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Sex differences in mental arithmetic, digit span, and *g* defined as working memory capacity

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Abstract

Meta-analyses are presented of sex differences in (1) the (mental) arithmetic subtest of the Wechsler intelligence tests for children and adolescents (the WISC and WPPSI tests), showing that boys obtained a mean advantage of .11*d*; (2) the (mental) arithmetic subtest of the Wechsler intelligence tests for adults (the WAIS tests) showing a mean male advantage of .47*d*; (3) the digit span subtest of the Wechsler intelligence tests for children and adolescents (the WISC and WPPSI tests), showing that girls obtained a mean advantage of .134*d*; (4) the digit span subtest of the Wechsler intelligence tests for adults (the WAIS tests) showing a male advantage of .116*d* among adults. These results show that the sex differences on mental arithmetic are not consistent with the sex differences on digit span. It is proposed that the reason for this is that mental arithmetic is a measure of working memory capacity while digit span is a measure of immediate memory capacity. If this is accepted, the results indicate that there is virtually no sex difference in immediate memory capacity (measured by digit span) but a small male advantage among children and a substantial male advantage among adults in working memory capacity (measured by mental arithmetic). The results are further interpreted in terms of Kyllonen's theory that working memory capacity is *g*. If this is accepted, it follows that males have an advantage in *g* and that the higher average means obtained by men in IQ tests like the WAIS and the Progressive Matrices is attributable to their advantage in *g*.

Keywords: Sex differences; Mental arithmetic; Digit span; *g*; Working memory capacity

1. Introduction

We have been struck by an apparent anomaly in the literature on sex differences in arithmetical computation and in mental arithmetic. This is that females tend to have an advantage in arithmetical computation among children and there is no sex difference among older adolescents and adults, while males tend to have an advantage in mental arithmetic as children, adolescents and adults. The sex differences in arithmetical computation are quite well established from the meta-analysis of sex differences in mathematical abilities carried out by Hyde, Fennema and Lamon (1990), who calculated that girls have an advantage in arithmetical computation of .20*d* at ages 5–10 and of .22*d* at ages 11–14, and that there was no sex difference at ages 15–18. They do not give data for adults, but studies showing no sex difference in arithmetical computation among adults have been published by Schaie, Maitland, Willis and Intrieri (1998) and by (Schaie, 2005).

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In contrast to the female advantage in mental computation among children and the absence of a sex difference among adolescents and adults, we have observed in several studies that males have an advantage in the Wechsler mental arithmetic subtest among children in Scotland and the United States (Lynn & Mulhern, 1991), and in the Netherlands (Born & Lynn, 1994), and among adults in Scotland (Lynn, 1998) and in Japan (Lynn & Hattori, 1997).

We have three objectives in this paper: (1) to present a meta-analysis of sex differences among children and adults in the Wechsler mental arithmetic subtest; we believe this has not previously been done and that this analysis would establish whether there is a male advantage in this; (2) to present a meta-analysis of sex differences among children and adults in the Wechsler digit span subtest; we believe that this also has not previously been done and that this analysis would establish whether there is a sex difference in digit span and whether this is consistent with the sex difference in mental arithmetic (it might be supposed that this would be the case, since both tests require holding material in immediate memory); (3) to consider what theories could be advanced to explain the results of the meta-analyses of sex differences in the Wechsler mental arithmetic and digit span subtests.

2. Sex differences in mental arithmetic

In this section we present meta-analyses of sex differences among children and adults in the Wechsler mental arithmetic subtest. We confine our analyses to normative standardization samples because these are considered to have the advantages of sample representativeness and minimization of publication or experimenter bias (Burnett, 1986; Hedges, & Nowell, 1995). In order to identify all possible studies meeting our inclusion criteria we conducted computerized database searches of PsychInfo, Medline, and Web of Science. In addition we relied on previous knowledge accumulated through comprehensive searches of Current Contents. We believe that this was sufficient to locate all standardization samples of the WAIS, WPPSI and WISC for which sex differences have been reported. We are aware that there are other standardization samples, such as the French and Canadian WAIS-III, which we have not used because we could not find publications giving sex differences for these. We introduce a further refinement by combining samples. Cohen's *d* (the difference between the male and female means divided by the within group standard deviation) was adopted as the measure of effect size, and the mean *d* was calculated using the inverse variance method. Heterogeneity of effects sizes was tested using the *Q* statistic (Borenstein & Rothstein, 1999), and all statistics were calculated using a random effects model (Hunter & Schmidt, 2004).

The first analysis was of sex differences in 15 studies of the arithmetic subtest of the Wechsler intelligence tests for children and adolescents up to the age of 16 years (i.e. in the WPPSI and WISC tests). The results are shown in Table 1. The Forrest plot indicates a predominant but small male advantage, such that in 12 of the studies boys obtained higher average scores than girls. The weighted mean of the studies shows an advantage in favour of boys at .11*d*. However, the *Q* statistic clearly indicated heterogeneity in the sample ($Q=57.15$, $df=14$, $p<.000$). Both age ($Q=42.98$, $df=6$, $p<.000$) and test ($Q=16.24$, $df=3$, $p<.001$) were identified as moderators, with the strongest effect due to age. The data show a fairly consistent trend whereby in the youngest age groups girls have an advantage, which is transformed into a male advantage with increasing age.

Our second meta-analysis applied the same techniques and logic to examine sex differences in 13 studies of the arithmetic subtest of the Wechsler intelligence tests for adults, i.e. in the WAIS tests (these data include a small number of adolescents above the age of 16 years). Cohen's *d*s and their weighted means, with 95% confidence intervals are shown in Table 2. Inspection of the Forrest plot shows that in all of the studies men obtained higher average scores than women, and in all cases the lower bound of the 95% confidence interval was greater than zero. The overall weighted mean of the studies is a male advantage of .467*d*. However, again the test of heterogeneity indicated the presence of moderator variables ($Q=83.39$, $df=12$, $p<.000$). We found a major effect due to ethnicity ($Q=48.51$, $df=2$, $p<.000$) and a somewhat smaller effect of type of test ($Q=13.32$, $df=3$, $p=.004$). With regard to ethnicity, whereas the mean *d* for European and American samples is .47, that for East Asians is lower at .28 and that for South Asians is higher at .73.

3. Sex differences in digit span

In this section we present meta-analyses of sex differences among children and adults in the Wechsler digit span subtest. We have used the same techniques and logic as for the examination of sex differences in the studies of the arithmetic subtest. Sex differences in digit span in children and adolescents in the WPPSI and WISC tests are shown in Table 3. The overall Cohen's *d* shows a female advantage in digit span of .134 for children and adolescents, which contrasts with the small

Table 1
Sex differences on the arithmetic test of the WPPSI and WISC in children and adolescents

Age	Country	Citation	Test	*N*	*d*	95%	Confidence interval
13–15	Greece	Alexopoulos, 1979	WISC-R	300	.679	.445	.913
13–15(1)				300	.679	.445	.913
4–6	Japan	Hattori, 2000	WPPSI	591	.052	−.110	.214
4–6	USA	Kaiser & Reynolds, 1985	WPPSI	1199	−.088	−.201	.025
4–6(2)				1790	−.030	−.165	.105
5	Canada	Miller & Vernon, 1996	WPPSI	109	−.238	−.621	.145
5	England	Yule, Berger, Butler, & Tizard, 1969	WPPSI	150	.075	−.248	.397
5(2)				259	−.065	−.371	.241
6–13	Iran	Shahim, 1990	WISC-R	1400	.117	.012	.222
6–13(1)				1400	.117	.012	.222
6–16	Netherlands	Born & Lynn, 1994	WISC-R	2027	.183	.096	.270
6–16	Israel	Cahan, 2005	WISC-R	1100	.230	.111	.349
6–16	USA	Feingold, 1993	WISC	2200	.050	−.034	.134
6–16	USA	Jensen and Reynolds, 1983	WISC-R	1868	.063	−.028	.154
6–16	Scotland	Lynn & Mulhern, 1991	WISC-R	1395	.118	.013	.223
6–16	USA	Psych. Corp., 2005a	WISC-III	2200	.105	.021	.189
6–16	Taiwan	Taiwan Psych. Corp., 2005	WISC-R	1100	.183	.064	.301
6–16(7)				11890	.126	.077	.175
6–9	Finland	Konttila, 1998	WISC-R	407	.184	−.012	.379
6–9(1)				407	.184	−.012	.379
8–9	New Zealand	Lynn, Fergusson, & Horwood, 2005	WISC-R	897	−.070	−.201	.061
8–9(1)				897	−.070	−.201	.061
Combined(15)				16943	.111	.045	.176

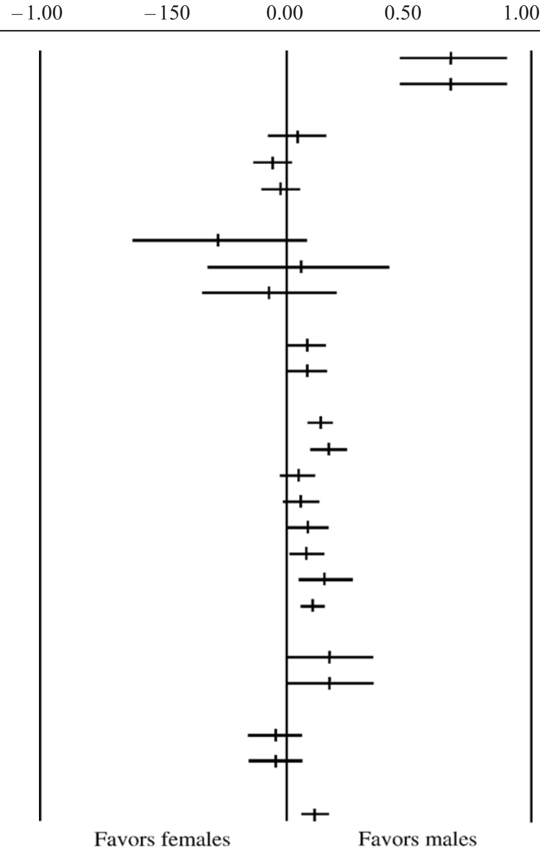


Table 2

Sex differences on the arithmetic test of the WAIS in adults

Enthnicity	Citation	Country	Test	Age	*N*	*d*	95% Confidence interval	
Caucasoid	Colom et al., 2002	Spain	WAIS-III	15–94	1368	.578	.470	.686
Caucasoid	Doppelt & Wallace, 1955	USA	WAIS	60–89	475	.395	.212	.578
Caucasoid	Ilai and Willerman, 1989	USA	WAIS-R	16–32	206	.336	.059	.613
Caucasoid	Kaufman, McClean, & Reynolds, 1988	USA	WAIS-R	16–74	1880	.334	.243	.425
Caucasoid	Lynn, 1998	Scotland	WAIS-R	16–64	200	.602	.317	.887
Caucasoid	Matarazzo, 1972	USA	WAIS	16–64	1700	.353	.257	.449
Caucasoid	Psych. Corp., 2005b	USA	WAIS-III	16–89	2450	.399	.319	.479
Caucasoid	Saggino, 2005	Italy	WAIS-III	65–100	400	.770	.565	.975
Caucasoid	Strange & Palmer, 1953	USA	W-Bell	31–34	214	.787	.497	1.077
Caucasoid	van der Sluis et al., 2006	Netherlands	WAIS-III	18–46	518	.420	.244	.596
Caucasoid					9411	.474	.385	.563
East Asian	Dai, Ryan, Paolo, & Harrington, 1991	China	WAIS-R	16–74	1406	.290	.185	.395
East Asian	Lynn and Hattori, 1997	Japan	WAIS-R	16–74	1402	.265	.160	.370
East Asian (2)					2808	.278	.204	.352
South Asian	Verma and Pershad, 1979	India	WAIS-R	20–39	1440	.729	.622	.836
South Asian					1440	.729	.626	.832
Combined (13)					13659	.467	.373	.562

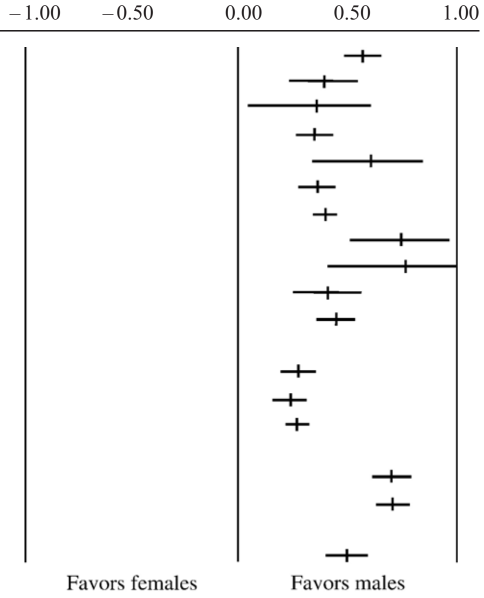


Table 3
Sex differences in the digit span test of the WPPSI and WISC in children and adolescents

Age	Country	Citation	Test	*N*	*d*	95%	Confidence interval
11	Mauritius	Lynn, Raine, Venables, Mednick, & Irwing, 2005	WISC-R	1258	−.056	−.167	.055
11 (1)				1258	−.056	−.167	.055
4–6	Japan	Hattori, 2000	WPPSI	591	−.360	−.523	−.197
4–6	USA	Kaiser and Reynolds, 1985	WPPSI	1199	−.310	−.424	−.196
4–6 (2)				1790	−.327	−.419	−.234
5	England	Yule et al., 1969	WPPSI	150	−.420	−.746	−.094
5(1)				150	−.420	−.743	−.097
6–13	Iran	Shahim, 1990	WISC-R	1400	−.060	−.165	.045
6–13(1)				1400	−.060	−.165	.045
6–16	Netherlands	Born and Lynn, 1994	WISC-R	2027	−.160	−.247	−.073
6–16	Israel	Cahan, 2005	WISC-R	1100	.010	−.108	.128
6–16	USA	Feingold, 1993	WISC	2200	−.142	−.226	−.058
6–16	USA	Jensen and Reynolds, 1983	WISC-R	1868	−.100	−.191	−.009
6–16	Scotland	Lynn & Mulhern, 1991	WISC-R	1395	−.150	−.255	−.045
6–16	USA	Psych. Corp., 2005a	WISC-III	2200	−.060	−.144	.024
6–16	Taiwan	Taiwan Psych. Corp., 2005	WISC-R	1100	−.070	−.188	.048
6–16(7)				11890	−.102	−.144	−.060
6–9	Finland	Konttila, 1998	WISC-R	407	−.150	−.345	.045
6–9(1)				407	−.150	−.345	.045
Combined (13)				16895	−.134	.187	−.081

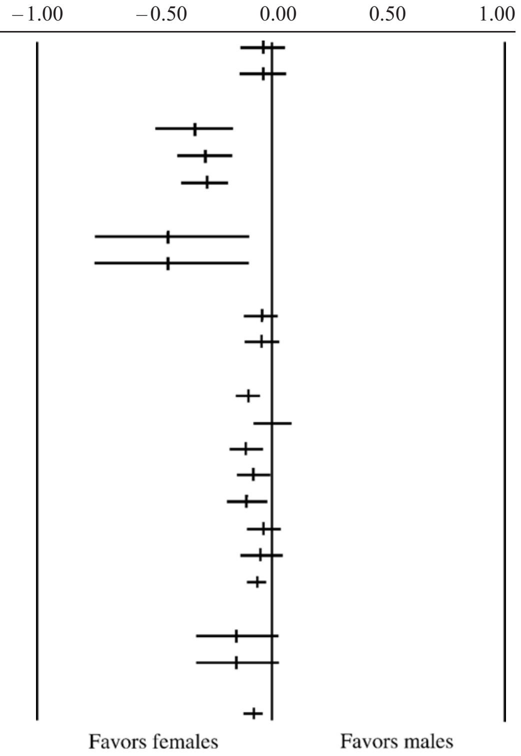
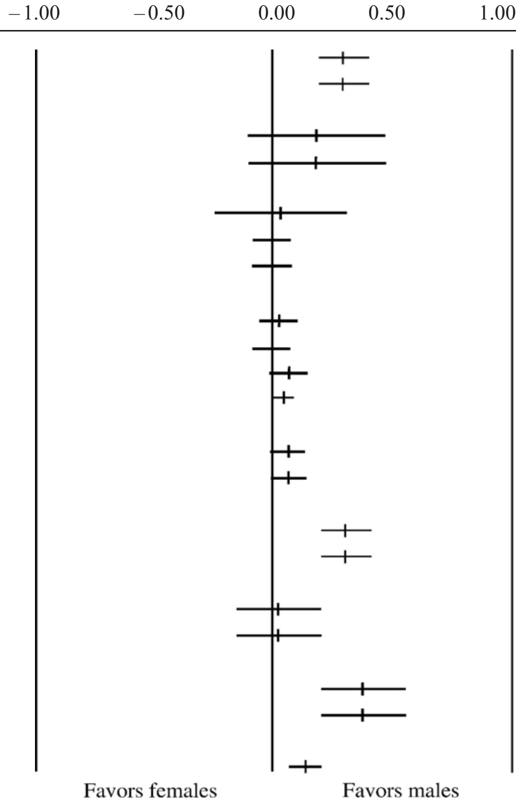


Table 4
Sex differences on the digit span test of the WAIS in adults

Age	Citation	Country	Test	Enthnicity	*N*	*d*	95%	Confidence interval
15–94	Colom et al., 2002	Spain	WAIS-III	Caucasoid	1368	.280	.173	.387
15–94 (1)					1368	.280	.174	.386
16–32	Ilai and Willerman, 1989	USA	WAIS-R	Caucasoid	206	.160	−.116	.436
16–32 (1)					206	.160	−.115	.435
16–64	Lynn, 1998	Scotland	WAIS-R	Caucasoid	200	.040	−.239	.319
16–64	Matarazzo, 1972	USA	WAIS	Caucasoid	1700	.000	−.095	.095
16–64 (2)					1900	.004	−.086	.094
16–74	Dai et al., 1991	China	WAIS-R	East Asian	1406	.070	−.035	.175
16–74	Kaufman et al., 1988	USA	WAIS-R	Caucasoid	1880	.000	−.090	.090
16–74	Lynn & Hattori, 1997	Japan	WAIS-R	East Asian	1402	.090	−.015	.195
16–74 (3)					4688	.048	−.009	.105
16–89	Psych. Corp., 2005b	USA	WAIS-III	Caucasoid	2450	.060	−.019	.139
16–89 (1)					2450	.060	−.019	.139
20–89	Verma and Pershad, 1979	India	WAIS-R	South Asian	1440	.260	.156	.364
20–89 (1)					1440	.260	.157	.363
60–89	Doppelt and Wallace, 1955	USA	WAIS	Caucasoid	475	.040	−.141	.221
60–89 (1)					475	.040	−.141	.221
65–100	Saggino, 2005	Italy	WAIS-III	Caucasoid	400	.328	.129	.527
65–100 (1)					400	.328	.131	.525
Combined (11)					12927	.116	.045	.187



male advantage in arithmetic of d=.111 for the same age group shown in Table 1. Although both effects are small, they are nevertheless significant as indicated by the 95% confidence intervals. Much as would be anticipated from an inspection of Table 3, the overall test of heterogeneity indicated the presence of moderators. Specifically, age was a strong moderator (Q=25.84, df=4, p<.001) such that the mean female advantage on digit span was clearly greater amongst five year olds at .42 than for 6 to 16 year olds at .10.

Sex differences in digit span in adults are shown in Table 4. There is a small male advantage of .116 d. The heterogeneity test (Q=36.49, df=10, p<.001) suggested the presence of moderators, with age again implicated as the major moderator (Q=34.55, df=3, p<.001), though given the paucity of degrees of freedom, this finding should be treated with some scepticism.

4. Discussion

There are five points of interest in the results. First, the meta-analysis of sex differences among children and adults on the Wechsler mental arithmetic subtest shows that males have a small advantage of .11d among children and younger adolescents, and a greater advantage of .47d among adults. This is a contrast with the female advantage in arithmetical computation among children and the absence of a sex difference among adolescents and adults noted in the introduction. These inconsistent sex differences suggest that different processes are involved in mental arithmetic from those in arithmetical computation.

Second, the meta-analyses of sex differences among children and adults in the Wechsler digit span subtest shows a small female advantage of .134 for children and adolescents and a small male advantage of .116 d among adults. These sex differences are not consistent with the sex differences in mental arithmetic. In all the studies the male advantage in mental arithmetic is greater than the male advantage in digit span. In fact among children, females generally perform better in digit span while males generally perform better in arithmetic. Among adults, there is a small male advantage in digit span while males again perform substantially better in mental arithmetic. These results suggest that the male advantage in mental arithmetic cannot be explained in terms of an advantage in digit span, although both tests require holding material in immediate memory.

Third, this inference raises the problem of how the male advantage in mental arithmetic can be explained. Evidently it cannot be explained by an advantage in arithmetical computation or by an advantage in digit span. We believe that the most plausible explanation is that males have an advantage in working memory capacity. The concept of working memory capacity has its origin in the work of Baddeley (1986, 1999) who has defined it as a storage system for handling problems that are concerned with common knowledge, show minimal learning effects, and involve "simultaneous processing and storage". Barrett, Tugade and Engle (2004, p. 553) offer the following definition: "it is the number of items that can be recalled during a complex working memory task; complex working memory tasks have simultaneous storage (maintaining information in an active state for later recall) and processing (manipulating information for a current computation) components". Mackintosh and Bennett (2003, p. 519) give a similar definition: "working memory is a system that holds information in a short term store while simultaneously performing operations on other information".

Mental arithmetic is a prototypical measure of working memory capacity. Mental arithmetic has been advanced as an operational measure of working memory capacity by Baddeley (1986, 1999) and by Kyllonen and Christal (1990). Mental arithmetic is also given as an example of working memory capacity by Mackintosh and Bennett (2003, p. 520): "the solution of a complex mental arithmetic problem requires one to perform one calculation, hold the result of that calculation in memory while performing new calculations, and then combine the results of all necessary calculations to provide an answer".

Working memory capacity measured by mental arithmetic should be distinguished from immediate memory capacity measured by the digit span test. The distinction is that working memory requires the holding of information in a memory store while performing some other task and then retrieving the information to carry out additional mental operations. The digit span test is simpler in so far as it only requires holding information in immediate memory and reproducing it (although the backward digit span with long numbers may involve working memory because the testees typically use the strategy of putting the number into working memory, dealing with the first three or four numbers in immediate memory, and then retrieving the remaining numbers from storage and dealing with these). We suggest therefore that the most reasonable interpretation of our results is that there is no appreciable sex difference in immediate memory (measured by digit span), but there is a male advantage in working memory (measured by the Wechsler mental arithmetic subtest).

This interpretation encounters the problem that there is no significant sex difference among 4–6 year olds in the mental arithmetic subtest; the male advantage appears among older children and young adolescents aged 6 to16 years (.11*d*). The explanation for this age difference is that the mental arithmetic problems designed for young children in the WPPSI and the WISC do not entail working memory. For instance, the last problem in the WPPSI is "James had 8 marbles and he bought 6 more. How many marbles did he have altogether"? Working memory is not required to produce the correct solution to this question because no information has to be placed into storage while other mental operations are carried out. Only immediate memory is required. Hence, the absence or virtual absence of a sex difference in mental arithmetic in children is consistent with the theory that there is a sex difference in working memory but not in immediate memory.

Fourth, if it is accepted that the most plausible explanation for the results is that males have an advantage in working memory capacity, the question arises of whether working memory capacity can be identified with g, and if so whether it can be inferred that males have an advantage in *g*.

The theory that *g* can be identified working memory capacity was first advanced by Kyllonen and Christal (1990) in a paper in which they reported that measures of working memory are highly correlated ($r=.80$ to .88) with measures of reasoning ability. They argued that reasoning ability is highly correlated with *g*, and hence working memory capacity must also be highly correlated with *g*. From this they concluded that "*g* is (little more than) working memory capacity" (the title of their paper). In a subsequent paper Kyllonen (1993) reported a correlation between measures of working memory and *g* of .99. He concluded from this that working memory and *g* must be the same construct and hence that "the parenthetical qualifier in the Kyllonen–Christal paper may have been an error … no other cognitive factor – knowledge, speed, or learning ability – correlated with g after the working memory factor was partialed out. Thus, we have our answer to the question of what g is. It is working memory capacity" (Kyllonen, 2002, p.433).

Kyllonen's theoretical rationale for identifying working memory capacity as g is that working memory capacity is entailed in the performance of all cognitive tasks. In this respect it is more general than domain specific knowledge and skills of, e.g. language, mathematics, spatial analysis, etc. Kyllonen's theory has been supported by several students of this problem. These include Jager, Sub and Beauducel (1997) who report a correlation between working memory capacity and g of .92 to .96; Ackerman, Beier and Boyle (2002), who report a correlation of .70; and Colom and his associates who in three studies report correlations of .96, .86 and .89 and conclude that "WM (working memory) and g are (almost) isomorphic constructs" (Colom, Abad, Rebello, & Shih, 2005, p.635).

However, there has been some dispute on this matter. Ackerman, Beier and Boyle (2005) on the basis of a meta-analysis suggested that the true score correlation between working memory and *g* was only .479. In their replies, both Oberauer, Shulze, Wilhem and Süss (2005) and Kane, Hambrick and Conway (2005) favoured a latent variable model of working memory in conformity with the work of Kyllonen. Kane et al.'s (2005) reanalysis of 13 studies using this model found a range of correlations between working memory capacity and *Gf* of .41 to 1.00 with a median correlation of .72. Similarly, Oberauer et al. (2005) re-analyzed the data presented by Ackerman and associates to suggest a correlation between working memory capacity and *g* of .85. Both Kane et al. (2005) and Oberauer et al. (2005) consider the definition and measurement of working memory capacity as a cause of the variability in findings.

We believe that Kyllonen's theory and the studies supporting it have not been seriously damaged by these criticisms. If he and others are correct in identifying working memory capacity with g, and if our conclusion that mental arithmetic is a measure of working memory capacity is accepted, then we are driven to the conclusion that males have greater average *g* than females. Consistent with this inference is the fact that the male advantage of .47*d* among adults in *g* measured by mental arithmetic is closely similar to the male advantage in *g* estimated by other methods. Thus, Nyborg (2005) has calculated that among adults males have an advantage of .46*d* in *g*. These two estimates are somewhat greater than the male advantage in IQ measured by tests like the WAIS and the Progressive Matrices, both of which are widely regarded as largely measures of g (e.g. Jensen, 1998). In the WAIS the male advantage is typically about .23*d* (about 3.5 IQ points) (Lynn, 1994; Colom, Garcia, Juan-Espinoza, & Abad, 2002). In the meta-analysis of the Progressive Matrices on general population samples the male advantage is calculated at .33*d* (5 IQ points) (Lynn & Irwing, 2004). In another study of the sex difference in g, measured from the SAT, Jackson and Rushton (2006) have reported a male advantage of .24*d* (3.6 IQ points). The reasons for these different estimates include age effects and that there is that there is no single definitive measure of *g*. All measures of *g* are approximations for the true *g*.

The present result is consistent with these previous studies. Whether g is measured as working memory capacity (as in the present study), as abstract reasoning ability/ fluid intelligence (as measured by the Progressive Matrices), or as the IQ of the WAIS, or from the SAT, all these approaches are consistent with the conclusion that that males have greater average *g* than females by somewhere between .24*d* (Jackson & Rushton, 2006) and the .47*d* obtained in the meta-analysis of sex differences in mental arithmetic/working memory capacity reported in this paper. Taken together, these studies suggest that the IQ difference between men and women can be explained (or even "over-explained") by a difference in *g*.

It should be noted, however, that a different conclusion has been reached by Jensen (1998) and by Colom and his associates, who have argued that the sex difference in IQ is not a difference in *g* but in second order factors (verbal, quantitative, spatial, etc.) (Aluja, Colom, Abad, & Juan-Espinoza, 2002; Colom, Juan-Espinoza, Abad, & Garcia, 2000; Colom et al., 2002; Dolan et al., 2006; Van der Sluis et al., 2006). It would require a further paper to discuss the reasons for this disagreement and to set out what we believe are the errors in the analyses presented by Jensen (1998) and by Colom and his associates. Readers are referred to Ashton and Lee (2005) for a useful exposition of the problems with these analyses.

Fifth, an unanticipated finding was the difference between ethnic groups such that the male-female difference is attenuated in East Asian cultures and somewhat amplified in India, as compared with western cultures. Since this study was not designed to elucidate this issue, we can only offer a speculative explanation. In a series of experiments, Majeres (1977, 1983, 1988, 1999) has demonstrated that females have an advantage in access and usage of phonological name codes. Bull and Johnston (1997) have also established an association between phonological memory and individual differences in maths computation. The possibility arises, therefore, that the effects of ethnicity are in fact linguistic in nature. If the representation of numbers in some languages places increased demands on the use of phonological name codes, this would favour women, and hence reduce the size of the observed sex difference in scores on mental arithmetic.

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