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# Sex differences on g and non-g intellectual performance reveal potential sources of STEM discrepancies

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ABSTRACT

The analysis of sex differences in cognitive abilities is largely confusing because these differences are masked by the pervasive influence of the general factor of intelligence (*g*). In this study a battery of five reasoning tests (abstract [AR], numerical [NR], verbal [VR], mechanical [MR], and spatial [SR]) was completed by a sample of 3233 young and old adolescents representative of the population. Using a latent variable approach, mean differences on the general factor were estimated after examining measurement invariance. Results show that the difference, favoring boys in latent *g* increases with age from two to four IQ points. Further, boys outperform girls in all the subtests and the observed differences were generally explained by *g*. However, mechanical reasoning is a systematic and strong exception to this finding. For the young adolescents, the observed difference in MR is equivalent to 10 IQ points, and this difference increases to 13 IQ points for the old adolescents. Only 1 (young) or 2 (old) IQ points of the sex difference in MR can be accounted for by *g*. The findings suggest that the persistent – and usually neglected average large advantage of boys in mechanical reasoning (MR) — orthogonal to *g* – might be behind their higher presence in STEM (science, technology, engineering, and math) disciplines. A new look at this relevant social issue is proposed in this study.



## 1. Introduction

Intelligence differences have often captured scientific and public interest (Deary, Penke, & Johnson, 2010; Jensen, 1998; Mackintosh, 1996, 1998). As underscored by Hunt and Wittmann (2008), this core psychological trait has broad implications for varied everyday life behaviors. In this regard, presumed sex differences in general intelligence (*g*) and cognitive abilities (verbal, numerical, spatial, and so forth) are of central interest (Halpern, 2000; Johnson, Carothers, & Deary, 2008; Lohman & Lakin, 2009). Setting the 20th century new "habits of mind" aside, and rejecting "to classify things as a prerequisite to understanding" (Flynn, 2010, p. 364), the approach of differentiating things to capitalize on their differential utility is worthy for society. Therefore, studies on intelligence tests, and also on sex differences, will continue to gather an understanding with educational, political, social, and ethical values (Rindermann, 2007).

Since Terman's (1916) finding of irrelevant sex differences in IQ on a sample of nearly one thousand American 4–16 year olds, the conclusion has been repeatedly asserted in terms of a negligible better performance of girls in IQ. Further research showed no significant sex differences on either IQ or *g* and in two main general cognitive abilities (fluid-abstract and crystallized-verbal intelligence) (Brody, 1992; Colom, García, Juan-Espinosa, & Abad, 2002; Colom, Juan-Espinosa, Abad, & Garcia, 2000; Deary, Irwing, Der, & Bates, 2007; Deary, Thorpe, Wilson, Starr, & Whalley, 2003; Halpern, 2000; Jensen, 1998; Lubinski, 2000; Mackintosh, 1996; Strand, Deary, & Smith, 2006).

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This general picture changed when specific cognitive abilities were considered (Reynolds, Keith, Ridley, & Patel, 2008). The literature yielded some consensus regarding significant sex differences on three core cognitive abilities, designed by Hyde (1990) as the "Holy Trinity", namely: verbal, visuospatial, and quantitative abilities (e.g. Carroll, 1992; Maccoby & Jacklin, 1974; Snow & Lohman, 1989). Halpern et al. (2007) reported a comprehensive review of the available scientific evidence to conclude that: (a) by the end of grade school and beyond, females tend to excel in verbal abilities, especially when assessment includes writing and language-usage items (e.g. word fluency, read, speed articulation, verbal analogies); (b) males outperform females on most measures of visuospatial abilities (e.g. mental rotation, spatial perception) and in quantitative abilities (e.g. geometry, problem-solving); and (c) sex differences in visuospatial and quantitative abilities are smaller for the mid-range of the ability distribution than for those with the highest levels of ability, because of the higher variability of male performance in visuospatial and quantitative abilities. This larger variability of male performance on cognitive tests, as well as a large percentage of male adolescents among high-scoring individuals, was found by Hedges and Nowell (1995) when reanalyzing data from six studies done between 1960 and 1992 with national representative samples in the United States. These male differences in variability and frequency in the upper tail were not found in reading comprehension, perceptual speed, and associative memory only. Moreover, all of the reported effect sizes were small except for abilities associated with vocational aptitude scales (e.g. mechanical reasoning), in which the average and top 10% of boys had much better performance than the average and top 10% of girls (Hedges & Nowell, 1995). Findings from the Lubinski and Benbow (2006) 20-year follow-up of longitudinal studies pointed out boys' overrepresentation in the upper tails, namely in math–science abilities and STEM fields.

Likewise, a wide body of research reviewed by Willingham and Cole (1997), including 24 large data sets, led to the conclusion that sex differences are small in elementary school grades ($d > .2$ favoring females at 4th grade in writing, language use, and reading). These differences become larger by the end of high school, and again girls outperform boys (e.g. writing, d between .5 and .6; language usage, d between .4 and .5). The comprehensive meta-analysis by Hedges and Nowell (1995) underscored males' disadvantage in verbal abilities by the middle to end of secondary school.

With respect to visuospatial ability, several meta-analyses (e.g. Linn & Petersen, 1985; Masters & Sanders, 1993; Voyer, Voyer, & Bryden, 1995) reported the largest and most consistent sex difference in the cognitive literature, although the effect size differed depending on the task. For example, chronometric mental rotation tasks showed effect sizes around .37; two-dimensional mental rotation tasks revealed effect sizes between .31 and .44; and complex three-dimensional mental rotation tasks found effect sizes between .70 and .95, always favoring males.

Several meta-analytic studies (e.g. Geary, 1996; Hyde, Fennema, & Lamon, 1990; Willingham & Cole, 1997) reported small sex differences in quantitative abilities in elementary school (until 4th grade) where girls outperform boys. This difference is almost zero in the remaining primary-school grades. Afterwards, a small male advantage through higher secondary-school grades is detected (d between .1 and .2). The nature of the task involved is again crucial for understanding these sex differences: in early elementary school years, quantitative ability is measured mainly through computational tasks, at which girls outperform boys; as we go through higher secondary-school grades, mathematical concepts require more reasoning abilities and become more spatial in nature (e.g. problem solving in geometry and calculus), which favors boys.

Various explanations for sex differences in cognitive abilities have been delivered, ranging from biological factors (e.g. Benbow, 1988; Hooven, Chabris, Ellison, & Kosslyn, 2004; Kimura, 2002; Lynn, 1994, 1999, 2001; Lynn, Allik, & Must, 2000) to those more socially rooted (e.g. Baenninger & Newcombe, 1995; Guiso, Monte, Sapienza, & Zingales, 2008; Hyde & Linn, 2006; Quaiser-Pohl, Geiser, & Lehmann, 2006) but these are mainly interactive (e.g. Ceci & Williams, 2010; Halpern et al., 2007). Regardless of the ultimate cause, theoretical accounts stressing the nature of the task, along with the involved cognitive processes, deserve close attention. In this respect, it becomes pertinent to note that observed sex differences may be masked by the variance explained by the general factor of intelligence or *g* (Johnson & Bouchard, 2007), or even by choices in curriculum made by boys and girls (Calvin, Fernandes, Smith, Visscher, & Deary, 2010). Interesting methodological issues have been discussed regarding different approaches (e.g. sum scores, factor score estimates, latent variables) for understanding results derived from studies investigating sex differences in intelligence (Steinmayr, Beauducel, & Spinath, 2010). Sex differences in STEM fields are also discussed regarding non-cognitive variables. Life values, personality dimensions, and vocational interests have been considered in the last decades for framing global sex differences and also for explaining why males are overrepresented on STEM's graduation and careers (Del Giudice, Booth, & Irwing, 2012; Ferriman, Lubinski, & Benbow, 2009; Su, Rounds, & Armstrong, 2009). These non-cognitive variables might play a role in adolescence when students start to explore and make vocational choices. These can also help to explain why sex differences on verbal, spatial and, quantitative abilities become more evident at junior and senior high school.

In this study we analyze two large, representative samples of young and old adolescents from Portugal totalling to 3233 participants. These samples completed an intelligence battery comprising five reasoning tests (abstract, numerical, verbal, mechanical, and spatial reasoning). Because of the pervasive influence of *g*, average sex differences are computed including and excluding *g* variance from the five tests. This would provide straightforward findings regarding the presence or absence of average sex differences in specific cognitive abilities.

## 2. Method

### 2.1. Participants

Two independent samples comprising 3233 students (1564 boys and 1669 girls) were considered. The first sample included 1714 students in the third cycle of elementary