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The NIH Toolbox Pattern Comparison Processing Speed Test: Normative Data

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Abstract

The NIH Toolbox Pattern Comparison Processing Speed Test was developed to assess processing speed. While initial validation work provides preliminary support for this test in both children and adults, more work is needed to ensure dependability and generalizability. Thus, this replication study examines descriptive data (including age effects), test–retest reliability, and construct validity in $n = 4{,}859$ participants ages 3–85 years (matched to 2010 census data). Although the Pattern Comparison was not appropriate for all 3 and 4 years old, by ages 5 and 6, more meaningful scores were apparent. There was evidence for convergent and discriminant validity. There was also a moderate practice effect (i.e., increase of 5.5 points) over a 1-week time frame. Pattern Comparison exhibits a number of strengths: it is appropriate for use across the lifespan (ages 5–85), it is short and easy to administer, and there is support for construct validity.

Keywords: NIH Toolbox; Processing speed; Pattern Comparison Processing Speed Test; Cognition; Neuropsychological assessment

Introduction

The National Institutes of Health Toolbox (NIHTB) for the Assessment of Neurological and Behavioral Function is a new battery of measures that evaluates cognitive, sensory, emotional, and motor functioning in <2 h (Gershon et al., 2010; Gershon, Wagster, et al., 2013). This battery was designed as part of the National Institutes of Health (NIH) Blueprint for Neuroscience Research to create a set of unified/integrated measures to assess neural and behavioral health. Specifically, the NIHTB was designed to create a "common currency" that could be utilized across diverse study designs and populations in large cohort studies and clinical trials. Each portion of this battery (i.e., cognition, sensation, emotion, and motor sections) takes <30 min to administer. In particular, the NIH Toolbox Cognition Battery (NIHTB-CB) includes subtests that evaluate: processing speed (PS); executive function; episodic memory; working memory; and language (Weintraub et al., 2013). This manuscript highlights the normative data for the NIHTB Pattern Comparison Processing Speed Test.

PS, or the amount of time required to complete a task, plays an influential role in multiple areas of cognition, including intelligence (Clay et al., 2009; Coyle, Pillow, Snyder, & Kochunov, 2011). Furthermore, PS is thought to serve as the foundation for other cognitive processes (Lindenberger, Mayr, & Kliegl, 1993; Salthouse, 1996; Sliwinski & Buschke, 1999). For example, deficits in PS are associated with subsequent deficits in other cognitive domains, especially working memory (Chiaravalloti, Christodoulou, Demaree, & DeLuca, 2003), attention (Mayes & Calhoun, 2007), executive functioning (Baudouin, Clarys, Vanneste, & Isingrini, 2009), and memory (Baudouin et al., 2009; Earles & Kersten, 1999; Salthouse & Coon, 1993).

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PS follows a well-defined trajectory over the lifespan; PS performance increases throughout childhood and adolescence, peaks in early adulthood and declines throughout adulthood and older age (Kail & Salthouse, 1994; Salthouse & Kail, 1983). Furthermore, it is among the most sensitive cognitive processes to neurological insult and has the ability to differentiate healthy populations from clinical populations (DeLuca, Chelune, Tulsky, Lengenfelder, & Chiaravalloti, 2004; Donders, Tulsky, & Zhu, 2001; Gontkovsky & Beatty, 2006). Several neurological diseases/disablements are characterized by PS deficits including multiple sclerosis (DeLuca et al., 2004; Demaree, DeLuca, Gaudino, & Diamond, 1999; Denney, Gallagher, & Lynch, 2011; Forn, Belenguer, Parcet-Ibars, & Avila, 2008; Kail, 1998; Rao, St Aubin-Faubert, & Leo, 1989), traumatic brain injury (Breed et al., 2008; Mathias & Wheaton, 2007; Perbal, Couillet, Azouvi, & Pouthas, 2003; Tombaugh, Rees, Stormer, Harrison, & Smith, 2007), schizophrenia (Gonzalez-Blanch et al., 2010; Morrens et al., 2008; Ojeda, Pena, Sanchez, Elizagarate, & Ezcurra, 2008), dementia (i.e. Alzheimer's disease and Vascular dementia (Breed et al., 2008; de Jager, 2004; de Jager, Hogervorst, Combrinck, & Budge, 2003; Heyanka, Mackelprang, Golden, & Marke, 2010; Mendez, Cherrier, & Perryman, 1997), and stroke (Gerritsen, Berg, Deelman, Visser-Keizer, & Meyboom-de Jong, 2003; Leskela et al., 1999; Loranger, Lussier, Pepin, Hopps, & Senecal, 2000).

Given the importance of PS as a foundation for other cognitive processes and the sensitivity of this construct to neurological insult, the NIHTB Cognitive development team identified this as one of the most important cognitive constructs for inclusion on the NIHTB-CB. As such, the team focused on developing a measure of PS that was brief and appropriate for use over the lifespan. Initial development work and validation data are highlighted in detail elsewhere (Carlozzi et al., 2014; Carlozzi, Tulsky, Kail, & Beaumont, 2013). Briefly, these development papers indicated support for the NIHTB Pattern Comparison Processing Speed Test in both children and adults. Specifically, in children ages 5–18, the Pattern Comparison Processing Speed Test had significant moderate correlations with convergent validity measures, and slightly smaller (but still significant) relationships with the divergent validity measures. With regard to the adults, as expected, the highest correlations were seen between the Pattern Comparison Processing Speed Measure and other measures of PS, smaller, but significant correlations were also seen with measures of working memory, and nonsignificant correlations were seen with a measure of language/crystallized intelligence. In addition, test–retest reliability for children (ages 3–15) was good (0.84), whereas test–retest reliability for adults (ages 20–85) was adequate (0.73). There was evidence for a small practice effect for both children (scores increased a mean of 0.67 scale score points; standardized effect size 0.42) and adults (scores increased a mean of 0.50 scale score points; standardized effect size 0.24) over a 2-week time frame. Although this preliminary work supported the reliability and validity of NIHTB Pattern Comparison Processing Speed Test in both children and adults, the utility of a convenience sample, and the small sample sizes within age bands, limits the generalizability of findings. The focus of this paper is to replicate these findings in the final version of the NIHTB Pattern Comparison Processing Speed Test in a larger, better characterized sample (i.e., the NIHTB Normative sample). The NIHTB Normative Sample was designed to match 2010 census data (with regard to race, ethnicity, and level of education) and focused on stratification by age (3–85), sex, and language preference (English and Spanish) (Beaumont et al., 2013). Such replication work is important, as it improves both the dependability and generalizability findings (Funder et al., 2014; Makel & Plucker, 2014; Schmidt, 2009). Furthermore, this work to broaden the generalizability of findings is especially important given that the NIH Toolbox is designed to be broadly utilized in the general population. Specifically, this study examined reliability, the utility of this task for use across the age span (i.e., ages 3–85), relationships with other demographic factors (i.e., gender, education, and race/ethnicity), as well as convergent and divergent validity.

Method

Participants

The NIHTB Pattern Comparison Processing Speed Test normative sample consisted of 4,859 participants ages 3–85 years ($n =$ 463 ages 3–4; $n = 701$ ages 5–7, $n = 2,269$ ages 8–19 years, $n = 1,009$ ages 20–59, and $n = 417$ ages 60–85). Sample recruitment was distributed across age, gender, race, and education strata (see Table 1). A subset of 537 participants (~11%) distributed across all ages 3–85 ($n = 62$ ages 3–4; $n = 80$ ages 5–7, $n = 210$ ages 8–19 years, $n = 102$ ages 20–59, and $n = 83$ ages 60–85) completed a retest 1 week later to assess test–retest reliability (Beaumont et al., 2013).

The NIHTB Pattern Comparison Processing Speed Test. This test required participants to identify whether two visual patterns are the "same" or "not the same" (responses were made by pressing a "yes" or "no" button). Patterns were either identical or varied on one of three dimensions: color (all ages), adding/taking something away (all ages), or one versus many (only ages 3–15 years; see Fig. 1). Scores reflected the number of correct items (of a possible 130) completed in 90 s; items were designed to minimize the number of errors that were made (i.e., items with <75% accuracy during development were not included in the final version of this task).

Table 1. Descriptive data for the NIHTB pattern comparison processing speed test normative sample

Demographic variable	*N*	%
Age		
3	219	4.5
4	244	5.0
5	223	4.6
6	220	4.5
7	258	5.3
8	214	4.4
9	225	4.6
10	239	4.9
11	223	4.6
12	220	4.5
13	225	4.6
14	235	4.8
15	226	4.6
16	216	4.4
17	226	4.6
18–29	268	5.5
30–39	310	6.4
40–49	256	5.3
50–59	195	4.0
60–69	166	3.4
70–79	148	3.0
80–85	103	2.1
Gender		
Male	2,226	45.8
Female	2,633	54.2
Primary language		
English	3,955	81.4
Spanish	904	18.6
Race/ethnicity		
Hispanic	1,604	33.0
American Indian/Alaska native[a]	190	4.0
Asian[a]	123	2.6
Black[a]	814	17.3
Native Hawaiian/Pacific Islander[a]	13	0.3
White[a]	3,700	78.8
Education (for adults, $n = 1{,}286$)		
Less than HS	293	22.8
HS graduate	315	24.5
Some college	266	20.7
College graduate	262	30.4
More than college	150	11.7

Note: [a]$n = 161$ missing race.

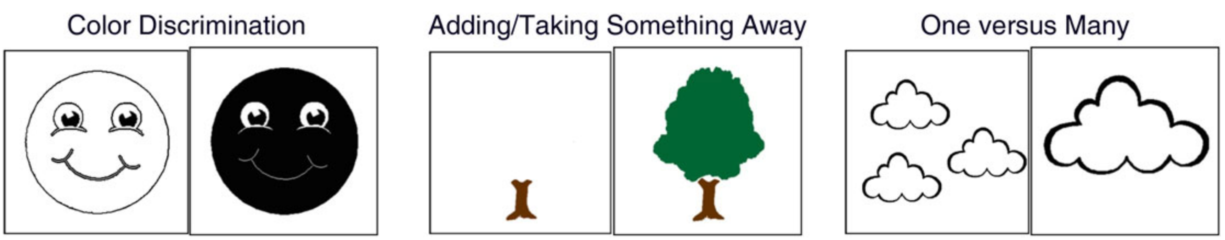

Fig. 1. Examples of types of discrimination on the NIH Toolbox Pattern Comparison Processing Speed Test.

Other processing speed measures. In order to evaluate the convergent validity of the NIHTB Pattern Comparison Processing Speed Test, a PS composite was derived from two other NIHTB-CB measures: the NIHTB Dimensional Change Card Sort (DCCS) and the NIHTB Flanker Inhibitory Control Test (Zelazo et al. 2013 2014). This composite reaction time measure included the mean reaction time for all dominant and non-dominant DCCS trials, and the mean reaction time for all Flanker trials (congruent and incongruent). In addition, we examined scores on the Oral Symbol Digits Processing Speed Test from the NIHTB (this test is an optional measure within the NIHTB for use in ages 8–85). The NIHTB Oral Symbol Digit Processing Speed Test requires the participant to match numbers with symbols according to a key at the top of the screen. The key is comprised of nine symbols that are each paired with a number from 1 to 9; this key is present at the top of the screen and the 144 test items (i.e., a series of symbols without numbers) is included on this same screen. The score is the number of items completed correctly in 120 s (maximum 144).

Measures of working memory. We examined scores on the NIHTB List Sorting Working Memory Test (Tulsky et al. 2013 2014). This task involves size order sequencing of familiar stimuli; the task is discontinued when two trials of the same series length were failed. Test scores consisted of combined total items correct on the one- and two-list versions of the task (maximum 28). Due to the well-established relationship between working memory and PS, we included the List Sort Working Memory Test as a measure of divergent validity. We hypothesize that the correlations between PS and working memory (i.e., Pattern Comparison and List Sorting) should be smaller than those found among the PS measures (i.e., Pattern Comparison, the NIHTB Processing Speed Composite, and Oral Symbol Digit), but larger than those found for the other divergent validity measures (i.e., Picture Vocabulary and Oral Reading Recognition, described below).

Measures of verbal functioning. We also examined scores on two NIHTB tasks designed to evaluate vocabulary comprehension and language using computer adaptive testing. The NIHTB Picture Vocabulary Test (Gershon et al., 2014; Gershon, Slotkin, et al., 2013) requires examinees to identify which of four pictures reflects a specific word. The NIHTB Oral Reading Recognition Test (Gershon et al., 2014; Gershon, Slotkin, et al., 2013) requires participants to pronounce words or letters presented on the computer screen. Vocabulary and Reading scores are calculated based on item response theory models. The NIHTB Picture Vocabulary Test and the NIHTB Oral Reading Recognition Test were included as measures of divergent validity.

Data analysis. This paper highlights findings for the NIHTB Pattern Comparison Processing Speed Test from the NIHTB normative sample. Specifically, we report analyses of test–retest reliability (including practice effects), associations of test scores with age and education, and convergent and discriminant validity. Age associations reflect the validity of the NIHTB cognition tests for detecting age-related improvements throughout childhood and adolescence, and cognitive decline during adulthood. Convergent and discriminant validity results provide evidence that the NIHTB Pattern Comparison Processing Speed Test is measuring the intended constructs.

For the NIHTB-CB measures listed above, scaled scores were created by first ranking the raw scores, next applying a normative transformation to the ranks to create a standard normal distribution, and finally rescaling the distribution to have a mean of 100 and an *SD* of 15. Pearson correlation coefficients between age and test performance were calculated to assess the NIH Toolbox Pattern Comparison Processing Speed Test to detect cognitive developmental growth during childhood and age-related cognitive decline during adulthood. Both Pearson correlation coefficients and intraclass correlation coefficients (ICC) with 95% confidence intervals were calculated to evaluate test–retest reliability. Convergent validity was assessed with correlations between the NIHTB-Pattern Comparison Processing Speed Test and other NIHTB measures of PS; evidence of discriminant validity consisted of lower correlations with NIHTB measures of working memory and language.

Results

Test–Retest Reliability

Overall, ICC for test–retest reliability for the NIHTB Pattern Comparison Processing Speed Test was 0.61 (95% CI: 0.55, 0.66; Pearson's $r = .84, p < .0001, n = 513$). The mean change from time 1 to time 2 was 5.5 points ($SD = 9.6$, Cohen's D effect size = 0.36). An examination of the practice effects by age indicated that practice effects were moderated by age (see Fig. 2, analysis of variance $F(12, 500) = 6.53, p < .0001$). Specifically, the practice effect is the largest for age 14–29, and minimal for the younger children (age 3–4) and older adults (50–85).

Age Effects

Figure 3 provides a graphic presentation of performance on the NIHTB Pattern Comparison Processing Speed Test. A curvilinear association between age and the NIHTB Pattern Comparison Processing Speed Test, $\beta = -2.07, SE = 0.0001, p < .0001$), was seen; 31.0% of the variance in pattern comparison performance was accounted for by this curvilinear relationship. As

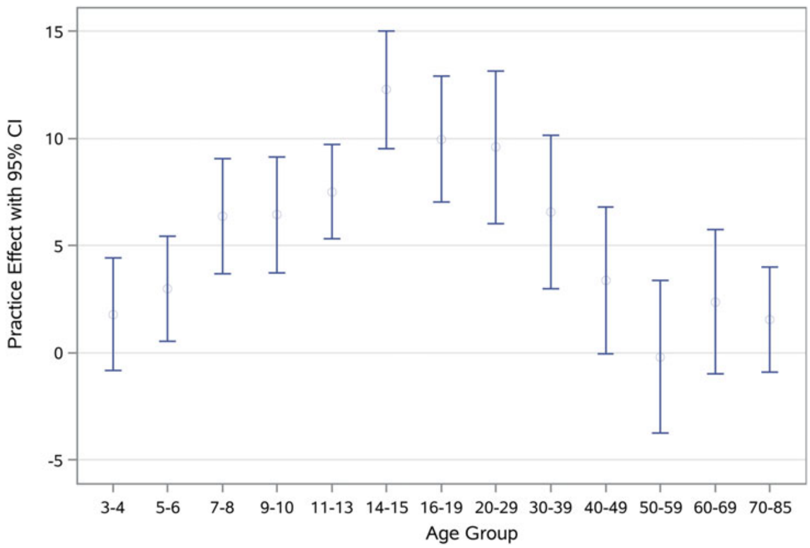

Fig. 2. Practice effects for the NIH Toolbox Pattern Comparison Processing Speed Test scores by age (mean scaled score difference ±2 standard error).

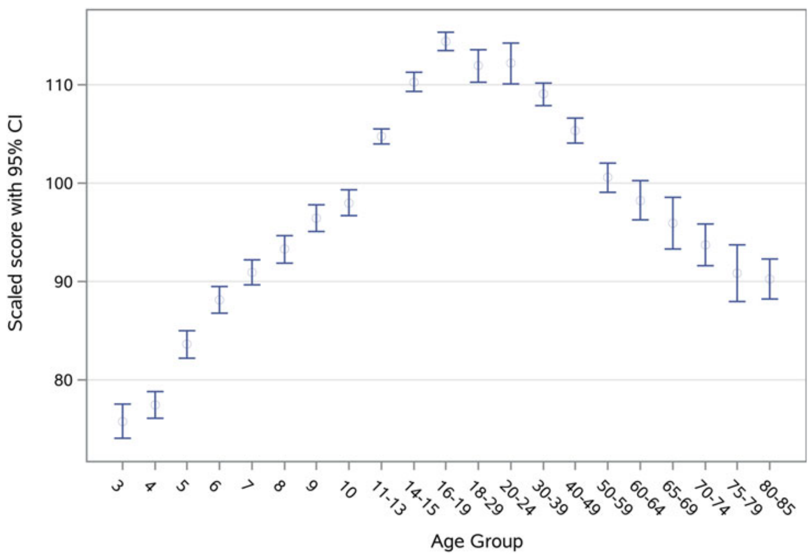

Fig. 3. The NIH Toolbox Pattern Comparison Processing Speed Test scores by age (scaled score ±2 standard error).

anticipated based on a large body of past evidence, there were better performances in successive age groups until age 19, then slightly poorer performances in successive age groups throughout adulthood. In addition, only 76% of 3–4 year olds completed the test, compared with 99% of participants age 5 and older. Of those who completed the test, the mean proportion of items completed correctly was 0.70 for ages 3–4, 0.90 for ages 5–7, 0.95 for ages 8–19, 0.98 for ages 20–59, and 0.97 for ages 60–85.

Other Demographic Comparisons

We also examined effect sizes (mean difference/pooled *SD*) for other demographic factors, after adjusting for age, gender, education, and race/ ethnicity. In adults, no difference in the NIHTB Pattern Comparison Processing Speed Test was found between males and females (ES = 0.02, $p = .80$). Adults with at least a high school degree performed better than those with less education (ES = 0.62, $p < .0001$). The effect of race/ethnicity was statistically significant ($p < .0001$), with white participants performing better than black (ES = 1.05) and Hispanic (ES = 0.52) individuals. In children, the difference in NIHTB Pattern Comparison Processing Speed Test scores between males and females was negligible (ES = 0.09, $p = .007$), as were the differences between groups based on parental education (ES = 0.00–0.08, $p = .026$). The effect of race/ethnicity was statistically significant in children as well ($p < .0001$), with white children performing better than black (ES = 0.47) and Hispanic (ES = 0.23) children.

Convergent and Discriminant Validity

Table 2 shows results for convergent and discriminant validity. In both younger (i.e., ages 20–59) and older adults (ages 60–85), correlations with other measures of PS were the highest (ranging from $r = .45$ to $r = .70$; all $p < .0001$), followed by correlations with working memory (ranged from $r = .33$ to $r = .44$; all $p < .0001$), and lowest for the measures of verbal comprehension (ranged from $r = .03$ to $r = .17$; all $p < .0001$) providing support for the NIHTB Pattern Comparison Processing Speed Test as a measure of PS. This same pattern of correlations was present for the oldest children (ages 13–19) but the correlations were more modest. For the two youngest groups (ages 3–7 and 8–12), the patterns of correlations were slightly different. While correlations with other measures of PS were high (ranged from $r = .48$ to $r = .62$; all $p < .0001$), the correlations for the two different types of discriminant validity measures were within the same range (correlations with working memory ranged from 0.26 to 0.38 and with language was 0.30 to 0.43), suggesting that the NIHTB Pattern Comparison Processing Speed Test and other subdomains of cognition are more interrelated in children ages 3–12 than in individuals 13 and over.

Normative Data

Normative data are included in Table 3 for reference.

Discussion

The NIHTB Pattern Comparison Processing Test is a 90-s test designed to evaluate PS across the lifespan (ages 3–85). Overall, findings from the present study replicate previous work (Carlozzi et al. 2013, 2014) that supports the reliability and validity of this new measure. In addition, findings highlight some potential limitations of using this measure with young children (i.e., below age 5), as well as in using this measure to assess clinical change over time.

First, although test–retest reliability was good, there was evidence for a practice effect, suggesting that participant performance improves with repeat test administration. While such practice effects can be characteristic of serial cognitive assessments (De Monte, Geffen, May, & McFarland, 2010; Duff et al., 2007; Machulda et al., 2013; McCaffrey, Duff, & Westervelt, 2000), it is important to take this into consideration when implementing these measures in longitudinal study designs. Specifically, work examining practice effects for other neuropsychological tests in the general population (i.e., "stable normal" groups) tend to demonstrate significant practice effects across the first three test administrations, followed by nonsignificant improvements for administrations four and five (Machulda et al., 2013). Furthermore, examination of serial assessments in clinical groups tends to demonstrate significant practice effects across the first two administrations, followed by significant declines thereafter (Machulda et al., 2013). In addition, there is evidence from clinical populations to suggest that the absence of a practice effect on certain cognitive measures may actually be indicative of cognitive decline (Duff et al., 2007). In addition, this practice effect is substantially larger than the one that was reported in previous studies (which was less than a 1 point increase over a

Table 2. Convergent and discriminant validity of the NIHTB pattern comparison processing speed test

	NIHTB Pattern Comparison Processing Speed Test				
	Ages 3–7 *r* (*df*)	Ages 8–12 *r* (*df*)	Ages13–19 *r* (*df*)	Ages 20–59 *r* (*df*)	Ages 60–85 *r* (*df*)
Convergent validity measures					
NIHTB DCCS/Flanker Processing Speed	0.48 (731)**	0.62 (847)**	0.55 (874)**	0.65 (875)**	0.65 (259)**
NIHTB Oral Symbol Digit	—	−0.42 (270)**	−0.26 (306)**	−0.45 (246)**	−0.39 (110)**
Discriminant validity measures					
Working memory					
NIHTB List Sorting	0.38 (845)**	0.26 (1,099)**	0.20 (1,135)**	0.33 (992)**	0.39 (398)**
Verbal functioning					
NIHTB Vocabulary Comprehension	0.36 (490)**	0.38 (846)**	0.20 (871)**	0.17 (696)**	0.29 (235)**
NIHTB Reading Decoding	0.43 (582)**	0.30 (1,102)**	0.21 (1,127)**	0.03 (770)	0.17 (325)*

Notes: NIHTB = National Institutes of Health Toolbox; unadjusted scaled scores were utilized in analyses; **$p < .0001$; *$p < .05$.

Table 3. Normative data for the NIH Toolbox Pattern Comparison Processing Speed Test

Age group	NIHTB Pattern Comparison Processing Speed Test (number correct)		
	N	Mean	*SD*
3	134	29.8	11.2
4	220	31.2	8.8
5	206	36.4	6.4
6	217	40.5	7.9
7	254	43.2	7.4
8	212	45.3	6.8
9	223	48.2	7.4
10	236	49.5	8.0
11	223	52.8	7.9
12	220	55.4	8.6
13	222	57.8	8.5
14	234	59.2	8.9
15	224	60.6	8.7
16	215	63.1	9.7
17	224	63.1	9.7
18–29	266	61.4	10.4
30–39	310	58.9	9.6
40–49	254	55.8	9.4
50–59	191	51.7	9.4
60–69	164	48.9	9.4
70–79	144	44.8	8.1
80–85	97	42.5	8.9

Note: This table reports unweighted means.

2-week time frame) (Carlozzi et al. 2013, 2014). Thus, more work is needed examining the serial assessment of the NIHTB Pattern Comparison Processing Speed Test in both "stable normal" and in clinical groups to better understand the utility of using this measure over time.

With regard to age, there were better performances in successive age groups until age 19, then slightly poorer performances in successive age groups throughout adulthood. In addition, practice effects were the largest for teenagers and young adults, and minimal for the younger children and older adults. This well-defined trajectory is characteristic of other PS measures (Kail & Salthouse, 1994; Salthouse, 1993) and provides additional support for its validity as a PS measure and replicates the patterns of findings reported for an earlier version of this task (Carlozzi et al. 2013, 2014). In addition, findings suggested that while this test can be used in some children ages 3 and 4, it is not appropriate for use in all 3 and 4 years old (as was evident in the fact that only 76% of children in the normative sample were able to successfully complete this test according to instructions with 70% accuracy). By age 5, 99% of participants were able to complete the test (with accurate discriminations for 90% of the total items administered); therefore, we would recommend using this measure with ages 5 and above, and only administering this measure to children below age 5 that are high functioning/developmentally advanced.

Findings with regard to other demographic factors (i.e., gender, education, and race/ethnicity) indicated that there was no gender effect on the NIHTB Pattern Comparison Processing Speed Test for adults, and only a negligible effect for children. This finding is not consistent with previous work in a smaller adult sample, which found that males performed slightly better than females on the NIHTB Pattern Comparison Processing Speed Test (Carlozzi et al., 2014). Findings for gender effects in the general literature is somewhat inconsistent (Klinteberg, Levander, & Schalling, 1987; Majeres, 1997, 1999; Peters, 1997; Roig & Placakis, 1992); when present, such effects tend to be small (Heaton, Taylor, & Manly, 2003). With regard to education, not surprisingly, adults with at least a high school degree performed better than those with less education, although this effect was negligible for children (based on parental education). While this is inconsistent with the previous study in adults on the NIHTB Pattern Comparison Processing Speed Test—which did not find education effects (Carlozzi et al., 2014), it is consistent with the general literature (Diehr, Heaton, Miller, & Grant, 1998; Gonzalez et al., 2006; Norman et al., 2011; Taylor & Heaton, 2001). Finally, the NIHTB Pattern Comparison also favored white participants over ethnic minorities for both adults and children. This finding is consistent with previous work examining the NIHTB Pattern Comparison Processing Speed Test in adults (Carlozzi et al., 2014), and is consistent with the general literature (Boone, Victor, Wen, Razani, & Ponton, 2007; Llorente, Turcich, & Lawrence, 2004; Schwartz et al., 2004). Demographically corrected norms for the NIHTB Pattern Comparison Processing Speed Test, and other measures within the NIHTB Cognition Battery are published elsewhere (Casaletto et al., in press).

Furthermore, findings examining convergent and discriminant validity were consistent with previously published findings (Carlozzi et al. 2013, 2014). Specifically, there were moderate relations with other measures that examined PS, slightly smaller associations with a related, but different domain of cognitive function (i.e., working memory), and less substantial relationships with domains of reading comprehension and language (see Table 1). Such findings are consistent with literature that highlights an overlap between PS and working memory (Chiaravalloti et al., 2003; Demaree et al., 1999), as well as literature that suggests that language and reading comprehension are not highly related to PS (Bell, Lassiter, Matthews, & Hutchinson, 2001).

While both reliability and validity were supported, it is important to acknowledge several study limitations. First, as mentioned above, this test is not appropriate for all children ages 3–4; only 76% of children were able to complete the task according to instructions. Therefore, while it may be an appropriate test for some children ages 3 and 4, caution should be taken with drawing inferences about poor performance in these young children. Furthermore, a moderate practice effect is also present. While more work is needed to explore this effect, studies designed to use this task multiple times should consider a design that minimizes these practice effects (e.g., administer the task at least one time prior to the baseline assessment to minimize the impact the practice effect will have on serial assessments). In addition, all of the measures included in our analyses are from the NIHTB, and thus share variance, which may cause an artificial inflation of the relationships among measures.

Regardless of such limitations, the NIHTB Pattern Comparison Processing Speed Test provides a brief, sensitive measure of PS that is both valid and reliable. Furthermore, this test can be used across the lifespan, although most reliably in ages 5 and above. Future work is needed to document the sensitivity of this measure to known neurological insult, especially those with upper extremity functioning difficulties. In addition, more work examining the serial assessment of this measure to better define and understand the presence of practice effects would be a logical next step.

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