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Research Article

Visual inspection time as an accessible measure of processing speed: A validation study in children with cerebral palsy

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Abstract

Objective: This study examined the validity of a visual inspection time (IT) task as a measure of processing speed (PS) in a sample of children with and without cerebral palsy (CP). IT tasks measure visualization speed without focusing on the motor response time to indicate decision making about the properties of those stimuli. **Methods:** Participants were 113 children ages 8–16, including 45 with congenital CP, and 68 typically developing peers. Measures were a standard visual IT task that required dual key responding and a modified version using an assistive technology button with response option scanning. Performance on these measures was examined against traditional Wechsler PS measures (Coding, Symbol Search). **Results:** IT performance shared considerable variance with traditional paper-pencil PS measures for the group with CP, but not necessarily in the typically developing group. Concurrent validity was found for both IT task versions with traditional PS measures in the group with CP. IT classification accuracy for lowered PS showed modest sensitivity and good specificity particularly for the modified IT task. **Conclusions:** As measures of PS in children with CP who are unable to validly participate in traditional PS tasks, IT tasks demonstrate adequate concurrent validity and may serve as a beneficial alternative measure of PS in this population.

Keywords: Cerebral palsy; assessment; processing speed; inspection time; neuropsychology; psychometrics

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Introduction

Cerebral palsy (CP) is the most common neurological condition associated with childhood physical disability, with incidence estimated at 2-3/1000 live births (Odding et al., 2006; Paneth et al., 2006). CP involves increased risk for speech, motor, and/or cognitive impairments. Although there is an extensive literature on risks for motor and sensory impairments associated with CP, the neuropsychological risks are less well characterized, stemming in part from the difficulty associated with valid test administration in this population (Coenen et al., 2018; Laporta-Hoyos et al., 2019; Stadskleiv, 2020). This is particularly true for individuals with more severe CP who are at significant risk for cognitive impairments, yet paradoxically face barriers to participation in standardized testing due to high motor and speech response demands inherent in common assessment instruments. These accessibility issues are most evident for processing speed (PS) measures in which the construct of interest is cognitive PS, yet performance outcomes are confounded by response demands which typically are clerical in nature, and often require significant graphomotor control and speed. These barriers and needs highlight the importance of developing alternative testing strategies that include modifications and response strategies that are accessible for individuals with motor and speech impairments in accord with the American Psychological Association Guidelines for Assessment and Intervention with Persons with Disabilities (American Psychological Association, 2022).

The use of modified neuropsychological and psycho-educational batteries to optimize inclusion and accessibility is not novel and many populations have benefitted from such modifications. Intelligence tests such as the Leiter International Performance Scale (Roid & Miller, 1995, 1997), Comprehensive Test of Nonverbal Intelligence (Hammill et al., 1997) and the Raven's Progressive Matrices (Raven, 1998) measure aspects of intellectual reasoning while largely mitigating hearing, language production, and significant motor response demands that may interfere with task performance (e.g., permitting pointing and use of card-exchange systems). There have been limited efforts to assess cognition using alternate formats to address the motor response limitations associated with severe CP. Modifications have included the conversion of items into forced-choice formats (Berninger et al., 1988) and measuring event-related brain potentials to indicate responses (Byrne et al., 1995). Standardized quadrant forced-choice format tests modified for computerized stimulus presentation with assistive technology response options have shown excellent measurement agreement with standard versions (Warschausky et al., 2011).

Slowed PS (i.e., longer processing time) is one of the most robust neuropsychological findings following traumatic brain

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injury (TBI) and a wide range of neurological diseases (Marco et al., 2012; Oprandi et al., 2021; Shultz et al., 2016; Treble-Barna et al., 2017). PS performance improves through childhood; developmentally, increased PS is associated with increased working memory capacity (Fry & Hale, 2000). PS is also associated with verbal learning; Wechsler Intelligence Scale for Children (WISC)-III PS predicts performance on list learning tasks (Donders & Nesbit-Greene, 2004; O'Jile et al., 2005). In children with ADHD, PS was found to be significantly associated with oral reading fluency performance (Jacobson et al., 2011).

While often used interchangeably, there are subtle definitional variations in concepts of speed of reasoning. PS broadly is the time required for identification, discrimination, and integration of stimuli and the associated time to make a decision about those stimuli. Visual inspection time (IT) is the time required to make an observation (visually) and to identify the visual/physical properties of the stimulus. Visual IT has been studied extensively as a measure of general speed of processing in typically developing samples. Data suggest that distinct factors of PS include movement time, decision time, perceptual speed, and visualization speed (O'Connor & Burns, 2003). Research suggests that while IT is a measure of general speed of processing, it more specifically measures speed of visualization as one component of PS (O'Connor & Burns, 2003). Studies have shown that IT correlates with general intellect (Chaiken, 1994), though some evidence suggests that there is no clear causal relationship between intellect and IT (Luciano et al., 2005).

Most experimental measures of IT target stimulus duration as the measurement of primary interest rather than speed of motor responding to evaluate PS; therefore, this is an appealing measure of an aspect of PS for use in a population of individuals with known motor and/or speech impairments. Rather than measuring speeded motor responses, traditional measures of IT involve brief (e.g., less than 1000 ms) stimulus presentations followed by probes for examinees to indicate what they have seen. While in typical PS measures speed of responding is the measured outcome, IT tasks manipulate stimuli at the front end by controlling the length of time the individual has access to the target stimulus (i.e., IT stimulus duration). Responses are judged by accuracy in describing the stimulus characteristics (correct/incorrect) rather than speed of responses. IT tasks can range from making a simple decision about a visual stimulus such as the shape or direction of a stimulus or may involve higher level abstract decision making depending upon the construct of interest. Accurate stimulus characterization following a short visualization period would reflect fast PS while the need for a longer visualization period reflects slower PS (Burns et al., 1999).

Children with CP have been shown to exhibit slower IT than typically developing peers with similar age, socioeconomic status and vocabulary level (Shank et al., 2010). Specifically, using a traditional IT task in which the child was required to use keyboard arrow keys to indicate which leg of a Pi stimulus was longer, children with CP had IT thresholds that were approximately a standard deviation slower than peers. Clearly, for a subset of children with CP, arrow key dexterity demands make even this type of testing inaccessible. To enhance the accessibility of the IT task, Kaufman et al. (2014) developed a modified version that could be used with an assistive technology pressure switch interface, further reducing the motor response demands.

The current study examined the validity of standard and modified versions of a visual IT test, as accessible measures of PS in children with CP compared to typically developing peers (TD). The modified version of IT included a single pressure switch response, allowing response selection from two on-screen choices which were "auto-scanned" following presentation of the stimulus probe. The goal of evaluating these IT measures is to determine their utility in the clinical setting, thus concurrent validity was assessed to establish potential overlap of constructs between the experimental measure and traditional clinical (paper-pencil) PS measures.

Method

Participants

Data were collected with University of Michigan Institutional Review Board approval, as part of a larger ongoing study examining the psychometrics of modified assessment instruments for children with CP. The research was completed in accordance with Helsinki Declaration. The participants included 45 children with a medical diagnosis of CP who were physically capable of completing all measures examined, and 68 typically developing (TD) children without any history of developmental, educational, or neurological problems who served as controls. The samples include the original 34 children with CP and 68 of the 70 typically developing peers from Shank et al. (2010) and a subset of the sample described in Kaufman et al. (2014) including all participants who were administered both the IT and WISC-III PS subtests. All children were between the ages of 8 and 16 years. Inclusion criteria for the group with CP included the ability to make a reliable dichotomous choice (Van Tubbergen et al., 2008) as well as sufficient fine motor dexterity to reliably depress a single computer keyboard key. In addition, all children were required to pass a graded IT training process that ensured ability to visually identify test stimuli from lures (e.g., circles, triangles), ability to match to target and practice of task demands under long stimulus durations (e.g., 2000–3000 ms), and comprehension of task instructions. Exclusion criteria included a history of clear major neurological disorder (i.e., onset of new condition that occurred after stable period of CP diagnosis such as tumor, brain injury from sports or auto accident or new onset encephalopathy) unrelated to CP or psychiatric condition (major depression or psychosis), and recent changes in medication with known or suspected cognitive or psychoactive effects. There was a significant group difference in medication use (TD group 22.1%, CP 60%), X^2 $(1, N = 113) = 16.69$, $p < .001$, $V = .38$. TD group medications included stimulants (5), psychiatric (2), allergy (4), and other (6). Medication in the CP group included stimulants (9), psychiatric (1), anti-seizure (4), anti-spasticity (4), allergy, (5) and other (13). Characteristics of the final groups were derived from a parent-completed intake form (Table 1). Group differences in gender distribution, age, socioeconomic status (Hollingshead, 1975) and receptive vocabulary were not statistically significant ($p > .05$ for all variables). There were significant group differences in gestation, t $(104) = 48.18$, $p < .001$, $p\eta^2 = .32$, birth weight, t $(106) = 49.61$, $p < .001$, $p\eta^2 = .32$, and seizure history, X^2 $(1, N = 110) = 13.44$, $p < .001$, $V = .35$, with shorter gestation, lower birth weight and significant seizure history in the group with CP.

There was a statistically significant group difference in race and ethnicity, with a relatively greater proportion of minority representation in the TD group than in the group with CP, χ^2 $(1, N = 113) = 18.97$, $p < .001$, Cramer's $V = .41$. In the TD Group 29.4% of the children was African American, while 4.4% of the group with CP was African American. Within the TD group, race and ethnicity differences in IT thresholds were not statistically significant, however, there were significant race and ethnicity differences in Coding, F $(3,68) = 5.56$, $p < .01$, $p\eta^2 = .21$, and

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Table 1. Background characteristics by group

Variable	CP (n = 45)	TD (n = 68)
Gender (% male)	62.2	52.9
Age (yrs; *M, SD*)	11.20 (2.55)	11.66 (2.50)
Hollingshead SES index (*M, SD*)	3.67 (1.11)	3.57 (1.18)
Child racial and ethnic group		
African American or Black	2 (4.4%)	20 (29.4%)
Hispanic/Latino	1 (2.2%)	2 (2.9%)
White (non-Hispanic)	39 (86.7%)	32 (47.1%)
Multiracial and Other	3 (6.7%)	14 (20.6%)
PPVT–III (standard score; *M, SD*)	102.73 (15.95)	108.91 (17.02)
Seizure History	17.8% positive	0% positive**
Gestation (weeks; *M, SD*)	32.48 (5.98)	38.41 (2.59)**
Preterm birth	67.4%	21.0%
Birth Weight (lbs; *M, SD*)	4.45 (2.49)	7.21 (1.55)**
Birth complications	56.1%	0.0%
Intraventricular hemorrhage	22.2%	0.0%
Hydrocephalus	11.6%	0.0%

Note: CP = cerebral palsy. TD = typically developing. SES = socioeconomic status.
PPVT–III = Peabody Picture Vocabulary Test—Third Edition.
**p < .001.

Symbol Search, F (3,68) = 6.55, p < .01, $p\acute{\eta}^2$ = .23, with lower performance in the minority groups. Those groups had lower levels of maternal education, which in turn was correlated with PSI performance, Spearman's r = .31, p < .05.

In the group with CP, 87.9% of the sample had spastic CP, 6.1% dystonic CP and 6.1% ataxic CP. Motor topographical subtypes were 48.8% diplegic, 43.9% hemiplegic and 7.3% mixed. Gross motor function was evaluated with the Gross Motor Function Classification System (GMFCS) (Palisano et al., 1997) with group functional levels as follows: Level 1 (near normal, walks without limitations) 68.90%, n = 31; Level II (mild difficulty; walks with limitations) 11.10%, n = 5; Level III (moderate difficulty; walks using a hand-held mobility device) 15.60%, n = 7; Level IV (moderate to severe difficulties; self-mobility with limitations - may use power chair) 2.20%, n = 1; and V (severely limited; transported in a manual wheelchair) 2.20%, n = 1. The level of manual dexterity of the group with CP was characterized with the Manual Ability Classification System (Eliasson et al., 2006) as follows: Level I (near normal; handles most objects successfully) 22.22%, n = 10; Level II (mild difficulty; handles objects but with reduced quality/speed) 66.67%, n = 30; Level III (moderate difficulty; handles objects with difficulty/needs help for activities) 8.89%, n = 4; Level IV (moderate to severe difficulties; handles a limited selection of easily managed objects) 0; and Level V (severely limited; does not handle objects and requires total assistance) 2.22%, n = 1. The four participants at Level III despite moderate difficulty handling objects were able to complete both PSI tasks, obtaining scale scores ranging from 1-5, with all but one scale score>1. The single participant at MACS V was able to complete the PSI tasks, obtaining raw scores of 21 and 12, and scaled scores of 1 and 2 on the Coding and Symbol Search task, respectively.

Measures

Inspection time task

All participants were seated upright in either a standard desk chair (if motor function permitted), or in a personal wheelchair at an angle most closely approximating a standard desk chair while maintaining participant comfort and ability to respond. Stimuli were presented using a visual angle of approximately 10° based on nose-to-screen distance at the initiation of task and stimulus height of 10 cm. Due to the presence of spasticity, fidgeting and uncontrolled movements in many participants, visual angle ultimately varied over the course of stimulus presentation but this did not appear to negatively affect ability to see stimuli. The IT tasks were administered using a standard personal computer with MultiSync LCD 1860NX screen by NEC (Magna, UT). Stimuli were presented using the Presentation stimulus delivery platform software (Neurobehavioral Systems, Inc., Albany, California).

Each child began the IT task with five pre-task training modules intended to establish the participant's capacity to comprehend task demands, as well as to provide scaffold training for those participants who may have conceptual difficulties with task demands. Graded conceptual training allowed children to first practice simple target identification and matching before moving on to the more complex final task demands. Prior to formal test administration, all participants practiced a slowed version of the final tasks (Figure 1) using both required response modalities; a standard keyboard (standard condition; Figure 1 upper) and a single button response pressure switch device with dichotomous choice scanning (modified condition; Figure 1 lower). All participants met criterion accuracy for each training module described below and continued to the formal task including counterbalanced participation in both the standard IT condition and the modified condition of the task.

Both the standard and modified versions of the IT task were identical throughout the period of stimulus presentation (see Figure 1, Steps A through E), with task variations occurring only for the selection screen (F), and the response modality (G). Participants were shown a fixation point for 3000 ms (A) with brightening (B) lasting 1500ms to assist with orientation to impending stimulus presentation. A clear screen (C) was followed by the target stimulus presentation with varying duration (D). A visual stimulus mask (E) was used to prevent visual rehearsal of the target (on-screen mask duration = 1000ms – (DurationTarget + 25 ms)). In the standard task condition (Figure 1, upper), mask stimuli are followed by a blank screen (F) which remains for duration of participant response using keyboard arrow keys to the question, "which side of the figure had the longer leg?" In the modified task condition participants were shown both a correct target and an inverse stimulus which served as a lure. A selection box alternated between stimulus choices at a scan rate determined by the participant to be a comfortable pace (i.e., allowed participant to initiate and complete motor response while preferred stimulus choice was selected). There were significant group differences in scan rate for both the standard (TD M = 1476.5 (103.8) msec, CP M = 1547.7 (252.00)), F (1,112) = 4.32, p < .05, $p\acute{\eta}^2$ = .04, and modified (TD M = 1476.5 (103.8) msec, CP M = 1585.7 (235.4)), F (1, 110) = 11.18, p < .01, $p\acute{\eta}^2$ = .09, conditions with slower scan rates in the group with CP. Response selection in the modified condition ($G_{modified}$) was by pressure switch (BigRed®, AbleNet, Inc. Roseville, MN).

A brief manual was utilized to ensure standardized training for IT task completion was employed for all participants. Assessments were completed in one session. Participants were given breaks as needed either by direct request of the participant, or by observation of the examiner that the participant was fatigued or inadequately engaged in testing. Due to the novel nature of the approach, a validity metric of engagement for participation is not available, though considerable care was taken for examiner monitoring of behavioral engagement of participants during testing. Testing was completed on a single day to minimize missed school and travel burden for participants. We randomized standard vs. adapted

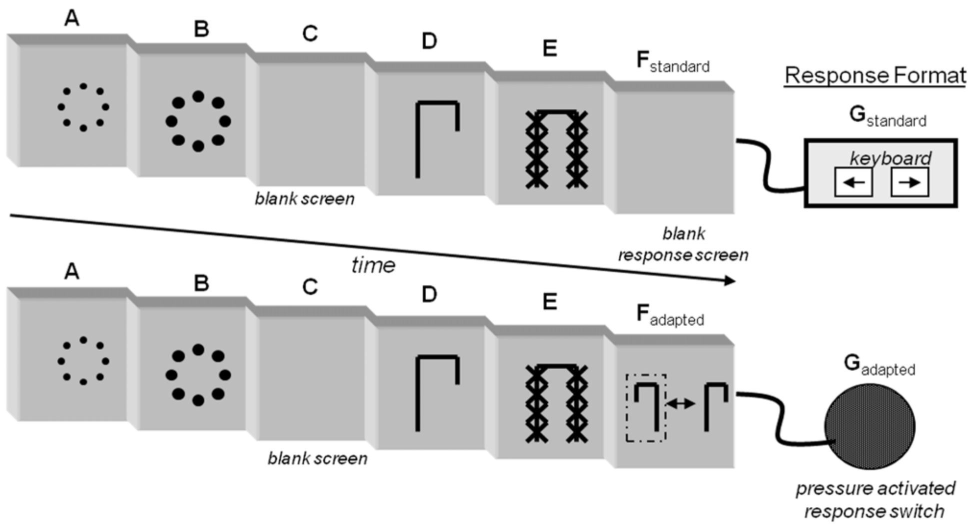

Figure 1. Standard (upper) and modified (lower) visual inspection time tasks. *Note:* In both standard (upper) and adapted (lower) versions of the IT task, participants are presented with a fixation point for 3000 ms (A) which briefly brightens for 1500 ms (B) then clears (C) to alert to pending stimulus presentation (D) of varying duration. Stimuli are immediately followed by a visual mask (E) to prevent visual rehearsal of the target stimulus. Standard administration (upper) followed with a blank screen ($F_{standard}$) and keyboard response ($G_{standard}$), while the adapted administration (lower) showed selection options with an alternating selection box ($F_{adapted}$) with pressure switch response to target ($G_{adapted}$).

administration order, and subsequently, participants completed neuropsychological measures.

Individual participant IT was determined by titration of the stimulus onset asynchrony, or, SOA (i.e., the time between the onset of the target stimulus and the mask). The SOA was modified after individual trials depending upon accuracy, with SOA increased by 17 ms after one incorrect response and decreased by 17 ms after a participant obtained 3 sequential correct responses at a given SOA. IT was calculated by averaging the SOA over the response data spanning eight directional reversals of SOA. This staircase time estimation technique is previously described by Wetherill and Levitt (Wetherill & Levitt, 1965). Group differences in mean number of trials and task duration were not statistically significant for either the standard or modified conditions.

Standard processing speed measures

All participants completed the Wechsler Intelligence Scale for Children – III (Wechsler, 1991) PS subtests including Coding and Symbol Search for use in analyses of criterion validity. The Coding subtests requires participants to reference a symbol coding key to transcribe appropriate symbols into empty boxes corresponding with provided numbers. The Symbol Search subtests requires participants to survey a row of symbols and indicating with cancelation of a yes or no box whether provided item symbols are present in the row of symbols to the right of the target symbols. Both PS measures are speeded tasks in which performance is scored based on the number of items correct in 120 s for Coding, and the number correct minus the number incorrect in 120 s for Symbol Search. The PS Index, derived from the Coding and Symbol Search scores has significantly greater reliability than either subtest (Watkins & Smith, 2013).

Peabody picture vocabulary test – III (Dunn & Dunn, 1997)

The PPVT–III is an individually administered test designed to measure single word receptive vocabulary. The PPVT-III has a test–retest reliability ranging from .91 to .94 (Mdn .92). The PPVT–III has excellent validity as demonstrated by its high correlations with other measures of verbal ability (Kaufman Brief Intelligence Test – Vocabulary, .81; Wechsler Intelligence Scale for Children – Third Edition Verbal Comprehension Index, .91).

Gross motor function classification system

Functional mobility was characterized using the Gross Motor Function Classification System (GMFCS; Palisano et al., 1997). The GMFCS, originally designed for use with children with CP, assesses gross motor functioning and activity limitations with a five-level ordinal scale. This scale differentiates between functional levels based on gross motor limitations and need for assistive devices for mobility. The GMFCS was administered by trained examiners at the time of study participation. Interrater reliability is .75, and both content and predictive validity have been well demonstrated in child and adult populations (Palisano et al., 1997; Sandstrom et al., 2004; Wood & Rosenbaum, 2000).

Data analyses

Because of the non-normal distributions of the IT data, these variables were logarithmically transformed prior to any statistical analyses (Kaufman et al., 2014). For the same reason, we used Spearman instead of Pearson correlations when comparing various psychometric measures.

Results

The average performances of the two groups on the psychometric variables of interest are presented in Table 2. There was a statistically significant main effect of group on the standard IT task, $F\ (1, 113) = 21.82$, $p < .01$, $p\eta^2 = 0.16$, as well as the modified IT task, $F\ (1, 113) = 16.09$, $p < .01$, $p\eta^2 = 0.13$, with the children with CP consistently having longer ITs than the TD group. In addition, the average performance of the group with CP on the WISC–III PS index was lower than that of the TD group, $F\ (1, 113) = 58.04$, $p < .01$, $p\eta^2 = 0.34$.

In order to determine the extent to which IT tasks and WISC–III PS measured overlapping constructs, Spearman correlations were computed between the respective variables. Due to significant group differences in race and ethnicity proportions, TD race and ethnicity subgroup correlation matrices (African American, non-African American) were examined and subgroup differences were not statistically significant; therefore, analyses were conducted

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Table 2. Inspection time and processing speed by group

Variable	CP (n = 45)		TD (n = 68)	
	M	(*SD*)	*M*	(*SD*)
Log $IT_{standard}$ (msec)	3.94	(0.83)	3.39	(0.43)**
Log $IT_{modified}$ (msec)	3.97	(0.80)	3.48	(0.49)**
PSI (standard score)	80.78	(16.50)	103.21	(14.50)**
Coding	5.49	(2.93)	10.19	(2.74)**
Symbol Search	7.60	(3.58)	10. 90	(3.03)**

Note: CP = cerebral palsy; TD = typically developing; IT = Inspection Time; PSI = Processing. *p < .05; **p < .01.

Table 3. Spearman correlations between inspection time variables and processing speed by group

Variable	1	2	3	4	5	6
Log $IT_{standard}$	–	0.83**	−0.49**	−.30*	0.31*	0.48**
Log $IT_{modified}$	0.69*	–	−.57**	−.27	0.32*	0.52**
WISC-III PSI	−0.19	−0.21	–	0.47**	−0.44**	−0.45**
PPVT-III	−0.11	−0.12	.39**	–	−0.06	0.03
GMFCS					–	.22
MACS						–

Note: Cerebral Palsy group correlations are above the diagonals, whereas Typically Developing group correlations are below the diagonal. WISC–III = Wechsler Intelligence Scale for Children—Third Edition. Correlations with GMFCS and MACS are only provided for the group with CP; GMFCS is not calculated for typically developing peers.
*p < .05, ** p < .01.

with the pooled TD sample. Table 3 presents Spearman correlation matrices, reflecting two potentially important phenomena. First, statistically significant correlations were noted only in the group with CP, including a significant difference in the correlations between $IT_{modified}$ and PSI in the group with CP versus TD group, $z = 2.19$, $p < .05$. Second, in the group with CP, the correlations with PS were fairly similar for the Adapted as compared to the Standard IT task, with no statistically significant difference between them ($z = 1.51$, $p = .61$), reinforcing largely equivalent levels of concurrent validity. At the PSI subtest level of analyses, the bivariate correlations between IT tasks, Coding and Symbol Search yielded similar group differences in associations to those obtained with PSI, with the exception of a relatively weaker correlation between $IT_{modified}$ and Symbol Search, $r = 2.8$, $p < .05$. Subsequent analyses were conducted with PSI scores, only. Interestingly, within the group with CP, MACS levels were significantly correlated with IT task performance as well as the PSI index and subtest scores, with lower performances associated with greater impairment in dexterity. Associations with length of gestation were not statistically significant. Finally, associations between the IT task performances and PPVT-III scores were marginally significant in only once instance and the between-group differences in strength of those associations was not statistically significant.

We then explored the contribution of other variables to performance on the two IT tasks in the group with CP. Specifically, we wanted to determine what proportions of the variance in performance on the two IT tasks could be explained by, respectively, fine motor dexterity, and a traditional measure of PS. We computed two linear regression models, one for the Standard IT task, and one for the Modified IT task. Table 4 presents these findings. Inspection of this table suggests that, in both models, PS was the only statistically significant predictor of IT performance. The total amount of variance (R^2) accounted ranged

Table 4. Regression models for inspection time (IT) tasks in group with cerebral palsy (n = 45)

	Standard IT task			Modified IT task		
Variable	SRC	*t*	*p* <	SRC	*t*	*p* <
MACS total score	0.14	0.91	.37	0.17	1.25	.22
WISC–III Processing Speed	−0.35	−2.28	.05	−0.51	−3.74	.001

Note: SRC = standardized regression coefficient.

from 0.23 for Standard IT, F (3, 41) = 4.12, $p < .02$, to 0.37 for Modified IT, F (3, 41) = 8.20, $p < .001$. Inspection of collinearity diagnostics did not reveal any threat to the validity of either model (e.g., all variance inflation factors < 1.25).

Finally, in the sample of children with CP for whom both traditional PS and IT tests were accessible, we evaluated the accuracy with which either of the two IT tasks could classify the children as having slowed speed of processing. For this purpose, we defined impairment on all variables (Standard IT, Modified IT and WISC–III PS) as a level of performance that would be below the 10^{th} percentile in the distribution of scores of the TD group. Using this criterion, rates of impairment in the group with CP were 44.44% ($n = 20$) on Standard IT, 37.78% ($n = 17$) on Modified IT, and 48.99% ($n = 22$) on WISC–III PS. The Standard IT task correctly classified 68.89 of the children with CP with regard to the presence or absence of impairment on WISC–III PS, with a sensitivity of 63.64%, a specificity of 73.91%, a likelihood ratio of 2.44 and an area under the curve of 0.69, indicating adequate to good performance. The Modified IT task correctly classified 75.56% of the same children, with a sensitivity of 63.64%, a specificity of 86.96%, a likelihood ratio of 4.88 and an area under the curve of 0.75 indicating good performance.

Discussion

This study was conducted to examine the validity of IT tasks as accessible measures of PS in children with CP. Children with CP, compared to a group of typically developing peers who did not differ in age, gender, socioeconomic status or receptive vocabulary, show significantly slower IT and lower traditional PS performance (WISC-III PSI). Children with CP exhibited lower performance on WISC-III PSI and both IT tasks. Shank et al. (2010) found slowed IT in children with CP with a standard IT task using participant samples that overlap with the present study samples. In this study, children with CP exhibited similarly slowed performance on both standard and modified IT tasks.

IT and PSI performances were significantly correlated only in the group with CP in the TD group; this suggested that in children with CP, but not necessarily in TD children, IT performance shared considerable variance with traditional paper-and-pencil tests of speed of processing. In a previous study, IT was significantly correlated with WISC-III Coding and Symbol Search subtests in a TD sample, but the correlation with the PS Index was not reported (Edmonds et al., 2008). As discussed in Kaufman et al. (2014), our IT approach designed for greater accessibility yields positive skew in the TD population that may hinder the ability to detect associations with other variables in this group. In addition, the group with CP exhibited much greater variability in IT performance than is noted in the TD group and the TD group had mildly restricted range in PSI scores which also may have attenuated IT-PSI correlations in the TD sample. In the group with CP, IT classification accuracy for impaired PSI included modest sensitivity and good specificity, particularly for the modified measure.

Thus, as measures of PS in children with CP, IT tasks demonstrate adequate concurrent validity and would be valid proxy measures of PSI in this population This is particularly important because for a subset of children with CP, graphomotor tasks are inaccessible. However, due to limited sensitivity of IT to PSI impairment, IT tasks would not be first choice measures when PSI tasks are accessible. However, lack of significant concurrent validity in the TD group suggests the possibility that IT performance may measure somewhat different constructs in different populations.

Understanding of the neuropathological substrate of slowed PS associated with CP, is complicated by a limited understanding of the neural substrate of PS in the typically developing population, as well as the heterogeneity of etiology and overt manifestations of CP. In typically developing right-handed children, simple reaction time has been associated with the integrity of the right hemisphere, fronto-occipital fasciculus and left cortico-spinal tract (Scantlebury et al., 2014). In right-handed young adults, speed of performance on N-back tasks is associated with increased activation of broad frontoparietal regions, though note is made that this is not as robust as primary regions of activation including bilateral occipital, left pre- and post-central gyri, right fusiform and right thalamus (Takeuchi et al., 2012). Slower processing has been associated with greater recruitment of prefrontal regions (Rypma et al., 2006). Periventricular leukomalacia (PVL), commonly associated with CP, frequently affects the retrolenticular portion of the internal capsule and posterior thalamic radiant tracts. While PVL is suspected as a risk factor for slowing (Bottcher et al., 2010), there are no studies to date that clearly demonstrate this association.

In addition to findings using a traditional IT testing strategy in which a two-button response period with a blank screen follows presentation of test stimuli, this paper also presents findings for a modified task version which includes dichotomous choice scanning and a single button response format. While little is gained in the modified IT task from a performance perspective, for those who cannot do either the standard clinical PS measures or the traditional IT task version these data demonstrate that the further modification is similarly valid using basic existing switch technology that is often familiar to individuals with severe motor impairment. As the IT task does not serve as a perfect proxy measure, rather than suggesting utilization of the IT testing strategy as an ideal approach, it is offered as an alternative strategy for assessment for PS when necessary due to motor impairments.

There are a number of methodological limitations that affect the generalizability of these findings. The sample with CP was largely at GMFCS and MACS Levels I, II, and III with average cognitive ability and a higher percentage with history of preterm birth, and therefore was not representative of the entire population of children with CP. Similarly, the small sample size precluded examining CP subtype differences based on motor type and topography. It would not be possible to study concurrent validity of IT tasks using PSI tasks in children with more significant motor impairments; however, validation studies of IT tasks using other accessible tasks including auditory IT tasks would be important in future studies with children with CP with more significant motor impairments. Our efforts organize around maximally reducing the motor demands associated with completion of these measures. Because the study required participants to be able to complete both “gold standard” measures of clerical PS in addition to the IT measure, we do not have sufficient variability in MACS scores in this study to explore the influence of fine motor dexterity on performance. As this does not directly influence examinations of validity testing, a future examination of this distinct from a validation study could be of interest. While the current study focuses on validation of the IT measure, future studies examining utilization of this measure in the clinical population with CP more broadly would benefit from inclusion of a more granular measurement of motor impairment than the MACS, such as the Movement Assessment Battery for Children – 2 (Henderson et al., 2007).

The significant variability in CP IT task performance may stem from a number of factors including working memory demands, visual perceptual demands, and fatigue, each of which would have to be studied by controlled task manipulations. The IT task demands may entail greater working memory loads than typical clinical PSI tasks, as the target stimulus is not present at the time of response. Related, the modified IT task includes a serial scanning strategy in which both response options are presented for dichotomous choice selection; the presence of both choices likely modifies the processing demands during choice making relative to the standard administration version. This issue further adds to target construct concerns as slower scanning speeds and longer response consideration could change the memory burden. Children with CP, particularly those with PVL, are at risk for visual and visuoperceptual impairments that may confound IT task performance, highlighting the need for further study of IT with auditory stimuli. While PSI is strongly correlated with the PPVT, the PPVT-III correlations with IT task performance are much less compelling, which suggests that the IT task is assessing more elemental functions such as visualization speed, relative to the more complex demands of the graphomotor PS measures. The staircase titration to establish IT threshold may cause fatigue in a population already prone to daytime fatigue (Sandella et al., 2011). Similarly, impairments in vigilance may confound IT performance in a population that is at risk for ADHD symptoms (Shank et al., 2010). Lastly, neuroimaging was not included in the study protocol, precluding more detailed characterization of the sample, as well as within group study of the neural substrates of IT performance.

This study provides partial support for use of traditional and modified IT tasks as measures of aspects of PS in children with CP. Future studies of IT in children with CP will need to utilize nonvisual stimuli and control for factors such as working memory and vigilance. Working memory demands can be studied by varying response prompt delay time. Vigilance can be studied by comparing staircase titration to odd-ball procedures. Similar to traditional PS measures that rely on speeded motor response, IT task performance relies on a complex set of cognitive functions and speed cannot be separated from perceptual content.

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