think of which end in 'ay' (time allowed: 2

min). This test was described by Ekstrom, French, Harman and Dermen (1976).

12. *Spelling*. The Schonell Spelling Test; this consists of 40 words which are read out to the subject, who writes them down. The score consists of the number spelled correctly.

The reaction times were recorded with an apparatus similar to that described by Jensen and Munro (1979). It consisted of a flat black metal box with the top side pitched at a 20° angle. On the top surface of the box was a 15 cm radius semicircle of 8 plastic, .75 in. microswitch pushbuttons which were lit from beneath. At the centre of the semicircle, nearest the subject, was a black 'home' button. Pressing the home button activated each trial which was programmed and timed by an Apricot microcomputer. The subject's data were recorded automatically on the working disc immediately after each trial. The apparatus measured reaction time (time between onset of a stimulus light and release of the home button) and movement time (time between the release of the home button and depression of the stimulus button). The consistency of response for reaction time and movement time was also measured as the standard deviation of responses across trials (Buckhalt & Jensen, 1989).

Three conditions were employed in the reaction time experiment. In the first condition simple reaction time was measured. Only one of the lights was employed and the others were masked. Sixteen trials were given, preceded by 3 practice trials. In the second condition choice reaction time was measured. All eight lines were employed. On each of the 16 trials one of the lights came on at random. The third condition involved the use of the odd-man-out paradigm. Thirty odd-man-out trials were presented in two blocks of 15 trials with a rest of approximately 1 min between them. In each of the trials, three of the eight buttons illuminated simultaneously and the subjects were asked to press the button which was furthest away from the other two (i.e., the odd man out). After the third condition another 16 trials of the second condition were given.

When errors occurred due to the subjects pressing the wrong button, the trials were repeated at the end of the block of trials in that condition. If errors recurred on repetition the trial was repeated until the correct response was made. Trials were logged as errors where the RT was less than 170 msec or greater than 999 msec, or greater than 1,999 msec on the OMO task, or where the MT was less than 40 msec or greater than 999 msec.

The following measures were obtained from the reaction time trials: the medians of the movement times, the simple reaction times, the complex (3 bit) reaction times and the odd-man-out reaction times (medians were taken rather than means to minimise the effects of occasional exceptionally fast or slow reaction times), and the variability of each of these reaction times as measured by the standard deviations.

Table 1. Means (and *SD*s) of cognitive test scores and of medians and standard deviations of simple, choice and OMO reaction times and movement times (msec) for boys (n=95) and girls (n=96), and deviation (D) scores and t-values associated with the differences between their means.

	Males		Females			
Test	*M*	*SD*	*M*	*SD*	D	*t*-value
Simple RT *Median*	371.95	(55.16)	380.49	(50.43)	0.16	-1.12
Choice RT *Median*	466.61	(59.56)	468.36	(57.85)	0.03	-0.20
OMO RT *Median*	850.42	(160.19)	897.33	(175.41)	0.28	-1.93
Simple MT *Median*	223.56	(56.32)	234.61	(58.42)	0.19	-1.12
Choice MT *Median*	250.71	(67.64)	255.91	(54.32)	0.08	-1.59
OMO MT *Median*	278.66	(89.39)	279.89	(79.35)	0.01	-1.89
Simple RT *SD*	114.40	(30.61)	114.88	(25.91)	-0.02	-1.33
Choice RT *SD*	134.22	(19.43)	133.78	(19.85)	-0.02	-0.59
OMO RT *SD*	303.84	(79.29)	325.78	(81.39)	0.27	-0.10
Simple MT *SD*	61.54	(20.03)	62.34	(20.33)	0.04	-0.28
Choice MT *SD*	73.85	(28.01)	68.37	(19.51)	-0.23	0.16
OMO MT *SD*	128.66	(47.61)	117.20	(47.12)	-0.24	1.67
Verbal comprehension	10.65	(4.01)	10.98	(3.57)	-0.09	-0.61
Reasoning	25.57	(8.67)	26.31	(8.22)	-0.09	-0.60
Verbal closure	6.11	(3.93)	6.97	(4.14)	-0.21	-1.46
Addition	17.63	(5.93)	18.07	(5.12)	-0.08	-0.56
Long term memory	5.46	(4.12)	6.27	(4.37)	-0.19	-1.33
Ideational fluency	11.83	(5.24)	12.42	(5.28)	-0.11	-0.77
Space relations	10.02	(4.33)	8.76	(4.27)	0.29	2.03*
Flexibility of closure	22.66	(9.39)	16.23	(9.38)	0.69	4.73**
Perceptual speed	15.11	(7.12)	16.58	(6.73)	-0.21	-1.46
Associative memory	3.85	(2.16)	4.76	(2.69)	-0.38	-2.56*
Word fluency	6.95	(3.21)	6.77	(3.32)	0.06	0.38
Spelling	11.48	(10.46)	14.51	(10.28)	-0.29	-2.02*

Note. RT — reaction time; MT — movement time; OMO — odd-man-out. D scores are differences between means expressed in standard deviation units.
* $p<.05$; ** $p<.001$.

RESULTS

Descriptive statistics are given for the boys and girls separately in Table 1. It will be seen that there were no statistically significant differences between boys and girls on any of the reaction time measures or on the general intelligence measures of vocabulary and non-verbal reasoning (as measured by Raven's Progressive Matrices). However, the boys obtained significantly higher means on the two visuospatial tests of space relations and hidden patterns, while the girls scored significantly higher on the two verbal tests of short term memory and spelling. These sex differences are consistent with the findings of a number of previous studies (Hyde & Linn, 1986).

Many of the previous studies in this area have been concerned with the correlations between reaction times and Raven's Progressive Matrices, and whether there were any significant correlations in the present sample was one of the principal points of interest in the study. The correlations of the 12 RT parameters with Raven's Matrices are shown in Table 2. It will be seen that all of the 12 correlations were positive and 10 were statistically significant. For example, fast reaction times, fast movement times and low variability were positively associated with Raven's Matrices scores (the correlations were actually negative because fast speeds on the RT task are represented by low times of responding, but the negative signs have been omitted from the table). Although the magnitudes of the correlations were quite low, the results as a whole clearly show that some degree of positive association between reaction times and psychometric intelligence was present among these young children.

Previous studies have tended to show that reaction times are more highly correlated than movement times with psychometric intelligence. There was no tendency in this direction in the present results and the correlations between movement times and intelligence are fractionally, but not significantly, greater than those between reaction times and intelligence.

Table 2. Correlations between means and variances of reaction times (RT) and movement times (MT) and scores on Raven's Progressive Matrices.

	Mean		Variance	
Task	MT	RT	MT	RT
Simple	.12*	.03	.18**	.08
Choice	.18 **	.14*	.20 **	.16 **
Odd-man-out	.20 **	.19**	.19**	.23***

* $p<.05$; ** $p<.01$; *** $p<.001$.

Previous studies have also tended to show that the more complex the reaction time task, the greater the correlation of the reaction times with psychometric intelligence. This is confirmed here in so far as the correlation of reaction time with intelligence increased from .03 (simple RT) to .14 (choice RT) to .19 (odd-man-out RT), the difference between .03 and .19 being statistically significant ($p<.05$).

Previous studies have also tended to show that the variability of the reaction times is more highly correlated with psychometric intelligence than the mean or median speed of reaction. There is a tendency for this to be the case in the present data, as the correlations with intelligence of RT variability were consistently higher than the correlations with intelligence of RT medians, although the differences were small and none of the individual comparisons was statistically significant.

The correlation matrix for the entire set of reaction time and psychometric intelligence measures is shown in Table 3. It will be seen that virtually all the correlations were positive (the signs of the reaction time measures have been inflected to make fast times representative of high scores) but most of them are somewhat lower than the correlations between the RT measures and Raven's Matrices. The most interesting features of the results are: (i) the two memory tests showed rather low correlations with reaction times, and this throws some doubt on the theory that memory storage capacity plays an important part mediating the association between reaction times and psychometric intelligence; and (ii) the perceptual speed test showed low correlations with the reaction times, indicating that the well established perceptual speed primary ability of Thurstone is a different primary from the information processing speed measured by the reaction time tasks.

The 12 psychometric intelligence measures were factored by principal components analysis. The first factor in a principal components analysis of a diverse set of cognitive tests is generally considered to represent Spearman's g (Jensen, 1985), and the loadings of tests on this factor indicate the degree to which the tests can be considered measures of Spearman's g.

Three tests were employed to determine the number of significant factors in the matrix. These were: (a) the number of factors with eigenvalues above unity; (b) the scree test; and (c) the map test of Zwick and Velicer (1986). All three tests indicated the presence of two significant factors. These were rotated by oblimin, which gives oblique factors. The loadings of the 12 tests on the general factor and the two rotated factors are shown in Table 4. It will be seen that all the tests (with the partial exception of the flexibility of closure test) have high loadings on the general factor. The first oblimin factor can be identified as verbal ability and the second as visuospatial ability.

Table 3. Matrix of correlations between all variables (decimal points have been omitted from the correlation coefficients and correlations between reaction times and intelligence have been inflected to remove negative signs).

	Variable																						
Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1 MM Simple RT																							
2 MM Simple MT	36																						
3 SD Simple RT	72	39																					
4 SD Simple MT	34	77	36																				
5 MM Choice RT	60	24	45	24																			
6 MM Choice MT	37	83	36	69	33																		
7 SD Choice RT	42	16	29	15	82	26																	
8 SD Choice MT	24	59	25	53	33	73	35																
9 MM OMO RT	20	08	19	10	53	13	48	13															
10 MM OMO MT	26	68	25	57	24	86	23	64	04														
11 SD OMO RT	13	10	14	11	36	14	34	12	84	05													
12 SD OMO MT	08	26	16	26	02	37	08	30	18	56	13												
13 Verb. comprehension	20	11	15	06	16	13	17	14	08	12	15	06											
14 Reasoning	03	12	08	18	14	18	16	20	19	20	23	19	34										
15 Verbal closure	03	05	04	07	14	02	17	01	13	01	14	14	41	35									
16 Addition	04	02	04	06	12	02	13	03	04	02	03	07	28	24	50								
17 Long term memory	12	02	07	01	22	01	20	01	10	02	04	03	51	35	50	49							
18 Ideational fluency	13	04	09	00	15	07	14	06	00	03	05	09	51	25	51	48	47						
19 Space relations	00	04	08	06	16	08	18	09	15	08	09	07	26	39	27	31	35	25					
20 Flexibility of closure	13	10	15	12	20	13	16	08	17	15	16	12	18	24	08	13	21	08	38				
21 Perceptual speed	04	02	11	02	05	09	16	14	08	10	12	10	31	33	42	44	37	35	39	19			
22 Associative memory	06	05	07	02	17	08	18	16	01	05	01	06	26	18	27	32	37	36	13	11	27		
23 Word fluency	01	02	01	05	03	09	04	13	04	06	08	05	25	26	30	25	24	32	19	05	18	38	
24 Spellings	13	03	11	01	19	05	07	07	10	01	16	09	60	31	58	37	45	56	14	03	29	46	33

Notes. Correlations of 12 and above are significant at the 5% level. MM—Mean median; RT—Reaction time; MT—Movement time; SD—Standard deviation; OMO—Odd-man-out.

Table 4. Loadings of the 12 psychometric tests on first principal component (g) and two oblimin rotated factors representing verbal and visuospatial abilities.

Psychometric test	g	Verbal factor	Visuospatial factor
Verbal comprehension	.69	.63	.14
Reasoning	.55	.26	.52
Verbal closure	.74	.61	.28
Addition	.67	.57	.21
Long term memory	.74	.61	.28
Ideational fluency	.73	.77	.00
Space relations	.51	.07	.77
Flexibility of closure	.26	-.19	.79
Perceptual speed	.61	.37	.44
Associative memory	.54	.68	-.18
Word fluency	.49	.55	-.05
Spelling	.73	.86	-.15
Eigenvalue	4.63	4.06	2.01

The next step was to carry out a similar analysis of the 12 reaction time measures. The results are shown in Table 5. In the first column are shown the loadings on the first principal component — which can be considered a general reaction time factor — on which all the measures had appreciable loadings. The same three tests were employed to determine the number of significant factors. The tests indicated the presence of three significant factors and these were rotated by oblimin. It will be seen that the first factor may be identified as movement times, the second as odd-man-out times and the third as simple and complex reaction times.

To examine the relationship between the psychometric measures and the reaction time measures the correlations were calculated for the three psychometric factors and the individual psychometric tests with the four reaction time factors. These results are shown in Table 6. It will be seen that Spearman's g and visuospatial ability are both significantly correlated with the reaction time general factor (RTg) and also with the narrower odd-man-out

Table 5. Factor loadings of reaction time parameters on first principal component (RTg) and on three oblique oblimin factors (MT, OMO and RT).

Reaction time parameter	Rtg	MT	OMO	RT
Simple RT *Median*	.62	.02	-.11	-.93
Simple MT *Median*	.80	.84	.02	-.07
Simple RT *SD*	.60	.08	-.15	-.84
Simple MT *SD*	.74	.77	.03	-.08
Choice RT *Median*	.63	.01	.40	-.69
Choice MT *Median*	.87	.92	.10	-.04
Choice RT *SD*	.56	.03	.45	-.53
Choice MT *SD*	.74	.78	.17	.00
OMO RT *Median*	.36	-.01	.92	-.05
OMO MT *Median*	.77	.92	.01	.05
OMO RT *SD*	.32	.07	.92	.11
OMO MT *SD*	.37	.56	-.26	.04
Eigenvalue	4.91	3.98	2.48	2.29

Note. RT — reaction time; MT — movement time; OMO — odd-man-out.

factor. Verbal ability has no association with any of the RT factors. These results are broadly confirmed for the individual psychometric tests. One curiosity is that the reasoning test alone has a significant association with the movement time factor.

The factor analysis indicated that reaction times can be broken into three or possibly four independent or largely independent components involved in movement time, simple, choice and odd-man-out tasks. These can be thought of as micro-cognitive or elementary cognitive processes which all contribute to the complex problem solving ability required for the problems set in intelligence tests like Raven's Matrices. If this is the case, a combination of all the reaction time parameters should produce a higher correlation with Raven's Matrices than the individual correlation of any of the reaction time components. In order to test whether this was so, the multiple correlation of all 12 reaction time parameters with Raven's Matrices was calculated. The multiple correlation coefficient, .36 (the adjusted R^2 was 0.07), was substantially greater than any of individual correlations shown in Table 2.

Table 6. Correlations of psychometric measures with the four reaction time factors (RTg, RT, MT and OMO).

Psychometric measure	RTg	MT	OMO	RT
Spearman's g	-.18**	-.04	-.14*	.12
Verbal factor	-.07	.02	-.05	.10
Visuospatial factor	-.18**	-.11	-.14*	.02
Verbal comprehension	-.19**	-.07	-.07	.13*
Reasoning	-.23***	-.20**	-.20**	-.05
Verbal closure	-.05	.04	-.12	.06
Addition	-.03	.06	-.03	.09
Long term memory	-.07	.09	-.06	.17**
Ideational fluency	-.10	.00	.00	.13*
Space relations	-.13*	-.06	-.13*	.03
Flexibility of closure	-.20**	-.09	-.12*	.10
Perceptual speed	-.12	-.07	-.08	.02
Associative memory	-.13*	-.05	-.11	.06
Word fluency	-.07	-.10	-.06	-.06
Spelling	-.12*	.01	-.10	.12*

Note. RTg — reaction time general factor; RT — reaction time; MT — movement time; OMO — odd-man-out.
* $p<.05$; ** $p<.01$; *** $p<.001$.

This indicates that the three micro-processes involved in reaction time tasks make independent contributions to the complex problem solving ability represented in a test like Raven's Matrices.

DISCUSSION

There are five principal points of interest in the results of this study. First, the results confirm for 9-year-olds the positive correlations between reaction times and psychometric intelligence found by previous researchers among university students and secondary school children. Second, when psychometric intelligence is factored into the general factor (Spearman's g) and the verbal and visuospatial factors, it appears that reaction times are associated with the

general and visuospatial factors but not the verbal factor. There appears, therefore, to be a visuospatial information processing element in the reaction time task which has not hitherto been identified.

Third, the factor analysis of the reaction times shows that these can be broken down into three components, namely movement times, simple reaction times and odd-man-out reaction times. This indicates that three independent processes are involved in the reaction time task. Fourth, the independent factors revealed in the factor analyses can be considered as micro-cognitive or elementary cognitive abilities which combine to determine performance on the complex problems presented in intelligence tests like Raven's Matrices. This is confirmed by the multiple correlation which shows that all the reaction time measures together reveal a substantially higher correlation with Raven's Matrices than any of the individual correlations between reaction time measures and Raven's Matrices.

Finally, an interesting negative result is that no factor of reaction time variability appeared in the factor analyses. It has sometimes been suggested that reaction time variability has the highest correlation with psychometric intelligence, and therefore that the capacity for sustained attention is the underlying ability responsible for the positive correlations between reaction times and psychometric intelligence (e.g., Mackintosh, 1986). In the set of 12 reaction time measures used in the study, six were median reaction times and six were variabilities. The six variabilities would have appeared as a factor if there were a capacity for sustained attention present in the performance of the tasks. The failure of such a factor to appear must tell against the attention hypothesis.

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