

Research Articles

Age and Sex Differences in Spatial and Mechanical Tilt in Adolescence: Evidence for the Mediating Effects of Processing Speed and *g*

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Tilt refers to an ability profile and is based on within subject differences in two abilities, yielding strength in one ability (e.g., academic) and weakness in another ability (e.g., mechanical). The current study examined sex differences in the development of mechanical and spatial tilt. Tilt was based on mechanical and spatial abilities contrasted with academic abilities (math or verbal), yielding mechanical tilt (mechanical > academic), spatial tilt (spatial > academic), and academic tilt (academic > mechanical/spatial). Participants were 13- to 17-year-olds from the National Longitudinal Survey of Youth (N = 6969), and tilt scores were based on the Armed Services Vocational Aptitude Battery. While sex differences in mechanical tilt (favoring males) increased with age, sex differences in spatial tilt did not, suggesting that sex differences are more sensitive to mechanical abilities. For males and females, academic tilt (math tilt or verbal tilt) increased with age, while mechanical and spatial tilt decreased with age. Finally, cascade models of mechanical tilt (which showed the largest sex differences) indicated that age-related increases in processing speed boosted *g*, which in turn influenced tilt. The results support vocational preference and investment theories. Such theories assume that, compared to females, males are more likely to invest in mechanical abilities and activities involving things (vs. people), boosting mechanical tilt. Future research might examine factors that influence sex differences in the development tilt such as developmental period (childhood vs. adulthood), ability level (intellectually disabled vs. gifted), and motivational variables (e.g., grit and self-efficacy).

Tilt refers to an ability profile contrasting two abilities and is based on within-subject differences between those abilities (e.g., spatial and academic) (for reviews, see Coyle, 2018; Coyle & Greiff, 2021; Lubinski, 2009, 2016). The differences produce relative strength in one ability (e.g., spatial) and weakness in a competing ability (e.g., academic). Tilt is attributed to differential investment in some abilities (e.g., spatial or academic) at the expense of others, leading to distinct types of tilt (e.g., spatial tilt or academic tilt) (Cattell, 1987, pp. 138–146; see also, Coyle, 2018; Coyle & Greiff, 2021, 2023). Tilt is weakly related or unrelated to IQ and general intelligence (*g*, variance common to tests), which largely explains the predictive power of cognitive tests. Despite its non-*g* loading, tilt predicts work and school outcomes (e.g., school grades, job performance). The predictive power of tilt is surprising because non-*g* variables typically have limited predictive power (e.g., Coyle, 2018; Jensen, 1998, pp. 270–305).

Early studies of tilt focused on *ability tilt*, based on math and verbal scores on standardized tests (SAT, ACT, PSAT), producing math tilt (math > verbal) and verbal tilt (verbal > math) (for reviews, see Coyle & Greiff, 2021; Lubinski,

2009, 2016; see also, Coyle, 2016, 2019; Coyle et al., 2014, 2015; Lubinski et al., 2001; Park et al., 2007). Later studies examined *tech tilt*, based on contrasts in non-academic technical tests (automotive, shop, electrical) and academic tests (math or verbal), yielding tech tilt (technical > academic) and academic tilt (academic > technical) (for reviews, see Coyle, 2018; Coyle & Greiff, 2021; see also, Coyle, 2019, 2020, 2021). Despite their non-*g* loading, ability tilt and tech tilt differentially predict educational and occupational achievements in STEM (science, technology, engineering, math) and humanities (e.g., journalism, law, philosophy) (for reviews, see Coyle & Greiff, 2021; Lubinski, 2009, 2016). Tech tilt and math tilt tend to predict STEM criteria, which involve math and technical skills (e.g., electronics, mechanics), whereas verbal tilt tends to predict humanities achievements, which involve verbal skills.

Ability tilt and tech tilt differ for males and females (for reviews, see Coyle & Greiff, 2021; Lubinski, 2009, 2016). Whereas males show high levels of tech tilt (compared to academic tilt) and math tilt (compared to verbal tilt), females show high levels of academic tilt (compared to tech tilt) and verbal tilt (compared to math tilt). Such differences

support theories of sex differences in vocational preferences and investment (Su et al., 2009; see also, Coyle & Greiff, 2021, 2023; Lippa, 1998; Stewart-Williams & Halsey, 2021; von Stumm & Ackerman, 2013). Males invest more in technical and STEM domains (yielding tech tilt and math tilt), whereas females invest more in non-technical academic and humanities domains (yielding academic tilt and verbal tilt).

The current study focused on *spatial and mechanical tilt*, a more recent type of tilt that differs for males and females (e.g., Coyle, 2022b; see also, Kell et al., 2013; Lakin & Wai, 2020; Wai et al., 2009; Wai & Lakin, 2020). Spatial and mechanical tilt are based on contrasts of spatial and mechanical abilities with academic abilities (math or verbal). Such contrasts produce spatial tilt (spatial > academic), mechanical tilt (mechanical > academic), and academic tilt (academic > spatial/mechanical), indicating relative strengths in spatial, mechanical, and academic domains, respectively.

Males and females differ in spatial, mechanical, and academic tilt, which differentially predict STEM and humanities outcomes (Coyle, 2022b; see also, Geary & DeSoto, 2001; Kell et al., 2013; Lakin & Wai, 2020; Wai et al., 2009; Wai & Lakin, 2020). Males typically show spatial and mechanical tilt (compared to academic tilt), whereas females typically show academic tilt (compared to spatial or mechanical tilt), a pattern consistent with sex differences in vocational preferences (e.g., Su et al., 2009; see also, Lippa, 1998; Stewart-Williams & Halsey, 2021). In addition, spatial and mechanical tilt predict STEM criteria (jobs, grades, college majors), which often involve spatial and mechanical abilities. In contrast, academic tilt (notably, verbal tilt) predicts humanities criteria, which are verbally loaded. Such results have been found for nongifted subjects with ability levels in the normal range, as well as gifted subjects with ability levels more than two standard deviations above average (Coyle, 2018, pp. 7–8; Coyle & Greiff, 2021; Johnson & Bouchard, 2007; Kell et al., 2013; Lubinski, 2009, 2010, 2016; Roznowski, 1987; Wai et al., 2009).

Whereas prior research examined sex differences in spatial and mechanical tilt (e.g., Coyle, 2022b; see also, Kell et al., 2013; Lakin & Wai, 2020; Wai et al., 2009; Wai & Lakin, 2020), the current study is the first to examine the development of spatial and mechanical tilt in adolescence for males and females. The study extends Coyle (2022b), who examined sex (but not age) differences in spatial and mechanical tilt using the National Longitudinal Survey of Youth (NLSY). The NLSY is a representative sample of 13- to 17-year-olds in the United States. The NLSY includes the Armed Services Vocational Aptitude Battery (ASVAB), a diverse battery of academic (verbal and math), spatial, and mechanical tests (Hering & McClain, 2003, pp. 1–14). In Coyle's (2022b) study, tilt was based on contrasts of spatial and mechanical abilities with academic abilities (math or verbal), yielding spatial tilt (spatial > academic), mechanical tilt (mechanical > academic), and academic tilt (academic > spatial/mechanical). Spatial ability was based on a test of spatial visualization, which measured the ability to identify an object from its parts. Mechanical ability was based on a test of mechanical comprehension, which mea-

sured mechanical knowledge and reasoning (e.g., the ability to infer the rotation of gears).

Coyle (2022b) found that spatial, mechanical, and academic tilt differentially predicted STEM and humanities criteria (e.g., jobs, college majors, abilities), with spatial and mechanical tilt predicting STEM criteria (which are spatially loaded) and academic tilt predicting humanities criteria (which are verbally loaded). In addition, sex differences varied with type of tilt, with males showing mechanical tilt and females showing academic tilt, with no sex differences in spatial tilt. Such results support research on sex differences in spatial and mechanical abilities (e.g., Linn & Peterson, 1985, p. 1486; see also, Geary & DeSoto, 2001; Lakin & Wai, 2020; Wai et al., 2009; Wai & Lakin, 2020). Males typically outperform females on tests of mechanical knowledge and reasoning, which were assessed by mechanical tilt. In contrast, sex differences are typically smaller or negligible for tests of spatial visualization, which were assessed by spatial tilt.

The current study is the first to examine the development of spatial and mechanical tilt, two abilities that show sex differences, typically favoring males (Linn & Peterson, 1985; see also, Geary & DeSoto, 2001; Lakin & Wai, 2020; Wai et al., 2009; Wai & Lakin, 2020). Its principal aim was to examine age-related changes in spatial and mechanical tilt for males and females, and whether processing speed and *g* explain such changes. Processing speed refers to mental speed and is measured by tasks that assess the ability to solve simple problems quickly and accurately. Such tasks include completing a coding chart or adding two digits (e.g., $4 + 4 = ?$). These tasks are assumed to measure speed of information processing, which facilitates the acquisition of specific abilities that produce tilt (cf. Coyle, 2022a, 2023).

The current study differed from prior tilt research in two ways. First, whereas prior research examined sex differences in spatial and mechanical tilt (Coyle, 2022b; see also, Kell et al., 2013; Lakin & Wai, 2020; Lubinski, 2009, 2016; Wai et al., 2009; Wai & Lakin, 2020), the current study examined age (and sex) differences in spatial and mechanical tilt in adolescence and whether processing speed and *g* mediated age-tilt relations. Tilt was measured from age 13- to 17-years, a period of rapid change in specific abilities (spatial, mechanical, academic) and processing speed, increasing the likelihood of detecting age and sex differences in tilt (Coyle, 2022a, 2023; Jensen, 2006, pp. 91–94; see also, Coyle et al., 2011; Fry & Hale, 1996; R. Kail, 1991, 2000).

Second, whereas prior research examined the development of tech tilt (Coyle, 2022a, 2023; see also, Coyle & Greiff, 2021, 2023), the current study examined the development of spatial and mechanical tilt. Tech tilt research indicates that, in adolescence, males show age-related increases in tech tilt, whereas females show increases in academic tilt, a pattern consistent with sex differences in vocational preferences (Su et al., 2009; see also, Lippa, 1998; Stewart-Williams & Halsey, 2021). While tech tilt is based on technical and mechanical tests (e.g., mechanical, electrical, automotive, shop) (e.g., Coyle, 2022a, 2023), no research has isolated and compared the development of me-

chanical tilt (based on mechanical tests) and spatial tilt (based on spatial visualization tests), key aims of the current study. Moreover, mechanical and spatial tilt are based on abilities that differ for males and females, with mechanical abilities showing large sex differences (favoring males) and spatial abilities (based on visualization) showing small sex differences (e.g., Linn & Peterson, 1985, p. 1486; see also, Coyle, 2022b; Geary & DeSoto, 2001; Lakin & Wai, 2020; Wai et al., 2009; Wai & Lakin, 2020). Such differences may influence sex differences in the development of spatial and mechanical tilt, a possibility discussed below.

The current study examined age and sex differences in spatial and mechanical tilt in adolescence. Following Coyle (2022a; see also, Coyle, 2022a, 2023; Coyle et al., 2011), tilt was based on the ASVAB in the NLSY. The ASVAB includes tests of mechanical abilities, spatial abilities, academic abilities (math or verbal), and processing speed for 13- to 17-year-olds. Spatial ability was based on a test of spatial visualization, which measured the ability to identify an object in a scrambled set of puzzle pieces. Mechanical ability was based on a test of mechanical comprehension, which measured mechanical knowledge and reasoning (e.g., the ability to infer the rotation of gears). Such tests are widely used to measure spatial and mechanical abilities (cf. Geary & DeSoto, 2001; Lakin & Wai, 2020; Linn & Peterson, 1985; Wai & Lakin, 2020). Processing speed was based on tests of coding speed and numerical operations, two standard tests of mental speed that measure the ability to complete a coding chart and solve simple arithmetic problems. *g* was based on the non-speeded (power) tests of the ASVAB, which produces a strong *g* factor and is strongly related to IQ (e.g., Coyle & Pillow, 2008; Ree & Carretta, 1994; see also, Coyle et al., 2014, 2015; Schmidt, 2011).

Following prior research (Coyle, 2022b; see also, Coyle, 2022a, 2023), spatial and mechanical tilt were based on contrasts of spatial and mechanical abilities with academic abilities (math or verbal), yielding spatial tilt (spatial > academic), mechanical tilt (mechanical > academic), and academic tilt (academic > spatial/mechanical). Spatial and mechanical abilities overlap empirically and conceptually with math and STEM abilities (e.g., Coyle, 2022b, see also, Coyle, 2023; Kell et al., 2013; Wai et al., 2009), minimizing the distinctiveness of spatial/mechanical abilities contrasted with math (rather than verbal) abilities. Therefore, compared to spatial/mechanical tilt based on verbal abilities, spatial/mechanical tilt based on math abilities may be less distinctive and less sensitive to sex or age differences (for similar arguments, see Coyle, 2022b, 2023).

Predictions about the development of spatial and mechanical tilt for males and females were based on vocational preference and investment theories (e.g., Coyle & Greiff, 2021, 2023; see also, Lippa, 1998; Stewart-Williams & Halsey, 2021; Su et al., 2009; von Stumm & Ackerman, 2013). Such theories assume that males are more interested in activities that involve *things* (e.g., machines, electronics, tools), which often involve mechanical and spatial abilities. In contrast, females are assumed to be more interested in humanities-based activities that involve *people*, which often involve academic abilities (notably, verbal abilities).

These differences are assumed to lead to differential investment in different domains, producing sex differences in spatial and mechanical tilt (favoring males) and academic tilt (favoring females). However, the strength of sex differences may vary with type of tilt (mechanical or spatial). Whereas mechanical tilt shows strong sex differences (favoring males), spatial tilt based on visualization tests shows weak or negligible sex differences (Coyle, 2022b; Linn & Peterson, 1985, p. 1486), potentially minimizing sex and age differences in spatial tilt.

A final set of predictions focused on relations among age, speed, and tilt for males and females. These predictions were based on processing speed theories (Coyle, 2022a, 2023; Jensen, 2006, pp. 91–94; see also, Coyle et al., 2011; R. Kail, 1991, 2000), which assume that age-related increases in mental speed facilitate the acquisition of specific abilities (e.g., spatial, mechanical, academic) that produce tilt. The current study examined tilt-speed relations from 13- to 17-years, a period of rapid increases in processing speed and specific abilities (Coyle, 2022b; Jensen, 2006, pp. 91–94; see also, Coyle et al., 2011; Fry & Hale, 1996; R. Kail, 1991, 2000). Based on processing speed theories, age-related increases in speed were expected to mediate age-tilt relations, with speed having a significant indirect (mediating) effect on age-tilt relations for males and females. In addition, *g* was also expected to contribute to the development of tilt, a prediction consistent with *cascade theories* (Fry & Hale, 1996; see also, Coyle, 2022a, 2023; Coyle et al., 2011; Tourva & Spanoudis, 2020). Cascade theories assume that age-related increases in speed boost *g*, which in turn influences specific abilities, leading to tilt. Such theories imply that age-tilt relations are mediated by both speed and *g* (rather than speed alone). The age-related effects of speed and *g* on mechanical abilities were expected to be stronger for males, who have stronger mechanical preferences than females.

In sum, the current study examined sex differences in the development of spatial and mechanical tilt. Two sets of predictions were tested.

1. The first prediction was that males would show increases in mechanical and spatial tilt in adolescence (age 13- to 17-years), whereas females would show increases in academic tilt (math or verbal). This prediction was based on vocational preference and investment theories (e.g., Coyle & Greiff, 2021, 2023; see also, Lippa, 1998; Stewart-Williams & Halsey, 2021; Su et al., 2009; von Stumm & Ackerman, 2013). Such theories assume that sex differences in vocational preferences (e.g., mechanical or academic) lead to differential investment in different abilities, producing sex differences in tilt. A related prediction was that sex differences in the development of mechanical tilt (vs. spatial tilt) would be particularly strong, owing to strong sex differences in mechanical preferences (favoring males).
2. The second prediction was that processing speed and *g* would mediate relations of age and tilt, for males and females. This prediction was based on processing speed and cascade theories (Fry & Hale, 1996; see

also, Coyle, 2022a, 2023; Coyle et al., 2011; Tourva & Spanoudis, 2020). Such theories assume that age-related increases in speed boost g , which in turn boosts the acquisition of specific abilities that produce tilt. A related prediction was that the effects of speed and g on mechanical tilt would be stronger for males than females, as age-related increases in speed and g were expected to exacerbate the (large) sex differences in mechanical abilities (favoring males) over time.

Method

Participants

Participants were drawn from the 1997 NLSY ($N = 8989$; Hering & McClain, 2003, pp. 1–14). The NLSY is a nationally representative sample of adolescents born in the United States between 1980 to 1984 and tested at age 13- to 17-years. Following prior tilt research with the NLSY (Coyle, 2022a, 2023), participants were selected if they had all ASVAB scores. There were 1365 13-year-olds (705 males, 660 females), 1415 14-year-olds (738 males, 677 females), 1434 15-year-olds (731 males, 703 females), 1468 16-year-olds (725 males, 743 females), and 1287 17-year-olds (628 males, 659 females).

Variables

Processing speed, g , and tilt were based on the ASVAB, which included two speeded tests and 10 power tests (Hering & McClain, 2003, pp. 82–84). The two speeded tests were *coding speed* (CS), which measured the speed of completing a coding chart, and *numerical operations* (NO), which measured the speed of solving simple arithmetic problems (mostly with single digits). The 10 power tests were (listed alphabetically): *arithmetic reasoning* (AR), which measured the ability to solve math word problems; *auto information* (AI), which measured knowledge of automobile parts and technology; *assembling objects* (AO), which measured the ability to identify an object from its parts; *electronics information* (EI), which measured knowledge of electronics and electrical principles; *general science* (GS), which measured understanding of concepts in the physical and biological sciences; *math knowledge* (MK), which measured the ability to solve math equations; *mechanical comprehension* (MC), which measured mechanical reasoning and understanding mechanical principles; *paragraph comprehension* (PC), which measured reading comprehension of paragraphs; *shop information* (SI), which measured knowledge of shop tools, terminology, and practices; and *word knowledge* (WK), which measured understanding the meanings of words.

The ASVAB power tests were presented using an adaptive procedure calibrating item difficulty with participant ability level. The speeded tests were presented using a non-adaptive procedure with all items presented in a fixed order to all participants. The power tests were scored using item response theory statistics, with higher scores indicating better performance. The speeded tests were scored based on number of correct items, adjusting for guessing and

completion time. All test scores were standardized ($M = 0$, $SD = 1$) prior to analysis.

Processing speed. Following prior research (Coyle, 2022a, 2023; Coyle et al., 2011), processing speed was based on the two ASVAB speeded tests: *coding speed*, which measured the ability to find a number quickly and accurately using a coding chart; and *numerical operations*, which measured the ability to solve simple arithmetic problems, mostly involving single digits (e.g., $4 + 4 = ?$). Such tests are widely used to examine the development of processing speed (e.g., R. Kail, 1991, 2000; Salthouse, 1996). For bivariate correlations, processing speed was the average of the scores on coding speed and numerical operations. For structural equation modeling, processing speed was a latent variable based on coding speed and numerical operations (see below).

Tilt. Spatial and mechanical tilt were based on ASVAB tests of spatial ability, mechanical ability, and academic abilities (verbal or math). Spatial ability was based on assembling objects (AO), which measured spatial visualization (e.g., ability to identify an object from its pieces). Mechanical ability was based on mechanical comprehension (MC), which measured mechanical reasoning (e.g., ability to infer the rotation of gears), knowledge, and principles (e.g., friction, energy). A composite measure of spatial/mechanical ability was based on the average of spatial and mechanical tests. Math and verbal abilities were based on the average of math (AR, MK) and verbal tests (GS, PC, WK), respectively. These abilities have been validated using structural equation modeling and confirmatory factor analysis with the ASVAB (e.g., Coyle & Pillow, 2008; Ree & Carretta, 1994; see also, Coyle et al., 2014, 2015; Schmidt, 2011).

Following prior tilt research (e.g., Coyle et al., 2014; Park et al., 2007), spatial tilt, mechanical tilt, and academic tilt were computed by (a) standardizing spatial, mechanical, and academic (verbal and math) scores in the full sample ($M = 0$, $SD = 1$), and (b) taking within subject differences in spatial/mechanical scores and academic scores (spatial/mechanical minus academic). Positive scores (spatial/mechanical > academic) indicated spatial/mechanical tilt. Negative scores (academic > spatial/mechanical) indicated academic tilt. All subjects showed some degree of tilt (spatial, mechanical, or academic), defined as tilt scores that differed from zero.

There were two measures of spatial and mechanical tilt, both contrasting spatial/mechanical scores with academic scores (math or verbal). The first measure contrasted spatial/mechanical scores with *math* scores (spatial/mechanical minus math), yielding spatial tilt (spatial > math), mechanical tilt (mechanical > math), composite spatial/mechanical tilt (composite > math), and math tilt (math > spatial/mechanical). The second measure contrasted spatial/mechanical scores with *verbal* scores (spatial/mechanical minus verbal), yielding spatial tilt (spatial > verbal), mechanical tilt (mechanical > verbal), composite spatial/mechanical tilt (composite > verbal), and verbal tilt (verbal > spatial/mechanical). The two tilt measures involved academic abilities (math or verbal) that are differentially sensitive to STEM and spatial abilities. Compared to verbal abil-

ities, math abilities overlap more with STEM (which often involves spatial abilities). As a result, spatial/mechanical tilt involving math (vs. verbal) abilities may be less sensitive to sex differences in the development of tilt (for similar arguments, see Coyle, 2022b, 2023).

g. *g* was based on a factor analysis of the first unrotated factor of ASVAB power tests. *g* factor scores for each subject were computed using regression (e.g., Frey & Detterman, 2004; see also, Coyle & Pillow, 2008; Koenig et al., 2008).

Statistical Analyses and Mediational Model

Analyses of variance (ANOVAs) examined sex (male, female) and age (13, 14, 15, 16, 17 years) differences in mean levels of spatial and mechanical tilt. *t*-tests examined sex differences (male-female) in mean levels of spatial and mechanical tilt at each age. Correlations (*rs*) examined relations of spatial and mechanical tilt with age and sex (female = 0, male = 1). Sex differences in correlations were examined using Fisher's *r* to *Z* test. Partial correlations (*prs*) examined relations of spatial and mechanical tilt with age and sex, controlling for speed and *g*. For correlations, speed was based on the average of the ASVAB speeded tests (CS, NO).

Following prior research (cf. Coyle, 2022a, 2023), cascade models estimated mediation effects of speed and *g* on age-tilt relations (Fig. 1). Structural equation modeling (SEM) with maximum likelihood estimation examined mediation effects and relations among variables. For SEM analyses, processing speed was estimated as a latent variable (Speed) using the ASVAB speeded tests (CS, NO). Key effects were total effects of age on tilt (Total), which measured unmediated age-tilt relations; direct effects of age on tilt, which measured mediated age-tilt relations after accounting for speed and *g*; and indirect effects, which measured the strength of mediation. Indirect (mediation) effects on age-tilt relations were estimated for speed (A-S-T), *g* (A-g-T), and speed and *g* (A-S-g-T) (Fig. 1). Indirect effects of speed and *g* (A-S-g-T) tested the cascade hypothesis, which assumes that age-related increases in speed boost *g*, which in turn influences tilt (e.g., Coyle, 2022a, 2023; see also, Fry & Hale, 1996; R. Kail, 1991, 2000). The cascade model also estimated the following paths (Fig. 1): age to speed (A-S), speed to tilt (S-T), age to *g* (A-g), *g* to tilt (g-T), and speed to *g* (S-g).

SEM multigroup analyses examined sex differences in path coefficients using chi-square difference tests ($\Delta\chi^2$). The multigroup analyses compared a model that constrained a key path to equality for both sexes to a model that estimated the path freely for both sexes. Significance was evaluated using 95% bias correct confidence intervals with 2,000 bootstrapped samples. Model fit was estimated using the chi-square statistic (χ^2), comparative fit index (CFI), and root mean square error of approximation (RM-

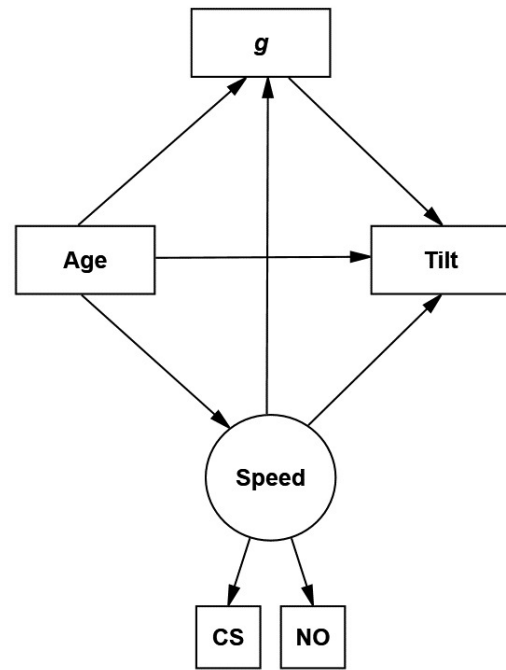


Figure 1. SEM cascade model with speed and *g* mediating age-tilt relations.

Sex differences (male-female) were examined in multigroup analyses comparing unconstrained and constrained models (see Method). Age = age in years. Speed = latent speed estimated using ASVAB coding speed (CS) and numerical operations (NO). Tilt = tilt score.

SEA). The χ^2 is sensitive to sample size and can produce significant results (indicating poor fit) with large samples; the CFI and RMSEA are less sensitive to sample size. Following Kline (2005), model fit was deemed adequate if CFIs were greater than .90 and RMSEAs were less than .08.

Unless otherwise stated, all effects are standardized and reported as significant at $p < .05$. Mean effects are reported in parentheses (e.g., M_r and M_β). Because the current sample was large ($N = 6969$), and because large samples can produce significant effects that are trivial in size, attention should be paid to the size of effects. The effects included standardized regression coefficients, correlations, and mean differences (male-female). Using Cohen's (1988) criteria, correlations (*rs*) of .10, .30, and .50 are considered small, medium, and large, respectively, and standardized mean differences (*ds*) of .20, .50, and .80 are considered small, medium, and large, respectively.

Results

Preliminary Correlations Among Variables

Appendix A reports correlations among tilt difference scores, age, *g*, and speed, with correlations for males and

females above and below the diagonal, respectively.¹ There were six tilt difference scores, based on spatial scores minus verbal or math scores (spatial-V, spatial-M), mechanical scores minus verbal or math scores (mech-V, mech-M), and spatial/mechanical composite scores minus verbal or math scores (spatial/mech-V, spatial/mech-M). Tilt difference scores were scaled so that positive scores indicated spatial or mechanical tilt, and negative scores indicated academic tilt (i.e., verbal or math). (Parentheses below report mean correlations.) For males and females, correlations among the six tilt difference scores were (males, females) significant and positive (.58, .59), indicating that people who showed spatial tilt (spatial > academic) generally also showed mechanical tilt (mechanical > academic). In addition, for males and females, tilt difference scores correlated negatively (males, females) with speed (-.16, -.20) and g (-.09, -.16), indicating that spatial and mechanical tilt were associated slower speed and lower g . (An exception was the two correlations of g with mechanical tilt difference scores, which were slightly positive for males.) Finally, for males and females, age correlated significantly and positively (males, females) with speed (.30, .29) and g (.28, .31), indicating that speed and g increased with age. Age also correlated negatively with (males, females) tilt differences scores (-.07, -.13), indicating that mechanical and spatial tilt decreased with age.

Age and Sex Differences in Mean Levels of Tilt

[Table 1](#) reports mean levels of spatial and mechanical tilt difference scores for males and females at each age (13 to 17 years). Also reported are tests for sex differences in tilt at each age (t_{M-F}) and standardized sex differences in tilt (d_{M-F}) at each age. Tilt difference scores were based on spatial or mechanical scores minus academic scores (math or verbal) so that positive scores indicated spatial or mechanical tilt (spatial/mechanical > academic) and negative scores indicated academic tilt (academic > spatial/mechanical), notably math tilt or verbal tilt.

Mean levels of tilt difference scores were analyzed using 2 (sex: male, female) $\times$ 5 (age: 13, 14, 15, 16, 17 years) analyses of variance (ANOVAs), performed separately for each tilt score (spatial tilt-V, spatial tilt-M, mech tilt-V, mech tilt-M, spatial/mech tilt-V, spatial/mech tilt-M) ([Table 2](#), Analyses 1 to 6). The ANOVAs produced significant main effects of age and sex for all tilt difference scores ($F > 7.91$), and significant sex $\times$ age interactions for mechanical tilt and mechanical/spatial composite tilt ($F > 2.56$), but not spatial tilt ($F < .66$) ([Table 2](#), Analyses 1 to 6). The significant effects persisted after adding covariates of g ([Table 2](#), Analyses 7 to 12) and speed ([Table 2](#), Analyses 13 to 18). (An exception was a nonsignificant main effect of sex for spatial tilt-M after covarying g .)

The significant main effects of age indicated a gradual shift from spatial/mechanical tilt to academic tilt (math or verbal) from age 13 to 17 years ([Table 1](#)). (Parentheses below report mean tilt difference scores.) The shift from spatial and mechanical tilt (positive scores) to academic tilt (negative scores) was observed for mean levels of (13, 14, 15, 16, 17 years) spatial-V (.11, .02, .02, -.03, -.11), spatial-M (.14, .03, .01, -.06, -.13), mech-V (.08, .02, .01, -.04, -.07), mech-M (.11, .04, -.01, -.06, -.09), spatial/mech-M (.09, .02, .01, -.04, -.09), and spatial/mech-M (.13, .04, .01, -.06, -.11). The significant main effects of sex varied with type of tilt (i.e., mechanical, spatial/mechanical, spatial). Males showed mechanical tilt and spatial/mechanical composite tilt (positive scores), while females showed academic tilt (negative scores) for (male, female) mech-V (.14, -.14), mech-M (.15, -.15), spatial/mech-V (.05, -.05), and spatial/mech-M (.06, -.06). In contrast, females showed spatial tilt (positive scores) and males showed academic tilt (negative scores) for (male, female) spatial-V (-.03, .04) and spatial-M (-.02, .02).

The significant sex $\times$ age interactions indicated that sex differences in tilt increased with age for mechanical tilt and spatial/mechanical composite tilt (mech-V, mech-M, spatial/mech-V, spatial/-M) but not for spatial tilt (spatial-V, spatial-M), which showed no significant sex differences with age ([Table 1](#)). (Parentheses report mean tilt difference scores.) Males generally showed high and steady levels mechanical tilt across ages (13, 14, 15, 16, 17 years) for mech-V (.18, .13, .12, .17, .09) and mech-M (.21, .16, .12, .16, .08). Males also showed spatial/mechanical composite tilt (with declines across ages) for mech/spatial-V (.13, .05, .04, .06, -.03) and mech/spatial-M (.16, .08, .04, .05, -.04). In contrast, females generally showed increases in academic tilt (negative scores) with age (13, 14, 15, 16, 17 years) for mech-V (-.03, -.10, -.11, -.25, -.22), mech-M (.01, -.09, -.13, -.28, -.25), spatial/mech-V (.05, -.02, -.02, -.13, -.15), and spatial/mech-M (.09, -.01, -.04, -.17, -.18). These findings were supported by the standardized male-female differences for each tilt score ([Table 1](#), d_{M-F}), and by tests of tilt difference scores from zero, which indicates no tilt ([Table 1](#), $t_{\text{tilt-0}}$). The two mechanical tilt difference scores (mech-V and mech-M) showed the largest sex differences overall (favoring males) ($M_d = .42$, averaged across ages), the largest sex differences at each age ($M_d = .30, .36, .36, .62, .45$, for 13 to 17 years, respectively), and the most differences from zero (18 of 20 $t_{\text{tilt-0}}$ tests) ([Table 1](#)). By comparison, the two spatial tilt difference scores (spatial-V and spatial-M) showed smaller sex differences (favoring females) ($M_d = -.08$, averaged across ages), smaller sex differences at each age ($M_d = -.08, -.09, -.13, -.03, -.07$, for 13 to 17 years, respectively), and fewer differences from zero (12 of 20 $t_{\text{tilt-0}}$ tests) ([Table 1](#)).

¹ [Appendix B](#) reports parallel correlations among tilt scores for subsamples that showed spatial tilt (spatial > academic), mechanical tilt (mechanical > academic), spatial/mechanical composite tilt (spatial/mech > academic), and academic tilt, notably verbal tilt (verbal > spatial/mechanical) or math tilt (math > spatial/mechanical).

Table 1. Means (and SDs) for spatial and mechanical tilt for males and females.

	Males				Females								
	<i>M</i>	<i>SD</i>	<i>n</i>	<i>t</i> _{tilt-0}	<i>M</i>	<i>SD</i>	<i>n</i>	<i>t</i> _{tilt-0}	<i>d</i> _{M-F}	<i>t</i> _{M-F}	<i>r</i> _{sex}	<i>pr</i> _{sex,g}	<i>pr</i> _{sex,speed}
Age 13													
Spatial tilt-V	.08	.81	705	2.47*	.14	.75	660	4.78**	-.08	-1.49	-.04	-.03	-.06*
Spatial tilt-M	.11	.79	705	3.78**	.18	.74	660	6.10**	-.08	-1.55	-.04	-.03	-.07*
Mech tilt-V	.18	.67	705	6.98**	-.03	.69	660	-1.15	.31	5.64**	.15**	.15**	.14**
Mech tilt-M	.21	.72	705	7.85**	.01	.71	660	.25	.29	5.32**	.14**	.14**	.12**
Spatial/mech tilt-V	.13	.61	705	5.53**	.05	.60	660	2.33*	.12	2.22*	.06*	.07*	.04
Spatial/mech tilt-M	.16	.62	705	6.99**	.09	.61	660	3.86**	.12	2.14*	.06*	.06*	.03
<i>g</i>	-.41	.93	705	---	-.49	.81	660	---	.10	1.84	.05	---	.19**
Speed	-.52	.77	705	---	-.28	.70	660	---	-.32	-5.87**	-.16**	-.24**	---
Age 14													
Spatial tilt-V	-.02	.87	738	-.73	.06	.75	677	2.09*	-.10	-1.92	-.05	-.04	-.06*
Spatial tilt-M	.01	.81	738	.22	.06	.68	677	2.40*	-.08	-1.41	-.04	-.03	-.07*
Mech tilt-V	.13	.66	738	5.43**	-.10	.63	677	-3.95**	.35	6.61**	.17**	.18**	.16**
Mech tilt-M	.16	.72	738	6.06**	-.09	.65	677	-3.73**	.37	6.95**	.18**	.18**	.15**
Spatial/mech tilt-V	.05	.64	738	2.30*	-.02	.58	677	-.81	.12	2.22*	.06*	.07*	.05
Spatial/mech tilt-M	.08	.64	738	3.56**	-.01	.55	677	-.71	.17	3.11**	.08**	.09**	.04
<i>g</i>	-.14	.96	738	---	-.23	.85	677	---	.10	1.79	.05	---	.19**
Speed	-.28	.87	738	---	-.03	.73	677	---	-.32	-6.07**	-.16**	-.24**	---
Age 15													
Spatial tilt-V	-.04	.84	731	-1.14	.08	.78	703	2.58*	-.14	-2.59*	-.07**	-.06*	-.08**
Spatial tilt-M	-.04	.83	731	-1.26	.06	.73	703	2.11*	-.12	-2.34*	-.06*	-.06*	-.10**
Mech tilt-V	.12	.70	731	4.79**	-.11	.64	703	-4.73**	.36	6.72**	.18**	.18**	.16**
Mech tilt-M	.12	.77	731	4.26**	-.13	.69	703	-5.11**	.35	6.58**	.17**	.17**	.13**
Spatial/mech tilt-V	.04	.64	731	1.88	-.02	.61	703	-.85	.10	1.94	.05	.06*	.04
Spatial/mech tilt-M	.04	.67	731	1.67	-.04	.60	703	-1.64	.12	2.33*	.06*	.07*	.02
<i>g</i>	.06	1.00	731	---	-.02	.88	703	---	.09	1.61	.04	---	.20**
Speed	-.16	.93	731	---	.16	.82	703	---	-.36	-6.89**	-.18	-.27**	---

	Males				Females								
	<i>M</i>	<i>SD</i>	<i>n</i>	<i>t</i> _{tilt-0}	<i>M</i>	<i>SD</i>	<i>n</i>	<i>t</i> _{tilt-0}	<i>d</i> _{M-F}	<i>t</i> _{M-F}	<i>r</i> _{sex}	<i>pr</i> _{sex,g}	<i>pr</i> _{sex,speed}
Age 16													
Spatial tilt-V	-.05	.87	725	-1.63	-.01	.83	743	-.49	-.04	-.85	-.02	-.01	-.03
Spatial tilt-M	-.06	.82	725	-1.93	-.05	.75	743	-1.92	-.01	-.15	-.01	.01	-.04
Mech tilt-V	.17	.71	725	6.52**	-.25	.65	743	-10.39**	.62	11.81**	.30**	.30**	.28**
Mech tilt-M	.16	.77	725	5.72**	-.28	.68	743	-11.39**	.62	11.80**	.29**	.29**	.26**
Spatial/mech tilt-V	.06	.66	725	2.41*	-.13	.63	743	-5.61**	.29	5.61**	.15**	.16**	.13**
Spatial/mech tilt-M	.05	.67	725	2.13*	-.17	.60	743	-7.66**	.36	6.69**	.17**	.18**	.13**
<i>g</i>	.36	1.04	725	---	.19	.88	743	---	.18	3.38**	.09**	---	.23**
Speed	.10	.92	725	---	.39	.84	743	---	-.33	-6.31**	-.16**	-.27**	---
Age 17													
Spatial tilt-V	-.15	.03	628	-4.42**	-.08	.80	659	-2.49*	-.09	-1.61	-.05	-.02	-.06*
Spatial tilt-M	-.15	.03	628	-4.63**	-.12	.76	659	-3.89**	-.05	-.87	-.02	-.01	-.05
Mech tilt-V	.09	.03	628	3.01**	-.22	.62	659	-8.90**	.45	8.07**	.22**	.23**	.20**
Mech tilt-M	.08	.03	628	2.58*	-.25	.67	659	-9.66**	.45	8.11**	.22**	.22**	.19**
Spatial/mech tilt-V	-.03	.03	628	-1.23	-.15	.60	659	-6.24**	.18	3.22	.09**	.11**	.07*
Spatial/mech tilt-M	-.04	.03	628	-1.25	-.18	.61	659	-7.78**	.23	4.08	.11**	.12**	.08**
<i>g</i>	.46	1.04	628	---	.22	.88	659	---	.25	4.45**	.12**	---	.26**
Speed	.20	.94	628	---	.44	.87	659	---	-.27	-4.83**	-.13**	-.26**	---

Note. * $p < .05$; ** $p < .01$. $t_{\text{tilt-0}}$ = t -test for difference in tilt value from 0, which indicates no tilt. $d_{\text{M-F}}$ = Cohen's d for sex difference. $t_{\text{M-F}}$ = t -test for sex difference. r_{sex} = correlation between sex (female = 0, male = 1) and variable. $pr_{\text{sex,g}}$ = partial correlation between sex and tilt, controlling for g . $pr_{\text{sex,speed}}$ = partial correlation between sex and tilt, controlling for speed. Age = age in years. Spatial and mechanical tilt are based on ASVAB spatial/mechanical scores minus academic scores (math or verbal) so that positive scores indicate spatial/mechanical tilt and negative scores indicate academic tilt (math or verbal). Spatial tilt-V = spatial scores minus verbal scores. Spatial tilt-M = spatial scores minus math scores. Mech tilt-V = mechanical scores minus verbal scores. Mech tilt-M = mechanical scores minus math scores. Spatial/mech tilt-V = spatial/mechanical composite minus verbal scores. Spatial/mech tilt-M = spatial/mechanical composite minus math scores. g = g score based on ASVAB tests, excluding speed tests (i.e., CS, NO). Speed = processing speed based on the average of ASVAB speed tests (CS, NO).

Table 2. Analyses of variance of sex and age on spatial and mechanical tilt difference scores, with and without *g* or speed

Analysis and Criterion	F_{Sex}	F_{Age}	$F_{\text{Sex} \times \text{Age}}$	F_g	F_{speed}
No Covariates					
1. Spatial tilt-V	14.16**	13.21**	.39	---	
2. Spatial tilt-M	7.91**	24.08**	.66	---	
3. Mech tilt-V	300.93**	8.50**	5.81**	---	
4. Mech tilt-M	300.35**	15.73**	6.29**	---	
5. Spatial/mech tilt-V	46.72**	15.40**	2.56*	---	
6. Spatial/mech tilt-M	67.61**	28.07**	3.56**	---	
Covarying <i>g</i>					
7. Spatial tilt-V	7.21**	2.64*	.62	257.44**	---
8. Spatial tilt-M	3.73	8.72**	.95	164.30**	---
9. Mech tilt-V	308.04**	5.33**	5.99**	10.99**	---
10. Mech tilt-M	296.06**	15.65**	6.22**	1.30	---
11. Spatial/mech tilt-V	60.17**	4.59**	3.07*	149.54**	---
12. Spatial/mech tilt-M	76.45**	16.27**	3.92**	52.15*	---
Covarying Speed					
13. Spatial tilt-V	20.93**	7.61**	.42	---	29.13**
14. Spatial tilt-M	30.32**	5.82**	.78	---	166.50**
15. Mech tilt-V	254.65**	2.72*	5.77**	---	62.58**
16. Mech tilt-M	209.84**	1.04	6.43**	---	384.41**
17. Spatial/mech tilt-V	30.80**	7.19**	2.56*	---	60.60**
18. Spatial/mech tilt-M	24.29**	4.30**	3.75**	---	483.40**

Note. * $p < .05$; ** $p < .01$. $F = F$ test for effects of sex (F_{Sex}), age (F_{Age}), sex $\times$ age interaction ($F_{\text{Sex} \times \text{Age}}$), as well as covariates of g (F_g) and speed (F_{speed}). Spatial and mechanical tilt are based on ASVAB spatial/mechanical scores minus academic scores (math or verbal) so that positive scores indicate spatial/mechanical tilt and negative scores indicate academic tilt (math or verbal). Spatial tilt-V = spatial scores minus verbal scores. Spatial tilt-M = spatial scores minus math scores. Mech tilt-V = mechanical scores minus verbal scores. Mech tilt-M = mechanical scores minus math scores. Spatial/mech tilt-V = spatial/mechanical composite minus verbal scores. Spatial/mech tilt-M = spatial/mechanical composite minus math scores. $g = g$ score based on ASVAB tests excluding speed tests (e.g., CS, NO). Speed = processing speed based on the average of ASVAB speed tests (CS, NO).

Correlations of Tilt with Sex and with Age

[Table 1](#) (r_{sex}) also reports correlations of sex (0 = female, 1 = male) with tilt difference scores. Correlations were performed separately at each age and for each tilt score. (Parentheses report mean correlations, averaged across multiple tilt difference scores.) Consistent with the analyses of mean levels of tilt, correlations of mechanical tilt difference scores (mech-V and mech-M) with sex were positive (favoring males), relatively strong, consistently significant, and generally increased from 13 to 17 years ($M_r = .15, .18, .23, .30, .22$). Further, the mechanical tilt correlations with sex remained significant at all ages (13, 14, 15, 16, 17, years) after controlling for g ($M_{pr} = .15, .18, .18, .30, .23$) or processing speed ($M_{pr} = .18, .13, .16, .15, .27, .20$), despite correlations of sex at all ages with g ($M_r = .05, .05, .04, .09, .12$) or speed ($M_r = -.16, -.16, -.18, -.16, -.13$). In contrast, correlations of spatial tilt (spatial-V and spatial-M) with sex were weaker and less consistently significant at all ages ($M_r = -.04, -.05, -.07, -.02, -.04$, ages 13 to 17, respectively), as were correlations of spatial/mechanical tilt composite scores (spatial/mech-V and spatial/mech-M) with sex ($M_r = .06, .07, .06, .16, .10$, ages 13 to 17, respectively).

[Table 3](#) (Analyses 1 to 6) reports correlations of age with tilt difference scores for males and females, with tests of male-female differences in correlations ([Table 3](#), Z_{M-F}). Also reported are correlations of age with tilt scores for subsamples that showed spatial tilt, mechanical tilt, or academic tilt (math tilt or verbal tilt) ([Table 3](#), Analyses 7 to 18). (Parentheses below report mean correlations, averaged across tilt scores.) For tilt difference scores, correlations of age with tilt scores were *negative* for (male, female) spatial tilt difference scores ($-.09, -.11$), mechanical tilt difference scores ($-.04, -.13$), and spatial/mechanical composite difference scores ($-.08, -.15$), with stronger correlations for mechanical tilt and mechanical/spatial composite tilt difference scores for females ([Table 3](#), Analyses 1 to 6). The negative correlations indicate that increases in age were associated with increases in academic tilt (negative relations), especially for females. For subsamples showing spatial or mechanical tilt (or their composite), correlations of age with tilt were generally nonsignificant and near zero for males ($M_r = -.01$) and significant and negative for females ($M_r = -.07$), indicating that females showed age-related declines in spatial and mechanical tilt ([Table 3](#), Analyses 7 to 12). Finally, for subsamples showing academic tilt (i.e., verbal tilt or math tilt), correlations of age with tilt were gen-

Table 3. Correlations of age with spatial and mechanical tilt difference scores and tilt scores for subsamples that show spatial tilt, mechanical tilt, and academic tilt (verbal or math)

	Males		Females		
Variable correlated with age	r_{age}	n	r_{age}	n	$Z_{\text{M-F}}$
1. Spatial tilt-V	-.08**	3527	-.09**	3442	.42
2. Spatial tilt-M	-.10**	3527	-.13**	3442	1.27
3. Mech-V	-.03	3527	-.11**	3442	3.36**
4. Mech-M	-.05**	3527	-.15**	3442	4.22**
5. Spatial/mech tilt-V	-.07**	3527	-.12**	3442	2.11*
6. Spatial/mech tilt-M	-.09**	3527	-.17**	3442	3.40**
7. SpatialV spatial tilt	-.02	1716	-.03	1833	.30
8. SpatialM spatial tilt	-.06*	1763	-.06**	1799	.00
9. MechV mechanical tilt	.04	2068	-.11**	1435	4.38**
10. MechM mechanical tilt	.04	2090	-.08**	1419	3.49**
11. Spatial/mechV spatial/mech tilt	-.01	1889	-.07**	1630	1.78
12. Spatial/mechM spatial/mech tilt	-.03	1907	-.08**	1581	1.47
13. SpatialV verbal tilt	.06**	1811	.08**	1609	-.59
14. SpatialM math tilt	.09**	1764	.08**	1643	.29
15. MechV verbal tilt	.02	1459	.05*	2007	-.87
16. MechM math tilt	.08**	1437	.08**	2023	.00
17. Spatial/mechV verbal tilt	.09**	1638	.08**	1812	.30
18. Spatial/mechM math tilt	.13**	1620	.11**	1861	.60

Note. * $p < .05$, ** $p < .01$. Age = age in years. Spatial tilt-V = spatial scores minus verbal scores. Spatial tilt-M = spatial scores minus math scores. Mech tilt-V = mechanical scores minus verbal scores. Mech tilt-M = mechanical scores minus math scores. Spatial/mech tilt-V = spatial/mechanical composite minus verbal scores. g = g score based on all ASVAB tests. SpatialV spatial tilt = spatial tilt (spatial>verbal) for Spatial-V. SpatialM spatial tilt = spatial tilt (spatial>math) for Spatial-M. MechV mechanical tilt = mechanical tilt (mechanical>verbal) for Mech-V. MechM mechanical tilt = mechanical tilt (mechanical>math) for Mech-M. Spatial/mechV spatial/mech tilt = spatial/mechanical tilt (spatial/mech>verbal) for Spatial/mech-V. Spatial/mechM spatial/mech tilt = spatial/mechanical tilt (spatial/mech>math) for Spatial/mech-M. SpatialV verbal tilt = verbal tilt (verbal>spatial) for Spatial-V. SpatialM math tilt = math tilt (math>spatial) for Spatial-M. MechV verbal tilt = verbal tilt (verbal>mechanical) for Mech-V. MechM math tilt = math tilt (math>mechanical) for Mech-M. Spatial/mechV verbal tilt = verbal tilt (verbal>spatial/mech) for Spatial/mech-V. Spatial/mechM math tilt = math tilt (math>spatial/mech) for Spatial/mech-M. To facilitate interpretation, all specific tilt scores (spatial, mechanical, academic) were converted from negative to positive so that higher scores indicate more tilt. g = g score based on all ASVAB tests.

erally positive and significant for both males ($M_r = .08$) and females ($M_r = .11$), indicating that both sexes showed age-related increases in academic tilt (Table 3, Analyses 13 to 18).

Cascade Analyses of Age and Sex Differences in Mechanical Tilt

Sex differences in age-mechanical tilt relations were probed using SEM cascade models, which assume that age-related increases in processing speed boost g , which influences specific abilities that produce tilt. Because sex differences in age-tilt relations were found for mechanical tilt and its difference scores (but not spatial tilt or its difference scores) (cf. Table 3, Analyses 3-6, 9-10), the cascade analyses examined sex differences in age-tilt relations for mechanical tilt scores (mech-V, mech-M) and subsamples that showed mechanical tilt (mechV mech tilt, mechM mech) (Tables 4, 5, 6).

Fig. 1 depicts the SEM model for the cascade analysis of mechanical tilt difference scores and related subsamples. Indirect (mediation) effects on age-tilt relations were estimated for speed (A-S-T), g (A- g -T), and speed and g (A-S- g -T) (Fig. 1). Indirect effects of speed and g (A-S- g -T)

tested the cascade hypothesis, which assumes that age-related increases in speed boost g , which in turn influences tilt. The cascade model also estimated the following paths in the model (Fig. 1): age to speed (A-S), speed to tilt (S-T), age to g (A- g), g to tilt (g -T), and speed to g (S- g). Sex differences in path coefficients were examined using chi-square difference tests ($\Delta\chi^2$), which compared a model with the path coefficient constrained to be equal for males and females to a model with the same path coefficient varying freely for males and females.

Table 4 reports cascade analyses for mechanical tilt difference scores, which contrasted mechanical scores with verbal scores (mech-V, Analysis 1) or math scores (mech-M, Analysis 2). Mechanical tilt difference scores were scaled so that positive scores indicated mechanical tilt and negative scores indicated verbal tilt (for mech-V) and math tilt (for mech-M). Effects were similar for mech-V and mech-M; therefore, the effects below are averaged for mech-V and mech-M and reported in parentheses. Consistent with the bivariate correlations (cf. Table 3, Analyses 3 and 4), total effects of age on mechanical tilt difference scores were *negative* for males (-.04) and females (-.13), indicating that mechanical tilt decreased (and academic tilt increased) with age (Table 4, Total). In contrast, effects of age on speed

were (male, female) *positive* (.32, .36), indicating that speed increased with age, while effects of speed on tilt were *negative* (-.50, -.37), indicating that faster speed predicted academic tilt (verbal tilt or math tilt). Effects of age on *g* were positive and significantly stronger for males (.07) than females (.02), as were effects of *g* on mechanical tilt difference scores (.42, .26, for males and females, respectively). Consistent with these effects, speed mediated age-mechanical tilt relations (A-S-T) for males (-.16) and females (-.13). Moreover, *g* (along with speed) also contributed (A-S-g-T) to the mediation (males, females) for both sexes (.10, .05). (An exception was the mediation of speed and *g* on age-tilt relations for mech-V for females.) The latter effects (A-S-g-T) support cascade models, which assume that age-related increases in speed boost *g*, which in turn boosts tilt.

[Table 5](#) (Analyses 1 and 2) reports cascade analyses for subsamples that showed mechanical tilt (mechanical > academic) for mech-V and mech-M. As before, the pattern of effects was similar for mechanical tilt scores based on mech-V and mech-M; therefore, the effects below are averaged for mech-V and mech-M and reported in parentheses. Total effects of age on mechanical tilt were *positive* but small for males (.04) and *negative* for females (-.10), indicating that males showed slight age-related increases in mechanical tilt and females showed decreases in mechanical tilt. Consistent with processing speed theories, effects of age on speed were (males, females) positive (.30, .30), as were effects of speed on *g* (.73, .78). In contrast, effects of speed on tilt were (males, females) negative (-.44, -.23), whereas effects of *g* on tilt were positive for males (.28) but mixed in sign for females (-.04), with all male-female differences being significant. Consistent with these effects, speed mediated age-tilt relations (A-S-T) for males (-.13) and females (-.07). Moreover, *g* (along with speed) also contributed (A-S-g-T) to the mediation for males (.06) and females (.04 and -.02, for mech-V and mech-M, respectively), a pattern consistent with cascade theories.

[Table 6](#) (Analyses 1 and 2) reports cascade analyses for subsamples that showed verbal or math academic tilt (academic > mechanical) using mech-V (for verbal tilt) and mech-M (for math tilt). The pattern of effects was similar for verbal tilt and math tilt; therefore, unless otherwise stated, the effects below are averaged for verbal and math tilt and reported in parentheses. The current results differed from the prior results for mechanical tilt (cf. [Table 5](#)) in two ways. First, whereas the prior total effects of age on mechanical tilt were positive for males but negative for females (cf. [Table 5](#), Total), total effects of age on academic tilt (verbal tilt or math tilt) were positive for (male, female) both sexes (.05, .07) ([Table 6](#), Total). Second, whereas the prior effects of age, speed, or *g* on mechanical tilt differed for males and females (cf. [Table 5](#), $\Delta\chi^2$), the analogous effects on academic tilt differed significantly for males and females ($\Delta\chi^2 < 2.65$, [Table 6](#)). In addition, effects of speed on tilt were small and nonsignificant for (male, female) verbal tilt (-.04, .08) but large and significant for math tilt (.33, .37). A similar pattern was observed for effects of *g* on tilt for (male, female) verbal tilt (.10, -.09) and math tilt (-.38, -.32). The results suggest that math tilt (but not ver-

bal tilt) is sensitive to age-related changes in speed and *g*, a conclusion revisited in the Discussion. Finally, and consistent with the analyses of mechanical tilt (cf. [Table 5](#)), indirect effects of speed and *g* on verbal tilt and math tilt were (male, female) generally significant (-.06, -.06), a pattern consistent with cascade theories.

Discussion

The current study was the first to examine sex differences in the development of spatial and mechanical tilt in adolescence (13- to 17-years), a period of rapid change in specific abilities that produce tilt. Test scores were drawn from the NLSY, which includes the ASVAB. The ASVAB includes tests of specific abilities (e.g., spatial, mechanical, academic), processing speed, and *g*. Tilt scores were based on within subject contrasts of spatial and mechanical abilities with academic abilities (math or verbal), yielding spatial tilt (spatial > academic), mechanical tilt (mechanical > academic), and academic tilt (academic > spatial/mechanical). The results were largely consistent with the hypotheses, with exceptions noted below.

1. First, for sex differences in mean levels of tilt, males generally showed mechanical tilt (mechanical > academic), and females generally showed academic tilt (academic > mechanical), with sex differences in tilt increasing with age (from 13 to 17 years) ([Table 1](#)). In contrast, sex differences in spatial tilt (based on a test of spatial visualization) were negligible, a finding consistent with weak sex differences in spatial visualization (vs. mechanical reasoning) (e.g., Linn & Peterson, 1985; see also, Geary & DeSoto, 2001; Lakin & Wai, 2020; Wai et al., 2009; Wai & Lakin, 2020). The results support vocational and investment theories (Coyle & Greiff, 2021, 2023; see also, Lippa, 1998; Stewart-Williams & Halsey, 2021; Su et al., 2009; von Stumm & Ackerman, 2013). Such theories assume that males and females have different vocational preferences, leading to differential investment in different areas. Males invest more in things (vs. people) and mechanical activities (e.g., engineering, computers), boosting mechanical tilt. In contrast, females invest more in people (vs. things) and academic activities (notably, verbal), boosting academic tilt.
2. Second, the direction of tilt relations with age varied with type of tilt ([Table 3](#)). For tilt difference scores (spatial/mechanical minus academic), tilt relations with age were generally *negative*, indicating that academic tilt (math or verbal) increased with age ([Table 3](#), Analyses 1-6). Consistent with these findings, age-tilt relations for subsamples showing academic tilt were *positive*, indicating that academic tilt increased with age ([Table 3](#), Analyses 13-18). In contrast, age-tilt relations for subsamples showing mechanical or spatial tilt were mostly *negative*, indicating that mechanical and spatial tilt decreased with age ([Table 3](#), Analyses 7-12). The positive age-tilt relations for academic tilt subsamples support investment theories, which assume that tilt increases with age due to cu-

Table 4. Exploratory SEM cascade analyses of processing speed and g mediating relations of age and mechanical tilt difference scores for males and females

	Analysis 1: Mech-V					Analysis 2: Mech-M				
	Male		Female		$\Delta\chi^2$	Male		Female		$\Delta\chi^2$
Fit statistics										
χ^2	46.38**		28.76**			89.59**		50.45**		
CFI	1.00		1.00			.98		.99		
RMSEA	.03		.02			.11		.08		
Path coefficients										
A-T	-.01	[-.05, .02]	-.06**	[-.09, -.02]	2.59	-.01	[-.04, .03]	-.03	[-.07, .01]	1.52
A-S	.32**	[.29, .35]	.36**	[.33, .39]	.01	.31**	[.28, .35]	.36**	[.32, .39]	.01
S-T	-.26**	[-.34, -.18]	-.13**	[-.21, -.05]	5.41*	-.73**	[-.79, -.66]	-.60**	[-.68, -.53]	3.60
A-g	.06**	[.04, .09]	.01	[-.02, .04]	8.03*	.07**	[.04, .10]	.02	[-.01, .04]	9.49**
g-T	.22**	[.16, .29]	-.04	[-.11, .02]	32.53**	.61**	[.55, .67]	.35**	[.29, .42]	25.72**
S-g	.74**	[.71, .76]	.77**	[.75, .79]	.10	.72**	[.70, .75]	.77**	[.74, .79]	1.03
Age-tilt effects										
Total	-.03	[-.06, .01]	-.11**	[-.14, -.08]		-.05**	[-.08, -.01]	-.15**	[-.18, -.12]	
A-S-T	-.08**	[-.11, -.06]	-.05**	[-.08, -.02]		-.23**	[-.26, -.19]	-.21**	[-.25, -.18]	
A-g-T	.01**	[.01, .02]	.01	[-.01, .01]		.04**	[.03, .06]	.01	[-.01, .02]	
A-S-g-T	.05**	[.04, .07]	-.01	[-.03, .01]		.14**	[.12, .16]	.10**	[.08, .12]	

Note. * $p < .05$; ** $p < .01$. All effects are standardized. Brackets report 95% confidence intervals. A = age in years. S = latent speed variable based on the speed tests (CS and NO). T = tilt score. g = g score based on ASVAB, excluding speed tests (i.e., CS and NO). Analysis 1 = analysis of mechanical tilt difference scores based on Mech-V (mechanical minus verbal). Analysis 2 = analysis of mechanical tilt difference scores based on Mech-M (mechanical minus math). χ^2 = chi-square goodness of fit statistic ($df = 2$ for all models). CFI = comparative fit index. RMSEA = root mean square error of approximation. $\Delta\chi^2$ = chi-square difference test comparing model with path coefficient constrained to be equal for males and females to model with path coefficient varying freely for males and females.

Table 5. Exploratory SEM cascade analyses of processing speed and g mediating age-mechanical tilt relations for males and females

	Analysis 1: MechV mech tilt					Analysis 2: MechM mech tilt				
	Male		Female		$\Delta\chi^2$	Male		Female		$\Delta\chi^2$
Fit statistics										
χ^2	8.76*		3.21			23.14**		5.12		
CFI	1.00		1.00			.99		1.00		
RMSEA	.04		.02			.07		.03		
Path coefficients										
A-T	.09**	[.05, .13]	-.06*	[-.12, -.01]	18.21**	.09**	[.04, .13]	.01	[-.05, .07]	6.12*
A-S	.30**	[.26, .35]	.30**	[.24, .35]	1.26	.29**	[.25, .34]	.29**	[.23, .34]	.97
S-T	-.25**	[-.33, -.16]	-.05	[-.17, .07]	9.19**	-.63**	[-.72, -.54]	-.41**	[-.54, -.29]	10.44**
A-g	.08**	[.04, .12]	-.01	[-.06, .03]	10.96**	.08**	[.04, .11]	.02	[-.03, .06]	5.51*
g-T	.10*	[.02, .18]	-.18**	[-.27, -.08]	19.81**	.45**	[.36, .54]	.11	[-.01, .22]	25.05**
S-g	.71**	[.68, .75]	.77**	[.74, .81]	.09	.74**	[.71, .78]	.79**	[.75, .82]	.33
Age-tilt effects										
Total	.04*	[.01, .08]	-.11**	[-.17, -.07]		.04	[-.01, .08]	-.08**	[-.13, -.03]	
A-S-T	-.08**	[-.11, -.05]	-.01	[-.05, .02]		-.18**	[-.23, -.15]	-.12**	[-.17, -.08]	
A-g-T	.01*	[.01, .02]	.01	[-.01, .01]		.03**	[.02, .05]	.01	[-.01, .01]	
A-S-g-T	.02*	[.01, .04]	-.04**	[-.07, -.02]		.10**	[.07, .13]	.02*	[.01, .05]	

Note. * $p < .05$; ** $p < .01$. All effects are standardized. Brackets report 95% confidence intervals. A = age in years. S = latent speed variable based on the speed tests (CS and NO). T = tilt score. g = g score based on ASVAB, excluding speed tests (i.e., CS and NO). Analysis 1 = analysis of mechanical tilt scores based on MechV. Analysis 2 = analysis of mechanical tilt scores based on MechM. χ^2 = chi-square goodness of fit statistic ($df = 2$ for all models). CFI = comparative fit index. RMSEA = root mean square error of approximation. $\Delta\chi^2$ = chi-square difference test comparing model with path coefficient constrained to be equal for males and females to model with path coefficient varying freely for males and females.

Table 6. Exploratory SEM cascade analyses of processing speed and g mediating age-academic tilt relations (based on mechanical tilt difference scores) for males and females.

	Analysis 1: MechV verbal tilt					Analysis 2: MechM math tilt				
	Male		Female		$\Delta\chi^2$	Male		Female		$\Delta\chi^2$
Fit statistics										
χ^2	6.31*		10.99**			14.86**		17.20**		
CFI	1.00		1.00			.99		.99		
RMSEA	.04		.05			.07		.06		
Path coefficients										
A-T	.06*	[.01,.11]	.04	[-.01,.09]	.13	.09**	[.04,.15]	.04	[-.01,.09]	1.79
A-S	.33**	[.28,.38]	.39**	[.34,.43]	.01	.34**	[.28,.39]	.37**	[.33,.42]	.91
S-T	-.04	[-.17,.09]	.08	[-.01,.18]	2.65	.33**	[.20,.46]	.37**	[.27,.47]	2.63
A-g	.05*	[.01,.09]	.03	[-.01,.06]	1.03	.05*	[.01,.09]	.02	[-.02,.06]	1.77
g-T	.10	[-.01,.20]	-.09*	[-.17,-.01]	.03	-.38**	[-.49,-.28]	-.32**	[-.40,-.24]	.01
S-g	.78**	[.74,.81]	.76**	[.73,.79]	.39	.79**	[.75,.82]	.76**	[.73,.80]	.04
Age-tilt effects										
Total	.02	[-.03,.07]	.05*	[.01,.09]		.08**	[.03,.13]	.08**	[.04,.13]	
A-S-T	-.01	[-.06,.03]	.03	[-.01,.07]		.11**	[.07,.16]	.14**	[.10,.18]	
A-g-T	-.01	[-.01,.01]	-.01	[-.01,.01]		-.02*	[-.04,-.01]	-.01	[-.02,.01]	
A-S-g-T	-.02	[-.06,.01]	-.03*	[-.05,-.01]		-.10**	[-.14,-.07]	-.09**	[-.12,-.06]	

Note. * $p < .05$; ** $p < .01$. All effects are standardized. Brackets report 95% confidence intervals. A = age in years. S = latent speed variable based on the speed tests (CS and NO). T = tilt score. g = g score based on ASVAB, excluding speed tests (i.e., CS and NO). Analysis 1 = analysis of verbal tilt scores based on MechV. Analysis 2 = analysis of math tilt scores based on MechM. To facilitate interpretation, MechV verbal tilt scores and MechM math tilt scores were converted from negative to positive so that higher scores indicate more verbal tilt (for MechV verbal tilt) or math tilt (for MechM math tilt). χ^2 = chi-square goodness of fit statistic ($df = 2$ for all models). CFI = comparative fit index. RMSEA = root mean square error of approximation. $\Delta\chi^2$ = chi-square difference test comparing model with path coefficient constrained to be equal for males and females to model with path coefficient varying freely for males and females.

mulative investment. The negative age-tilt relations for spatial/mechanical tilt subsamples were not expected and suggest that schooling may inhibit the development of spatial and mechanical tilt, a hypothesis revisited below.

3. Third, for both males and females, SEM cascade analyses indicated that age-related changes in processing speed boosted g , which in turn influenced mechanical tilt, which produced the largest differences in age-tilt relations (Tables 4 and 5). The results support processing speed and cascade theories (Fry & Hale, 1996; see also, Coyle et al., 2011; Coyle, 2022a; R. Kail, 1991, 2000; Tourva & Spanoudis, 2020). Such theories assume that age-related increases in speed boost g , which promotes the acquisition of specific abilities that produce tilt. The cascade analyses of mechanical tilt (which showed the largest sex differences) indicated that the effects of speed and g on mechanical tilt were generally stronger for males than females (Table 5, Analyses 1 and 2). The findings support vocational preference and investment theories (Coyle & Greiff, 2021, 2023; see also, Stewart-Williams & Halsey, 2021; Su et al., 2009; von Stumm & Ackerman, 2013). Such theories assume that sex differences in mechanical preferences (favoring males) produce differential investment in mechanical abilities, and that age-related increases in speed and g magnify such differences over time.

The effects noted above were robust to the use of different statistical controls and tilt measures. For example, the age-related increases in sex differences in tilt remained significant after controlling for processing speed and g (Table 2, Analyses 7-18). In addition, the negative relations of age with mechanical and spatial tilt, and the positive relations of age with academic tilt, replicated using contrasts of mechanical and spatial abilities with verbal (e.g., mech-V or spatial-V) or math abilities (e.g., mech-M or spatial-M) (Table 3, Analyses 7-18). Similarly, the cascade effects of speed on g , and g on tilt, replicated using mechanical abilities contrasted with verbal (mech-V) or math abilities (mech-M) (Tables 4 and 5, Analyses 1 and 2), indicating that the cascade effects were robust to different tilt measures.

The results suggest that sex differences in tilt vary with type of tilt (mechanical vs. spatial), with relatively large sex differences (favoring males) in mechanical tilt and smaller sex differences in spatial tilt (based on spatial visualization). Such results support research on spatial abilities, with sex differences being stronger for mechanical reasoning than spatial visualization (e.g., Linn & Peterson, 1985; see also, Geary & DeSoto, 2001; Lakin & Wai, 2020; Wai et al., 2009; Wai & Lakin, 2020). The results also support vocational preference and investment theories (Coyle & Greiff, 2021, 2023; see also, Stewart-Williams & Halsey, 2021; Su et al., 2009). Such theories assume that males invest in things (vs. people) and mechanical activities, boosting mechanical tilt, whereas females invest in people and verbal activities, boosting academic tilt (notably, verbal tilt).

Lubinski and colleagues (Lubinski, 2009, 2010, 2016) found similar sex differences in the Study of Mathematically Precocious Youth (SMPY) (see also, Kell et al., 2013; Lakin & Wai, 2020; Wai et al., 2009; Wai & Lakin, 2020). The SMPY is a longitudinal study of gifted subjects who took diverse tests around age 12 years and scored in the top 1% on the SAT, which is strongly g loaded. Consistent with the current study, the SMPY results indicated that spatial and mechanical tilt were stronger for males (than females). The generalizability of sex differences in spatial and mechanical abilities (at different ability levels) is theoretically important, given the assumptions of differentiation theories (e.g., Blum & Holling, 2017; Breit et al., 2022; Tucker-Drob, 2009). Such theories suggest that non- g factors such as tilt may be less influential at nongifted (vs. gifted) ability levels, when test scores are more saturated with g and less saturated with non- g variance, potentially neutralizing sex differences in tilt.

A few results deserve further discussion. First, compared to mechanical tilt, sex differences in spatial tilt were generally weak and null at each age (Table 1, Spatial tilt-V, Spatial tilt-M). The null and weak effects of spatial tilt, contrasted with the significant and strong effects of mechanical tilt, suggest that spatial and mechanical tilt tap different abilities that contribute to sex differences (Linn & Peterson, 1985; Voyer et al., 1995). In the current study, spatial tilt was based on a spatial visualization task (*assembling objects*), which measured the ability to identify an object in a set of scrambled puzzle pieces. Such tasks tap object identification and spatial memory, two abilities that typically favor females (cf. Geary, 2022), potentially reducing sex differences in tilt. In contrast, mechanical tilt was based on a mechanical comprehension task, which measured mechanical reasoning and knowledge of mechanical principles. Such tasks typically show large sex differences (favoring males), which would magnify sex differences in mechanical (vs. spatial) tilt.

Second, whereas academic tilt generally increased with age from 13 to 17 years, mechanical and spatial tilt generally decreased with age, especially for females (Table 3, Analyses 7-18). The age-related increases in academic tilt support investment theories, which assume that investments in specific abilities (math, verbal) cumulate over time, producing analogous types of tilt (math tilt, verbal tilt) (e.g., Coyle & Greiff, 2021, 2023; von Stumm & Ackerman, 2013). In contrast, the age-related *decreases* in mechanical and spatial tilt were unexpected. One explanation is that, compared to academic abilities, mechanical and spatial abilities (that produce tilt) receive little attention in school from 13 to 17 years, inhibiting the growth of such abilities (cf. Lakin & Wai, 2020; Wai & Lakin, 2020).

Third, whereas sex differences in the paths of cascade models were absent for academic tilt, such differences were found for mechanical tilt, with cascade effects (speed on g ; g on tilt) being stronger for males (Tables 5 and 6, $\Delta\chi^2$). The results are consistent with investment theories (Coyle & Greiff, 2021, 2023; see also, Lippa, 1998; Stewart-Williams & Halsey, 2021; Su et al., 2009; von Stumm & Ackerman, 2013). Such theories assume that sex differences in me-

chanical investment (favoring males) produce sex differences in mechanical tilt, and that age-related increases in speed and g magnify such differences over time. A separate result concerned indirect effects of speed and g on tilt (A-S- g -T) for the two types of academic tilt (i.e., verbal tilt and math tilt). While indirect effects for math tilt were found for both sexes, indirect effects for verbal tilt were not found for males, whose total (unmediated) age-verbal tilt relation was near zero (indicating no effect). The near zero effect suggests that, in males, there was no age-related increase in verbal tilt to mediate and that any increase in verbal tilt was attributable to non- g factors (e.g., unique reading strategies), which were not affected by speed or g .

Finally, spatial/mechanical tilt difference scores (spatial/mechanical minus academic) correlated negatively with g and speed (which is strongly g loaded), a pattern found for both sexes (Appendix A). The negative relations indicated that spatial and mechanical tilt were related to lower ability levels. Such a pattern has also been found for tech tilt, which is also related to lower ability levels (Coyle, 2022a, 2023). The negative relations suggest that people with lower ability levels self-select into non-academic domains (e.g., automotive and technical), which often involve spatial and mechanical skills (cf. Coyle, 2022a, 2023; Lakin & Wai, 2020; Wai & Lakin, 2020). Such self-selection may produce sex differences in spatial and mechanical tilt, as males and females differentially self-select into domains that promote mechanical or academic abilities.

Limitations

The current study has limitations that should be acknowledged. First, although investment was assumed to produce tilt, investment was not measured directly but was assumed to increase with age. Future research should use more direct measures of investment. One such measure is differential exposure to spatial and mechanical (vs. academic) activities. Exposure to such activities could be assessed in school, at-home, and out-of-school (e.g., clubs) and measured in frequency, duration, and intensity. If tilt arises from differential exposure, then differential exposure to spatial and mechanical (vs. academic) activities may account for sex and age differences in complementary forms of tilt.

Second, spatial and mechanical ability were each based on a single ASVAB test. Spatial ability was based on assembling objects, which measured the ability to identify an object from scattered parts. Mechanical ability was based on mechanical comprehension, which measured mechanical knowledge and reasoning. Future research should measure spatial and mechanical abilities using multiple tests. Following Uttal et al. (2013), spatial ability could be measured using tests of static spatial abilities, such as judging the relative positions of landmarks, and dynamic spatial abilities, such as mental rotation or paper folding. Similarly, mechanical ability could be measured using tests of mechanical knowledge (e.g., labeling different types of gears) and reasoning (e.g., inferring the rotation of gears). Consistent with prior research (Voyer et al., 1995; see also, Lauer et al., 2019; Linn & Peterson, 1985), sex differences (favor-

ing males) in spatial/mechanical tilt should increase with age in childhood and be strongest for tilt based on dynamic spatial abilities, which are associated with large sex differences.

Finally, the current results were based on cross-sectional age differences in the NLSY and therefore causal claims are not warranted. The NLSY consists of US adolescents born between 1980 and 1984 and tested at age 13- to 17-years. Based on the NLSY sample characteristics, the observed sex and age differences may be peculiar to the NLSY and should be replicated to rule out cohort and cultural effects such as the gender equality paradox. The gender equality paradox refers to the observation that sex differences in STEM participation and related traits (e.g., mechanical abilities) *increase* in cultures with higher levels of gender equality (Stoet & Geary, 2018). Consistent with the paradox, changes in gender equality over time may influence STEM participation and affect sex differences in spatial and mechanical tilt. In particular, if gender equality has increased since the mid-1990s (when the NLSY sample was tested), such increases may magnify sex and age differences in STEM participation and related forms of tilt (e.g., spatial and mechanical tilt).

Implications

The current study has theoretical, practical, and methodological implications for specific abilities and tilt. First, the study has implications for differentiation theories (Blum & Holling, 2017; Breit et al., 2022; Tucker-Drob, 2009). Such theories assume that specific abilities (e.g., spatial/mechanical and academic) increase at higher ability levels and older ages in childhood and that such increases are attributable to ability specialization, which leads to tilt (a type of specialization). If tilt increases at higher ability and age levels, then sex differences in tilt should be larger for older and gifted children, who should show elevated tilt levels, and smaller for younger and non-gifted children, who should show diminished tilt levels.

Contrary to differentiation theories, correlations of age with spatial and mechanical tilt were negative, indicating that spatial and mechanical tilt *declined* with age (Table 3). Such a pattern is inconsistent with differentiation and investment theories, which assume that age-related increases in investment in childhood facilitate ability differentiation and specialization, boosting tilt (a type of specialization). The finding that spatial and mechanical tilt declined with age may be attributed to lack of opportunities to develop spatial and mechanical abilities in schools, which focus on academic abilities at the expense of non-academic abilities, potentially inhibiting the development of non-academic abilities (cf. Wai & Lakin, 2020). Such a possibility suggests that the predictions of differentiation and investment theories may be limited to abilities supported by schools and incorporated in school curricula. Investment in a particular ability is possible only if schools, families, and societies support the development of the ability. Without such support, investment in a particular ability may not be possible and ability differentiation (and tilt) may not be observed.

Second, the current study has implications for cascade models (e.g., Fry & Hale, 1996; see also, Coyle, 2022a, 2023; Coyle et al., 2011; Tourva & Spanoudis, 2020). Cascade models assume that in adolescence, age-related increases in processing speed increase g , which in turn increases the acquisition of specific abilities that produce tilt. In the current study, support for cascade models was found for mechanical tilt, with age-tilt effects influenced by speed and g . Future research should examine the effects of speed and g on age-tilt relations in early to late adulthood (e.g., 20- to 80-years). Based on differentiation theories and cognitive aging research (Blum & Holling, 2017; see also, Salthouse, 1996), the gradual slowing of processing speed (and declines in g) over the lifespan may inhibit ability specialization, resulting in age-related declines in tilt. Another possibility is to track longitudinal changes in the effects of speed and g on tilt in childhood (cf. R. V. Kail, 2007). Consistent with cascade and speed theories, age-related increases in speed (and g) should lead to increases in the acquisition of specific abilities that produce tilt, with changes in speed *preceding* changes in tilt (rather than vice versa).

Third, the current study has implications for the use of ability profiles in educational and vocational settings. Ability profiles measure within subject variation in two or more abilities (e.g., spatial/mechanical and academic). Tilt represents an ability profile involving two distinct abilities, typically an academic ability (i.e., math or verbal) and a non-academic ability (e.g., spatial or mechanical). Teachers can use ability profiles to tailor instruction to students, engaging strengths while compensating for weaknesses. High school and college counselors can use ability profiles to provide vocational advice, aligning students' profiles with prospective college majors and jobs in different domains (e.g., STEM, humanities).

Ability profiles can also be used by gifted and talent programs to identify the *missing Einsteins*—high ability students with distinctive ability profiles, including strengths in non-academic domains (e.g., spatial and mechanical) (Wai & Lakin, 2020). Such students may be overlooked in schools, which focus on academic domains (i.e., math and verbal). The lack of attention to non-academic domains may limit opportunities to develop non-academic abilities and may suppress sex differences in such abilities, particularly for gifted students, who typically show exaggerated ability profiles (e.g., Lohman et al., 2008). Moreover, the lack of attention to non-academic abilities may be especially disadvantageous for gifted females with strengths in spatial and mechanical abilities. Such females may not be able to develop such abilities outside of school due to lack of family or societal support, especially in cultures that enforce sex stereotypes that inhibit female participation in spatially loaded STEM fields (cf. Stoet & Geary, 2018).

Fourth, the current study has implications for the interpretation of effect sizes for tilt. Whereas correlations of sex (0 = female, 1 = males) with spatial tilt were negligible at all ages ($M_r = -.04, -.05, -.07, -.02, -.04$, for 13- to 17-year-olds), correlations of sex with mechanical tilt were stronger and increased with age ($M_r = .15, .18, .18, .30, .22$, for 13- to 17-year-olds) (Table 1). Cohen (1988) suggested that cor-

relations of .10, .30, and .50 could be considered small, medium, and large, respectively. More recently, Gignac and Szodorai (2016) meta-analyzed the distribution of correlations in individual differences research. They found that correlations in the 25th, 50th, and 75th percentiles corresponded to correlations around .10, .20, and .30, which they suggested could be considered small, medium, and large, respectively. Using these criteria, the correlations of sex with mechanical tilt would be small to medium based on Cohen's (1988) criteria or medium to large based on Gignac and Szodorai's (2016) criteria. In comparison, the correlations of sex with g would be negligible to small at all ages ($M_r = .05, .05, .04, .09, .12$, for 13- to 17-year-olds; Table 1) based on Cohen's (1988) or Gignac and Szodorai's (2016) criteria.

Finally, the current study has implications for claims that tilt effects are spurious (e.g., Sorjonen et al., 2024). Such claims assert that tilt effects can be attributed to the constituent abilities of tilt (e.g., spatial or academic) rather than their difference (e.g., spatial minus academic). Such claims are contradicted by evidence that tilt effects and tilt heritabilities persist after controlling for their constituent abilities (Woodley of Menie et al., 2025). In addition, tilt levels increase at slower (vs. faster) life history speed, which is related to investment and ability specialization in specific domains (Woodley of Menie et al., 2025; see also, Woodley, 2011; Woodley of Menie et al., 2015, 2021). Such findings suggest that tilt arises from prolonged investment in specific domains (e.g., STEM or humanities), boosting some abilities at the expense of others, leading to ability profiles with distinct patterns of strengths and weaknesses.

Future Research

Future research could extend the current study in a few ways. First, whereas the current study examined sex differences in age-tilt relations in adolescence (ages 13 to 17 years), future research might examine age-tilt relations in adulthood, notably from 20 to 80 years. This age range represents a period of *developmental dedifferentiation*, in which specific abilities become more g loaded and less loaded with variance from specific abilities (Blum & Holling, 2017; see also, Deary et al., 1996; Garrett, 1946; Woodley, 2011). Such dedifferentiation may reduce sex differences in tilt, which would become less loaded with variance from specific abilities (e.g., mechanical abilities) that produces tilt. Second, whereas tilt has been examined for gifted (e.g., SMPY) and nongifted (current study) samples, future research might examine tilt for people with intellectual disabilities, whose ability levels are two or more standard deviations below average. Such low ability levels are assumed to produce *ability dedifferentiation*, in which specific abilities become more g loaded (and less loaded with specific variance), potentially neutralizing sex differences in tilt (cf. Deary et al., 1996; Detterman & Daniel, 1989; see also, Breit et al., 2021, 2022). Finally, whereas the current study examined g loaded factors that mediate tilt (e.g., speed), future research might examine non- g factors that mediate tilt. Such factors include mechanical interests, which show strong

sex differences, and motivation and personality traits (e.g., conscientiousness and grit), which may contribute to the acquisition of specific abilities that produce tilt.

Conclusion

The current study is the first to examine sex differences in the development of spatial and mechanical tilt in adolescence (from 13 to 17 years). Tilt was based on within subject contrasts of mechanical and spatial abilities with academic abilities (math or verbal), yielding mechanical tilt (mechanical > academic), spatial tilt (spatial > academic), and academic tilt (academic > spatial or mechanical). While sex differences in mechanical tilt (favoring males) generally increased with age, sex differences in spatial tilt did not, suggesting that sex differences are more sensitive to mechanical reasoning (vs. spatial visualization). Age-related *increases* were found for academic tilt (math tilt or verbal tilt), while age-related *decreases* were observed for mechanical and spatial tilt, perhaps because schooling supports the development of academic abilities (math and verbal) but inhibits spatial or mechanical abilities. Finally, cascade models of mechanical tilt (which showed the largest sex differences) indicated that age-related increases in processing speed boosted *g*, which in turn influenced tilt. Future

research might consider factors that influence sex differences in the development tilt such as developmental period (childhood vs. adulthood), ability level (intellectually disabled vs. gifted), and motivation (e.g., grit or self-efficacy).

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Appendix A. Correlations among age and spatial tilt difference scores (spatial-academic), mechanical tilt difference scores (mechanical-academic), and spatial/mechanical tilt difference scores (spatial/mech-academic), for males (above diagonal) and females (below diagonal)

	1	2	3	4	5	6	7	8	9
1. Age	---	-.08**	-.10**	-.03	-.05**	-.07**	-.09**	.30**	.28**
2. Spatial tilt-V	-.09**	---	.78**	.38**	.07**	.87**	.52**	-.23**	-.08**
3. Spatial tilt-M	-.13**	.77**	---	.21**	.40**	.63**	.85**	-.19**	-.22**
4. Mech tilt-V	-.11**	.44**	.23**	---	.71**	.79**	.54**	.02	-.07**
5. Mech tilt-M	-.15**	.10**	.42**	.70**	---	.43**	.82**	.07**	-.21**
6. Spatial/mech tilt-V	-.12**	.88**	.62**	.82**	.44**	---	.64**	-.14**	-.09**
7. Spatial/mech tilt-M	-.17**	.53**	.86**	.54**	.83**	.63**	---	-.08**	-.26**
8. <i>g</i>	.29**	-.17**	-.16**	-.16**	-.12**	-.20**	-.17**	---	.66**
9. Speed	.31**	-.09**	-.23**	-.16**	-.29**	-.14**	-.30**	.67**	---

Note. * $p < .05$; ** $p < .01$. Age = age in years. Spatial and mechanical tilt are based on ASVAB spatial/mechanical scores minus academic scores (math or verbal) so that positive scores indicate spatial/mechanical tilt and negative scores indicate academic tilt (math or verbal). Spatial tilt-V = spatial scores minus verbal scores. Spatial tilt-M = spatial scores minus math scores. Mech tilt-V = mechanical scores minus verbal scores. Mech tilt-M = mechanical scores minus math scores. Spatial/mech tilt-V = spatial/mechanical composite minus verbal scores. Spatial/mech tilt-M = spatial/mechanical composite minus math scores. *g* = *g* score based on ASVAB tests excluding speed tests (i.e., CS, NO). Speed = processing speed based on the average of ASVAB speed tests (CS, NO).

Appendix B. Correlations of age with subsamples that show spatial tilt, mechanical tilt, spatial/mechanical tilt, or academic tilt (verbal or math), for males (above diagonal) and females (below diagonal)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Age	---	-.02	-.06*	.04	.04	-.01	-.03	.06**	.09**	.02	.08**	.09**	.13**	.30**	.28**
2. SpatialV spatial tilt	-.03	---	.56**	.17**	.01	.72**	.28**	a	-.19**	-.17**	-.05	-.12	-.16**	-.15**	-.05
3. SpatialM spatial tilt	-.06**	.53**	---	.10**	.18**	.41**	.68**	-.16**	a	-.04	-.08	-.13**	-.14*	-.15**	-.16**
4. MechV mechanical tilt	-.11**	.25**	.09**	---	.48**	.57**	.31**	-.07*	-.02	a	-.20**	-.18**	-.11**	-.06**	-.12**
5. MechM mechanical tilt	-.08**	.01	.20**	.51**	---	.21**	.66**	-.03	-.09**	-.09	a	-.10**	-.14**	-.01	-.20**
6. Spatial/mechV spatial/mech tilt	-.07**	.74**	.35**	.61**	.22**	---	.39**	-.18**	-.20**	-.17**	-.09*	a	-.17**	-.13**	-.08**
7. Spatial/mechM spatial/mech tilt	-.08**	.21**	.65**	.35**	.65**	.37**	---	-.12**	-.13**	-.08	-.14*	-.17**	a	-.10**	-.21**
8. SpatialV verbal tilt	.08**	a	-.11*	-.09*	-.09*	-.06	-.09	---	.59**	.19**	.11**	.71**	.30**	.13**	.04
9. SpatialM math tilt	.08**	-.19**	a	-.07	-.13**	-.18**	-.12	.60**	---	.11**	.21**	.38**	.65**	.04	.07**
10. MechV verbal tilt	.05*	-.16**	-.08*	a	-.13**	-.24**	-.18**	.26**	.16**	---	.54**	.62**	.38**	-.11**	-.08**
11. MechM math tilt	.08**	-.03	-.16**	-.10*	a	-.08*	-.33**	.15**	.25**	.54**	---	.34**	.66**	-.09**	.03
12. Spatial/mechV verbal tilt	.08**	-.27**	-.14**	-.25**	-.14**	a	-.13**	.72**	.41**	.67**	.33**	---	.42**	.04	.01
13. Spatial/mechM math tilt	.11**	-.11**	-.26**	-.11*	-.22**	-.14**	a	.34**	.69**	.41**	.70**	.47**	---	-.02	.09**
14. g	.29**	-.11**	-.16**	-.23**	-.22**	-.16**	-.22**	.10**	.02	-.01	-.02	.07**	.01	---	.66**
15. Speed	.31**	-.02	-.17**	-.18**	-.28**	-.10**	-.27**	.08**	.09**	.03	.12**	.06**	.12**	.67**	---

Note. * $p < .05$, ** $p < .01$. a = correlation could not be computed because tilt scores are based on mutually exclusive subsamples. Age = age in years. To facilitate interpretation, all tilt scores were converted from negative to positive so that higher scores indicate more tilt. SpatialV spatial tilt = spatial tilt (spatial>verbal) for Spatial-V. SpatialM spatial tilt = spatial tilt (spatial>math) for Spatial-M. MechV mechanical tilt = mechanical tilt (mechanical>verbal) for Mech-V. MechM mechanical tilt = mechanical tilt (mechanical>math) for Mech-M. Spatial/mechV spatial/mech tilt = spatial/mechanical tilt (spatial/mech>verbal) for Spatial/mech-V. Spatial/mechM spatial/mech tilt = spatial/mechanical tilt (spatial/mech>math) for Spatial/mech-M. SpatialV verbal tilt = verbal tilt (verbal>spatial) for Spatial-V. SpatialM math tilt = math tilt (math>spatial) for Spatial-M. MechV verbal tilt = verbal tilt (verbal>mechanical) for Mech-V. MechM math tilt = math tilt (math>mechanical) for Mech-M. Spatial/mechV verbal tilt = verbal tilt (verbal>spatial/mech) for Spatial/mech-V. Spatial/mechM math tilt = math tilt (math>spatial/mech) for Spatial/mech-M. g = g score based on all ASVAB tests, excluding speed tests (i.e., CS, NO). Speed = processing speed based on the average of ASVAB speed tests (CS, NO).