Virtual Haptic Visual Discrimination Test

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***Abstract*—This paper presents a virtual HVDT system that simulates the actual HVDT using virtual reality technology. Our virtual HVDT system incorporates discrimination measures of different shapes, sizes, textures, and configurations. The users can not only improve but also evaluate their haptic discrimination capability by probing virtual 3D objects using one or two haptic devices. Our virtual HVDT system can be the potential substitute for the expensive actual HVDT done with real objects. An experiment was conducted in order to examine the correlation coefficients between three properties (size, shape, and configuration) of our virtual HVDT for normal adults. The results of this experiment lead us to confirm that our virtual HVDT can simulate the actual HVDT. Our work is an attempt to develop a tool for helping handicapped children improve their haptic visual discrimination capability using haptic virtual reality technology.**

***Index Terms*— Haptic Visual Discrimination Test; Virtual Reality; Cognitive Ability; Vocational Evaluation; Rehabilitation**

I. INTRODUCTION

Cognition is “the mental action or process of acquiring knowledge and understanding through thought, experience, and senses [1], and it generally includes attention, perception, thinking, and memory [2]. Cognitive impairment does not only hinder daily life [3], but it also severely degrades one’s quality of life [4]. To prevent such difficulties from frustrating the future of handicapped children, an appropriate occupational therapy is necessary. Further, it is necessary to assess the cognitive abilities of the patient prior to its application to properly conduct such treatment.

This study is motivated from the HVDT (haptic visual discriminant test) [5] of McCarron-Dial System (MDS) [6][7][8]. The MDS is a series of neuropsychological and behavioral measures that were introduced to the rehabilitation field in 1973 [7]. This HVDT consists of real tangible components, such as photographic plates representing various objects, sets of shapes and sizes, textures and configurations, etc. For the rest of this paper, we will call this conventional HVDT with the actual objects, as the “actual HVDT.” However, because this actual HVDT is too expensive (US$1470.00 for HVDT, US$9707.00 for MDS package for ages 4 through adults [8]), many families with medically handicapped children cannot afford this tool for vocational evaluation and rehabilitation.

We developed a virtual HVDT, which is a tool for helping handicapped children improve their haptic visual discrimination capability using haptic virtual reality technology. In this paper, after a brief summary of our prior study, we will proceed with a survey of existing HVDT and an examination on our ongoing development of virtual HVDT. Then, some evaluation issues of our system will be elaborated, followed by our conclusion and plans for future works.

II. PRIOR STUDY

This research has been initiated by our prior study of haptic-visual gaming system [9]. In our previous work, we had conducted two experiments of “haptic shape recognition test.” The first experiment was performed with only verbal information about the target 3D objects (sphere, torus, tetrahedron, hexahedron, octahedron, dodecahedron, and icosahedron) without any visual information provided to the test subjects. The second was performed by providing the visual knowledge of target shapes. These two tests were undertaken five times respectively by the subjects, and the results showed that the visual knowledge of the 3D shapes greatly upgraded the participants’ accuracy in discerning objects. One of the extreme results was found in the case dealing with the octahedron, where its average number of correct answers was 9.2 out of 25 without visual information and 23.6 out of 25 with visual information.

It was also interesting to notice that the rate of accurate discernment improved as we repeated the trials of recognition. For instance, the average number of correct answers of tetrahedron was 10 out of 25 in the 1st trial, whereas in the 5th trial it was 19 out of 25. These haptic shape recognition tests allowed us to conclude that our haptic shape recognition system can help to enhance a person’s ability to discern tactile textures and 3D shapes if it is applied as a training tool. Note that these experiments in our former studies are closely related to the HVDT of the McCarron-Dial System.

III. ACTUAL HAPTIC VISUAL DISCRIMINATION TEST

Historically, HVDT was first came from Ward Halstead’s [10][11] monograph, “Brain and Intelligence; a quantitative study of the frontal lobes”. This work has significant influence on both the theoretical and practical aspects of clinical psychology and neuro-psychology. HVDT is one of the assessments of MDS. It was developed as an empirically based multi-factor assessment. Originally introduced to the field of rehabilitation as a vocational evaluation tool, its use has been expanded to include applications in all areas of neurocognitive assessment and treatment.

A. McCarron-Dial System (MDS)

The MDS is a standardized and quantitative test kit for evaluating cognitive functioning in tactile sensitivity, spatial synthesis, and object integration of partial information as a whole. It is considered as an effective method to examine the handicapped and the mentally disabled individuals as it is based upon verbal-spatial-cognitive, sensory, motor, emotional, and integration-coping factors. These five factors were derived from an assessment of three categories: verbal and synthetic-spatial skills, sensorimotor skills, and emotional-coping skills. The organization of the MDS is summarized in Table 1 [12].

The MDS can be used as a tool for clinicians to evaluate the implications of functional deficits on a patient's performance and vocational evaluation as well as for rehabilitation training. The MDS assessments are interpreted in different ways depending on the nature and goal of the evaluation as well as the training and professional orientation of the evaluator. Results from standardized tests are interpreted in the context of the individual's history and the information gained from qualitative observation of the person's behavior. These interpretations may draw attention to vocational, educational, or clinical diagnostic issues [8].

Table 1
Five Factors of MDS and their Assessments

Factor	Assessment
Verbal-Spatial-Cognitive	Wechsler Adult Intelligence Scale (WAIS-R or WAIS-III) and Peabody Picture Vocabulary Test-III (PPVT-III); or the Cognitive Test for the Blind (CTB) for visual impairment
Sensory	Bender Visual Motor Gestalt Test (BVMGT) and Haptic Visual Discrimination Test (HVDT), or Haptic Sensory Discrimination Test (HSDT) for visual impairment
Motor	McCarron Assessment of Neuromuscular Development (MAND) or MAND-VI (Visual impairment) Fine Motor Skills Assessment: Beads-in-Box; Beads-on-Rod; Finger Tapping; Nut and Bolt; and Rod Slide Gross Motor Skills Assessment: Hand Strength; Finger-Nose-Finger; Jumping; Heel-Toe Walk; and Standing On One Foot)
Emotional	Observational Emotional Inventory (OEI), Observational Emotional Inventory-Revised (OEI-R), Emotional Behavioral Checklist (EBC) or Behavioral Checklist for Students (BCS)
Integration-Coping	Dial Behavior Rating Scale (BRS) and Street Survival Skills Questionnaire (SSSQ) and/or Survey of Functional Adaptive Behaviors (SFAB)

B. *Haptic Visual Discrimination Test*

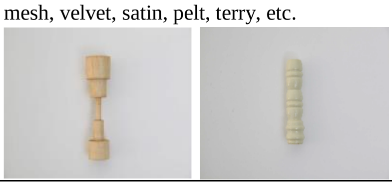
The HVDT consists of physically tangible objects: photographic plates representing various objects that had to be identified by the examinees, a folding screen (to obscure objects from the examinee's field of vision), sets of shapes and sizes, textures and configurations, one package of HVDT score forms, and the test manual. Figure 1 shows the objects of the actual HVDT. It requires tactile manipulation of objects (obscured from the visual field) to discriminate their particular shape, size, texture, or configuration and visual recognition of the objects from a photograph.

Figure 1: Actual HVDT of McCarron-Dial System [15]

The HVDT system can be helpful for patients with: (1) mental retardation, (2) mental illness, (3) specific learning disabilities, and (4) neuro-psychological disabilities (i.e., higher brain center structural or functional disorders). It can also be used to treat the blind or the deaf. Other than rehabilitation, it has been used to help normal but functionally delayed children.

The system consists of 48 items, arranged to provide discriminating measures of shape, size, texture, and configuration. Each of the four categories contains 12 items. Sample items from each category are illustrated in Table 2.

Table 2
Sample Items from each category of the actual HVDT

Property	Sample Items
Shape	star-shaped decagonal prism, hexagonal prism, triangular prism, rigid body globular, etc.
Size	1 inch cube, 0.625 inch nut, 0.75 inch cylinder 1.5 inch handle, etc.
Texture	mesh, velvet, satin, pelt, terry, etc.
Configuration	

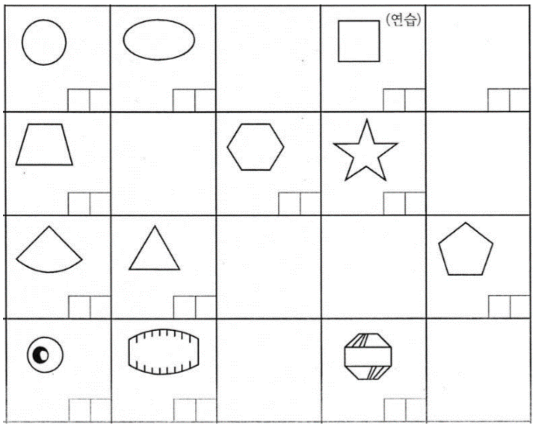
IV. VIRTUAL HAPTIC VISUAL DISCRIMINATION TEST

Recent advancement of virtual reality technology allowed us to develop many software tools for medical rehabilitation. Virtual reality (VR) by definition is a computer-mediated environment that can simulate physical presence in places in the real or imaginary worlds. Virtual reality provides an illusion of the reality which can be realized by a careful implementation of five human sensory phenomena: the visual, auditory, haptic, olfactory (smell), and palatal (taste) perceptions. Figure 2 is the score sheet for shape, size, texture, and configuration tests.

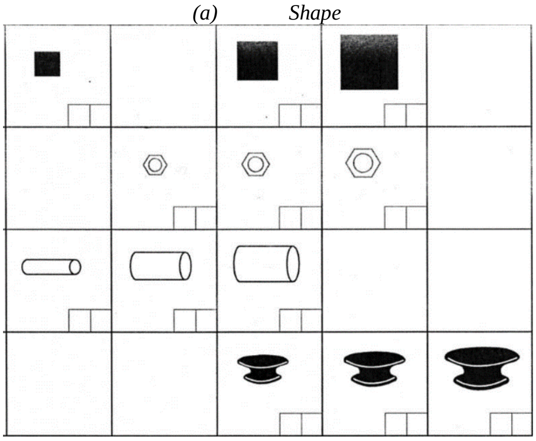
Among the five perceptions, haptic perception is the third most prevailing sensation following after vision and audition in computer-human interactions. Thus haptics technology was developed to apply the senses of touch to make the interactions more realistic [13] [14].

Our virtual HVDT system is a simulation of the actual HVDT. It has four different components: shape test tool, size test tool, texture test tool, and configuration test tool. Based upon the components, there are 48 items in terms of shape (no.1~no.12), size (no.13~no.24), texture (no.25~no.36), and configuration (no.37~no.48), each with 12 tests alike.

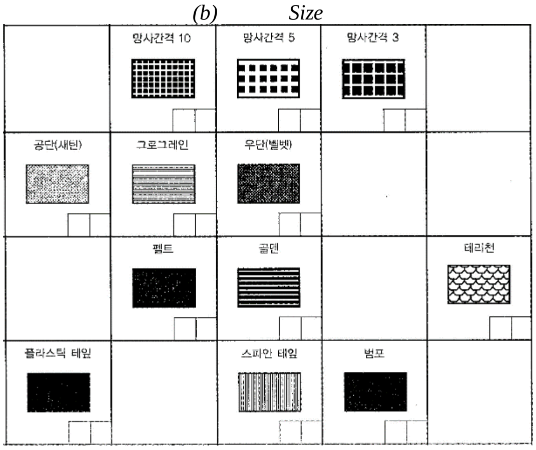
Our system is equipped with two PHANToM Omni haptic devices which provide six spatial degrees of freedom (forward/back, up/down, left/right, pitch, yaw, and roll) and three force degrees of freedom (forward/back, up/down, and left/right). It allows users to evaluate and improve their haptic virtual discrimination capability by probing virtual 3D objects using one or two haptic devices. Objects are in a series of Euclidian geometric shapes including a circle, ellipse, triangle, square, and cross. The system also can be used as a gaming system for two users to compete with their haptic visual discrimination capabilities. Figure 3 presents screenshots of our virtual HVDT system.



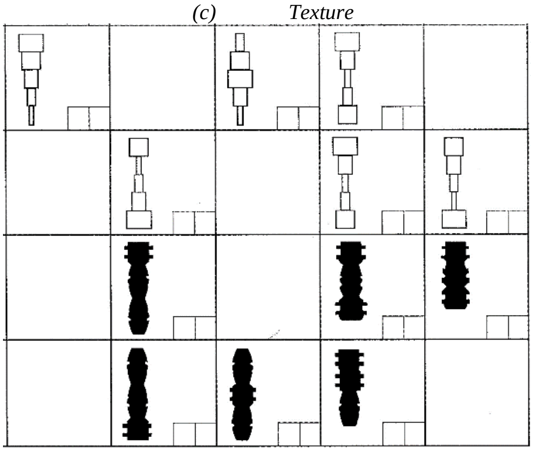
(a) Shape



(b) Size



(c) Texture



(d) Configuration

Figure 2: Haptic Visual Discrimination Test Score Sheet

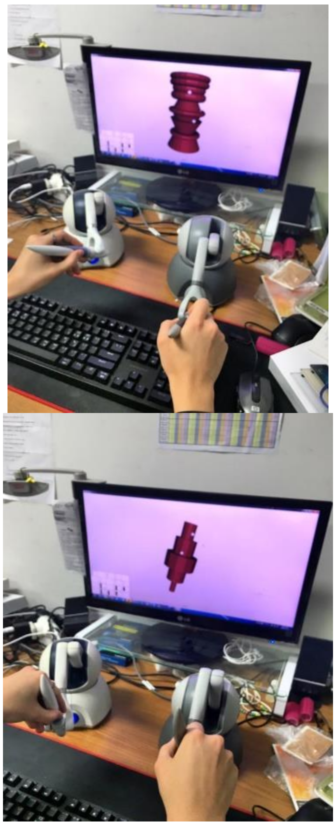


Figure 3: Screenshots of the virtual HVDT

Prototypes of objects from the actual HVDT kit are shown in the following figures:

- Figure 4 presents the objects of the shape test kit, which are items no.5 (star-shaped decagonal prism), no.6 (hexagonal prism), no.8 (triangular prism), and no.11 (rigid body globular).
- Figure 5 indicates those in the size test kit: items no.13 (1.25 inch cube), no.17 (1 inch cylinder), no.16 (0.625 inch nut), and no.24 (2 inch handle).
- Figure 6 displays four items of texture test kit: items no.27 (mesh), no.28 (grosgrain), no.32 (terry), and no.36 (plastic tape).
- Figure 7 illustrates some complex cylinders in configuration test kit; they are items no.37 (3A cylinder), no.38 (4A cylinder), no.39 (1A cylinder), and no.40 (5B cylinder).

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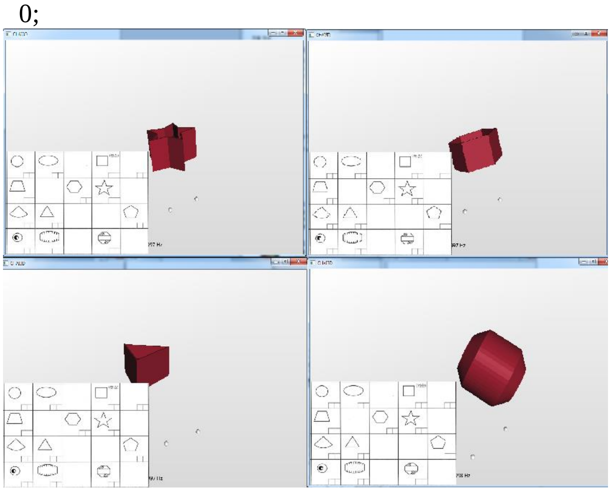

Figure 4: Virtual HVDT for shape test: no.5 (star-shaped decagonal prism), no.6 (hexagonal prism), no.8 (triangular prism), and no.11 (rigid body globular)

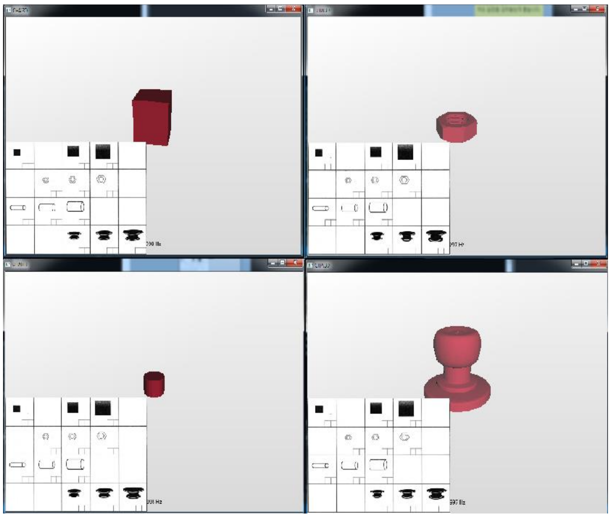

Figure 5: Virtual HVDT for size test: no.14 (1.25 inch cube), no.16 (0.625 inch nut), no.20 (1 inch cylinder), and no.24 (2 inch handle)

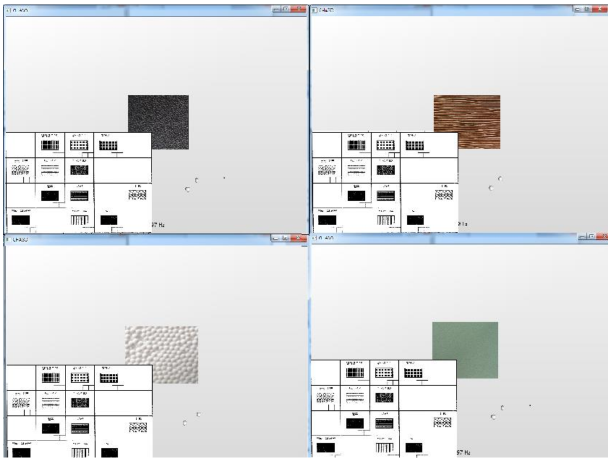

Figure 6: Virtual HVDT for texture test: no.27 (mesh), no.28 (grosgrain), no.32 (terry), and no.36 (plastic tape)

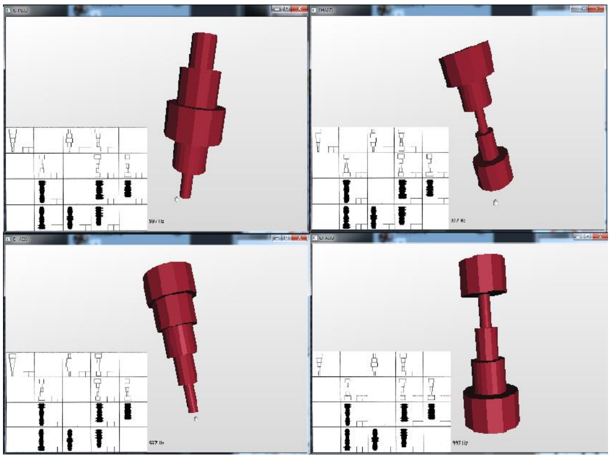

Figure 7: Virtual HVDT for configuration test: no.37 (3A cylinder), no.38 (4A cylinder), no.39 (1A cylinder), and no.40 (5B cylinder)

V. Evaluation Model

The reliability of the actual HVDT was already validated by the experiments conducted on 51 normal children and adults with neuropsychiatric disorders in 1976 [6]. The test and retest reliability coefficients were r=.91 for normal children and r=.93 for adults with neuropsychiatric disorders. Our virtual HVDT adopts the analytical measures of the actual HVDT, such as the level of difficulty and the discrimination rate, etc.

A. *Assessments Function*

McCarron and Dial analyzed the difficulty, the discrimination ability, and validity of 48 items composing the actual HVDT for normal children and adults with neuropsychiatric disorders [5][6][7][15]. The excerpt of the analysis is presented in Appendix.

Some items with the highest discrimination rates are summarized in Table 3 and 4. It is interesting to notice that the highest discrimination rates are similar but different between two groups, particularly in texture property.

Table 3
Items with the highest discrimination rate for normal children

Property	Items with the highest discrimination	Value
Shape	no.7 (round floor triangle)	.77
	no.12. (hard ellipse)	.54
Size	no.13 (1 inch cube), no.17 (1/2 inch nut)	.62
	no.19 (3/4 inch cylinder), no.20 (1 inch cylinder)	.54
Texture	no.30 (satin), no.31 (Pelt), no.32 (terry)	.54
	no.28 (grosgrain), no. 29 (velvet)	.46
Configuration	no.39 (1A cylinder)	.77
	no.37 (3A cylinder)	.62

Table 4
Items with the highest discrimination rates for adults with neuropsychiatric disorders

Property	Items with the highest discrimination	Value
Shape	no.8 (triangular prism)	.75
	no.7 (round floor triangle), no.11 (hard sphere)	.67
Size	no.19 (3/4 inch cylinder)	.83
	no.20 (1 inch cylinder)	.75
Texture	no.29 (velvet)	.83
	no.30 (satin), no.31 (pelt), no.32 (terry)	.58
Configuration	no.38 (4A cylinder), no.39 (1A cylinder)	.83
	no.37 (3A cylinder), no. 48. (2B post)	.67

B. *Correlation Coefficients*

We are also interested in the correlation analysis of components (size, shape, texture, and configuration) of the actual HVDT. The correlation coefficients between properties for normal children and neuropsychiatric disordered adults are analyzed in Table 5 and 6 [15].

Table 5
Correlation coefficients for normal children using the actual HVDT

Property	Shape	Size	Texture	Configuration
Shape	1.00			
Size	0.26	1.00		
Texture	0.30	0.58	1.00	
Configuration	0.54	0.25	0.04	1.00

Table 6
Correlation coefficients for neuropsychiatric disordered adults using the actual HVDT

Property	Shape	Size	Texture	Configuration
Shape	1.00			
Size	0.60	1.00		
Texture	0.53	0.54	1.00	
Configuration	0.57	0.48	0.56	1.00

In our study, an experiment was conducted in order to examine the correlation coefficients between three properties (size, shape, and configuration) of our virtual HVDT. Normal adults aged 24 to 29 participated in this experiment. Test subjects were undertaken the shape tests, the size tests, and the configuration tests. The raw scores obtained from this experiment are converted to the standard scores. We used the same conversion table as the actual HVDT (presented in Table 8 in Appendix) to change the raw scores to the standard scores for evaluating sensory factors. For example, if an examinee guesses correctly for 7 items in shape test, the raw score will be 7 and converted to the standard score 40. After all, the correlation coefficients are calculated. The results of this experiment are shown in Table 7.

Table 7
Correlation coefficients for normal adults using the virtual HVDT

Property	Shape	Size	Texture	Configuration
Shape	1.00			
Size	0.67	1.00		
Texture	-	-	1.00	
Configuration	0.53	0.80	-	1.00

The split-half reliability coefficient with the Spearman–Brown correction for this experiment or normal adults using virtual HVDT is r=.89, that is similar to r=.91 for normal children and r=.93 for adults with neuropsychiatric disorders for the case of the actual HVDT. These results allow us to confirm that our virtual HVDT can simulate the actual HVDT. An in-depth study of the correlation between the actual HVDT and the virtual HVDT is still needed.

VI. CONCLUSION AND PLANS FOR FUTURE WORK

We developed a virtual HVDT, which can be used for providing appropriate visuo-haptic experiences and testing the levels of such sensing abilities. Our HVDT system provides discrimination measures in terms of shapes, sizes, textures, and configurations of different 3D virtual objects. Through such incorporation, it allows users to evaluate and improve their haptic visual perception by object probing with haptic devices.

Current status of our virtual HVDT can simulate well the actual subtests such as shapes, sizes, and configurations. However, it still needs improvement in its quality of texture subtests. If we can add successfully the texture subtests, we believe that this study can replace the expensive actual HVDT and also be useful for the cognition development of handicapped children.

In addition, our system presented a possible integration of vision and haptic perception of physically or mentally disabled children. Recent advancements in computational neuroscience and brain imaging research have added new insights into the underlying mechanisms and identified possible brain regions involved in visual-haptic integration [16]. However, there is still a gap between the results of computational studies and those of brain imaging studies. Our experiment is an attempt to mitigate such discrepancy.

In the future, we will focus our subsequent research on developing virtual HVDT using the proposed system with a better understanding of the visual-haptic integration process. System usability and the haptic reality of our system also need improvement. It can be done by refining the haptic attributes such as stiffness, damping, static friction, dynamic friction, etc. Also, we need to devise some experiments to validate the effectiveness of our virtual HVDT system.

APPENDIX

McCarron and Dial proposed a McCarron-Dial work evaluation method including the HVDT in 1976 [6]. We adopted the same sensory factor conversion table of the actual HVDT for the evaluation of our experiments. Table 8 presents the conversion table of sensory factors of the actual HVDT.

Table 8
Sensory factors conversion table [15]

Standard Score \ HVDT Subtests	Shape	Size	Texture	Configuration
25	6	3	1	3
28				
31				
34				
37				
40	7	4	2	4
43				
45				
49				
52				
55	8	5	3	5
58				
61		6	4	6
64				
67				
70	9	7	5	7
73				
76				
79				
82				
85	10	8	6	8
88				
91				
94				
97				
100	11	9	7	9
103				
105				
109				
112		10	8	10
115	12			
118				
121				
124				
127				
130		11	9	11

McCarron and Dial also analyzed the difficulty, the discrimination ability, and the validity of 48 items composing the actual HVDT [7]. Table 9 and Table 10 present the analysis of each item for the group of normal children and for the group of neuropsychiatric disorders respectively.

- The difficulty is a qualitative evaluation.
- The discrimination ability is calculated by the ratio of correct answers to trials.
- The validity is measured by the construct validity (the degree to which a test measures what it claims, or purports, to be measuring).

Note that these tables are excerpted from the HVDT manual [15].

Table 9
Analysis of 48 items of the actual HVDT for normal children [15]

	Category	Difficulty	Discrimination ability	Validity
Shape	1. cross type	.96	.15	.39
	2. circle	.65	.38	.28
	3. ellipse	.72	.46	.38
	4. trapezoid	.57	.00	.12
	5. star shape	.80	.31	.20
	6. hexagon	.67	.31	.16
	7. round floor triangle	.70	.77	.56
	8. triangle	.82	.46	.47
	9. pentagon	.67	.31	.30
	10. cone cylinder	.49	.46	.32
	11. hard sphere	.72	.31	.30
	12. hard ellipse	.74	.54	.47
Size	13. 1 inch cubes	.55	.62	.48
	14. 1¼ inch cubes	.37	.15	.24
	15. ½ inch cube	.96	.08	.26
	16. ⅝ inch nut (internal iameter)	.41	.46	.39
	17. ½ inch nut (internal iameter)	.43	.62	.36
	18. ⅜ inch nut (internal iameter)	.18	.23	.23
	19. ¾ inch cylinder	.45	.54	.39
	20. 1 inch cylinder	.33	.54	.37
	21. ½ inch cylinder	.90	.15	.22
	22. 1½ inch diameter knob	.28	.31	.20
	23. 1¾ inch diameter knob	.37	.15	.20
	24. 2 inch diameter knob	.59	.31	.28
Texture	25. 5mesh	.33	.15	.15
	26. 10mesh	.35	.31	.22
	27. 3mesh	.35	.23	.17
	28. grosgrain	.28	.46	.45
	29. velvet	.41	.46	.38
	30. satin weave	.33	.54	.43
	31. felt	.43	.54	.45
	32. terry	.53	.54	.47
	33. corduroy	.41	.23	.25
	34. spine	.28	.00	.12
	35. sail cloth	.20	.20	.20
	36. plastic tape	.30	.23	.23
Configuration	37. 3A cylinder	.51	.62	.49
	38. 4A cylinder	.65	.31	.37
	39. 1A cylinder	.49	.77	.63
	40. 5B cylinder	.31	-.08	-.07
	41. 2B cylinder	.22	.08	.08
	42. 4B cylinder	.35	.23	.26
	43. 5A post	.43	.23	.04
	44. 4A post	.31	.00	.02
	45. 2A post	.14	.31	.35
	46. 4A post	.16	.38	.34
	47. 3B post	.24	.46	.38
	48. 2B post	.24	.46	.40

Table 10
Analysis of 48 items of the actual HVDT for adults with neuropsychiatric disorders [15]

	Category	Difficulty	Discrimination ability	Validity
Shape	1. cross type	.79	.50	.45
	2. circle	.74	.33	.37
	3. ellipse	.77	.50	.49
	4. trapezoid	.47	.58	.47
	5. star shape	.81	.25	.29
	6. hexagon	.81	.50	.45
	7. round floor triangle	.62	.67	.51
	8. triangle	.64	.75	.60
	9. pentagon	.47	.50	.35
	10. cone cylinder	.28	-.08	-.08
	11. hard sphere	.53	.67	.48
	12. hard ellipse	.83	.25	.33
Size	13. 1 inch cubes	.55	.58	.46
	14. 1¼ inch cubes	.53	.00	.07
	15. ½ inch cube	.87	.50	.53
	16. ⅝ inch nut (internal diameter)	.30	.50	.36
	17. ½ Inch nut (internal diameter)	.36	.42	.43
	18. ⅜ inch nut (internal diameter)	.30	.58	.35
	19. ¾ inch cylinder	.38	.83	.65
	20. 1 inch cylinder	.40	.75	.59
	21. ½ inch cylinder	.85	.50	.45
	22. 1½ inch diameter knob	.36	.33	.26
	23. 1¾ inch diameter knob	.36	.08	.21
	24. 2 inch diameter knob	.62	.75	.61
Texture	25. 5mesh	.15	.25	.25
	26. 10mesh	.30	-.25	-.21
	27. 3mesh	.34	.33	.24
	28. grosgrain	.09	.25	.42
	29. velvet	.47	.83	.60
	30. satin weave	.40	.58	.60
	31. felt	.47	.58	.49
	32. terry	.30	.58	.46
	33. corduroy	.49	.50	.38
	34. spine	.06	.08	.27
	35. sail cloth	.11	.08	10
	36. Plastic tape	.32	.08	.20
Configuration	37. 3A cylinder	.49	.67	.55
	38. 4A cylinder	.64	.83	.57
	39. 1A cylinder	.53	.83	.67
	40. 5B cylinder	.40	.25	.29
	41. 2B cylinder	.45	.17	.11
	42. 4B cylinder	.49	.50	.38
	43. 5A post	.32	.08	.11
	44. 4A post	.34	.42	.33
	45. 2A post	.23	.50	.55
	46. 4A post	.17	.33	.33
	47. 3B post	.47	.25	.27
	48. 2B post	.43	.67	.41

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