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Development of a Paper-and-Pencil Test to Measure Eye-Hand Coordination*

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A paper-and-pencil test (Eye-Hand Coordination Test: EHCT) to measure eye-hand coordination was developed and administered to 8 groups of 155 disabled and normal subjects. The EHCT consists of 24 items and provides a profile of 9 coordination scores. The internal consistencies of the 9 coordination scores were found to be acceptable. The concurrent validity of the EHCT was examined by means of the relationships of the scores with apparatus measures of coordination and found to be excellent. In addition, the profiles of the coordination scores were found to be able to distinguish people with different disabilities. This last finding suggested the possibility that the EHCT could be developed in the future as a diagnostic instrument to identify the specific underlying problems that cause failures in eye-hand coordination tasks.

Key words : e*ye-hand coordinatrion, paper-and-pencil test, profile, validity*

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Coordination can be defined as the ability to perform effectively on a given task by using two or more independent functions simultaneously in a harmonious way. Recent advancements in neurophysiology have stimulated many experimental studies designed to understand human coordination. Those studies of coordination have typically been with single movements, usually to flashed stimuli. However, coordination in a natural task is much more difficult. The functional elements of coordination such as eye and hand all need to act with respect to a common coordinate system and remain synchronized in time across multiple actions (Pelz, Hayhoe, & Loeber, 2001).

Coordination in a natural task has been theorized and studied almost exclusively in Robotics and Control Engineering. The Cybernetics principle is one of the theoretical mechanisms that have been successfully used to build control systems in those sciences. The primary concern of those sciences is to build efficient and flawless systems and machines rather than to understand human abilities. Nevertheless, some psychologists have considered the Cybernetics principle to be a useful frame of reference to understand physical and social-psychological functions of humans (Wiener, 1948; Miller, 1978; Powers, 1973, 1978, 1979; Carver & Scheier, 1981).

In practice, measurements of coordination are commonly obtained by using apparatuses such as Joseph Tiffin's Purdue Pegboard and Grooved Pegboard (Lafyette Instrument Company, 1985), Minnesota Rate of Manipulation Test (Jurgensen, 1943; American Guidance Service, 1969), Track Tracing Test (Knights & Moule, 1968), Single Dimension Pursuit Test (Magill, 1989), Rotary Pursuit (Senders, Wallis, & Senders, 1956; Nishida, 1984), and Mobile Vocational Evaluation (Roberts, 1945). Those apparatuses, however, are expensive, often cumbersome to use, and have serious limitations for group-test. Another disadvantage of most existing measurement tools is that they give only general and overall assessments of the phenotypic performances without differentiated information about underlying mechanisms (see Binet & Henri, 1895; Wechsler, 1939; Smith, 1982; Zolten, Harrell & Butler, 1989; Brickenkamp, 1962; Margolis, 1972; Talland, 1965). 'Double-coding Test' is a paper-and-pencil test that was most recently developed to measure eye-hand coordination (Lufi, 2001). The subject is presented with a series of numbered boxes to be filled with correct symbols. The score of the test is the number of small boxes with correct symbols filled by the subject in a given time. Double-coding Test like other previous paper-and-pencil measures of eye-hand coordination provides only a single score and thus a kind of single-item test.

The objective of this study was to develop and validate a paper-and-pencil instrument to measure eye-hand coordination. According to the Cybernetics principle (Miller et al., 1960), failure in a task of coordination may be attributed to latent problems in one or more faculties of sub-functions: comprehension, perception, evaluation and kinetic motion. Since it is believed that the same underlying faculties of sub-functions (except the kinetic sub-function) are involved in many different kinds of coordination, identification of difficulties in the latent faculties underlying a kind of coordination such as eye-hand coordination may help predict the quality of performances in other kinds of coordination such as two-hands coordination.

A paper-and-pencil instrument to measure eye-hand coordination was constructed in this study that examined the reliability and validity of the instrument. The possibility that the instrument could be used for diagnosis was explored with 8 groups of disabled and normal subjects. If the groups with different disabilities show different response patterns on the coordination scores, it would encourage future exploration to achieve this objective with the instrument. However, due to the editorial consideration for the space limitation, the property of the instrument as a diagnostic tool to identify the underlying difficulties will be only briefly described in discussion. The full account and detailed analysis of the diagnostic property will be reported elsewhere in a separate article.

The Instrument

A paper-and-pencil instrument to measure eye-hand coordination was developed in the present study. The instrument is called Eye-Hand Coordination Test (EHCT). It was intended to be suitable for group testing, psychometrically reliable and valid, and able to provide differentiated information about the underlying strengths and weaknesses of the examinees. The EHCT is suitable for group testing because it is a paper-and-pencil test. It can be made to be psychometrically reliable and valid because in part it consists of multiple items. It is able to provide differentiated information about the latent locus of coordination problems. As described in detail below, the EHCT provides a profile of 9 coordination scores instead of a single score. The different patterns of the profile could be consulted to identify specific underlying problems involved in sub-functions.

According to neurophysiological studies (Inoue, Kawashima, Satoh, Kinomura, Goto, Koyama, Sugiura, Ito, & Fukuda, 1998; Jueptner. Jenkins, Brooks, Frackowiak, & Passingham, 1996; Mushiake & Strick, 1993, 1995; van Donkelaar, Stein, Passingham, & Miall, 1999; Crawford, Henderson, & Kennard, 1989; Hikosaka & Wurtz, 1985), separate neural systems contribute to the coordination of eye and hand movements to visual target locations as well as to remembered target locations. In particular, the cerebello-thalamo-cortical system appears to be preferentially involved in movements based upon external sensory cues such as those arising from the appearance of a visual (visually triggered) target. By contrast, the basal ganglio-thalamo-cortical system appears to be preferentially involved in movements based upon internal cues such as those required to direct the eye and hand to a remembered (internally generated) target location. In line with this view of dissociation between the two types of eye-hand coordination, two types of items were designed for the EHCT: line-drawing items and track-tracing items. Line-drawing items provide coordinates that serve as visual cues marking the exact positions of the target figure to be copied by the examinee. By contrast, track-tracing items do not provide such coordinates so that the examinee must generate the track to be traced accurately by him/herself. Each item type includes two forms. Figure 1 shows examples of the two forms of line-drawing type items and Figure 2 shows examples of the two forms of track-tracing type items.

For the line-drawing items, target figures that are abstract patterns of connected straight lines are presented either on a square mat consisting of dotted grids or on a square mat consisting of simple dots that are lined-up straight in rows and columns. The number of intersections of the dotted grids on the former is the same as the number of dots on the latter, and the two mats

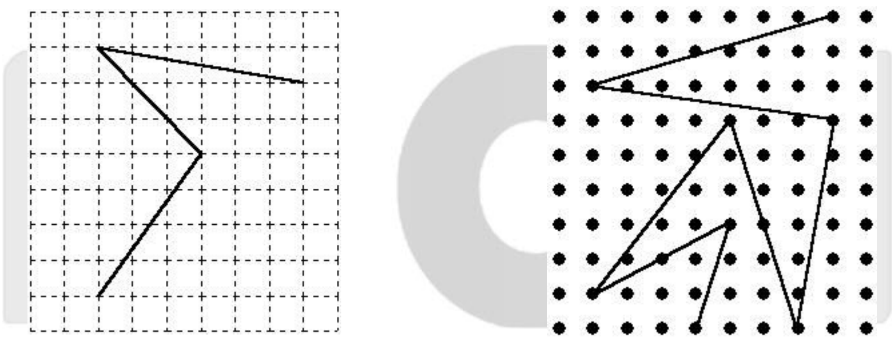

Figure 1. Examples of the two forms of line-drawing items

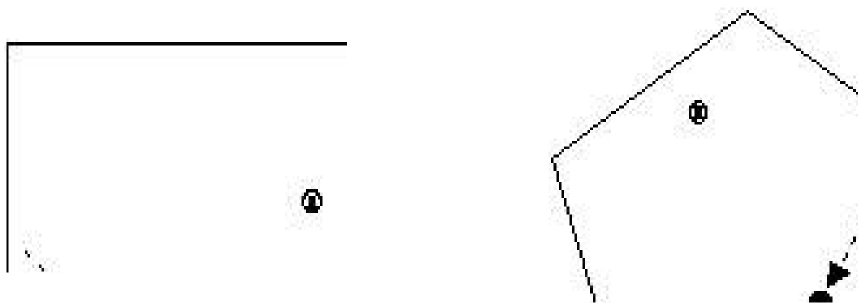

Figure 2. Examples of the two forms of track-tracing items.

are of the same size. When the target figure is presented on the mat of dotted grids, the examinee copies the figure on the same location in an empty mat of simple dots. In contrast, when the target figure is presented on the mat of simple dots, the examinee copies it on the same location in an empty mat of dotted grids. The grids and dots on which the target figures are presented may be used as coordinates by the examinee to identify exact locations of the figure to be copied. Therefore, performance on line-drawing items depends on comprehension of the task and the rules, perceptions of the coordinates and the lines drawn by the performer him/herself, comparison (evaluation) of the lines drawn against those in the target figure, and the execution of steady hand movement (kinetics).

For the track-tracing items, a small ball that is intended to appear as if it was moving is located at an arbitrary place inside a frame. The starting direction of the ball is indicated with an arrow behind the ball. The destination of the ball is designated by a dot inside the frame. The shape of the frame is either a closed rectangle or a closed pentagon. The examinee's task is to trace the expected track of the ball to the designated destination with a pen. The examinee should abide by two rules to perform this task: (1) the ball should always move straight before it hits any wall of the frame; (2) the ball always changes direction at a right angle (90°) from the in-coming path when it hits the frame wall. Note that the track of the ball after hitting a wall of the frame is not supposed to be governed by general laws of physics, as is the case in a billiard game. The examinee should keep the rule of 90° inflection in mind throughout the performances on track-tracing items. If the examinee perfectly abides by these two rules, the ball always arrives at the designated destination. Performance on track-tracing items depends on comprehension of the task and the rules, perceptions of the starting direction, the tracing lines and the destination, comparison (evaluation) of the tracing lines against the implicit tracks, and the execution of steady hand movement (kinetics).

Method

The EHCT was administered to 8 groups of adults and children along with other tests and apparatuses to measure coordination. The data were analyzed here to evaluate the reliability and validity of the EHCT.

Subjects

A sample of 155 subjects participated in the present study. The sample consisted of 8 groups: 25 adults with mental retardation; 9 adults with limb disabilities; 12 adults with weak-sightedness; 11 children with weak- sightedness; 17 children with attention deficit and hyperactive disorder (ADHD); 22 adults with artificially impaired eyesight; 32 normal adults, and 27 normal children.

The twenty-five adults (13 males and 12 females) with mental retardation were sampled from those who were officially registered in the Korean government as persons with mental retardation of the first, second, or third degree. The average age of the selected adults with mental retardation was 23.92 years with a standard deviation of 7.25 years. Mentally retarded individuals with any other additional mental and/or physical problems were excluded from the present study. The average verbal IQ of the selected adults with mental retardation was 47.20 with a standard deviation of 4.79.

The nine adults (5 males and 4 females) with limb disabilities were sampled from those who were officially registered in the Korean government as persons with physical handicap of the second, third, or fourth degree. The average age of the selected adults with limb disabilities was 37.50 years with a standard deviation of 9.51 years. Those subjects had disabled the hands and/or arms that had been used as the primary hand or arm before becoming handicapped. Their handicapped arms were still partially functional and they used the handicapped arm to respond to the EHCT. Individuals with limb disabilities of the first degree were excluded from the present study because their handicapped arms were not functional enough to respond to the EHCT. Individuals having any additional mental and/or physical problems were also excluded from being selected into this group.

The twelve adult males with weak-sightedness (amblyopic) were sampled from those who were officially registered in the Korean government as persons with visual disability of the first, second, third, fourth, fifth, or sixth degree. Individuals with any other additional cognitive, emotional, and/or physical problems were excluded from the present study. The average age of the selected adults with weak-sightedness was 28.69 years with a standard deviation of 9.71 years.

The eleven children (8 males and 3 females) with weak-sightedness were sampled from those who were officially registered in the Korean government as persons with visual disability of the first, second, third, fourth, fifth, or sixth degree. Children with any additional cognitive, emotional, and/or physical problems were excluded. The average age of the selected children with weak-sightedness was 15.26 years with a standard deviation of 2.09 years.

The seventeen male children with ADHD were sampled among those who had visited The Psychiatry Hospital of Chungbuk National University. Children with any other additional cognitive, emotional, and/or physical problems were excluded from the present study. The average age of the selected children with ADHD was 9.22 years with a standard deviation of 1.69 years. The average verbal IQ of the selected children with ADHD was 98.40 with a standard deviation of 12.68.

Adults with artificially impaired eyesight were included in the present study in order to see if the performances of individuals with trait impairment could be distinguished from the performances of the individuals who fail in the coordination tasks due to inappropriate test situations or non-optimal test circumstances. The 22 adults (3 males and 19 females) were sampled from college students with normal eyesight who were enrolled in psychology courses. The eyesight of those students was artificially impaired either by asking them to wear a pair of thick glasses or to cover one of the eyes: 5 students were tested on EHCT with their left eye covered; 5 students were tested on EHCT with their right eye covered; and 12 students were tested on EHCT wearing a pair of thick glasses. Students with any identified mental and/or physical problems were excluded. The average age of the selected adults with artificially impaired eyesight was 20.83 years with a standard deviation of 2.21 years.

The thirty-two normal adults (7 males and 25 females) were sampled from college students who were enrolled in psychology courses. Students with any identified mental and/or physical problems were excluded. The average age of the selected normal adults was 22.72 years with a standard deviation of 5.23 years.

Finally, the twenty-seven normal children (10 males and 17 females) were sampled from elementary and middle schools. Children with any identified mental and/or physical problems were excluded from being selected into this group. The average age of the selected normal children was 12.54 years with a standard deviation of 2.76 years.

Measurements

Two sets of measurements were used. The first set included the two item types of the EHCT (line-drawing items and track-tracing items). The second set consisted of measurements of coordination by Purdue Pegboard, Mobile Vocational Evaluation (MVE), and a simple test called 'Symbol Writing'. The second set of measurements was used to evaluate the concurrent (criterion) validity of the EHCT.

The EHCT includes 12 line-drawing items and 12 track-tracing items as described above. For each items in the EHCT, 9 separate coordination scores are obtained either by human scorers or by a computer as described in detail below.

The Purdue Pegboard measures dexterity for two types of activity: one involving gross movements of hands, fingers, and arms, and the other involving primarily what might be called ‘fingertip’ dexterity. Fingertip dexterity is a term indicating the ability to manipulate a small object through a small space. Four separate scores can be obtained with the Purdue Pegboard: right hand; left hand; both hands; and assembly. For the scores of right hand, left hand, and both hands, the subject puts as many pegs as possible into the holes on the board using the right hand for 30 seconds, left hand for 30 seconds and both hands for 30 seconds. For the assembly score, the subject assembles washers, collars and pegs in the pegboard as many as possible in 60 seconds using both hands.

MVE is a battery of instruments that measure finger dexterity, wrist-finger speed, arm-hand steadiness, manual dexterity, two-arm coordination, reaction time, two-hand coordination, and aiming (Hester, Baltrukenas, & Derum, 1992). Among these measurements, two-arm coordination and aiming were used in the present study. Two-arm coordination is measured by Two-Arm Tracing Apparatus and defined as the ability to move both arms in a simultaneous and coordinated manner. For two-arm coordination, the subject manipulates a stylus by moving the handles of the apparatus to keep the stylus on a star-shaped pattern. Aiming is measured by the Hole Plate and defined as the ability to move a hand to specific positions accurately. For aiming, the subject holds a stylus and puts it into the specified holes without touching the edges of the holes. The scores from the two MVE tasks are computed from a combination of the number of errors the subject makes and the time for which the subject takes to complete each task.

'Symbol Writing' is a simple paper-and-pencil test used to measure coordination in the Occupational Aptitude Test for Adults that was developed by the Ministry of Labor of Korea (2000). The subject is presented with a series of small square boxes (8 mm x 8 mm) and asked to write a symbol such as "≠" or "×" in as many boxes as possible in a short period of time. The score of the test is the number of boxes filled with the symbol without overshooting through the frame of the box. Symbol Writing is a kind of single-item test.

Procedure

Each subject was tested individually because apparatuses measures were included in the present study. The administration of the EHCT alone took 15 to 25 minutes and the entire measurement session took 40-50 minutes to complete. There was no time limit for the EHCT, but the subjects were encouraged to finish it as quickly as they could and their time was measured.

To control for possible order effects and fatigue effects, the order in which the measurements (EHCT, Purdue Pegboard, Two-Arm Tracing Apparatus, Hole Plate, and Symbol Writing) were administered was counter-balanced by a Latin-square arrangement. Ten different measurement orders were used with 14-17 subjects assigned to each order. The subjects in each of the 8 subject groups were distributed across the 10 measurement orders as evenly as possible.

All subjects used their primary hands to respond to the EHCT. The subjects with limb disabilities (of the second, third or fourth degree) used their handicapped hands that used to be primary before being handicapped to respond on the EHCT. The subjects with artificially impaired eyesight either wore thick glasses or covered one of their eyes to respond on the EHCT.

All subjects used the same brand of 'sign-pen' to make responses on the EHCT. The particular brand of pen produced black water-based lines of about 0.5 mm thickness. In order to maintain the quality of the pen constant across the subjects, a pen was used only for a single subject and a new pen was used for the next subject.

Scoring

Nine separate coordination scores were obtained from the response on each item of the EHCT. The nine coordination scores are: (1) 'Location' — sum of the distance (in pixels) between an inflection point of the response figure and the corresponding point of the target figure, divided by the number of inflection points of the target figure; (2) 'Goal' — degree to which the examinee is judged as intending to do what is required by the task (this score is subjectively judged by scorers); (3) 'Shape' — degree to which the response is judged to be similar in overall shape with the target figure or the implicit target track (this score is subjectively judged by scorers); (4) 'Inflection' - absolute difference between the number of inflection points in the response figure and that in the target figure; (5) 'Disconnection' — number of spots where the response lines are broken; (6) 'Secession' — number of times the response drawing goes astray more than 1 mm outside the designated response area; (7) 'Overlap' — percentage of pixels by which the lines of the response figure are overlapped by the corresponding lines of the target or correct figure when the latter is superimposed on the former; (8) 'Correction' — number of times local correction (local re-drawing and local cancellation), as opposed to global correction, is made; If a drawing is globally cancelled and a complete redrawing is made, the number of straight lines in the target figure is the score for Correction); (9) 'Time' — time in seconds taken to complete each item type divided by the number of items of the type completed by the examinee (this score is for the item types, not for individual items).

Among the 9 coordination scores, 'Location', 'Inflection', 'Disconnection', 'Secession', 'Overlap', and 'Correction' are straightforward to score and thus are scored by a computer after the response sheets are scanned and converted into digitized image files. The examiner measured 'Time' with a stopwatch at the time of testing. 'Goal' and 'Shape' were scored subjectively by human scorers and thus are explained here in detail. Inter-scorer reliability was examined later for these two coordination scores.

Goal is a score for the examinee's intention and not for the accuracy of the response. Since the responses to line-drawing items should all consist of straight lines, drawings in the shape of circles, for instance, were scored as 0 for Goal. When the examinee was judged as intending to draw a closed figure such as a closed rectangle or a closed triangle for any line-drawing items, Goal for the item was also scored as 0. When the examinee put any additional lines that should not be or omitted any line that should be, it was scored as 1 for Goal. When the examinee was judged as intending to draw the response figure as required, regardless of the accuracy in appearance of the figure, it was scored as 2 for Goal.

For track-tracing items, four criteria were used for the scores of Goal; whether or not the ball started in the correct direction indicated by the arrow; whether or not the ball finally arrived at the designated destination point; whether or not the ball changed direction at a right angle (90°) from the in-coming path when it hit the frame wall for the first time; and whether or not the response traces were straight. When none of the criteria was found in the response figure, scorers assigned 2 for Goal. When any one of the criteria was found, score 1 was assigned to the response. When two or more criteria were found, the response drawing was scored as 0 for Goal.

Unlike Goal, Shape is a score for accuracy. For responses on line-drawing items, when any inflection point or end point of the response figure was off the corresponding point of the target figure more than two intersection marks on the grid mat, the response figure tended to be greatly distorted in shape. In such a case, scorers assigned 1 for the score of Shape. It was also scored as 1 when the overall size of the response figure was markedly different from the size of the target figure. When a drawing was entirely cancelled and a complete redrawing was made, it was scored as 1 for Shape (In other words, the first drawing was scored). When any two or more of the above conditions co-existed, it was scored as 0 for Shape. Otherwise, Shape for the response on the line drawing items was scored as 2.

For track-tracing items, two criteria were used to determine the scores for Shape; whether or not any inflection angle in the response drawing was smaller than 45° or greater than 135°; and whether or not the number of inflection points was correct. When none of the criteria was found in the response drawing, scorers assigned 2 for Shape. When any one of the criteria was found, scorers assigned 1 to the response. When both criteria were found, the response drawing was scored as 0 for Shape.

Results

Inter-scorer agreement

Scorers determined two coordination scores, Goal and Shape, subjectively with three score categories (0, 1, and 2). Inter-scorer agreements on the two coordination scores were examined with kappa, a procedure suggested by Fleiss (1981). For this purpose, four different scorers independently determined Goal and Shape scores of 9 randomly selected subjects' responses according to the scoring criteria described above in detail. Four judgment sets resulted: Goal scores of line-drawing items; the Goal scores of track-tracing items; the Shape scores of line-drawing items; and the Shape scores of track-tracing items. Each judgment set consisted of 9 subjects x 12 items judgments made by each of the 4 scorers. Therefore, each judgment set forms a 108 judgments x 4 scorers score matrix. Kappa was computed separately for each of the four matrices of judgment sets.

Since the satisfactory level, or the cut-off value, of kappa for the judgments of 4 scorers is not clear, Cronbach's α, which is a popular index of consistency, was considered as a supplementary index of agreement. When applied to the judgments of multiple scorers, a high value of Cronbach's α would indicate the degree to which the judgments of different scorers co-vary (or are consistent) with one another.

Table 1 shows the values of kappa and Cronbach's α along with percentages of agreement for the four judgment sets. All kappa values exceeded .60. Applying Fleiss' criteria, the kappa values in Table 1 suggest at least *fair* or *good* levels of agreement among the 4 scorers. With the criteria suggested by Landis & Koch (1977), the agreements among the 4 scorers seem to be generally *substantial*. The values of Cronbach's α in Table 1 show excellent consistency among the 4 scorers and support the interpretation of kappa values as fair, good and substantial. That is, responses scored as high by a scorer tend to be scored as high by other scorers. The proportion of agreement in Table 1 provides additional information about the agreements among the 4 scorers. Each scorer made 108 judgments (9 subjects x 12 items) for each judgment set. The proportion of agreement in Table 1 is the average proportion of agreement in the 108 judgments between any two scorers. Table 1 shows that, on average, at least 3/4 of judgments by any two scorers agreed exactly.

Internal consistency

Table 1. Inter-scorer Agreements on Goal and Shape for the Two Item Types, Based on 9 Subjects by 12 Items by 4 Scorers Judgments

	Line-drawing Item		Track-tracing Item	
Indices	Goal	Shape	Goal	Shape
Fleiss (1981) kappa	0.65	0.62	0.60	0.74
Cronbach's α	0.95	0.94	0.94	0.97
Proportion (%) of Agreement	0.82	0.78	0.75	0.83

The scores on the 12 line-drawing items are summed up to obtain the corresponding coordination scores of line-drawing type items and the scores on the 12 track-tracing items are summed up to obtain the corresponding coordination scores of track-tracing type items. The means and standard deviations of the coordination scores of the 8 subject groups are provided in Appendix.

Since each coordination score is the sum of the scores on 12 individual items, reliability of the coordination score could be examined with Cronbach's α, an index of internal consistency among items.

Table 2 shows the values of Cronbach's α for the nine coordination scores of the two item types. Except for the Location score for track-tracing items, all other coordination scores showed values of greater than .70, generally considered to be an acceptable level of internal consistency. Goal and Shape, the scores that are subjectively determined by scorers, showed extremely high internal consistency. Note that the values of Cronbach's α for Goal and Shape in Table 2 indicate the internal consistency among the 12 individual items but not among the scorers as described above. This result provides additional support for the reliability of the scores determined subjectively by human scorers. The relatively low value of Cronbach's α for the Location score of track-tracing type items will be explained later in discussion.

Table 2. Cronbach's α for the Coordination Scores of the Two Types of Items

Coordination Score	Item Type	
	Line-drawing Item	Track-tracing Item
Overlap	.92	.85
Inflection	.80	.77
Disconnection	.72	.85
Goal	.95	.96
Correction	.87	.78
Shape	.95	.93
Location	.74	.58
Secession	.78	.84

Note. α coefficient for 'Time' coordination score could not be obtained because time was measured for each of the two types of items but not for individual items. All α coefficients are based on 155 observations.

Concurrent validity

Four different tests, Purdue Pegboard, Two-Arm Tracing Apparatus of MVE, Hole Plate of MVE, and Symbol Writing, were used as criteria to examine the concurrent validity of the coordination scores obtained with the EHCT. Four separate scores were obtained with the Purdue Pegboard: right hand; left hand; both hands; and assembly. The scores from the two MVE tasks, Two-Arm Tracing Apparatus and Hole Plate, were computed on the bases of the number of errors the subject made and the time that the subject took to complete the task.

Symbol Writing provided a single score.

It was observed that the scores from the four criteria tests were highly correlated with one another, suggesting that they may be different measures of a single underlying construct. Therefore, principal component analysis was conducted with four scores from Purdue Pegboard, two scores from the MVE subtests, and a score from Symbol Writing test. Only the first principal component yielded eigenvalue greater than 1.0. The first eigenvalue was 5.09 and accounted for 72.7% of the total variance. The loadings for the scores from the criteria tests on the first principal component were as follows: 0.889 for the right hand score of Purdue Pegboard, 0.874 for the left hand score of Purdue Pegboard, 0.927 for the both hands score of Purdue Pegboard, 0.892 for the assembly score of Purdue Pegboard, 0.751 for the Two-Arm Tracing score, 0.722 for the Hole Plate score, and 0.891 for the Symbol Writing score.

This result clearly suggested that there is no need to consider each criteria test separately. Even though the measures obtained with different apparatuses are supposed to evaluate different kinds of coordination, they may simply be different measures of the same latent construct. Consequently, a principal component score of the criteria tests was computed by weighting each score with its eigenvector on the first principal component. The weighted scores of the criteria tests were summed up to obtain 'Composite Criterion Score (CCS)'.

Table 3 shows zero-order correlations between the CCS and the coordination scores of the EHCT. All coordination scores except Time had statistically significant correlations with the CCS. The non-significant correlation between the CCS and Time should not be interpreted as indicating the absence of a relationship between the two variables. The true relationship between the two variables may be suppressed by the influences of the other coordination scores when they are highly correlated with both Time and the CCS. For instance, Overlap is positively

Table 3. Zero-order Correlations between Composite Criterion Score and the Coordination Scores from the EHCT

	Pearson Product Moment Correlation Coefficient	
Coordination Score	Line-drawing Item	Track-tracing Item
Shape	.63**	.63**
Disconnection	-.29**	-.20*
Location	-.44**	-.30**
Goal	.51**	.61**
Secession	-.42**	-.33**
Correction	-.19*	.17*
Inflection	-.35**	-.20*
Overlap	.71**	.62**
Time	-.12	-.07

Note. Numbers are Pearson product moment correlation coefficients of the coordination scores with the composite criterion score. All correlation coefficients are based on 155 observations.
* $p < .05$. ** $p < .01$.

correlated with the CCS as shown in Table 3. It is also positively correlated with Time. Then, the negative but strong correlation between Time and the CCS can be severely suppressed in the zero-order correlation between the two. Therefore, direct relationships between the CCS and the coordination scores were examined by multiple regression analysis in which the CCS was regressed on the nine coordination scores for each of the two item types.

Table 4 confirms the expectation that scores of Time have very strong negative relationships (βs = -.308 and -.297) with the CCS. That is, the subjects with poor coordination ability (low CCS) tended to take longer to complete the EHCT tasks than those with high coordination ability, provided that the other coordination scores remain constant.

Table 4. Standardized regression coefficients and the coefficient of determination from the multiple regression analyses with the Composite Criterion Score as the dependent variable and the coordination scores of the EHCT as the independent variables

Coordination Score (Independent variables)	Standardized Regression Coefficient (*SE*)	
	Line-drawing Item	Track-tracing Item
Shape	.42(.16)**	.42(.17)**
Disconnection	-.07(.07)	.03(.07)
Location	-.01(.07)	.03(.07)
Goal	-.14(.14)	.05(.16)
Secession	.02(.07)	-.24(.06)**
Correction	.06(.07)	.19(.07)**
Inflection	.06(.08)	.26(.07)**
Overlap	.54(.09)**	.37(.10)**
Time	-.31(.07)**	-.30(.07)**
R^2	.58**	.57**

Note. All regressions are based on 155 observations.
* $p < .05$. ** $p < .01$.

An important fact to notice in Table 4 is that the nine coordination scores as a set have very strong predictive power for the CCS as indicated by the coefficients of determination (or the squared multiple correlations). The nine coordination scores as a set from line-drawing items accounted for 58% of variability in the CCS, $F(9,\ 145) = 22.65$, $p < .01$. The nine coordination scores from track-tracing items accounted for 57% of variability in the CCS, $F(9,\ 145) = 21.33$, $p < .01$. In an additional analysis, 70.8% of the variability in the CCS was accounted for by the combined set of 18 coordination scores from the two types of items.

Discussion

A common underlying mechanism may operate in many different kinds of coordination. This point was at least partially confirmed by the principal component analysis with the criteria tests. The MVE measures and the Purdue Pegboard measures use different kinds of apparatuses and are supposed to evaluate different kinds of coordination, but the scores from those apparatus measures showed very high correlations with one another. This result clearly supports the position that a common underlying mechanism may determine several coordination performances of different kinds.

In accordance with neurophysiological perspectives, two types of items were designed to measure eye-hand coordination. Line-drawing items provide visual cues and coordinates, marking the exact positions of the target figure to be copied. Track-tracing items do not provide such coordinates so that the examinee must generate the track to be traced by him/herself. Nine coordination scores are obtained from the responses on each of the two types of items. The psychometric properties of the coordination scores will be discussed here.

Inter-scorer agreements

With 4 scorers who made judgments on 9 subjects' responses, inter-scorer agreements on the two subjective scores (Goal and Shape) were examined with kappa, a procedure suggested by Fleiss (1981). Cohen's kappa (Cohen, 1960) provides an index of the degree to which two scorers agree with each other after correcting for the agreements that are possibly due to chance. Fleiss (1981) suggested a generalization of Cohen's kappa that can be used in situations where there are more than two scorers and/or score categories. According to Fleiss (1981), kappa values exceeding .75 suggest strong agreement above chance, values in the range of .40 to .75 indicate fair to good levels of agreement above chance, and values smaller than .40 are indicative of poor agreement above chance levels. On the other hand, Landis & Koch (1977) suggested that kappa values greater than 0.81 suggest almost perfect agreement, values in the range of .61 to .80 indicate substantial agreement, values in the range of .41 to .60 indicate moderate agreement, values in the range of .21 to .40 indicate fair agreement, and values less than .20 suggest poor agreement. Relying on these suggestions, the inter-scorer agreements for scoring Goal and Shape in the present study seem to be at least good or substantial as compared to chance.

Kappa's calculation uses a term called the proportion of chance (or expected) agreement. This is interpreted as the proportion of times scorers would agree by chance alone. However, the term is relevant only under the conditions of statistical independence of scorers (Maclure & Willett, 1987; Uebersax, 1987). Since scorers are instructed with predetermined scoring criteria and rules, scorers are clearly not independent. Consequently, the relevance of the proportion of chance agreement, and its appropriateness as a correction to actual levels of agreement is very questionable. For this reason, Cronbach's α and proportion of agreement were also used as supplementary indices. These supplementary indices of inter-scorer agreements strengthened the conclusion based on kappa.

Internal consistency

One merit of the EHCT as a paper-and-pencil instrument is that the coordination scores are based on responses on multiple items and thus, psychometric test theories can be easily applied. The reliabilities of the nine coordination scores were examined with Cronbach's α, probably the most well known index of internal consistency. The coordination scores obtained with EHCT were found to be internally consistent, meaning that enough amount of their variability can be accounted for by the underlying latent trait to be measured rather than by random measurement errors.

An exception, though, was observed with the Location score for track-tracing type items. The location score for track-tracing items showed relatively low internal consistency (α = .58). In contrast, the same Location score for line-drawing items showed an acceptable level of internal consistency (α = .74). As described earlier, the Location score is the sum of the distance (in pixels) between inflection points of the response figure and the corresponding points of the target or correct figure, divided by the number of inflection points in the target figure. That is, the Location score is determined by the degree to which the subject locates the positions of inflection points accurately within the response area. The response areas for line-drawing items are provided with coordinates marked visually with either dots or dotted grids to help locate the accurate positions (see Figure 1). On the other hand, the response areas for track-tracing items are not provided with such visual coordinates (see Figure 2). Because of the lack of visual coordinates in track-tracing items, the accuracy of responses with respect to the locations of inflection points might have been less consistent across track-tracing items.

Why would the lack of visual coordinates reduce the consistency in locating positions? Even though this question may seem trivial, van Donkelaar & Staub (2000) provides an interesting insight into this question. In their experiment, the timing of hand movement onset relative to saccadic offset was markedly different in two types of tasks, the coordination of eye and hand movements to visual (visually triggered) target locations and that to remembered (internally generated) target locations. Specifically, the hand movement temporally overlapped with the saccade to a much greater degree in the remembered condition than in the visual condition (see also van Donkelaar, Siu & Walterschied, 2004; van Donkelaar, Lee & Drew, 2002; Nyffeler, Pierrot-Deseilligny, Pflugshaupt, von Wartburg, Hess, & Mri, 2004). In other words, individuals performing the coordination of eye and hand movements to remembered or internally generated target locations such as those in track-tracing items in the present study tend to respond hastily, presumably due to the anxiety of forgetting or losing the target locations. Moreover, for track-tracing items, there was a rule that the ball should change direction always at a right angle (90°) from the in-coming path when it hits the wall of the frame. This rule is not consistent with the general laws of physics. This novel requirement may have added additional anxiety. Haste out of anxiety could have made the accuracy in locating positions inconsistent over track-tracing items.

If this speculation is correct, the internal consistency of the Location score might increase as the subject becomes adapted to track-tracing tasks. As expected, Cronbach's α computed with the Location scores on the first 6 track-tracing items was .37 while that computed with the last 6 track-tracing items was .51. Furthermore, there was a clear decreasing trend in Location scores as the subjects proceeded from the first track-tracing item to the last one (note that a decreasing trend in Location scores means an improvement in performances). The mean of the Location score for the first track-tracing item was 13.35, 12.23 for the second item, 7.94 for the third item, and so on to 5.26 for the last item. As the subjects' performances improved with respect to Location score, they also became more consistent. Therefore, the internal consistency of Location score for track-tracing items may be a function of practice or adaptation. If so, the relatively low internal consistency of Location score for track-tracing items may not necessarily be attributed to measurement errors that are theoretically considered to be random or chance elements threatening the reliability of the measurement.

Concurrent validity

Similar profile trends were observed in the scores from the two types of items. The profiles of adult groups on the coordination scores of line-drawing items show a similar trend with their profiles on the scores of track-tracing items. Likewise, the profiles of children groups on the coordination scores of line-drawing items show a similar trend with their profiles on the scores of track-tracing items. This similarity in profile trends between the two types of items suggests that they are equivalent measures of the same construct.

The nine coordination scores as a set showed very strong predictive power for the composite criterion score (CCS) as shown in Table 4. The nine coordination scores of line-drawing items accounted for 58% (multiple correlation = .76) of variability in the CCS; the nine coordination scores of track-tracing items accounted for 57% (multiple correlation = .75) of variability in the CCS; and 70.8% (multiple correlation = .84) of the variability in the CCS was accounted for by the combined set of 18 coordination scores from the two types of items. This result, along with the zero-order correlations between the CCS and the individual coordination scores, clearly indicates that the coordination scores as a profile set obtained with the EHCT have concurrent validity as measures of eye-hand coordination.

Although the coordination scores as a set demonstrated very strong accountability for the CCS, some of them appeared not to have direct relationship with the CCS. When the CCS was regressed on the 9 coordination scores, the regression coefficients of Disconnection, Location and Goal scores from both of the two types of items were not statistically significant (see Table 4). In contrast, the zero-order correlations of those three scores with the CCS are generally substantial as shown in Table 3. What would this contrasting pattern of correlation and regression results mean with respect to the validities of those three scores? It would not mean that those three scores are invalid measures of coordination. It certainly indicates that those three scores have indirect relationships with the CCS through other coordination scores of the EHCT. The relationships of Disconnection, Location and Goal scores with other coordination scores and the lack of direct relationships of them with the CCS would together suggest that they carry information on some aspects of coordination under-represented by the CCS. For instance, Disconnection may reflect the subject's tendency of hesitation that is not reflected on the scores of the criteria tests combined in the CCS. Likewise, the comprehension or cognitive sub-function as measured with the Goal score is certainly not represented in the scores obtained with the criteria tests. The correlations of verbal IQ were 0.60 with the Goal score of the line-drawing items and also 0.60 with the Goal score of track-tracing items. The specific aspects of coordination that are measured uniquely by the three scores may be the focal points of determination in future studies.

Group differences

An additional objective of the present study was to explore the possibility that the EHCT could be used to diagnose the specific locus of underlying problems for those who fail in coordination tasks. The present study explored the possibility that the EHCT could be developed as a diagnostic instrument in the future.

If it is possible to diagnose the common underlying mechanism, the information obtained with a kind of coordination, e.g., eye-hand coordination, could be used to predict the quality of performances in other kinds of coordination. The profiles of the nine coordination scores obtained with the EHCT could provide differentiated information about the underlying strengths and weaknesses of the examinees, which may be generalized to other kinds of coordination performances.

The possibility that the EHCT could be used for diagnosis was explored with 8 groups of disabled and normal subjects. The first thing to notice was that the 8 subject groups showed distinctively different profiles on the nine coordination scores. The fact that the groups with different disabilities showed different response patterns on the coordination scores encouraged future exploration to achieve this objective with the EHCT. There is another interesting pattern to notice in the profile figures of adults and children groups. The differences among the adult groups tend to be pronounced more in the coordination scores of line-drawing items than in the coordination scores of track-tracing items. In contrast, the differences in profiles among the children groups tend to be pronounced more on track-tracing items than on line-drawing items. Although the reasons for this pattern are to be determined in the future, line-drawing items may be more useful than track-tracing items to diagnose the performances of adults while track-tracing items may be more useful to diagnose children's performances.

Conclusion

The EHCT has practical and theoretical advantages over many existing apparatuses to measure eye-hand coordination. It is suitable for the purposes of quick screening and group testing because it is a paper-and-pencil test. Because it consists of multiple items, its psychometric properties can be easily evaluated by subjecting it to traditional test theories. In the present study, the EHCT clearly demonstrated its internal consistency and concurrent validity. Other types of reliability and validity could also be easily applied to the EHCT to examine its additional psychometric properties in the future. It may be developed in the future as an instrument to diagnose the underlying latent problems causing failures in coordination tasks. It is believed that a Cybernetics system operates in many different kinds of coordination tasks. Therefore, if it is possible to diagnose the functional elements for eye-hand coordination, the information could be used to predict the quality of performances in other kinds of coordination as well.

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눈-손 협응능력을 측정하기 위한 지필검사의 개발

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눈과 손의 협응능력을 측정하기 위한 24문항으로 구성된 지필검사(Eye-Hand Coordination: EHCT)를 개발하여 장애를 가지고 있는 사람과 장애가 없는 사람 155명(8 집단)을 대상으로 신뢰도와 타당도를 검증하였다. EHCT에서 산출되는 9개의 협응점수는 각각 건실한 신뢰도(내적 일관성)를 지닌 것으로 나타났고, 장비를 이용하는 다른 협응능력 측정치들을 준거로 사용한 타당도 검증에서 매우 우수한 심리측정적 속성을 가지는 것으로 나타났다. 더 나아가서, 9개의 협응점수들로 구성된 프로화일은 각기 다른 장애를 가진 집단들을 변별하는 특성이 있음이 확인되었다. 각기 다른 장애를 가진 집단들을 변별하는 프로화일은 본 검사가 향후에 협응과제에서 실패하는 원인에 대한 진단적 도구로 발전될 수 있는 가능성을 가지는 것으로 판단되었다.

주요어 : 눈-손 협응, 지필검사, 프로화일, 타당도

Appendix

Means and Standard Deviations of the Coordination Scores of Line-drawing Items and Track-tracing Items by Subject Groups

Item Type	Coordination Score		Subject Group							
			MR-A	WS-A	WS-C	LD-A	AD-C	N-A	N-C	AI-A
			(N=25)	(N=12)	(N=11)	(N=9)	(N=17)	(N=32)	(N=27)	(N=22)
	Shape	M	14.28	17.58	21.64	22.00	21.65	23.94	23.19	23.80
	(0-24)	SD	7.89	4.69	3.44	2.82	1.99	.24	1.61	.58
	Disconnection	M	3.16	4.00	1.18	4.44	.76	1.12	2.33	.50
	(0-∞)	SD	4.16	6.26	1.66	6.40	1.09	2.02	2.41	.80
	Location	M	285.87	378.39	121.89	114.09	195.43	53.40	117.91	82.35
	(0-∞)	SD	149.80	396.66	62.02	68.94	341.39	42.45	203.65	128.81
	Goal	M	15.48	21.08	22.27	23.67	23.71	23.95	23.88	23.56
Line-	(0-24)	SD	7.52	2.64	1.84	.70	.77	.42	1.28	.21
drawing	Secession	M	3.84	15.50	5.72	2.77	4.29	1.43	2.92	.90
Item	(0-∞)	SD	3.60	9.21	3.46	2.53	3.19	1.41	2.60	1.47
	Correction	M	10.44	12.33	12.72	23.22	16.76	8.59	17.81	10.18
	(0-∞)	SD	13.08	14.56	11.20	10.08	9.71	7.33	14.33	8.21
	Inflection	M	3.96	1.08	.00	.33	.52	.18	.07	.22
	(0-∞)	SD	5.00	1.31	.00	.50	.94	.73	.26	.61
	Overlap	M	1.84	1.86	3.64	5.72	3.58	7.51	5.95	7.17
	(0-∞)	SD	2.03	1.53	2.29	2.48	2.01	1.39	2.05	1.07
	Time	M	24.36	39.77	58.93	59.76	40.06	32.45	42.58	33.68
	(0-∞)	SD	10.13	35.14	31.68	24.03	17.39	8.55	12.44	8.90
	Shape	M	7.28	14.25	15.82	20.11	16.18	22.14	20.67	22.14
	(0-24)	SD	7.94	6.74	4.75	4.04	3.97	1.80	5.15	1.58
	Disconnection	M	3.80	7.08	3.36	2.88	.52	2.09	1.74	2.36
	(0-∞)	SD	5.98	8.21	3.10	2.97	.87	2.49	2.22	2.47
	Location	M	135.47	158.15	120.95	83.28	105.34	83.93	85.78	88.82
	(0-∞)	SD	109.70	207.19	77.28	40.99	37.90	46.61	33.42	49.85
	Goal	M	8.76	15.67	18.73	20.67	20.47	22.68	22.81	21.85
Track-	(0-24)	SD	8.98	6.03	3.69	4.27	1.97	1.42	3.13	1.32
tracing	Secession	M	5.28	17.91	22.00	11.00	13.58	6.62	8.14	4.59
Item	(0-∞)	SD	5.57	12.14	14.33	6.59	11.72	7.41	6.26	3.23
	Correction	M	2.76	9.75	7.72	15.55	5.23	12.59	11.00	13.27
	(0-∞)	SD	3.65	11.63	7.55	10.44	8.31	10.12	7.65	11.05
	Inflection	M	14.40	7.50	9.00	4.66	9.17	7.96	6.55	3.72
	(0-∞)	SD	9.03	4.40	11.86	3.00	6.38	10.66	9.14	3.08
	Overlap	M	1.70	2.64	3.21	3.53	2.27	4.40	3.67	4.36
	(0-∞)	SD	1.99	1.89	1.04	1.57	.76	.82	1.05	1.07
	Time	M	12.49	24.56	30.05	23.51	11.77	20.00	18.85	20.00
	(0-∞)	SD	4.41	16.88	13.79	8.52	4.60	7.58	6.64	5.92

Note. Abbreviated notations for subject groups are as follows: MR-A = Adults with mental retardation; LD-A = Adults with limb disability; WS-A = Adults with weak sightedness; WS-C = Children with weak sightedness; AD-C = Children with attention deficit/hyperactive disorder; AI-A = Adults with artificially impaired eyesight; N-A = Normal adults; N-C = Normal children. M = Mean; SD = Standard deviation

The numbers in the parenthesis under the score names are the possible range of scores.