Assessment of in-hand manipulation: Tool development

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ABSTRACT

Objective: The aim of this study is to develop an assessment tool for in-hand manipulation skills (IHMS) and establish its psychometric properties. **Design:** Items are pooled based on literature and expert opinion. Content validation was performed by ten rehabilitation professionals. The test was administered to 123 typically developing, and 15 children with hand dysfunction-cerebral palsy (3), developmental coordination disorder (5), and Down syndrome (7). The latter group was given intervention, specific to upper extremity for 15 days, and test was readministered. Rasch analysis for rating scale structure, fit statistics, and dimension analysis was done. **Results:** Content validation was analyzed qualitatively. Suggestions were incorporated which consisted of instructions for scoring and test administration. The four-level ordinal rating scale was appropriate according to Rasch analysis. Of fifty items, three misfit items from translation subscale were removed based on fit statistics and clinical decision. The final test has 47 items. The tool had excellent inter-tester reliability and test stability and was responsive to change. **Conclusion:** Assessment of in-hand manipulation is a robust tool for clinical use in assessment IHMS.

Key words: Assessment, hand dysfunction, motor skills, tool development

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INTRODUCTION

Hand function is a continuum of activities that encompass gross grasp and release and a number of fine functions with the most sophisticated of these being in-hand manipulation (IHM). Exner defined IHMS as "adjustment of an object within the hand for optimal orientation after grasp" and classified the skill into translation, shift, and rotation.[1,2] Translation is described as the linear movement of an object achieved by alternating movement between fingers and palm.[3] Shift is the adjustment of an object achieved by alternating movement between finger and thumb pads. In rotation, an object is moved around one or more of its axes. All of these skills can be performed in isolation and while holding one or more objects within the palm. The latter skill is termed "with stabilization." Thus, all of the components of IHM, i.e., translation, shift, and rotation can be performed singly or with stabilization. Moreover, shift and rotation can be further classified into simple and complex.[1]

IHM skills (IHMS) are components of fine motor skills that are routinely used by children and adults during performed of activities of daily living, recreation, and work. Many authors have proposed methods to assess IHMS. These include two tests and two assessment protocol.

IHMS has been unequivocally been established as a prerequisite to academic and leisure activities. Delay

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or deficiencies in IHMS can be one of the reasons for poor academic performance and apparent clumsiness in children.[4,5,6] Many of these dysfunctions can be effectively managed with focused intervention aimed at increasing proficiency of hand use. Therefore, there is a need to have sensitive, easily available tool to assess this function.

There are two tests and three assessment protocols described in literature to assess IHMS. The two tests are IHM test – quality section (IMT-Q)[4] and test of IHM (TIHM)[7] which has been recently revised by Pont *et al*. and named as TIHM-R.[8] The assessment protocols are unnamed protocol[5,7] and the Observation Protocol on IHM and Functional Skill Development.[9] These methods differ from each other on the basis of type of task administered, scoring criteria, and the number of IHMS assessed. Difference in testing methods, scoring criteria, incomplete evaluation of IHMS and lack of psychometrics leads to inconclusive evidence on which tool to use as an outcome measurement for IHMS and a need to develop a standardized tool to assess IHMS.

Tool development can be broadly classified into tools developed according to the classical response theory and those developed according to item response theory.[10] In child development research, a combination of the two approaches is ideal. The classical response theory recognizes that a test must have content validity, test–retest stability, inter-rater reliability and be sensitive enough to pick up change with intervention also known as responsiveness, the item response theory seeks to establish robustness of the tool within itself and as related to the person. These characteristics include hierarchy of items, difficulty level of items, the function of equal separation between scores, and ability to the test discriminate between levels of functioning. These functions are undertaken by Rasch analysis.[10]

The aim of this study was to develop a tool following stringent methods of tool development. The objectives undertaken for this process are as follows:

- To develop an assessment on IHMS using a two-step Delphi process
- To evaluate content validity and test–retest, inter-rater reliability, and responsiveness of the IHMS
- To evaluate item hierarchy, item fit, item difficulty, and scoring of the IHM using Rasch modeling.

METHODS

Ethical approval was obtained from the Institutional Ethical Board, and the study was conducted in two phase: Phase I was tool development and Phase II was evaluation of responsiveness.

Phase I: Tool development

Construct

Based on literature review, the construct was identified and defined. The construct was identified as IHMS. It was defined as adjustment of an object in the hand after grasp. Exner's classification of IHMS was followed to identify the subcategories. These were finger to palm translation, palm to finger translation, shift, simple rotation, and complex rotation each with and without stabilization.[8]

Dimensionality of the construct

According to definitions found in literature, IHMS is a complex construct and can be further divided into subconstructs on the framework of types of IHMS. Hence, it was hypothesized that IHMS is a multidimensional construct and the dimensions identified were translation, shift, and rotation.

Item pool generation

Items were pooled on the basis of literature and experts opinion. The number of items for the test was decided on the basis of the table of specification for IMT-Q section.[9] A total of fifty items were pooled [Table 1]. The test constructed in an activity format, and common activities were included. This was ensured by interviewing a group of parents (10) of children between 3 and 9 years of age to assess if the items chosen were familiar to their children. Only those items that were unanimously considered familiar and easily available to the target group were retained. Instructions to administer the test were formulated.

Scale design

Type of measurement

The tool is meant to be a discriminative (performance based) tool. It was expected to help in identifying children with IHMS dysfunction when their performance was compared

Table 1: Specifications of number of items in each subscale

IHM	Total items	Without stabilization	With stabilization
Finger to palm translation	10	4	6
Palm to finger translation	11	5	6
Shift	5	3	2
Simple rotation	12	9	3
Complex rotation	12	9	3
Total	50	30	20

IHM: In-hand manipulation

with age-matched norms. The tool is also expected to identify hand skill maturation in children. The quality of skill was considered in determining the child's score.

Scaling

Based on the qualitative nature of the construct, a 4-point ordinal scale was formulated for scoring [Appendix 1].

Target population

IHMS is seen as early as 12–15 months of age, but the lower age limit of 3 years 6 months was decided for this study to ensure that the child was able to follow instructions. All components of IHMS develop by the age of 9–10 years, but speed and skill improve until 12 years of age.[8] The scoring criteria for this test were confined to quality of skill; hence, the upper age limit was kept at 9 years 6 months.

Children were recruited from local schools. Children whose parents consented to their child's participation and who assented to the study were recruited. Teachers and parents were given a questionnaire and who assess the child's preferred hand for skilled activities. The questionnaire is given below. A standard handedness questionnaire cannot be used in India as handedness is preferred for cultural reasons. Hence, even left-handed individuals are expected to use their right hand for certain activities such as eating, writing, and offering objects to another person. Hence, preferred hand was considered as the hand the child chose for fine functions.

Children were recruited based on school reports to reports to ascertain that they were typically developing children younger than six were recruited if the pediatrician's report confirmed that they were typically developing.

Validation

Content validity

The final test administered to 123 typically developing children. Children in the relevant age group of both genders, and those with ability to understand test instructions were included. Informed consent from teachers/parents and assent from the child were obtained. The test administered is described in Appendix 1.

Reliability

The recorded activities of 12 children (1 girl and 1 boy in each age group) were scored by 2 of the authors blinded to each other's scoring. The test was administered to these 12 children after a gap of 2 weeks to assess test–retest stability.

Phase II: Responsiveness

Fifteen children with hand dysfunction were recruited for this phase. Participants included children with Down syndrome, and clumsiness are reported by teachers (7), children with developmental coordination disorder (5), and children with cerebral palsy classified as Manual Ability Classification System II (3). No effort was made to ensure a homogenous population as the aim of this study was to identify the metrics of the tool and not effects of intervention on a particular group of children. Children were excluded if they had any history of upper limb surgery, severe sensory loss (auditory or visual) or were unable to understand test instructions. Informed consent was taken from parents/caregivers and assent was taken from each child and test was administered. Fifteen days of intervention was given in the form of circuit training comprising proximal strengthening, grip strengthening, proprioceptive training, and task-specific activities for hand.

Duration of each training session was 25 min the test was readministered the day after the last intervention session. Proximal strengthening exercises were included as proximal joint stability is a prerequisite for IHM.

The Figure 1 depicts the steps taken to develop the tool.

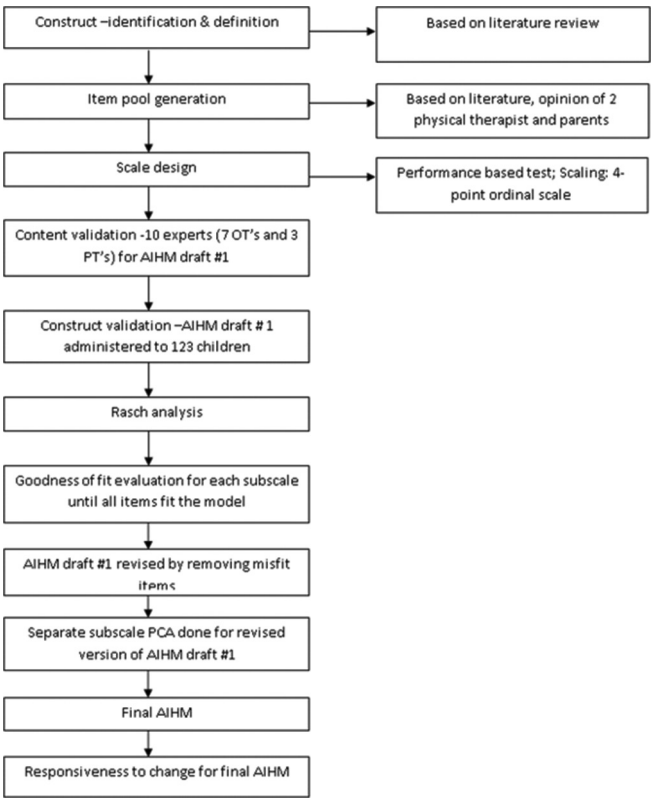

Figure 1: Steps in development of assessment of in-hand manipulation

Data analysis

Data were analyzed as follows.

Content validity was analyzed as below:

- Items which had score of 8 or above on the Likert scale given by 80% of raters were retained
- Items which were scored below 6 by 80% of raters were discarded
- Other items were discussed in a consensus meeting and were retained/modified/discarded.

Test–retest stability and inter-tester reliability were determined by intraclass correlation (ICC) coefficients.

Factor analysis was done to determine internal consistency[11] and factor loading followed by Rasch analysis partial credit scale model.[12,13]

Data were analyzed using SPSS 17 for Windows (SPSS Inc., Chicago, IL, USA) and WINSTEPS (version 3.71.0.1) for windows, Beaverton, Oregon, USA).

Step I – Rating scale analysis

The aptness of the four-level ordinal scale was analyzed according to the following guidelines:[14]

1. Each category of the scale should have minimum of ten responses
2. Average measures should increase monotonically across the scale categories
3. Outfit mean square (Mnsq) value for each category should be <2.0
4. Step calibration should increase monotonically across the scale category.

The rating scale categories are considered disordered if they did not follow the above guidelines and reorganization of the scale categories would be deemed necessary.

Step II – Goodness of fit for person and items

Fit statistics was used to evaluate the person and item fit based on observed data and Rasch assumptions. The fit statistics is reported as two Chi-square ratios: infit and outfit statistics. Mnsq and *Z* standard distribution statistics (Zstd) are given for both infit and outfit. An item was considered as underfit when Mnsq was >1.3 and Zstd is >2.0 and is overfit when Mnsq is <0.75 and Zstd is <−2.0. The above values of infit and outfit Mnsq and Zstd and clinical decision were used to remove misfit items.

Based on the initial observations from factors analysis that IHMS is a multi-dimensional construct, fit analysis was done for each subscale separately and unfit items were removed. Fit analysis was rerun until all the items fit the model.

Step III – Dimensionality

The test is considered unidimensional when the eigenvalue of the first contrast was of 3.0 (<5% of variance). An eigenvalue above 3.0 indicates that the residual contrast has strength of three items and the test may be multidimensional. Principal components analysis (PCA) was done separately for each subscale and the total scale.

RESULTS

Content validation

Five therapists completed the content validation. None of the items were considered invalid by more than 1 responder. Hence, none of the items were removed. Suggestions were incorporated which consisted solely of instructions for scoring and test administration.

Construct validity

Factor analysis revealed that the scale loaded on three factors translation, shift, and rotation. The correlation of these subscales ranged from 0.7 to 0.9 for shift. A high correlation coefficient suggested that the items have too little dissimilarity between them.

Reliability

Inter-tester reliability was acceptable at an ICC of 0.87. Test–retest stability was excellent at 0.95 for translation, 0.91 for shift with stabilization, 0.89 for simple rotation, and 0.82 for complex rotation.

Results of Rasch analysis are described as follows.

Rating scale analysis

Rasch analysis showed that the four-level ratings scale (0–3) used for the test had the ability to discriminate performance of a child across the score. The category frequency count, outfit values, average measures, and step calibration for the scoring scale are depicted in Table 2. The categories were redundant. The outfit Mnsq was <2 for all four categories. Both averages measure and step calibration increased monotonically from 0 to 3. Based on these results, the rating scale was accepted. The rating scale analysis was done separately for children with hand dysfunction as a part of the responsiveness study data. None of the categories were found redundant and it followed other assumptions of the Rasch model such as optimal number of responses in each category, hierarchical scoring, and adequate data in each category for stable estimate.[11]

Person response validity

Based on goodness-of-fit analysis, 26 (21%) children were found misfitting as more than 5% children were misfitting their data was removed. After eliminating misfitting children's data, further goodness-of-it analysis for test items was done with data of 97 (78.8%) children who demonstrated accepted fit.

Goodness-of-fit analysis for items

Fit analysis for items was done separately for each subconstruct of IHMS based on factor analysis results that IHMS is multidimensional. Tables 3, 4, and 5 depict fit statistics for all three subscales. Based on above-mentioned fit criteria and clinical decision, three items from translation subscale, i.e., translation 3, 4, and 10 were removed.

Table 2: Rating scale analysis for four-level ordinal rating scale of assessment of in-hand manipulation

Category label	Category count (%)	Average measure	Outfit Mnsq	Step calibration
0	247 (4)	−3.99	1.28	None
1	1065 (17)	−0.72	1.14	−3.96
2	1817 (30)	2.02	0.53	0.21
3	3021 (49)	7.14	0.86	3.75

Mnsq: Mean square

Table 3: Fit statistics for 24 items of rotation subscale

Item	Infit		Outfit	
	Mnsq	Zstd	Mnsq	Zstd
SR1	0.81	−1.0	0.52	−0.8
SR2	0.97	−0.1	0.80	−0.4
SR3	0.88	−0.6	0.56	−0.7
SR4	0.98	0.0	0.66	−0.5
SR5	0.93	−0.3	0.55	−0.7
SR6	1.00	0.0	0.71	−0.3
SR7	0.85	−1.0	0.64	−0.6
SR8	1.02	0.2	0.73	−0.3
SR9	0.57	−2.7	0.37	−1.3
SR10	0.67	−2.5	0.69	−1.7
SR11	1.20	1.3	1.02	0.2
SR12	1.34	2.2	1.30	1.5
CR1	1.87	4.5	1.51	1.0
CR2	0.94	−0.3	0.76	−0.4
CR3	0.70	−2.1	0.54	−1.0
CR4	1.09	0.6	0.94	0.0
CR5	1.05	0.4	0.85	−0.2
CR6	0.65	−2.4	0.53	−1.3
CR7	1.02	0.2	0.92	−0.2
CR8	1.13	0.8	1.04	0.2
CR9	1.16	1.1	1.13	0.7
CR10	1.01	0.1	0.91	−0.1
CR11	1.13	1.0	1.02	0.2
CR12	0.79	−1.4	0.60	−1.0

SR: Simple rotation, CR: Complex rotation, MnSq: Mean square, Zstd: Standardized *Z* value

Hierarchy of in-hand manipulation skills

Hierarchical order of items of three subscales on the basis of measure is depicted in Table 6. Higher values of measure indicate higher difficulty levels. The results demonstrate that the easiest items were of translation subscale and the most difficult ones were from complex rotation. Most of the items in shift subscale had higher measure as compared to simple rotation. The person-item map [Figure 2] depicts this difficulty continuum of IHMS for typically developing children.

Test dimensionality

PCA was done after eliminating three misfitting items. The PCA of translation and shift showed unidimensional nature of these subconstructs. The first residual contrast of translation subscale had an eigenvalue of 2.6 suggestive

Table 4: Fit statistics for 21 items of translation subscale

Item	Infit		Outfit	
	Mnsq	Zstd	Mnsq	Zstd
T1	0.80	−0.8	0.43	−0.6
T2	0.93	−0.2	0.78	0.0
T3*	1.60	2.1	1.66	1.7
T4*	1.61	2.6	4.20	4.1
T5	0.67	−1.5	0.61	−0.3
T6	0.63	−1.7	0.47	−0.7
T7	0.84	−0.7	0.63	−0.5
T8	0.73	−1.2	0.64	−0.4
T9	0.66	−1.6	0.44	−0.8
T10	1.37	1.4	2.40	1.6
T11	1.02	0.2	0.74	−0.1
T12	0.74	−1.0	0.55	−0.5
T13	0.87	−0.6	0.64	−0.8
T14*	1.42	1.9	2.04	1.7
T15	0.88	−0.6	0.74	−0.5
T16	0.97	0.0	1.12	0.5
T17	0.98	0.0	1.03	0.2
T18	0.73	−1.3	0.71	−0.9
T19	0.82	−0.9	0.76	−0.7
T20	0.59	−2.1	0.62	−1.3
T21	1.70	2.6	1.74	1.1

*Items removed. T: Translation, MnSq: Mean square; Zstd: Standardized *Z* value

Table 5: Fit statistics for five items of shift subscale

Item	Infit		Outfit	
	Mnsq	Zstd	Mnsq	Zstd
S1	0.98	0.0	0.81	−0.4
S2	0.77	−1.0	1.14	0.5
S3	1.52	2.2	1.77	1.2
S4	0.70	−1.7	0.49	−1.5
S5	0.86	−0.7	1.22	0.7

S: Shift, MnSq: Mean square, Zstd: Standardized *Z* value

Table 6: Hierarchical ordering and measures for the 47 items of 3 subscales of assessment of in-hand manipulation

Item	Measure	Brief description	Item	Measure	Brief description
T1	−4.08	Pick bean	SR1	−1.72	Unscrewing a jar lid
T2	−3.97	Pick coin	SR2	2.03	Rolling clay to form roll
T5	−3.26	Pick beans	SR3	−1.02	Pick marker to write
T6	−3.17	Pick coins	SR4	−2.04	Bolt and nut activity
T7	−2.90	Pick colors or pegs	SR5	−1.88	Plastic top
T8	−3.08	Pick plastic chips	SR6	−0.79	Feeling objects
T9	−3.17	Pick cubes	SR7	1.16	Manipulating marker
T10	−3.36	Clay activity	SR8	−0.72	Crayon
T11	−3.46	Replace coin back	SR9	−1.25	Peg and pegboard activity
T12	−3.46	Manipulating chip	SR10	4.50	Key and lock activity
T13	−2.46	Bean activity	SR11	1.66	Bolt and nut activity
T15	−2.38	Moving cube for stacking	SR12	4.72	Peg activity
T16	−1.32	Handling coins	CR1	1.41	Picking pen and writing activity
T17	−1.64	Putting pegs	CR2	1.78	Coin activity
T18	−1.02	Placing back plastic chips	CR3	1.60	Paper clip activity
T19	−0.87	Bean activity	CR4	1.91	Cube activity
T20	−1.56	Moving cubes stacking	CR5	1.60	Bottle lid activity
T21	−3.08	Make a ball of clay	CR6	2.27	Erasing activity
S1	0.33	Separating playing cards	CR7	3.00	Playing with pegs
S2	−0.15	Turning pages	CR8	3.00	Playing with pegs
S3	−1.88	Adjusting pen to write	CR9	4.34	Playing with pegs
S4	1.48	Pushing top of pen	CR10	8.04	Peg and pegboard
S5	0.91	Shifting key	CR11	6.27	Coin activity
			CR12	7.64	Picking and turning cubes

T: Translation, S: Shift, SR: Simple rotation, CR: Complex rotation

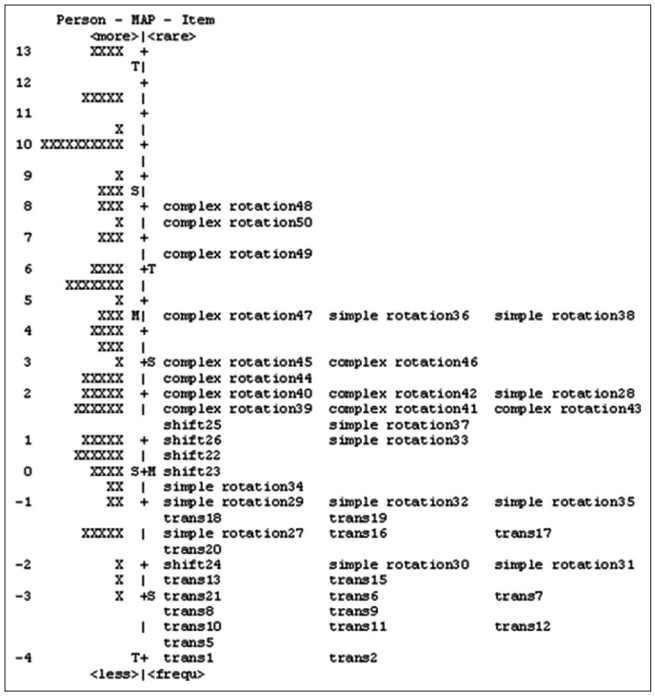

Figure 2: Person-item map for 47 items of assessment of in-hand manipulation in typically developing children

of unidimensionality. The shift subscale also demonstrates unidimensionality based on its first residual contrast which had an eigenvalue of 1.7. The rotation subscale had an eigenvalue of 3.6 indicative of a hidden construct. Rotation subscale has two components simple and complex rotation. This was considered as the reason for eigenvalue of more than 3.

When the two subscales were analyzed separately, simple rotation had an eigenvalue of 2.1 and complex rotation had an eigenvalue of 2.8 on first contrast confirming the hypothesis.

All three subscales were combined and PCA was done for complete scale of IHMS. The complete scale had an eigenvalue of 8.6 on first residual contrast.

Responsiveness to change

The person-item map as shown in Figures 3 and 4 showed that children with hand dysfunction were able to perform on difficult item postintervention as compared to preintervention. Most of them performed well on easier items of translation subscale, before intervention. On comparing rating scale analysis for pre- and post-intervention data, the frequency count increased for the highest category level and decreased for the lowest category level showing improvement in skill acquisition, thus establishing the ability of the scale to pick up change with intervention or responsiveness.

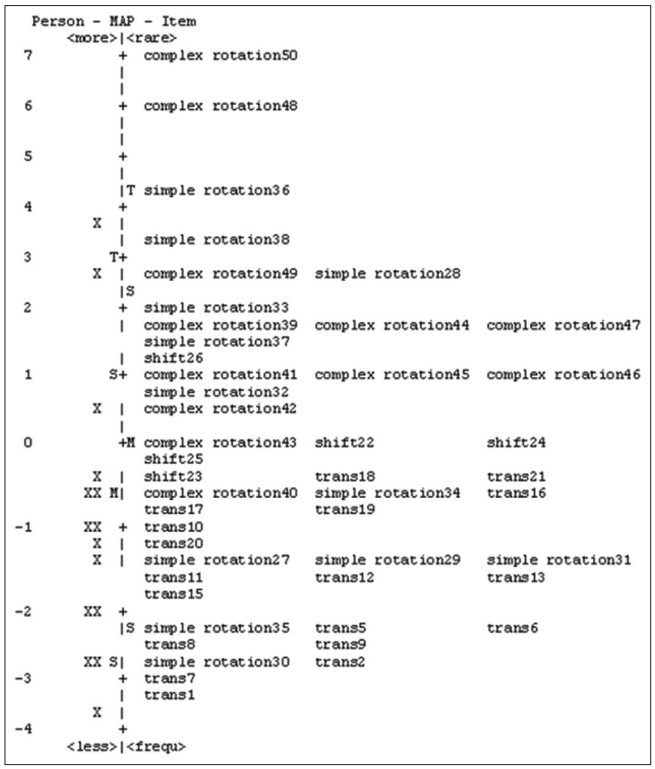

Figure 3: Preintervention person-item map for children with hand dysfunction on Assessment of in-hand manipulation

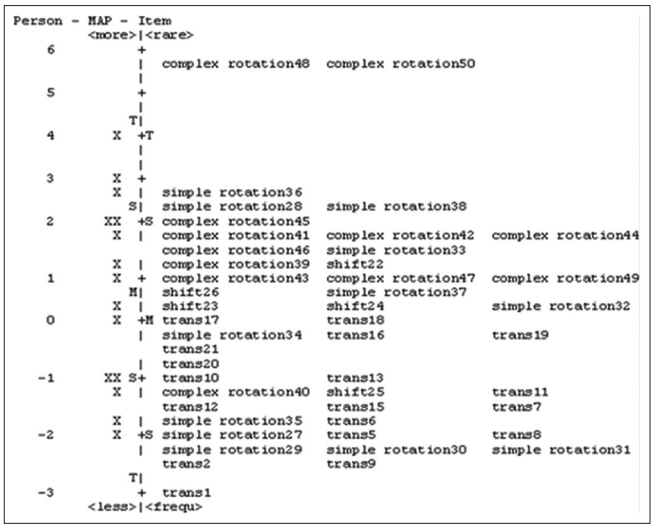

Figure 4: Postintervention person-item map for children with hand dysfunction on assessment of in-hand manipulation

DISCUSSION

The assessment of IHM (AIHM) was developed to assess IHMS for children. The number of items pooled in each subscale was based on from literature.[1] However, we ensured that the items were familiar to Indian children from all socioeconomic strata. The final comprises 47 items - 19 in translation, 5 in shift, and 24 in rotation subscale.

Three items from translation subscale, taking the lid off the jam jar, moving the lid to put on jam jar, and crumpling of the paper to make a ball of it, were removed based on clinical decision and fit statistics. The size of the lid and paper was not changed according to the size of child's hand, and hence these activities involved more proximal joint strength than IHMS. This may be one of the reasons for under-fit of these items and formed the clinical basis for removing the item. Two of the under-fit items based on manipulation clay were retained based on theoretical constructs as manipulating clay is undeniably a component of IHMS. One of the items, from shift subscale-adjusting pen so that finger and thumb, is closer to writing pad was under-fitting but it was retained as it is an important activity for children when they write. In complex rotation, one item-picking and rotating pen to write was under fitting. It was retained based on clinical decision and published literature.[9]

The hierarchy of skill difficulty observed in this study as depicted by item measure was that items in translation subscales were easiest than those in complex rotation were most difficult. Some of the items from simple rotation were easier as compared to shift items. The reason for this can be attributed to the child's familiarity to the object used in the particular activity. Hand skill development is based not only on neuromaturation but also on cultural demands and previous exposure to the object can have significant effect on skill development. In shift, the most difficult items were - pushing pen top with one hand and shifting of key to the tip of the fingers. Children may not have manipulated a lock and key previously, and pushing single handed requires more strength then manipulation. Hence, we suggested that these items may be used with clinical judgment for younger children.

Those items in simple rotation which had lower measure, as compared to shift were items involving commonly used objects such as plastic top, nut and bolt, crayons, and pegs. Ease in manipulating these objects may be due to prior experience with these objects. The number of items in shift subscale was few (5) as compared to other subscales. This was decided based on Exner's specification table.[9] However, there is a need to add more items to shift subscale before concluding that shift is more difficult than simple rotation.

Based on literature, we had initially hypothesized that IHMS is a multidimensional construct and translation, shift, and rotation are its subconstructs. Initial factor analysis conformed this hypothesis. According to PCA, translation and shift subscale met criteria, confirming the unidimensional nature of these constructs. Rotation

subscale had an eigenvalue of 3.6 suggestive of hidden construct or dimension. The PCA showed that simple and complex rotation was loaded as two contrasts. Both types of IHMS require the child to rotate the object within the hand, but in simple rotation, the object is rotated through one-fourth or one-half around its axis, where as in complex rotation the object should be rotated 180–360° around its axis. Considering this difference in the skill, and results of PCA analysis, rotation subscale was divided into simple and complex rotation and dimension analysis was repeated, conforming the hypothesis. Thus, these two types of rotation may be considered as separate constructs. Therefore, from the results of our study, the components of IHMS are translation, shift, simple rotation, and complex rotation with and without stabilization.

The four-level ordinal scale used in this study was deemed appropriate. The test has 47 test items divided into 4 subscales translation, simple shift, and complex rotation. The test items were easy and children were interested in the test. Time required to administer this test is 15–20 min, and therapists may require more time to administer the test to younger children, due to shorter attention span and emerging skills. We suggest that the test may be administered in two sessions for younger children. The test should be administered with the child positioned comfortably on a chair, feet rested on floor and elbow flexed to 90°.[15] The test items have to be handed to the child and quality of movement observed simultaneously, for accurate observation of skill, we recommend video analysis; however, analysis can be done with naked eye if an assistant is present to hand object to the child.

This study was done on children from a wide age group. This was done to allow for interpretation of the development of IHMS. As is evident from the item difficulty map, the continuum of skill development is in the order of translation, simple shift, simple rotation, complex shift, and finally complex rotation. Translation is completed by the age of 6 years and complex rotation is still developing at the upper age limit of the children included in this study. Thus, this study gives a map of the development of IHMS in childhood.

Strength

The current study has attempted to develop a tool to comprehensively evaluate IHMS in children taking into consideration the limitations of existing tools. This tool has a wider applicability in terms of skills and age compared to TIHM and TIHM-R. The current tool by describing the items and methodology of testing makes the assessment of IHMS easily available to the clinician. IMT-Q the other comprehensive tool available does not list the test items in sufficient details for reproduction. The clarity of test items, scoring, the research rigor, and analysis using both classical response and item response construct are the main strength of this study. AIHM can be used as an outcome measure in children with dysfunction including children with developmental coordination disorder, cerebral palsy, attention deficit disorder, children with sensory processing dysfunctions, and in children who have difficulty with hand skills not attributable to a medical reason. The AIHM is sensitive enough to show effect of intervention and hence can be used as an outcome measure to gauge the effectiveness of treatment protocol.

Limitation and future research

The time taken to complete the item is an important aspect of skill maturation. However, we did not consider this in our scoring criteria. Hand size of the child should be considered when designing a test for fine as size of object may affect the quality of skill. Future research is warranted on improving the quality of this test considering the hand size and speed of skill. Future research on children with fine motor dysfunction and developing age appropriate norms for IHMS are also future goals.

CONCLUSION

The AIHM is a robust tool to assess IHMS in children.

This tool can be used to identify and plan remediation of dysfunctions of hand skills related to writing, craft, life skills, and play activities. The specific subset of IHMS can be identified as the scale is divided into four constructs. This test can be easily administered by teachers, therapists, and other child-care experts.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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Appendix 1

Assessment of in-hand manipulation

Scoring scaling: a 4-point ordinal scale was formulated for scoring. The scale ranges from 0 to 3.

0: No manipulation within the hand is noticeable. The hand is used only for grasp

1: Initiation of manipulation is noticeable, but in-hand manipulation is incomplete. The child may prematurely release the object

2: Definite in-hand manipulation occurs. However, there is use of proximal finger parts/execution is slow and clumsy.

3: The child manipulates the object within the hand smoothly, quickly and completely and uses the distal finger pads predominantly.

Activity 1: Material required: Pen, pencil, paper, and marker

1. Ask child to push the pen cap with single hand and write his name
2. Place pencil on table such that the writing end is toward the little finger and ask to write his name and then turn the pencil to erase it
3. Place pencil on table such that writing end is toward the thumb and ask them to draw something. Give them a marker to fill color and then ask them to turn the marker to put the cap back.

Serial number	Type of in-hand manipulation	Skill	Score	Drops	Substitution pattern
1	Shift (with stabilization)	Holding pen and pushing top of pen with same hand			
2	Shift (without stabilization)	Adjusting pen so that finger and thumb is closer to writing pad			
3	Simple rotation (without stabilization)	Pencil is placed horizontally on table with writing, end on ulnar side of child's hand and child picks up and rotates pencil for writing			
4	Simple rotation (without stabilization)	Rotating a marker to put top on after			
5	Complex rotation (without stabilization)	Pencil is placed horizontally on table with writing end on radial side of child's hand, child picks up and rotates marker for writing			
6	Complex rotation (without stabilization)	Turning a pencil over to use the eraser			

Activity 2: Materials required - coins, cubes, beans and jar

(A) Cubes:

Place four cubes on table. Ask the child to pick up one cube, hold it in his palm and then place it on the table. Then ask him to take the rest of the cubes from table (one by one) and hold them in his palm. Then ask the child to stack these cubes on the first one.

Serial number	Type of in-hand manipulation	Skill	Score	Drops	Substitution pattern
7	Finger to palm translation (with stabilization)	Picking up cubes of approx. 1"/2" in size one by one in same hand while holding 1 cube in-hand			
8	Palm to finger translation (without stabilization)	Child moves one cube (each side=1 inch), from palm to finger tips for stacking			
9	Palm to finger translation (with stabilization)	Child has two cubes of approximately 1 inch in one hand, he or she moves one from palm to finger for stacking			
10	Complex rotation (without stabilization)	Picking up, placing cubes of approximately 1"or 2" turning over cubes			
11	Complex rotation (with stabilization)	Picking up, turning over and placing cube of 1" or 2" size while holding 2-3 cubes in same hand			

(B) Playing with coins:

1. Ask child to pick and hide one coin in his hand and then replace it back on table
2. Ask child to pick 3-4 coins one by one and hold them in his fist, later place them in line on table
3. Ask child to turn one coin of the lined on table. Later ask child to hold 2-3 coins in-hand and then turn the other coins lined on table.

Serial number	Type of in-hand manipulation	Activity	Score	Drops	Substitution pattern
12	Finger to palm translation (without stabilization)	Child picks up a Re. 1 coin and hides it in the same hand			
13	Finger to palm translation (with stabilization)	Child has two 1 Re. coin in-hand he or she picks up third coin and hides it in the same hand			
14	Palm to finger translation (without stabilization)	Moving Re. 1 coin out from palm to finger to replace it back			
15	Palm to finger translation (with stabilization)	Handling coins of different size to put in purse or piggy bank			
16	Complex rotation (without stabilization)	Picking up and placing a coin upside down			
17	Complex rotation (with stabilization)	Placing a coin upside down while holding 2-3 coins in-hand			

(C) Small jar filled of beans:

1. Ask child to open the jar, place lid on table and pick 1 bean and hold it in his palm
2. Place 4-5 beans on table and ask child to pick them one by one and hold them in his fist
3. Ask the child to replace beans in container one by one and then close the jar lid.

(D) Dice and chips (chutes and ladders)

Play with dice and chips (chutes and ladders). As the child to take four chips (one by one) and hold them in fist. Keep them at starting point of game (one by one).

Serial number	Type of in-hand manipulation	Skill	Score	Drops	Substitution pattern
18	Simple rotation (without stabilization)	Unscrewing a jar lid			
19	Complex rotation (without stabilization)	Turning over the jar lid before placing			
20	Finger to palm translation (without stabilization)	Picking up a bean and holding it in palm			
21	Finger to palm translation (with stabilization)	Picking more than one bean from table and holding it in palm			
22	Palm to finger translation (without stabilization)	Moving beans from palm to fingers to put back in container			
23	Palm to finger translation (with stabilization)	To take one bean from palm to finger while holding many beans in same hand			
24	Finger to palm translation (with stabilization)	Picking up plastic chips ½" in diameter and placing them in same hand			
25	Palm to finger translation (without stabilization)	Moving chip ½" in diameter, from palm to fingers, for putting it back in container			
26	Palm to finger translation (with stabilization)	Placing back plastic chips (same size) in container by translating from palm to finger while holding several plastic chips			

Activity 3: Materials required - Clay

Take a piece of clay in-hand move it to finger tips and make - (a) a ball out of it; (b) cylinder out of it (do not use table).

Serial number	Type of in-hand manipulation	Skill	Score	Drops	Substitution pattern
27	Finger to palm translation (without stabilization)	To pick up a piece of clay that is approximately 0.25 inch thick and 1 inch in diameter and hold in fist			
28	Finger to palm translation (with stabilization)	A piece of clay that is approximately 0.25 inch thick and 1 inch in diameter and hold in fist while holding little clay in-hand			
29	Simple rotation (without stabilization)	Rolling small ball of clay approximately 1 inch in diameter, back and forth to form an elongated shape			

Activity 4: Materials required: Pegs shaped like man and pegboard

1. Ask child to hold one or two pegs in-hand and then pick other pegs and place them in the pegboard
2. Place pegs horizontal on table. First ask child to pick one peg and place in pegboard. Ask the child to hold two pegs in-hand and then pick the third one to place in pegboard.

Serial number	Type of in-hand manipulation	Skill	Score	Drops	Substitution pattern
30	Finger to palm translation (with stabilization)	Picking up pegs of approximately 1 inch or 2 inch in length, one at a time, to hold more than two in same hand			
31	Palm to finger translation (with stabilization)	Putting pegs that are approximately 1 inch or 2 inch in length on table while holding more than two pegs in same hand (or use wax colors)			
32	Simple rotation (without stabilization)	Picking up a small peg approximately 1 inch or 2 inch, from a surface, and rotating it from a horizontal to a vertical position, for placement into a pegboard			
33	Simple rotation (with stabilization)	Picking up a small peg from a surface, and rotating it from a horizontal to a vertical position for placement into a pegboard, while holding two small pegs in same hand			

(A) Turning of pegs

1. Ask them to make the man stand on his head
2. To make man stand back on his feet's
3. Make man do somersaults
4. Keep two pegs in-hand (with face toward little finger and then as the child to rotate and keep them in pegboard so that they stand on feet.

Serial number	Type of in-hand manipulation	Skill	Score	Drops	Substitution pattern
34	Complex rotation (without stabilization)	To turn a peg approximately 1 inch or 2 inch in length, saying "the man no more wants to stand on his head"			
35		To turn a peg approximately 1 inch or 2 inch in length, saying "the man no more wants to stand on his head"			
36		To pick up a peg (same size as above) and turn it over and over in radial fingers, while indicating "the man wanted to do somersaults"			
37	Complex rotation (with stabilization)	Two 1 inch or 2 inch sized pegs shaped as person are placed in child's hand, with head at ulnar side of child's palm, after child moves one peg to finger surface, he or she rotates peg for placement in pegboard			

Activity 5: Material required: Keys and lock

Place key ring with three keys in-hand and ask child to shift one of them to place in lock and then open lock.

Serial number	Type of in-hand manipulation	Skill	Score	Drops	Substitution pattern
38	Shift (with stabilization)	Holding key ring with keys in-hand, shifting one for placement			
39	Simple rotation (with stabilization)	Child has two keys in palm of one hand (with holding end aligned with radial fingers), and he/she moves one from palm to finger surface, and then rotates the key for placement in lock			

Activity 6-13: Material required: Playing cards, story book, plastic top, nut and bolt, paper, color, and paper clip. For feeling objects and shapes familiar objects such as cube, bean, coin, or chip can be given.

Serial number	Type of in-hand manipulation	Skill	Score	Drops	Substitution pattern
40	Shift (without stabilization)	Separating playing cards			
41		Turning pages in a story book			
42	Simple rotation (without stabilization)	Spinning plastic top			
43		Feeling objects and shapes to identify them			
44		Putting on or removing bolts from nuts of approximately 2.2 cm in diameter			
45	Simple rotation (with stabilization)	Putting/removing bolts from nuts, while holding 2-3 bolts in same hand			
46	Complex rotation (without stabilization)	Turning a paper clip, so that the opposite end can be used for placement on a piece of paper			
47	Simple rotation (without stabilization)	Removing crayon from box and preparing for coloring			