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Evidence of validity in a new method for measurement of dexterity in children and adolescents

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Abstract

Aim: Many everyday activities involve manipulation of objects with the fingertips. Thus, accurate assessment of a person's ability to co-ordinate fingertip forces is important. We evaluated a recently developed assessment tool (the Strength-Dexterity Test, SD-test), which is based on manipulation of unstable objects, for a paediatric population.

Methods: A **Rasch model** was used to examine the validity and reliability of the SD-test in a sample of 56 typically developing children/adolescents **(30 boys; age 4.9 to 17.3 years, mean 9.7, SD 3.7 years)**. In addition, we examined how performance on this test relates to widely used tests for assessment of gross manual dexterity (assessed with the **Box and Blocks Test)** and finger strength **measured with a pinch meter.**

Results: The constructs measured with the 78 item SD-test include dexterity and strength, and form a unique single latent trait, named fingertip force co-ordination, that improves with age. The SD-test has internal scale validity when applied to a typical paediatric population. **Positive correlations (significant at p<0.001) were found between all three tests.**

Interpretation: We provide preliminary evidence of construct validity in the SD-test. **Our findings suggest that this test has the potential to be developed into a promising tool for assessment of dexterity in children.**

Short title: Dexterity measurement in children

What this paper adds:

- This study provides preliminary evidence in a paediatric sample for construct validity for a new test that measures fingertip force co-ordination when manipulating unstable objects.
- **The study indicates that the Strength-Dexterity Test is a promising tool for assessment of dexterity in children.**

Most everyday activities require the manipulation of objects with the fingertips, an ability that is often referred to as dexterity. Various factors influence performance in manipulative tasks, such as independence of finger movements, speed, strength, and eye-hand co-ordination (for review see [1]). In addition, precise control of the fingertip forces employed to the object is critical to object manipulation. [2, 3]

Impaired fine motor skills are common in neurodevelopmental disorders. Therefore, accurate assessment of a person's ability to control the fingertip forces would be clinically useful for planning and evaluation of treatment. Currently, there are no such tests available. For example, the Box and Blocks test [4] and tests that involve moving pegs (e.g. Nine Hole Peg Test) reflect multiple aspects of motor control such as pre-shaping the hand, grasping, moving and releasing the object, moving the arm and/or hand. In the "precision grip – lift task", developed by Johansson and co-workers (see [5] for review), the fingertip forces employed to the contact surfaces are measured. However, in this paradigm, the object is *stable* and subjects use an automatised grip-lift synergy that provides grasp stability by a strong temporal coupling of grip and lift forces.[6]

Recently, a new method (Strength-Dexterity-test, SD-test[7]) to assess a person´s ability to control the direction of the fingertip force vectors in the manipulation of *unstable* objects has been developed. This ability to precisely control the direction and strength of fingertip forces is crucial for many every-day activities, e.g. getting dressed or eating. The SD-test task consists of compressing a spring (see Figure 1) without buckling, which requires control of the direction and strength of finger tip forces, based on sensory-motor feedback. This test has been has been used in adults[7] and has also been assessed for repeatability. [7] The motivation for studying a paediatric population originates from the need to develop tools that are sensitive to small but nevertheless relevant changes in dexterity in typical and atypical development.

We aimed first, to analyse the internal scale validity of the SD-test in a typical paediatric population by employing a Rasch measurement model. Second, we wanted to investigate how the SD-test relates to tests for pinch strength and manual dexterity. Third, we examined how performance varies with age and whether there are any sex differences.

Method

Participants

We examined a sample of 56 typically developing children aged 4.9 to 17.3 years **(mean 9.7, SD 3.7 years; 30 boys)**; 2 of the 56 participants were left-handed. The participants were recruited from local nurseries and schools and had no history of neurological or neurodevelopmental problems. Testing was performed either at home, at school, or at the nursery.

Ethics

Ethics approval was granted by the Regional Ethics Committee of Stockholm, Sweden. Written informed consent was obtained from the parents of the participants below 16 years of age, with assent from the children themselves. For those over age 16 years written consent was obtained from the participants only.

Methods

First, the Box and Blocks Test of Manual Dexterity[4] was presented. Then maximal strength for "opposition pinch" (**using both the index and middle fingers)** was measured (Model PG-60 pinch gauge, B&L engineering, Tustin, CA). Next, the SD-test was presented. This test consists of compressing a variety of springs **(with three-fingered pinch using both the index and the middle fingers, see Figure 1)** to their solid length **(i.e. the coils touching)** without buckling. The springs are characterised by two indices: the strength index (specifies the force required to compress the spring, indicated by spring specification labelled 1-13) and the dexterity index (specifies the degree of mechanical instability, i.e. the tendency of the spring to buckle, indicated by spring specification labelled A-H). Both indices are a function of the geometry of the spring and the physical properties of the material used, and are adjusted independently for the different springs. The original SD-test kit consists of 82 compression springs. In our study, only subsets of springs with strength requirements below and slightly exceeding the participant's maximal pinch force were used. **Therefore, the number of springs presented varied between participants, with a mean of 73 springs (range 53-82 springs).** Springs were presented in random order and the participants were asked to compress each spring with the dominant hand. A binary score was used to record a success (at least one of the three allowed trials per spring results in complete compression, score 1) or failure (none of the three allowed trials per spring results in complete compression, score 0). **Only compression of a spring to its solid length** was scored as success. The correct finger posture required a slight flexion at all joints to prevent hyperextension, while the 4^{th} and 5^{th} digits were curled out of the way (Figure 1). Instructions and demonstration of the correct finger posture were given, and the participants were allowed sufficient time to familiarise themselves with the task. The participants were reminded to keep elbow and forearm in a stable position on the table, **and to maintain opposition pinch.** Breaks were provided to prevent fatigue and maintain concentration. On average, the test procedure for each participant lasted approximately 15 minutes.

Statistics

We applied a Rasch model analysis for dichotomous data (using WINSTEPS 3.65.0 software; copyright 1999-2006, John M Linacre 2008, www.winsteps.com) to examine whether the test items (i.e. the different springs) measure one single latent trait, which we named co-ordination of fingertip forces. An analysis was performed on the full set of raw data to examine internal scale validity and reliability of the SD-test. The aims were to evaluate whether the items (i) define a uni-dimensional construct, (ii) were appropriately spread along the continuum of increasing difficulty, (iii) were appropriately targeted to the sample of typically developing children and adolescents, (iv) are sensitive to detect differences among person ability measures.

Reliability was evaluated in terms of whether the items could separate persons into distinct levels of ability; the separation ratio was transformed into a strata index describing the number of significantly different levels of measures.[8] Dimensionality was further examined by a Principal Components Analysis (PCA) of the standardised residuals. Regression analyses were then used to investigate whether the SD-test shared variance with pinch strength and performance on the Box and Blocks test, and to characterise developmental curves of performance on the three tests. Finally, sex differences in performance were analysed using one-way **Analysis of Variance (ANOVA) for both the whole data set and as a function of age. Levene's test of homogeneity of variances was used to test whether the two sex groups where homoscedatic. For the SD-test this was not the case, thus sex differences were also investigated using the non-parametric Mann-Whitney U test. An alpha of 0.05 was used throughout as threshold for statistical significance; for all analysis two tailed tests were used.**

Rasch analysis

A central assumption of the Rasch model is that the probability of a particular participant passing a particular test item is determined by two parameters: the ability level of the participant and the difficulty level of the item.[9] Both parameters are measures on the same interval scale, which represents the latent trait a test is assumed to measure.

In a Rasch analysis raw scores are transformed into interval measures by a log odds transformation of the probability of a correct response, using the unit logits for calibrating items and measuring persons. Test items are then listed in an ordered way and participants are ordered according to their abilities **with respect to the measured trait**. A higher measure indicates a more difficult item or better ability respectively. The difficulty of each item is shown by the item calibrations; the higher the measure, the more difficult the item. Goodness-of-fit statistics are used to evaluate the degree of fit between the actual patterns of responses and the Rasch assumptions. Acceptable goodness-of-fit statistics for the participants give evidence of person response validity, and goodness-of-fit statistics for the items give evidence whether the items meet the requirements of uni-dimensionality. Infit statistics indicate unexpected scores close to the estimated item's difficulty or the participant's ability. Outfit statistics give information on unexpected responses far from those expected (i.e. are sensitive to outliers). Mean square values are a ratio of the observed and the predicted residual variance and have an expected value of 1, with a higher value indicating that the observed scores have greater variation than predicted, and a lower value indicating that observed scores have less variation than expected. A test is by convention considered to have acceptable uni-dimensionality when at least 95% of the items fit the Rasch measurement model. [9,10] For this study, the infit mean square residual value ≤1.4 with an associated Z-value of ≤2.0 was used for acceptable goodness-of-fit.[10,11] In an additional Principal Components Analysis (PCA) on the Rasch residuals, we used Linacre's guidelines for PCA supporting good unidimensionality if the measures explain >60% of the variance and the 1st contrast no more than 5% **(**WINSTEPS manual, John M Linacre 2008, www.winsteps.com**).**

Reliability can be inferred from the standard error (SE) of the estimated calibrations given for each measure of items and subjects. The person separation index defines the statistically distinct number of ability strata for the scale and indicates the precision of the measure and its sensitivity to detect differences among person ability measures. A separation value should be greater than two in order to separate difficulty levels of items or ability levels of persons. Discernible Strata are calculated with the formula (4G+1)/3, where G is the separation ratio scale index obtained in the Rasch analysis, comparing the "true" spread of the measures with their measurement error.[8]

Results

Rasch analysis

A Rasch analysis was performed on the full set of raw data obtained from the original 82 spring set. Subsequently, four items that were not mastered by any of the participants were removed. A second Rasch analysis was then performed on the remaining set of 78 items (Table 1). Twenty items (see bottom of Table 1) were shown to have no calibration value, i.e., these items were manageable for every participant and thus did not contribute to the ability measures of a participant. These items were nevertheless kept in the set because the intended future target group for the SD-test includes people with impaired hand function for whom these easier items may be relevant. Table 1 shows the item calibration values and goodness-of-fit statistics for the 78-item SD test performed on the data obtained from the 56 typical children. The item calibration ranged from -7.64 to 8.56 logits (with a mean value as default set to 0). All items except two (<3%) showed good fit to the Rasch Model at the individual item level, which indicates a valid uni-dimensional scale. The items were well distributed along the full calibration range and were appropriately targeted for the sample, with exception of the 20 items at the lower end of the scale. The persons' ability measures range was -5.15 to 8.16 logit (mean 0.31). The SE for persons ranged from 0.50 to 0.66 for measures lower than 5.39 logit and increased up to a maximum of 0.84 for higher measures. All participants except two (3.5%) showed accurate fit to the model assertions. Dimensionality was further supported by the Principal Component Analysis, which showed that the variance explained by measures was 71%, and that the unexplained variance explained by the first contrast was 3.6%. The separation value 5.02 and the reliability 0.96 indicate that the distribution of persons could be separated into statistically distinct strata, which in our case produced seven strata.

Correlational structure of the SD-test and other measures

Pinch strength measured with the pinch meter ranged from 17.8 to 129.0 (mean 48.3, SD 19.9) Newtons. Box and Blocks test scores for 55 participants (one boy did not complete this test) ranged from 32 to 76 (mean 52.2, SD 10.6). Correlations between the tests are summarised in Table 2, Figures 3a and 3b. Positive correlations were found between all tests. Of particular interest was whether performance on the Box and Blocks test (Figure 3a) and pinch strength (Figure 3b) accounted for independent variance in the SD-test. Thus, a regression analysis of SD-test scores on pinch strength and scores from the Box and Blocks test was performed. **The multiple R^2 was 0.72, with significant relations with both pinch strength ($t(52)=5.63$;**

p<0.0001; beta 0.51 ± 0.09 (SE)) and the Box and Blocks test (t(52)=4.78; p<0.0001; beta 0.44 ± 0.09 (SE)). Unique contributions (i.e. squared semi partial correlation coefficients) of pinch strength and the Box and Blocks test to SD-test variance were 16.9% and 12.1%, respectively. Shared pinch strength and Box and Blocks test variance accounted for the largest fraction, 43.2%, of SD-test variance. These relations are illustrated in a Venn diagram (Figure 4).

SD-test performance as function of age
Performance on all tests increased with age (Table 2). SD-test measures versus age are shown in Figure 5. We were particularly interested in whether SD-test scores improved when controlling for pinch strength. A regression of SD-test on age and pinch strength was therefore performed. The multiple R^2 of this correlation was 0.80, with significant relations with both pinch strength (t(53)=3.99; p<0.0002) and age (t(53)=7.26; p<0.0001). Improvement in performance with age was thus also seen in the non-pinch strength related variance of the SD-test, which presumably reflects dexterity. A second regression model was tested in which SD-test scores were regressed simultaneously on age, pinch strength and Box and Blocks test scores. Significant relationships with age (t(51)=4.63; p<0.0001) and pinch strength (t(51)=3.81; p<0.0003) remained, whereas the relationship with the Box and Block test (t(51)=1.35; p=0.183) was non-significant.

Sex differences
Overall effects of sex on SD-test performance were investigated using one-way ANOVA. No significant sex differences in mean scores were found on the SD-test (F(1, 54)=0.91; p=0.343; see Figure 5), the Box and Blocks test (F(1, 53)=0.022; p=0.881), or pinch strength (F(1, 54)=0.78; p=0.382). **Levene's test for homogeneity of variances showed homogeneous variances in males and females for Box and Blocks (F(1, 54) = 1.95; p = 0.168) and pinch strength (F(1, 54) = 2.62; p = 0.111) whereas the variances for the SD test were not homogeneous in the two sex groups (F(1, 54) = 4.96; p = 0.030). However, a Mann-Whitney U test did not reveal a sex difference for the SD test (U = 346; p = 0.470).** To investigate whether there were sex differences in developmental curves on the SD-test, a general linear model with SD-test as dependent variable, sex as categorical predictor, and age as continuous predictor was utilised. This revealed a significant effect of age (F(1, 52)=166.4; p<0.0001) and sex (F(1,52 =5.67; p=0.021) and a significant sex × age interaction (F(1, 52)=9.64; p=0.003), i.e. the increase in SD-test performance with age showed a steeper slope in male children. The corresponding model for pinch strength revealed a significant age effect (F(1, 52)=48.5; p<0.0001) but no effects of sex (F(1, 52)=0.35; p=0.557) or sex × age interaction (F(1, 52)=0.97; p=0.330). Similarly, for the Box and Blocks test, there was a strong effect of age (F(1, 52)=80.0; p<0.0001), but only weak evidence for an effect of sex (F(1, 52)=2.9; p=0.092) or sex × age interaction (F(1, 52)=3.4; p=0.070).

Discussion
We have, in a paediatric population, explored a new method for assessment of dexterity based on manipulation of *unstable* objects. The Rasch analysis confirmed the internal scale validity that the SD-test measures one single latent trait named

fingertip force co-ordination. The SD-test was able to separate the participants into different levels of ability, which indicates its potential to be a useful tool for descriptive as well as evaluative purposes. Test items were appropriately spread along the continuum of increasing difficulty and were shown to adequately challenge a sample of typically developing children and adolescents. **In addition to examining a sample of typically developing children, we explored a small sample of children with CP, in whom varying degrees of hand impairment were seen (data not presented). This exploratory analysis showed that the children with CP were widely distributed on the person ability scale, which indicates that the SD-test is sensitive to hand motor impairment and suggests that it has the potential to be developed to a clinically useful tool for assessing dexterity in children with atypical development. However, this needs to be further investigated in a much larger sample of children with hand motor impairment.**

Large positive correlations were found between performances on pinch strength, the Box and Blocks Test, and the SD-test. Since it is well established that both speed of performance (e.g. [4, 12,13]) and grip strength (e.g. [14, 15, 16]) improve with age, this was not surprising considering the large age range of our sample. **Further work that includes administering the SD-test in the context of larger test batteries and in more homogeneous samples regarding age would be required to determine the factor structure of the SD-test in more detail.** Nevertheless, our results provide preliminary evidence that there is a unique and uni-dimensional latent trait measured in the SD-test. A small proportion of this non-strength related variance was shared with the Box and Block test, whereas the rest (see Figure 4) was unique to the SD-test and is likely to reflect individual differences in dynamic control of fingertip force vectors. Figure 4 also illustrates that each of the three tools we used assesses a distinctly different feature of hand function beyond the commonalities they share. **One should note, however, that since performance on all tests were positively correlated, estimates of the relative importance of the Box and Block test and the pinch strength as predictors of SD test may have low reliability**

No significant overall effect of sex on performance in either of the tests was found. This could be a consequence of limited power with the current sample size. However, across the investigated age range, for all three tests, a steeper slope was seen in boys. Surprisingly, we found a significant sex × age interaction for the SD-test but not for pinch strength. This might indicate that sex differences in dexterity develop with age.

Functional magnetic resonance imaging (fMRI) studies on manipulation of *stable* objects have shown that the precision grip is controlled by a bilateral fronto-parietal-cerebellar network.[17] Within this network, activity in several areas is modulated by the magnitude of the forces produced, indicating that these areas are involved in the control of the precise fingertip force level.[18, 19] In manipulation of *stable* objects, stability (i.e. coordination between the grip force and the lift force) is provided by an automatised grip-lift synergy[6], whereas in manipulation of *unstable* objects the direction of the fingertip force vectors (which are probably controlled by circuits receiving constant somato-sensory and visual feedback) becomes critical. Little is known about the neural correlates underlying the precise control of the fingertip forces in manipulation of *unstable* objects. Milner et al [20,21], using fMRI, have explored neural mechanisms of the manipulation of objects with simple and objects with complex dynamics, and found evidence for strong activation in the ipsilateral cerebellum and selective activation of areas including the contralateral secondary somato-sensory cortex and the ipsilateral inferior parietal lobule when objects with complex dynamics were manipulated. Recent fMRI studies using paradigms that include items from the SD-test, indicate that there are areas in the basal ganglia and within the bilateral frontal-parietal-cerebellar network that modulate their activity when visual and friction conditions are altered, or the dexterity demand is increased ([22] and own unpublished data). We propose that the SD-test also has the potential to become a tool for systematic investigation of neural correlates of dexterity in both typical and atypical populations.

Conclusions

Our study confirms aspects of validity and reliability of a new method that assesses dexterity in a population of typically developing children. **We suggest that the SD-test, after further development, will be a useful tool for the assessment of dexterity in children and for investigation of neural correlates of dexterity.**

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Table 1. Strength-Dexterity test, measurement report and fit indices for 78 items; data from the 56 typical participants are included in this Rasch analysis. Items are ordered by decreasing difficulty.

Measure	*SE*	*Infit*		*Outfit*		*Item*
		MnSq	*Z-value*	*MnSq*	*Z-value*	*hierarchy*
8.56	1.23	2.00	1.4	9.90	9.9	H6
6.80	1.22	0.21	-1.2	0.07	-0.8	B13
6.80	1.22	0.21	-1.2	0.07	-0.8	C13
6.80	1.22	0.21	-1.2	0.07	-0.8	D13
6.42	0.87	1.82	1.3	9.90	6.5	H2
6.35	1.40	0.10	-1.0	0.05	-0.9	F13
5.75	0.76	1.00	0.2	0.32	2.7	H4
5.62	0.99	1.27	0.6	8.48	2.7	B12
5.62	0.99	0.32	-1.0	0.10	-0.7	C12
5.49	1.03	1.14	0.4	0.60	0.1	E13
4.80	0.82	0.56	-0.7	0.26	-0.6	F12
4.77	0.64	0.51	-1.3	0.18	-0.5	E11
4.39	0.59	0.75	-0.6	0.59	0.1	C11
4.39	0.59	0.91	-0.1	0.47	-0.1	F11
4.07	0.56	2.57	3.3	5.98	2.5	H3
4.07	0.56	0.77	-0.6	0.46	-0.1	F10
3.76	0.53	0.89	-0.3	0.42	-0.3	D11
3.49	0.51	0.71	-1.0	0.34	-0.5	B11
3.38	0.60	1.12	0.5	1.00	0.4	D12
3.04	0.57	0.73	-1.1	0.58	0.1	E12
1.90	0.45	0.79	-0.9	1.14	0.4	G10
1.26	0.43	1.38	1.5	1.72	1.0	G9
1.26	0.43	0.62	-1.7	0.37	-1.0	B10
1.26	0.43	0.71	-1.2	0.40	-0.9	D10
1.01	0.44	0.75	-1.0	0.44	-0.8	E10
0.73	0.42	0.68	-1.3	0. 35	-0.9	G6
0.71	0.42	0.39	-3.1	0.23	-1.5	C10
0.56	0.42	1.46	1.7	1.70	1.0	H1
0.55	0.42	0.75	-1.0	0.70	-0.2	B9
-0.13	0.41	0.49	-2.7	0.27	-1.2	D9
-0.60	0.40	1.04	0.2	0.70	-0.2	G8
-0.78	0.40	0.87	-0.6	0.56	-0.5	E9
-0.78	0.40	0.87	-0.6	0.60	-0.4	F9
-1.69	0.40	1.07	0.4	0.60	-0.4	G7
-1.70	0.40	0.72	-1.6	0.52	-0.5	D8
-1.75	0.41	1.26	1.3	2.14	1.4	C9
-2.73	0.44	0.86	-0.6	0.58	-0.2	E8
-2.73	0.44	0.85	-0.6	0.39	-0.5	F7
-3.14	0.46	0.82	-0.7	0.34	-0.5	B8
-3.36	0.48	0.87	-0.4	0.36	-0.4	A8
-3.36	0.48	0.81	-0.6	0.74	0.1	C8
-3.36	0.48	1.21	0.8	1.60	0.8	G5
-3.88	0.53	1.74	2.0	9.90	3.8	F8
-4.18	0.57	0.88	-0.2	0.31	-0.6	A7
-4.53	0.62	0.72	-0.7	0.58	-0.1	B6
-4.96	0.68	0.50	-1.2	0.10	-1.3	D6
-4.96	0.68	1.09	0.3	0.31	-0.6	F1
-4.96	0.68	1.72	1.5	9.90	6.9	G1
-5.50	0.80	0.76	-0.3	0.12	-1.1	C7
-5.50	0.80	1.08	0.3	0.79	0.1	D7
-5.50	0.80	0.76	-0.3	0.12	-1.1	E7
-5.50	0.80	1.08	0.3	0.79	0.1	F6
-6.34	1.07	0.85	0.1	0.09	-1.0	B7
-6.34	1.07	0.75	0.0	0.07	-1.1	C5
-6.34	1.07	1.05	0.3	0.17	-0.8	C6
-6.34	1.07	0.85	0.1	0.09	-1.0	E6
-6.34	1.07	1.23	0.5	0.73	0.1	F2
-6.34	1.07	0.85	0.1	0.09	-1.0	F5

-7.64	1.86	MINIMUM	ESTIMATED	MEASURE	for items;	A6, B4, B5, C3, C4, D1, D2, D3, D4, D5, E1, E2, E3, E4, E5. F3. F4. G2. G3. G4.

SE=standard error, MnSq=mean square

Table 2. Zero-order correlations (Pearson r) between test results and age. All correlations were significant at $p < 0.001$. The correlations are based on all 56 typical subjects, except for the Box and Blocks test, which was completed by 55 subjects. **Confidence intervals (95%) for the *r* values are given in parenthesis.**

	Pinch Strength	**Box and Blocks Test**	**Strength-Dexterity Test**
Age	**0.70 (0.53 - 0.81)**	**0.79 (0.66 - 0.87)**	**0.86 (0.77 - 0.91)**
Pinch Strength	**-**	**0.60 (0.40 - 0.74)**	**0.78 (0.65 - 0.86)**
Box and Blocks	**-**	**-**	**0.74 (0.59 - 0.84)**

Table 3: The raw scores (2nd column from left) and the person measures from the Rasch analysis (78 items; 56 typical children)

ENTRY NUMBER	RAW SCORE	COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEA CORR.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
7	56	58	8.16	.84	.92	.1	1.06	.3	.26	98.3	96.9	007dmh2
34	56	58	8.16	.84	.74	-.3	.13	-1.9	.30	98.3	96.9	038dmh4
35	49	57	5.56	.55	.98	.0	.30	-.9	.55	89.5	91.3	039dmh4
19	44	48	5.39	.74	.67	-.8	.14	-1.2	.51	97.9	94.9	023dmh4
20	44	48	5.39	.74	.67	-.8	.14	-1.2	.51	97.9	94.9	024dmh4
16	42	48	4.42	.66	.70	-1.0	.15	-1.2	.60	95.8	92.6	020dfh4
28	42	58	3.59	.53	.69	-1.0	.21	-1.2	.75	91.4	91.2	032dmh3
39	42	58	3.59	.53	1.40	1.3	.88	.1	.70	91.4	91.2	043dmh3
30	40	58	3.02	.54	.47	-1.9	.15	-1.2	.79	96.6	92.2	034dmh3
37	40	58	3.02	.54	.71	-.9	.25	-.9	.78	93.1	92.2	041dmh3
17	38	48	2.78	.63	.24	-2.6	.08	-1.2	.74	100.0	93.4	021dfh4
36	38	53	2.46	.56	1.51	1.4	1.74	.9	.71	88.7	92.3	040dfh4
27	38	58	2.43	.55	.98	.1	9.71	3.8	.77	93.1	92.8	031dmh3
31	38	58	2.43	.55	.55	-1.4	.18	-1.0	.82	96.6	92.8	035dfh3
32	38	58	2.43	.55	.26	-3.0	.09	-1.3	.83	100.0	92.8	036dfh3
40	38	58	2.43	.55	.95	.0	.36	-.6	.80	93.1	92.8	044dfh3
42	37	53	2.16	.55	1.13	.5	.53	-.2	.75	90.6	92.1	046dfh2
18	36	48	2.04	.59	.68	-.9	9.90	5.4	.71	95.8	92.3	022dmh4
44	36	53	1.86	.55	.75	-.7	.33	-.6	.79	94.3	91.6	048dfh2
45	35	53	1.56	.54	1.55	1.6	9.90	4.4	.73	88.7	91.0	049dfh2
46	34	47	1.50	.59	1.18	.6	.54	-.1	.75	89.4	91.4	050dmh2
33	34	58	1.27	.53	.90	-.2	.33	-.4	.84	87.9	91.0	037dfh4
54	34	58	1.27	.53	.55	-1.7	.16	-.8	.85	94.8	91.0	058dmh2
38	32	48	.78	.54	.77	-.9	.42	-.2	.80	97.9	89.2	042dfh2
47	31	53	.45	.53	1.88	2.6	5.26	2.2	.75	81.1	90.1	051dmh2
4	29	48	-.08	.54	1.32	1.1	1.00	.4	.79	87.5	89.9	004dmh1
50	29	58	-.11	.53	1.07	.3	6.44	2.5	.84	93.1	91.5	054dfh2
29	28	42	-.29	.55	.83	-.5	.34	-.2	.80	90.5	89.3	033dfh1
15	28	47	-.34	.54	.86	-.4	.65	.1	.82	91.5	90.1	019dmh1
53	28	48	-.37	.54	.78	-.7	.31	-.3	.84	91.7	90.1	057dmh2
52	27	48	-.65	.54	.50	-1.8	.18	-.6	.86	91.7	90.0	056dfh2
12	26	42	-.90	.55	1.52	1.5	1.27	.6	.75	83.3	89.2	015dfh1
41	26	48	-.94	.54	.54	-1.6	.19	-.6	.86	93.8	90.3	045dmh1
43	26	48	-.94	.54	.78	-.6	9.90	5.9	.81	93.8	90.3	047dmh2
49	26	48	-.94	.54	.51	-1.7	.19	-.6	.87	93.8	90.3	053dmh2
23	25	43	-1.23	.54	1.18	.6	5.18	2.4	.77	86.0	89.4	027dfh1
26	25	48	-1.23	.54	.47	-1.9	.17	-.8	.87	95.8	90.5	030dfh1
48	25	48	-1.23	.54	.61	-1.3	.27	-.5	.86	95.8	90.5	052dmh2
56	25	48	-1.23	.54	.95	.0	.86	.3	.84	91.7	90.5	060dfh2
24	24	43	-1.52	.54	.75	-.7	.46	-.4	.83	93.0	89.2	028dfh1
11	23	43	-1.81	.54	.68	-1.0	.30	-.8	.84	93.0	89.0	014dfh1
25	23	43	-1.81	.54	1.58	1.6	3.28	1.9	.74	83.7	89.0	029dmh1
2	21	37	-2.33	.54	.63	-1.3	.30	-1.1	.82	91.9	87.5	002dmh1
22	21	47	-2.37	.53	1.07	.3	1.17	.5	.83	89.4	89.8	026dmh1
9	21	43	-2.37	.53	.52	-1.7	.22	-1.3	.85	93.0	88.9	012dmh1
14	21	43	-2.37	.53	1.45	1.4	.99	.2	.79	79.1	88.9	018dfh1
3	20	43	-2.65	.52	.75	-.8	.41	-.8	.84	90.7	88.3	003dfh1
6	20	48	-2.65	.52	1.94	2.5	9.90	9.9	.71	79.2	89.5	006dmh1
51	20	53	-2.65	.52	1.13	.5	.88	.2	.84	88.7	90.5	055dfh2
8	19	31	-2.72	.57	.71	-.9	.35	-1.0	.80	90.3	85.9	010dmh1
55	19	43	-2.92	.52	.51	-1.9	.22	-1.4	.85	93.0	87.8	059dfp2
21	17	48	-3.44	.50	.43	-2.5	.18	-1.4	.86	97.9	88.4	025dfh1
10	14	37	-4.18	.49	1.46	1.6	1.18	.5	.71	75.7	84.6	013dmh1
1	13	37	-4.42	.49	.91	-.3	.82	.1	.76	86.5	84.4	001dfh1
13	11	30	-4.87	.50	1.60	2.2	1.22	.5	.65	66.7	80.2	016dmh1
5	10	46	-5.15	.49	.86	-.5	.39	-.4	.77	87.0	86.7	005dmh1
MEAN	30.0	48.8	.31	.56	.91	-.3	1.65	.3		91.1	90.4	
S.D.	10.3	7.0	3.04	.07	.39	1.3	2.86	2.1		6.2	2.8	

Figure legends

Figure 1: Compression spring and correct finger positions for task performance.

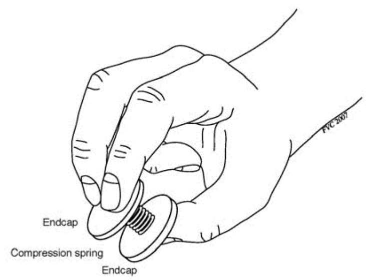

Figure 2**:** Map of item calibrations and person measures including 78 items and 56 typically developing children/adolescents. Each " # " represents two items and each " * " represents one item. Items at the higher end of the scale are more difficult than items at the lower end, and persons at the higher end of the scale are more able than those at the lower end of the scale. The numbers indicate age categories; group 1 = 59-83 months **(n=21),** group 2 = 84-119 months **(n=15**), group 3 = 120-155 months **(n=10),** and group 4 = 156-208 months **(n=10). M=male, f=female. 1SD** = marker indicating measures one standard deviation away from the mean measure, **2SD** = marker indicating measures two standard deviations away from the mean measure. M=male, f=female.

```
Logits      Items           - MAP -         Persons
      <more difficult items>  |     <more able persons>
  9                      2STD +
             *                |
                              |
  8                           +               m2  m4
                              |
                              |
  7                           +
            *#                |
             #                |  2STD
  6                           +
            *#                |               m4
             *                |               m4  m4
  5                           +
             #                |
             #           1STD |               f4
  4          #                +
             *                |               m3  m3
             #                |  1STD
  3          *                +               m3  m3
                              |               f4
                              |               m3  f3  f3  f4  f3
  2          *                +               m4  f2  f2
                              |               f2  m2
            *#                |               f4  m2
  1          *                +
            ##                |               f2
                              |  Mean         m2
  0          *           Mean +               m1  f2
                              |               m1  f1  m2
            *#                |               f2
 -1                           +               f1  m1  m2  m2
                              |               f1  f1  m2  f2
            *#                |               f1  f1  m1
 -2                           +
                              |               m1  m1  f1  m1
             #                |  1STD         f1  m1  m1  f2
 -3          *                +               f2
            *#                |               f1
                              |
 -4          *                +
             *           1STD |               f1  m1
             *                |
 -5         *#                +               m1  m1
                              |
            ##                |  2STD
 -6                           +
           ###                |
                              |
 -7 ##########                +
       <less difficult items> | <less able persons>
```

Figures 3a and 3b**:** Scatter plots and regression lines of SD-test participant ability measures (SDT score) versus Box and Blocks scores (BB score) (A), and pinch strength scores (PS score) (B). Both correlations were significant (p<0.0001).

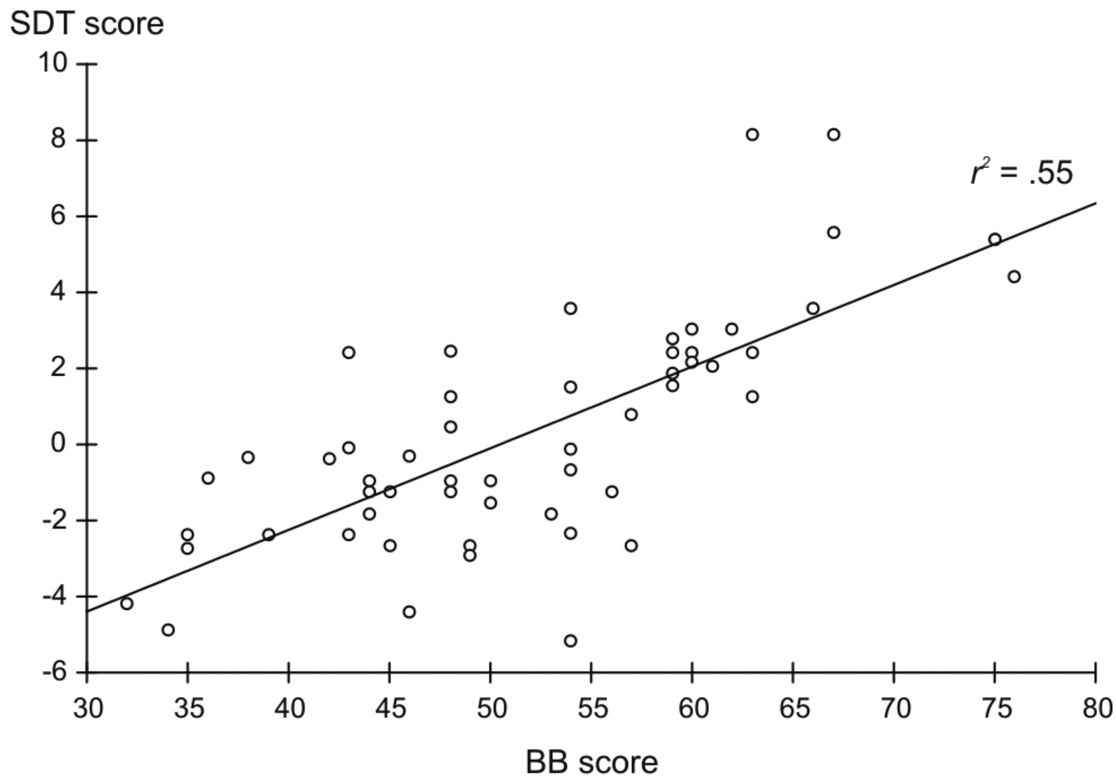

Fig. 3a

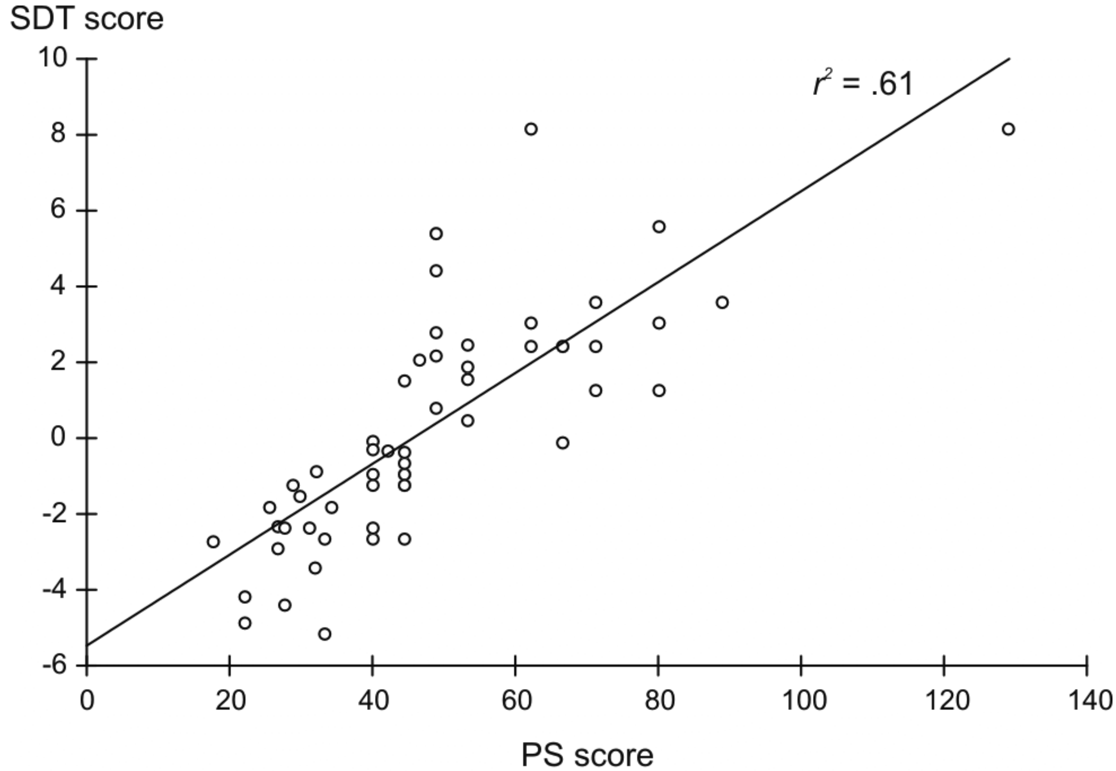

Fig. 3b

Figure 4: Schematic Venn diagram illustrating the unique and shared contributions of the PS and BB tests to variance in the SD-**test, as calculated from the n = 55 participants that completed all tests.** Each circle represents the total variance of a test. Overlapping regions represent shared variances. The numbers in each sub-region indicate the **percentage** of the total SD-test variance accounted for by that partition. **The unique contribution of pinch strength was 16.9 %, and 12.1 % for the Blocks and Box test. Shared variance between pinch strength and Box and Blocks test was 43.2%. The variance unique to the SD-test was 27.8%.**

Figure 4

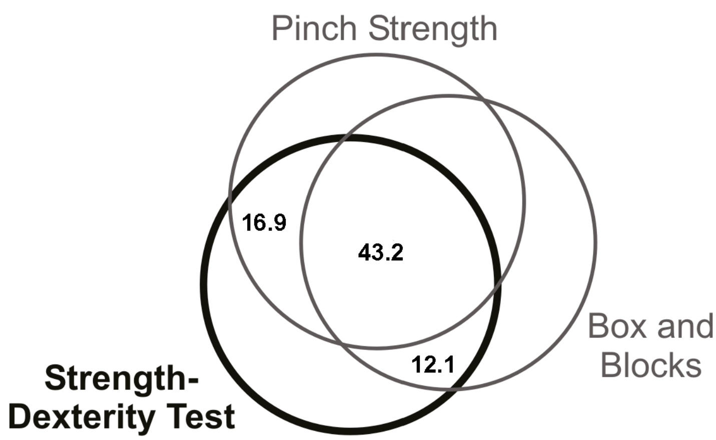

Figure 5: Scatter plots and regression lines of SD-test participant ability measures versus age, plotted separately for males and females. There was no difference in mean performance of the SD-test between boys and girls, but the increase in SD-test performance with age showed a significantly steeper slope in male children (see text).

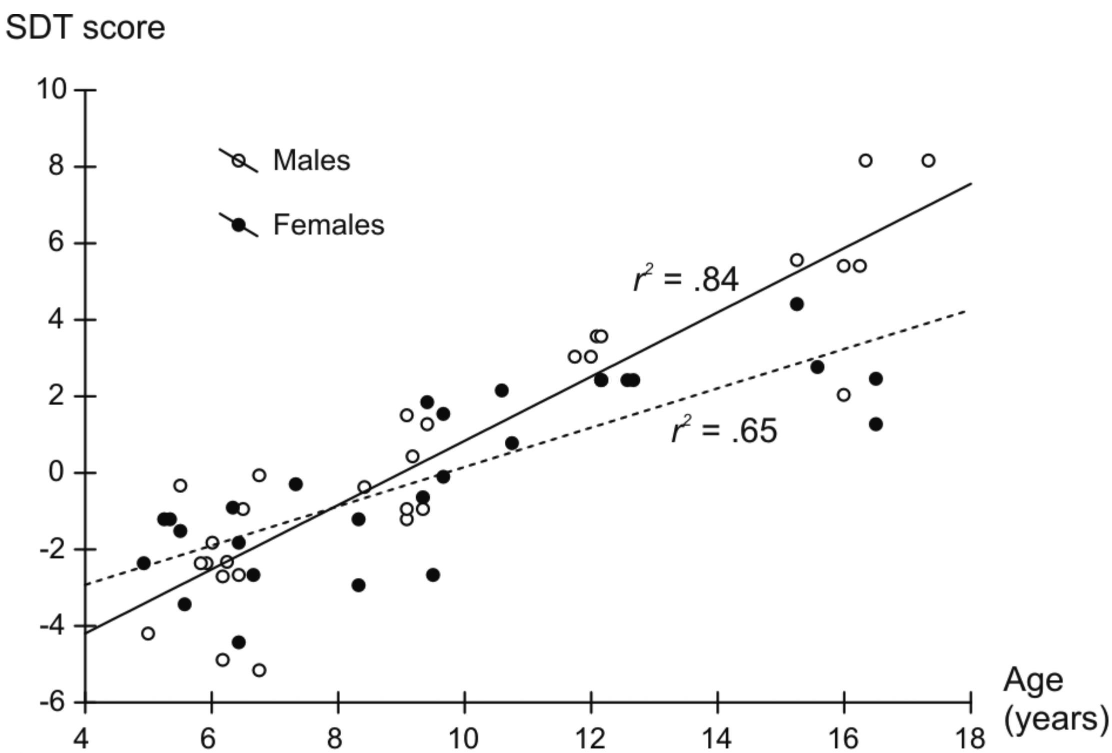

Fig. 5