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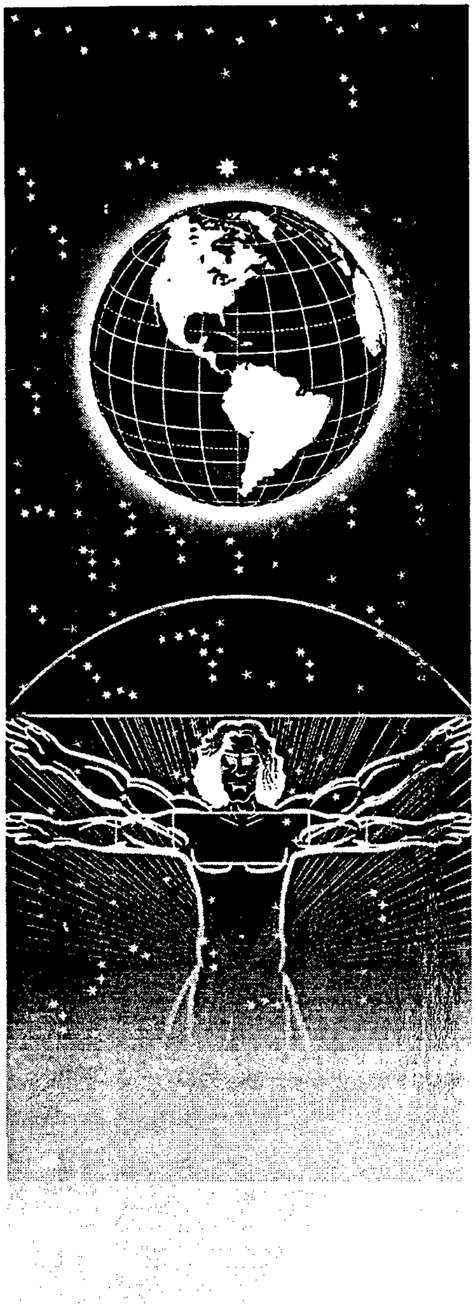

UNITED STATES AIR FORCE ARMSTRONG LABORATORY

COGNITIVE AND PSYCHOMOTOR ABILITIES: A FURTHER INVESTIGATION OF THEIR RELATIONSHIP

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This paper has been reviewed and is approved for publication.

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A study was conducted to expand our understanding of the relationship between cognitive and psychomotor abilities. The tests were administered as might occur in personnel selection and classification. A paper-and-pencil multiple aptitude battery and a wide-ranging, computer-based psychomotor test battery were administered to 429 male and female military recruits. A confirmatory factor analysis yielded the higher order factors of general cognitive ability (g) and psychomotor / technical knowledge (PM/TK). The PM/TK factor was interpreted as representing Vernon's (1969) practical factor (k:m) (see P.E. Vernon, Intelligence and Cultural Environment, London: Methuen) . In the joint analysis of these two batteries, g and PM/TK each accounted for about 31% of the common variance. No residualized lower order factor accounted for more than 7%. The higher order PM/TK factor influenced a broad range of lower order psychomotor factors.

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PREFACE

This effort was performed under Work Unit 1123A101, Pilot Selection and Classification Support, in support of Aircrew Selection and Classification. The authors thank Mr James Earles for his helpful comments. This paper was accepted for publication by the *International Journal of Selection and Assessment* and is expected to be published in 1997.

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COGNITIVE AND PSYCHOMOTOR ABILITIES: A FURTHER INVESTIGATION OF THEIR RELATIONSHIP

SUMMARY

An experiment was conducted to expand our understanding of the relationship between cognitive and psychomotor abilities. A cognitive aptitude battery and a psychomotor battery were administered to 429 military recruits. A confirmatory factor analysis yielded higher-order factors of general cognitive ability (*g*) and psychomotor/technical knowledge (PM/TK). PM/TK was interpreted as Vernon's (1969) practical factor (k:m). In the joint analysis of these batteries, *g* and PM/TK each accounted for about 31% of the common variance. No residualized lower-order factor accounted for more than 7%. PM/TK influenced a broad range of lower-order psychomotor factors. The first practical implication of these findings is that psychomotor tests are expected to be at least generally interchangeable. A second implication is that the incremental validity of psychomotor tests beyond cognitive tests is expected to be small. These findings should help guide test developers and inform personnel selecting agencies regarding the expected utility of psychomotor tests.

INTRODUCTION

Frequently, taxonomies of human performance make distinctions between elements on the basis of content and appearance. Mathematical ability is divided from verbal ability because the tests used to measure them have a differing content and look. Math items involve numbers and verbal items involve words. Close inspection of the scores show a correlation between the two that belies the apparent differences. For example, we computed the correlation of sums for the two verbal versus the two math subtests from the Armed Services Vocational Aptitude Battery and got a correlation of .744. Other test batteries show similar results (e.g., .70 for the Scholastic Achievement Test [Ree & Carretta, in press]; .74 for the Air Force Officer Qualifying Test [Steuck, Watson, & Skinner, 1988]). This is because of a common underlying source factor.

Similarly, cognitive tests and psychomotor tests bear little superficial similarity. Cognitive tests require answering questions on an answer sheet while psychomotor tests are usually computer-administered and use control sticks, the computer pointing device called the mouse, and foot pedals. The dissimilarity between cognitive and psychomotor tests has caused several researchers to consider them as unrelated to one another.

Cognitive ability has been studied for about a century. The emerging consensus is that cognitive abilities have a hierarchical structure (Carretta & Ree, 1996; Gustafsson, 1984; Ree & Carretta, 1994a; Vernon, 1969) with general cognitive ability, *g*, at the apex, lower-order common factors such as verbal, math, and spatial, with test scores at the lowest level. The hierarchical model demonstrates that *g* accounts for a major portion, frequently more than half, of the variance of the lower-order common factors and the test scores. The hierarchical structure is found not to differ across sex and racial/ethnic groups (Carretta & Ree, 1995; DeFries, et al. 1974; Michael, 1949; Ree & Carretta, 1995). Further, cognitive ability tests consistently have been demonstrated to be highly useful predictors in training and education (Lavin, 1965; Ree, Carretta, & Teachout, 1995), job performance (Hunter & Hunter, 1984; Ree & Earles, 1992), and many other life experiences (Brand, 1987). These practical characteristics create a compelling reason to continue to study cognitive ability and its relationships.

Like cognitive ability, psychomotor ability has been studied for about a century. Fleishman and Quaintance (1984) have identified no fewer than 11 conceptually separate domains of psychomotor performance. Historically, psychomotor abilities have been seen as lower order factors not influenced by a higher order factor (Cronbach, 1970; Fleishman, 1964). Recently, Ree and Carretta (1994b) examined the relationship of a limited battery of cognitive tests and psychomotor tracking tests. They found both lower-order and higher-order cognitive and lower-order and higher-order psychomotor factors. However, their cognitive tests were limited to verbal and mathematical and their psychomotor tests to tracking tasks only. They did not study other cognitive or psychomotor domains.

Vernon (1947; 1950; 1969) in a series of studies has suggested a factor comprised of both cognitive and psychomotor abilities. This major factor influences spatial, perceptual, and mechanical cognitive factors as well as psychomotor factors. This factor is often labeled as "practical" and abbreviated as k:m.

There have been few studies of the equality of factor structure of psychomotor abilities among sex and ethnic groups (Carretta, 1997; Carretta & Ree, 1997). However, the job-related validity of psychomotor tests has been studied extensively (see Ree & Carretta, 1994b, for a review).

Although others (Ackerman, 1988) have chosen to study the acquisition of psychomotor skills and the relationship between cognitive and psychomotor skills during acquisition (Fleishman & Hempel, 1954, 1955; Reynolds, 1952), we have chosen to investigate the relationship of cognitive and psychomotor skills as they might be used for personnel selection. Specifically, first-time-tested scores will be used for psychomotor measures as opposed to asymptotic performance which is used in some theoretical studies. In the current study, we have extended past results in both the cognitive and psychomotor domains. This allows for an examination of the connection among a broader sampling of cognitive factors such as verbal, technical knowledge, and speed with a broader sampling of psychomotor factors such as arm-hand movement, finger dexterity, hand movement speed, and leg reaction time. This broader set of factors also allows for the investigation of whether the higher-order psychomotor factor found by Ree and Carretta (1994b) extends to other psychomotor domains and whether the Vernon (1947; 1950; 1969) k:m factor emerges.

The practical consequences of finding a higher-order psychomotor factor extends to ease in the development of alternate psychomotor test forms. Failure to find the higher-order factor would suggest that each psychomotor test measures unique factors and that the development of alternate forms would be made more difficult and costly due to the necessity of replicating the unique factor. Failure to confirm Vernon's (1947; 1950; 1969) k:m factor would make test developers less likely to use Vernon's theory to construct aptitude test batteries. Finally, factor results would help in the interpretation of other studies of the validity (Carretta & Ree, 1994; Hunter & Hunter, 1984; Wheeler & Ree, 1997) and incremental validity of psychomotor tests for the prediction of occupational criteria.

METHOD

Participants

The participants in this study were 429 enlisted recruits of the U. S. Air Force between the ages of approximately 18 and 24. They were mostly white (78%), almost evenly divided between males (48%) and females (52%), and graduates of high school or better (99%).

Measures

Paper-and-pencil cognitive tests. The Armed Services Vocational Aptitude Battery (ASVAB) is comprised of 10 tests that measure general cognitive ability (g), and the three lower-order factors of verbal/math (V/M), speed (SPEED), and technical knowledge (TK) (Ree & Carretta, 1994a). It requires about three hours to administer and is machine scored. The ASVAB is developed from a detailed written taxonomy that specifies both content and psychometric characteristics.

The verbal and quantitative tests are Word Knowledge (WK), Paragraph Comprehension (PC), Arithmetic Reasoning (AR), and Mathematics Knowledge (MK). WK measures knowledge of synonyms and PC measures reading comprehension. AR requires participants to solve word problems, and MK involves problem solving using high school-level mathematics.

Numerical Operations (NO) and Coding Speed (CS) are the two speed tests. NO is a series of 50 arithmetically trivial items (e.g., 6 +3 = 9; 60 / 15 = 4; 6 x 3 = 18; 7-2 = 5) that must be completed in three minutes. CS requires the examinee to find the number that goes with specific words from a table.

The technical knowledge tests are General Science (GS), Mechanical Comprehension (MC), Auto and Shop Information (AS), and Electronics Information (EI). GS measures knowledge of biology, earth science, and elementary physical science. MC assesses knowledge of mechanical principles and tools. AS provides a measure of knowledge of automotive systems and shop tools and practices. EI is a measure of knowledge about elementary electrical principles and electronics. Example items are presented in the *ASVAB Information Pamphlet* (DoD, 1984) given to all applicants prior to testing.

Psychomotor tests. Seventeen psychomotor tests were administered on a 386-based personal computer with a 14" color, non-interlaced, VGA monitor. The clock speed of the computer was 25 MHz and there were four megabytes of RAM. All tests were run in DOS. Peripheral devices included left- and right-hand control sticks, a mouse, keypad, and left and right foot pedals. Participants were instructed to use their left hand for the left control stick and their right hand for the right control stick, regardless of their handedness. Unpublished data on approximately 5,000 U. S. Air Force pilot applicants tested on similar psychomotor tests showed no advantage for left- or right-handed individuals.

The tests included Arm Movement, two versions of Complex Coordination (control stick and foot pedal), two versions of Dot the Circle (control stick and mouse), Gas Pedal, Key Tapping, Kinesthetic Memory, Leg Reaction, Rotary Pursuit, Scanning and Allocating, Track the Plane, two versions of Track Tracing (control stick and mouse), two versions of Trail Making (control stick and mouse), and Two-Hand Coordination.

The Arm Movement test measures the ability to rapidly make large arm movements (i.e., speed of limb movement; Fleishman, 1964). Two boxes appear, one each on the left and right sides of the screen. The participant uses a mouse to move a cursor from one box to the other and back. The score is the number of arm movements completed (ARM) in a fixed time limit.

The Complex Coordination tests (either left and right control sticks or right control stick and foot pedals) measure multilimb coordination (Fleishman, 1964). Using a dual-axis right control stick, participants are required to keep a one-inch cross centered on a dotted-line cross that bisects the screen horizontally and vertically. Simultaneously, using the left single-axis control stick, participants have to keep a one-inch vertical bar horizontally centered at the base of the screen (i.e., rudder). The scores are horizontal (CCH), vertical (CCV), and rudder (CCR) tracking error. Complex Coordination with foot pedals is identical to Complex Coordination, except that foot pedals are used to manipulate the one-inch vertical bar instead of the left control stick. The scores are horizontal (CPH), vertical (CPV), and rudder (CPR) tracking distance error.

The Dot the Circle tests (either right control stick or mouse) measure control precision (Fleishman & Quaintance, 1984). In this test, several circles appear simultaneously on the screen. The participant must move a cursor over any one of the circles. Once the cursor is centered on a circle, the participant presses the keypad ENABLE key to score points for that circle. The participant then moves the cursor over another circle and presses the ENABLE key again. This process is repeated. The participant is instructed to complete as many circles as possible in the time limit for the test. The scores of interest are the number of circles completed (DCC or DCM).

The Gas Pedal test measures rate control (Fleishman, 1964). A dial appears on the screen with a gauge indicating the desired "target" velocity. The participant must manipulate the foot pedals (i.e., gas pedal and brake) to align it with the moving gauge. The score is accumulated tracking distance error (GPT).

The Key Tapping test provides a measure of finger dexterity (Fleishman, 1964). The participant is told to rapidly press the left mouse button as many times as possible during ten, 30-second trials. The score is the number of key presses completed (KTT).

The Kinesthetic Memory test measures the ability to perform an arm movement and then repeat it from memory. During each item, a cross appears at the center of the screen over a fixed image of a circle. A second circle simultaneously appears at some other location on the screen. The participant uses the right control stick to move the cross from the circle in the center of the screen to the circle located elsewhere on the screen, and then back to the center. After completing this movement, the cross and the second circle disappear. The participant must remember the location of the second circle and duplicate the movement of the control stick to move the invisible cross over it. The scores for Kinesthetic Memory are summed horizontal (KTH) and vertical (KTV) distance error.

The Leg Reaction test measures simple reaction time. The image of a traffic signal with only a red and green light is displayed. When the signal is "green," the participant must press the right foot pedal to the floor. When the signal changes to "red," the participant must release the right pedal as quickly as possible and press the left foot pedal to the floor. When the signal changes back to "green," the participant must release the left pedal and press the right one again. The scores are mean release (LRR) and press (LRP) times.

The Rotary Pursuit test assesses pursuit tracking (Fleishman, 1964). An image of an airplane moves in a clockwise elliptical path on the screen. The participants use the right control stick to track the plane. The scores are horizontal (RPH) and vertical (RPV) tracking distance error.

Scanning and Allocating is a compensatory tracking task that measures rate control (Fleishman, 1964). Participants are told to simultaneously maintain the vertical alignment of four vertical lines using the right control stick. Participants can control only one vertical line at a time, switching among the lines by using the numeric keypad. The scores are summed tracking error defined as distance from vertical for the first (SA1), second (SA2), and third (SA3) time intervals.

Track the Plane is a compensatory tracking test that measures the psychomotor factor of rate control (Fleishman, 1964). A fixed image of an airplane is shown at the center of the screen along with a "gunsight" that is being forced away from the airplane by a random function. Participants maneuver the right control stick to keep a "gunsight" centered on the airplane. The score is accumulated tracking distance error (TTP).

The Track Tracing tests (either the right control stick or mouse) measure manual dexterity (Fleishman, 1964). A maze is shown on the screen. Participants must maneuver a circle through the maze. Participants have five minutes to complete ten mazes that get progressively more difficult. The score is the number of mazes completed (TTC or TTM).

The Trail Making tests (either the right control stick or mouse) measure control precision (Fleishman, 1964). A single circle is shown on the screen. The participant maneuvers a cursor over the center of the circle. When the cursor is centered on the circle, the participant must either press the ENABLE key or click the mouse button, depending on test form. Upon completing this action, the first circle disappears, a second circle appears, and the process is repeated. The score is the number of circles completed in a fixed time limit (TMC or TMM).

Two-Hand Coordination is a pursuit tracking task (Fleishman, 1964). An airplane (target) moves in a fixed, elliptical pattern at a varying rate. The participant controls the horizontal and vertical movement of a "gunsight" using the right and left control sticks. The participant's task is to keep the gunsight on the target. The scores are summed horizontal (THH) and vertical (THV) tracking distance error.

Procedures

The ASVAB was administered as part of routine qualification for enlistees. The greatest time between testing and military enlistment is two years, but most applicants test in the six months just prior to enlistment. The psychomotor tests were administered early in basic military training and the participants were informed that their psychomotor scores would not affect their military careers or job assignments.

Analyses

Analyses included descriptive statistics, correlations, regressions, and confirmatory factor analyses. All statistical tests used a p ♋ 0.01 Type I error rate.

Because the participants had all been selected, at least in part, on the basis of their ASVAB scores, they constituted a preselected, range-restricted sample. Pearson (1903) observed that range restriction often has the effect of reducing the variability of scores and substantially reducing the correlations computed in such samples. Thorndike (1949) observed that correlations sometimes change signs when range restriction occurs. Ree, Carretta, Earles, and Albert (1994) explained the sign change phenomenon and how the Lawley (1943) theorem corrects both sign change and magnitude of range-restricted correlations. The method of Lawley (1943) was used to correct the sample correlations, means, and standard deviations for range restriction. Values from the normative sample (Ree & Carretta, 1994a) were used for the corrections.

Cognitive test scores were used in a regression to predict each of the psychomotor test scores in observed and range-restriction-corrected form. This was done to provide an estimate of the commonality (i.e., overlap) of the psychomotor scores with cognitive ability. These multiple correlations were corrected for overfitting using the method of Wherry (1931). Three sets of regressions were performed with the psychomotor scores as the criteria. The first set of regressions used only the four verbal and math tests (AR, WK, PC, and MK) as predictors, while the second set used the six speed and technical knowledge tests (GS, NO, CS, AS, MC, and EI), and the third set used all ten tests. These three analyses were conducted to investigate common sources of variance between cognitive and psychomotor tests. The correlations between the four verbal and math tests and the psychomotor tests measure the g and psychomotor overlap. The correlations between the six speed and technical knowledge tests and the psychomotor tests measure the overlap between psychomotor and g plus perceptual speed and technical knowledge. The correlations between all ten paper-and-pencil tests and the psychomotor scores provides one estimate of the overall overlap between cognitive and psychomotor abilities.

Confirmatory factor analyses were conducted using EQS, version 4.01 (Bentler, 1993). The model tested was based on earlier studies of the cognitive battery (Ree & Carretta, 1994a), prior studies of psychomotor tests (Ree & Carretta, 1994b; Hunter, 1980), and hierarchical structure of aptitude (Gustafsson, 1984; Vernon, 1950). The proposed model had an hierarchical factor structure. At the top of the hierarchy is g with three lower-order cognitive factors from the paper-and-pencil test and seven lower-order factors from the psychomotor tests. Additionally, there was a higher-order psychomotor/technical knowledge (PM/TK) factor that influenced all psychomotor tests and the technical knowledge scores from the paper-and-pencil test. The model was estimated in residualized form such that the effects of the higher-order factors were removed from the lower-order factors (Schmid & Leiman, 1957). To determine whether the general higher-order factor was still an estimate of psychometric *g*, the loadings for the cognitive tests in the present study were compared to and correlated with estimates for the cognitive tests computed without the presence of the psychomotor tests (Ree & Carretta, 1994a). Small differences between loadings and a high correlation between loadings for the two estimates would indicate that the present general factor was general cognitive ability.

Statistics used to test the fit of the model to the data (Bentler, 1990) were the Comparative Fit Index (CFI), root mean square error of approximation (RMSEA), and the average absolute standardized residuals (AASR). Additionally, the distribution of residuals was inspected. The percent of total variance and common variance was computed for each factor. We generally follow the guidance provided by the developers of these goodness-of-fit indices. As indication of good model fit, Bentler (1990) recommends that the CFI be .90 or greater. Browne and Cudeck (1993) interpret an RMSEA value of .08 as "reasonable" and would not accept models showing values greater than .10. The AASR should be as close to 0 as possible and present a symmetric distribution.

RESULTS

Examination of the descriptive statistics for the paper-and-pencil tests showed that the sample was range-restricted. Paper-and-pencil test scores were, on average, about .43 standard deviations above the normative mean, and average variances were about .41 the value of the normative variances. The observed and corrected-for-range-restriction correlations among the paper-and-pencil and psychomotor scores are shown in Table 1. It should be noted that some observed correlations (above the diagonal) changed sign as a result of the range-restriction correction. Ree et al. (1994) have described and explained this phenomenon.

Commonality analysis results from predicting each psychomotor score from the paper-and-pencil tests are presented in Table 2. Fifty-eight of the 81 regressions were statistically significant. For the analyses involving the four verbal and math tests, the average multiple correlations were .186 (uncorrected) and .283 (corrected-for-range-restriction). Multiple correlations of .351 (uncorrected) and .412 (corrected-for-range-restriction) were found for the speed and technical knowledge tests. For all 10 cognitive tests, the average multiple correlation based on uncorrected data was .361. For the range-restriction-corrected data, the average multiple correlation was .440.

Table 1.

Correlation Matrix

Score	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
1. GS	100	29	54	30	-01	-05	32	28	45	47	-10	-15	-18	-20	-09	-01	-05	-23	-27	-20	20	23	12	22	07	12	-26	-19	-19	-14	19	08	22	19	-14	-21	-14
2. AR	72	100	28	23	17	17	26	58	45	28	-01	-03	-16	-12	-19	-05	-07	-18	-20	-12	24	26	09	21	06	05	-27	-28	-28	-11	21	15	17	14	-14	-21	-10
3. WK	80	71	100	37	-02	04	26	20	35	37	-08	-13	-05	-10	-04	-03	-09	-20	-22	-14	13	15	07	13	06	08	-11	-10	-10	-11	09	06	13	11	-08	-12	-02
4. PC	69	67	80	100	10	14	05	22	20	16	-09	-05	-02	-03	05	-01	-04	-10	-09	-05	02	03	-01	02	01	-05	-02	-03	-07	02	03	01	02	-01	-04	-05	-02
5. NO	52	63	62	61	100	56	-05	25	-01	-12	-02	-01	05	01	-08	-06	-01	04	05	04	-01	-01	03	01	-04	-06	-01	03	01	08	-03	02	04	03	03	-01	06
6. CS	45	52	55	56	70	100	-09	16	-04	-13	-02	03	01	01	-09	-01	-09	02	04	-01	07	08	01	06	-01	01	-01	-01	01	01	02	05	08	07	05	-03	03
7. AS	64	53	53	42	31	23	100	04	60	58	-16	-21	-32	-29	-25	-01	-04	-38	-37	-34	38	33	22	28	10	15	-37	-38	-35	-28	31	21	30	28	-31	-28	-28
8. MK	70	83	67	64	62	52	42	100	26	12	-04	-02	-08	-06	-12	-05	-09	-11	-14	-09	15	20	04	21	10	05	-15	-16	-15	-01	05	09	13	09	-09	-18	-01
9. MC	70	68	59	52	41	34	74	60	100	55	-18	-24	-38	-36	-36	-04	-13	-48	-49	-39	47	40	22	35	12	13	-46	-47	-44	-31	38	26	36	32	-31	-33	-26
10. EM	76	66	68	57	42	34	75	59	74	100	-13	-19	-22	-17	-21	01	-09	-35	-36	-31	34	30	22	24	06	07	-33	-35	-31	-20	32	18	23	21	-26	-26	-24
11. RPH	-27	-20	-25	-27	-19	-19	-27	-22	-30	-27	100	74	12	12	07	-04	02	17	18	13	-26	-14	-21	-13	14	13	16	17	12	11	-18	-06	-13	-15	11	13	11
12. RPV	-31	-23	-30	-24	-21	-14	-32	-22	-35	-33	76	100	15	13	18	-07	-02	24	24	17	-34	-21	-27	-17	08	13	22	23	21	19	-26	-15	-23	-20	14	18	17
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16. LRR	-11	-09	-13	-12	-08	-14	-07	-12	-11	-07	-01	-03	05	07	09	100	12	08	08	07	-12	-12	01	-10	-06	-04	07	07	09	05	-12	-11	-10	-08	05	07	08
17. LRP	-20	-21	-23	-19	-16	-22	-14	-23	-23	-21	08	03	10	13	18	15	100	19	16	18	-17	-09	-08	-07	-13	-18	19	21	21	14	-13	-05	-14	-13	11	14	07
18. CPH	-44	-39	-40	-34	-23	-22	-51	-36	-58	-50	26	32	26	31	40	12	26	100	90	80	-49	-47	-29	-40	-20	-22	49	54	53	36	-33	-34	-44	-40	48	53	47
19. CPV	-47	-41	-40	-32	-22	-21	-51	-38	-59	-51	26	32	27	32	39	12	23	92	100	76	-48	-47	-28	-40	-17	-21	47	54	52	34	-31	-32	-43	-39	46	57	48
20. CPR	-33	-26	-25	-19	-12	-18	-42	-26	-46	-40	19	22	28	29	44	10	23	81	78	100	-46	-42	-23	-38	-13	-18	45	47	46	33	-28	-33	-43	-38	39	47	47
21. DCC	34	33	23	16	14	21	46	30	52	42	-30	-38	-37	-32	-43	-14	-22	-54	-53	-51	100	71	28	53	07	06	-50	-54	-51	-29	52	31	55	49	-32	-40	-33
22. DCM	40	38	28	20	18	25	45	37	50	43	-21	-28	-35	-33	-36	-15	-16	-54	-54	-48	74	100	23	69	08	07	-44	-46	-46	-32	50	46	68	60	-32	-40	-33
23. KTT	21	18	15	09	14	11	28	16	28	28	-24	-31	-20	-17	-22	-01	-11	-33	-32	-27	32	28	100	16	-01	03	-29	-31	-30	-29	26	11	25	22	-23	-26	-20
24. ARM	37	34	26	18	18	22	39	36	45	38	-19	-24	-30	-28	-31	-13	-13	-47	-47	-44	58	73	22	100	09	11	-33	-37	-38	-31	42	45	64	59	-25	-29	-32
25. THH	12	10	10	05	01	03	14	14	16	12	11	05	-02	-04	-14	-07	-15	-22	-20	-16	11	12	01	13	100	79	-07	-16	-13	-01	08	14	13	15	-06	-08	-08
26. THV	09	02	02	-08	-08	-01	15	03	12	07	13	11	-05	-06	-16	-04	-17	-21	-21	-19	09	10	04	13	79	100	-07	-14	-13	-03	08	10	15	18	-07	-12	-09
27. SA1	-36	-35	-19	-14	-15	-13	-45	-29	-51	-41	20	27	32	31	39	09	23	53	51	49	-55	-50	-33	-40	-10	-09	100	72	67	40	-35	-24	-39	-34	35	38	35
28. SA2	-29	-32	-16	-12	-09	-12	-43	-27	-50	-40	21	27	36	36	41	09	24	56	57	50	-58	-51	-34	-42	-18	-16	74	100	80	41	-38	-27	-42	-36	41	46	38
29. SA3	-34	-37	-23	-22	-16	-15	-44	-31	-50	-42	19	27	31	33	38	11	25	57	57	50	-55	-52	-33	-44	-16	-14	69	82	100	44	-38	-35	-46	-38	41	45	36
30. TTP	-14	-09	-06	02	05	-02	-27	-03	-28	-19	11	19	31	28	31	05	15	35	34	34	-30	-33	-30	-33	-03	-06	41	41	43	100	-31	-27	-30	-27	18	22	22
31. TTC	27	27	15	12	09	13	37	18	41	36	-22	-29	-35	-29	-36	-13	-16	-37	-36	-32	55	54	29	47	10	09	-39	-42	-42	-33	100	43	51	45	-27	-27	-28
32. TTM	19	22	14	11	12	14	27	19	31	25	-10	-19	-27	-26	-30	-13	-08	-37	-36	-37	35	49	14	48	16	11	-28	-31	-39	-28	45	100	53	49	-23	-23	-25
33. TMC	37	32	27	20	22	24	41	31	46	38	-20	-29	-35	-32	-36	-13	-19	-51	-50	-48	60	72	29	68	16	16	-45	-47	-51	-31	54	56	100	89	-33	-41	-39
34. TMM	30	25	20	11	15	19	36	23	39	32	-19	-25	-35	-31	-33	-11	-18	-45	-44	-43	53	64	26	63	18	20	-39	-41	-43	-28	48	51	90	100	-30	-37	-35
35. CCV	-27	-25	-19	-16	-11	-08	-39	-23	-38	-35	16	20	18	18	23	08	14	52	50	43	-37	-38	-26	-31	-09	-09	40	45	45	20	-31	-26	-38	-34	100	68	39
36. CCH	-39	-36	-29	-24	-20	-21	-41	-36	-45	-41	21	26	21	23	26	10	20	59	62	52	-47	-48	-31	-38	-11	-13	45	51	50	24	-33	-27	-48	-42	70	100	44
37. CCR	-13	-09	00	-01	04	01	-27	-04	-24	-21	12	17	21	24	27	08	07	45	46	47	-34	-34	-21	-33	-09	-11	36	40	38	24	-30	-26	-39	-36	40	44	100

Table 2.
Multiple Correlations of Psychomotor Tests with Cognitive Tests

	Verbal/Math Tests		Speed/Tech. Knowl. Tests		All 10 Tests	
Score	R	R_c	R	R_c	R	R_c
RPH	.110	.281	.195	.325	.229	.355
RPV	.130	.301	.261*	.375	.280*	.393
KMH	.161	.191	.403*	.384	.419*	.451
KMV	.140	.180	.384*	.405	.390*	.422
GPT	.215*	.282	.390*	.390	.414*	.462
LRR	.072	.146	.085	.167	.113	.187
LRP	.116	.252	.181	.288	.197	.303
CPH	.238*	.428	.499*	.597	.502*	.601
CPV	.264*	.442	.507*	.607	.510*	.609
CPR	.166	.287	.423*	.495	.433*	.507
DCC	.256*	.349	.505*	.555	.516*	.578
DCM	.285*	.409	.441*	.536	.463*	.568
KTT	.113	.199	.264*	.311	.273*	.333
ARM	.255*	.385	.377*	.472	.408*	.512
THH	.114	.161	.136	.177	.170	.218
THV	.128	.172	.197*	.232	.222	.286
SA1	.278*	.373	.480*	.525	.501*	.569
SA2	.284*	.346	.497*	.534	.515*	.566
SA3	.281*	.373	.457*	.517	.474*	.537
TTP	.174*	.174	.344*	.355	.355*	.384
TTC	.231*	.289	.413*	.443	.430*	.477
TTM	.154	.227	.283*	.329	.290*	.341
TMC	.200*	.342	.394*	.482	.404*	.501
TMM	.169	.284	.354*	.415	.365*	.450
CCH	.146	.255	.352*	.420	.358*	.429
CCV	.231*	.380	.359*	.476	.378*	.495
CCR	.116	.135	.313*	.320	.334*	.362

Note. R is the multiple correlation between the psychomotor test score and the paper-and-pencil tests. R_c is R corrected for range restriction.
* $p \leq .01$, corrected correlations cannot be tested for significance.

Confirmatory factor analysis found no special problems during estimation. The model fit the data well. The Comparative Fit Index was .920, the Root Mean Square Error of Approximation was .079, and the average absolute standardized residual was .032 in a symmetric distribution. Based on recommended levels of these indices (Bentler, 1990; Browne & Cudeck, 1993), evidence supports a good fit of the model to the data.

A substantial first higher-order factor was found that had loadings from all cognitive and psychomotor tests. It was interpreted as an estimate of psychometric *g* as all the cognitive tests had positive loadings. In addition, each of the psychomotor tests contributed to this factor such that better performance was positively related to better performance on the cognitive tests (i.e., some psychomotor loadings were negative because they represent error or response time scores where higher scores indicate poorer performance). The loadings of the cognitive tests were compared to previous loadings estimated (Ree & Carretta, 1994a) without the presence of the psychomotor tests to determine whether the higher-order factor was still a measure of *g*. The two sets of loadings were very similar with the current loadings slightly lower (mean difference of .04). The correlation between the two sets of loadings was .988.

The factor structure for the cognitive and psychomotor tests is shown in Figure 1 and the factor loadings are shown in Table 3. There were two hierarchical factors that were interpreted respectively as psychometric *g* and a higher-order psychomotor/technical knowledge factor (PM/TK). In addition, there were three lower-order cognitive factors and seven lower-order psychomotor factors. The lower-order factors were interpreted as verbal/math (V/M), perceptual speed (SPEED), technical knowledge (TK), kinesthetic memory (KM), leg reaction (LEG RT), pursuit tracking (PUR_T), complex coordination (CC), rate control (RATE CONT), arm/hand movement (ARM/HAND), and hand dexterity (HAND). The proportion of total and common variance attributed to the higher-order factors were 20.66% and 31.60% for *g* and 20.31% and 31.07% for PM/TK. The proportion of total and common variance accounted for by the residualized lower-order factors ranged from 0.91% and 1.39% for V/M to 4.41% and 6.74% for PUR_T.

The *g*-loadings of the paper-and-pencil cognitive tests were higher than those for the computer-based psychomotor tests. The ratio of the average *g*-loading of the cognitive (0.753) and psychomotor tests (0.231) was slightly more than three to one. The ranges of g-loadings were similar within the cognitive tests (0.383) and within the psychomotor tests (0.423). The *g*-loadings for the cognitive tests ranged from 0.551 (AS) to 0.934 (WK), whereas the g-loadings among the psychomotor tests ranged from 0.022 (THV) to 0.445 (CPV). The lowest *g*-loading among the cognitive tests was greater than the highest g-loading among the psychomotor tests.

DISCUSSION

The multiple correlations relating the verbal and math paper-and-pencil tests and the psychomotor tests had an average corrected-or-range-restriction correlation of .28, slightly lower than the .34 correlation reported by Ree and Carretta (1994b). For the Complex Coordination test, which was used in both studies, CCH and CCV differed by no more than .02. CCR, the last entry in Table 2, had a correlation less than one half the correlation reported in the previous study. We speculate that this was due to interference caused by participants taking a similar psychomotor test earlier in the battery (i.e., Complex Coordination with foot pedals). In general, Complex Coordination with foot pedals was more predictable from the verbal and math tests than was Complex Coordination using two control sticks.

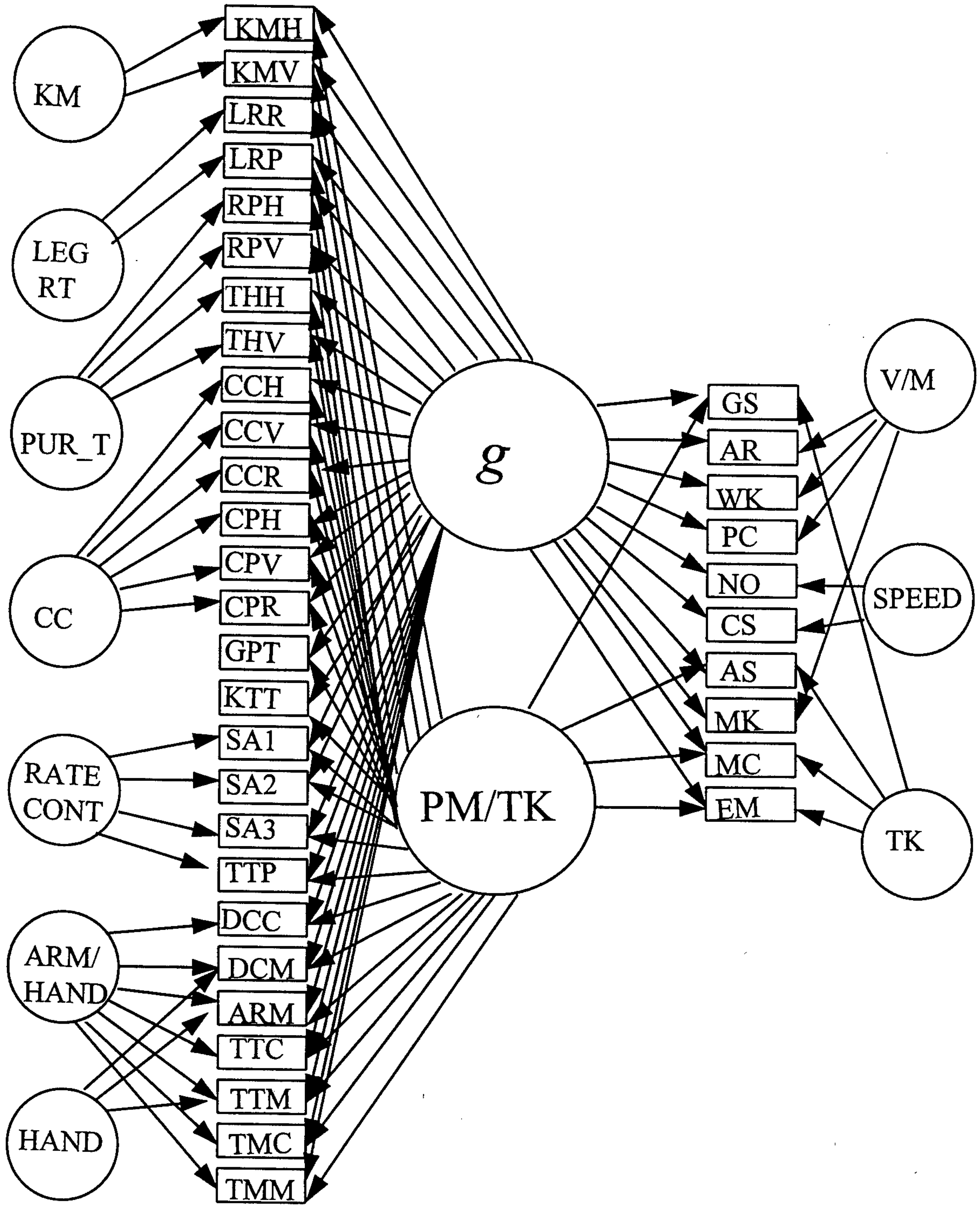

Figure 1. Factor Structure of Cognitive and Psychomotor Tests

Table 3.
Loadings of the Confirmatory Factor Analysis

Score	I g	II PM/TK	III V/M	IV SPEED	V TK	VI KM	VII LEG RT	VIII PUR_T	IX CC	X RATE CONT	XI ARM/ HAND	XII HAND
GS	.845	-.155			.215							
AR	.855		.298									
WK	.934		-.294									
PC	.824		-.114									
NO	.690			.724								
CS	.597			.399								
AS	.551	-.430			.542							
MK	.839		.385									
MC	.673	-.456			.304							
EM	.723	-.305			.409							
RPH	-.276	.261						.232				
RPV	-.305	.349						.220				
KMH	-.062	.490				.685						
KMV	-.159	.423				.892						
GPT	-.118	.534										
LRR	-.140	.107					.984					
LRP	-.252	.190					.099					
CPH	-.434	.592							.638			
CPV	-.445	.585							.600			
CPR	-.283	.595							.530			
DCC	.291	-.748									.045	
DCM	.355	-.685									.208	.343
KTT	.178	-.405										
ARM	.329	-.564									.291	.502
THH	.120	-.152						.845				
THV	.022	-.191						.894				
SA1	-.277	.632								.413		
SA2	-.240	.694								.579		
SA3	-.307	.652								.507		
TTP	-.062	.486								.150		
TTC	.203	-.612									.109	
TTM	.184	-.461									.261	.171
TMC	.320	-.641									.583	
TMM	.239	-.577									.781	
CCH	-.236	.488							.213			
CCV	-.355	.533							.224			
CCR	-.028	.524							.226			
% Total	20.66	20.31	0.91	1.85	1.62	3.42	2.64	4.41	3.23	2.12	3.13	1.08
% Common	31.60	31.07	1.39	2.82	2.48	5.23	4.04	6.74	4.94	3.25	4.79	1.65

Note. The factors are: *g* is psychometric *g*, PM/TK is higher-order psychomotor/technical knowledge, V/M is verbal/math, SPEED is speed, TK is technical knowledge, KM is kinesthetic memory, LEG RT is leg reaction time, PUR_T is pursuit tracking, CC is complex coordination, RATE CONT is rate control, ARM/HAND is arm and hand movement, and HAND is hand movement. g and PM/TK are higher-order factors and the others are residualized lower-order factors. All factors are orthogonal after residualization.

The factor representing psychometric *g* accounted for less of the common variance in the current study than was found in Ree and Carretta (1994b). This can be explained by the fact that this study used proportionally more psychomotor tests and also included the Speed and Technical Knowledge paper-and-pencil tests. The finding that the paper-and-pencil technical knowledge tests contributed to a higher-order psychomotor/technical knowledge factor was not surprising given Vernon (1947, 1950, 1969). Vernon identified that factor (i.e., k:m) variously as "practical," "spatial-mechanical," and "spatial-perceptual-motor." See Jensen (1980) for a more complete discussion. Confirmation of the k:m factor should reinforce the use of Vernon's hierarchical structure of abilities in aptitude battery construction. Hunter and Hunter (1984) have demonstrated the validity and incremental validity of tests contributing to the k:m factor for the 20% of United States workers performing low complexity jobs (see their Table 2). A practical implication of our findings is that test developers can replicate Vernon's k:m factor from among existing tests, even when they were not specifically designed to do so.

It is worth noting that the two higher-order factors accounted for almost twice as much common variance as all the lower-order factors combined (62.66% vs. 37.34%). These lower-order factors are specific factors. Wheeler and Ree (1997) have demonstrated that a general psychomotor tracking factor was more valid than specific psychomotor factors. The current results demonstrate that psychomotor tests of the factors of arm/hand movement, complex coordination, finger and hand dexterity, kinesthetic memory, leg reaction time, pursuit tracking, and rate control all contributed to the hierarchical *g* factor and the hierarchical psychomotor/ technical knowledge factor. These findings suggest that psychomotor tests of the factors investigated here cannot be expected to produce large incremental validity for training or job performance beyond that offered by reliable tests of *g*. Pending future studies of the validity and incremental validity of the general and specific factors represented by these psychomotor tests, it is likely that interchangeability of psychomotor tests in batteries will be a function of their loadings on the hierarchical g and PM/TK factors. That is, practitioners can expect psychomotor tests with equivalent loadings to be interchangeable in function.

The results from this study were consistent with those from Ree and Carretta (1994b) and extend our knowledge in several ways. In both studies, the cognitive and psychomotor scores were correlated with each other and both contributed to a higher-order factor representing psychometric *g*, and there were several lower-order psychomotor factors. These similar findings resulted even though an expanded psychomotor domain was used. Because the current paper-and-pencil battery included technical knowledge tests, the psychomotor scores contributed to a higher-order psychomotor/technical knowledge factor (PM/TK) as predicted by Vernon (1950). Previously, Ree and Carretta (1994b) demonstrated the existence of a higher-order psychomotor factor for tracking tasks. We have extended the higher-order factor to include arm and hand movement, finger dexterity, kinesthetic memory, leg movement and others. This study extends our understanding of human performance by using a broader range of cognitive and psychomotor measures. This study also enhances practicality by suggesting potential interchangeability of psychomotor tests and explaining the likely incremental validity of psychomotor tests. Further, it offers a confirmation of Vernon's practical k:m factor, which could bolster the use of k:m in personnel selection test construction.

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