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REVIEW

Seeing the gaps: a systematic review of visual perception tools for children with hemiplegia

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Abstract

Purpose. Visual perception difficulties are common in children with cerebral palsy – hemiplegia, however it is not known which assessment tool is the best for this population. This systematic review evaluates the clinimetric properties of visual perception assessments for children with hemiplegia.

Method. Databases were searched for assessments that: (i) measured visual perception; (ii) were reported in studies with children with hemiplegia and (iii) had clinimetric data available to assessors.

Results. Three assessments met criteria: the Test of Visual Perceptual Skills (TVPS), Motor-Free Visual Perceptual Test (MVPT) and Developmental Test of Visual Perception (DTVP). Factor analysis has been completed for the TVPS and DTVP, with both assessments and especially the TVPS, demonstrating some subtests that do not load significantly for the first factor of motor-free visual perception. All three assessments demonstrate variable construct and criterion validity with other clinical assessments. The DTVP, MVPT and TVPS demonstrate high test-retest reliability for total scores, but individual TVPS subtests are less reliable.

Conclusions. The MVPT and DTVP show the best clinimetric data, however, less research has been completed on these tests than the TVPS. Further research is required to confirm the validity and reliability of the MVPT and DTVP for children with hemiplegia.

Keywords: *Visual perception, hemiplegia, cerebral palsy, children, assessment*

Introduction

Approximately 35% of children with cerebral palsy have hemiplegia, which is a predominantly unilateral distribution of sensory and motor impairments consequent to a contralateral lesion of the immature brain [1]. Visual function is often impaired in children with hemiplegia [2–5] and needs careful assessment in order to determine the most appropriate intervention. In a study of 105 children with cerebral palsy, significant visual deficits were identified with over 80% displaying abnormal function on the developmental eye movement test, 20.9% displaying oculomotor difficulties and 32.4% displaying visual perception deficits [6]. Studies report that visual deficits may exist in as many as 78% of children with hemiplegia and many children have abnormalities in more than one domain [7].

Visual deficits in children with hemiplegia are most commonly identified by tests that measure aspects of visual registration such as acuity, visual fields or tests of ocular motor function, for example nystagmus. While some children will demonstrate problems in these areas [3], assessment of visual registration needs to be considered as only one part of a more extensive assessment framework that includes all phases of visual processing such as registration, as well as the cognitive vision aspects of perception and visual motor integration. In this framework, visual registration is the point at which an individual becomes aware of visual information [8] and is the first stage of visual processing. Deficits

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in registration will affect competency in subsequent processing phases. Visual perception is defined as the ability to understand [9], interpret or give meaning to information from seen objects or environments [10]. Other important aspects of cognitive vision, such as arousal, attention and memory of past experience also have a significant impact on visual registration and perception [11,12]. For visual function to be fully assessed, tests need to assess the breadth of all these aspects when used in combination. The second phase of this visual processing sequence, visual perception, has significant implications for function and may impact motor planning for bimanual activity and gross motor tasks in children with hemiplegia.

Two cortical visual pathways have been described in processing the visual information that comes from the occipital cortex: the dorsal stream and the ventral stream [13]. The dorsal stream processes information coming from the occipital cortex to the posterior parietal cortex [13]. While traditionally thought to have its role in identifying the spatial aspects of visual perception, more recent research shows the dorsal stream's function is in the real-time control of action, transforming moment to moment information about the location and disposition of objects into the coordinate frames required to perform the action [14]. Rather than producing visual percepts, the role of the dorsal stream is to facilitate skilled actions. In contrast, the ventral stream, which processes information from the occipital cortex to the temporal cortex, computes the size, location, shape and orientation in relation to other objects and surfaces in the scene that is necessary to recognise objects. The ventral stream processes the identity of the object and its location within the scene, not its disposition with respect to the observer, with a particular emphasis on memory of past experience and the storage of visual percepts for future use [14]. While both streams are necessary for processing visual information to achieve perception and skilled action, both serve significantly different roles. This has been observed in patient populations, with some patients with posterior parietal lesions having difficulty configuring movements to pick up objects, but having no difficulty describing the size, orientation or shape of objects, indicating dorsal stream dysfunction and similarly other patients who are unable to distinguish between objects but have preserved ability to use form perception to guide a broad range of movements, indicating ventral stream impairment [15].

Visual perception includes several specific subsections [16] (as shown in Table I). All of these subsections contribute to visual perception and have important implications for functional tasks. Visual perception, however, is not inclusive of those tests that are primarily used to assess the presence of unilateral spatial neglect (USN). While there are some similarities between deficits in visual perception and USN, it is important to consider that USN is characterised by the failure to report or respond to people or objects presented to the side opposite a brain lesion [17]. In USN, the failure to respond to stimuli cannot be accounted for by either motor or sensory deficits [18] (as is the case for visual perception difficulties in children with hemiplegia). It is, therefore, necessary for USN and visual perception deficits to be examined separately, using different assessment tools.

Tests of Visual Motor Integration, another important aspect of visual function, are similarly not included in the category of visual perception assessments. Visual perception is an aspect of visual motor integration, but as this is essentially about the motor output as a result of perceived visual information, this process and its assessments are considered one step on from pure visual perception.

Visual perception is often impaired in children with hemiplegia and has a significant influence on function [19–22]. Studies report that children with CP perform significantly worse than age-matched typically developing children (TDC) on the Motor-Free Visual Perceptual Test (MVPT) and the Test of Visual Perceptual Skills (TVPS) [19–21]. Visual perception is more impaired in children with spastic cerebral palsy subtypes [23] and can co-exist as a separate deficit to an impairment in non-verbal intelligence [24]. Children with hemiplegia, who have no cognitive deficits, scored significantly lower on visual perceptual tests than TDC, with this having some predictive ability for specific school function measures, such as reading and writing [25].

Visual perception deficits in children with hemiplegia are prevalent and require careful assessment and management by clinicians. However, selection and application of visual perception assessment tools for this population is inconsistent. Previous studies have investigated the clinimetric properties of individual assessments, but none have systematically reviewed all of the available visual perception assessments used in this population. This review aims to synthesise and clarify the clinimetric and administration properties of available visual perception assessments, to facilitate more informed implementation for children with hemiplegia.

Method

Search strategy

Papers were identified by searches of six computerised bibliographic databases: PubMed (1950 to July 2010), Medline (1982 to July 2010), CINAHL

Table I. Assessments for the perception of the visual modality.

	Domain	Spatial				Modality specific: characteristics
Subtest	Definition	Shape	Orientation	Size	Temporal	Colour
Visual discrimination	A subject's ability to match or determine exact characteristics of two forms by identifying the matching form among a group of similar forms.	✓	✓	✓		
Visual spatial-relationships/ visual spatial orientation	Describes a subject's ability to determine from a group of forms of identical configuration, the one single form or part of a single form that is going in a different direction from the other forms.		✓			
Visual form-constancy	A subject's ability to find a specific form that may be a different size, rotated, reversed or hidden among other forms from the baseline form.	✓	✓	✓		
Visual figure-ground	Describes a subject's ability to perceive a form visually, and to find this form hidden in a conglomerated ground of matter.	✓	✓	✓		
Colour discrimination	Describes a subject's ability to perceive the difference of varying colours.					✓
Interstimulus interval – unilateral	Describes a subject's ability to indicate differences in order of presentation of stimuli to a single hemispace.				✓	
Temporal order judgment	Describes a subject's ability to distribute attention across hemispaces to stimuli of varying stimulus onset asynchronies.		✓		✓	

(1981 to July 2010), EMBASE (1966 to July 2010), Cochrane (1996 to July 2010), Web of Science (1900 to July 2010). Key search terms were matched to medical subject heading (MeSH) and were exploded or used as keywords. These included 'hemiplegia' and 'cerebral palsy' combined with terms to limit the search to the paediatric population ('child' OR 'adolescent'). These were added to terms specific to vision ('vision' OR 'visual'). The reference lists of identified papers were used to ensure an exhaustive search.

Inclusion and exclusion criteria

For the purpose of this review, hemiplegia was defined as a form of cerebral palsy that affects the motor and sensory outcomes predominantly on one side of the body. Visual perception is defined as the ability to understand, interpret or give meaning to visual information [9,10,13]. Visual perception assessments traditionally include subtests such as visual discrimination, visual memory, visual-spatial relationships, form constancy, visual-sequential relationships, figure-ground and visual closure and other assessment items that authors claim measure visual perception [16,26].

To be included in this review, assessments were required to: (1) measure visual perception (denoted by the ICF domain b1561 as 'mental functions involved in discriminating shape, size, colour and other ocular stimuli' [27]; (2) contain at least 30% of items related to assessment of visual perception; (3) be reported in studies with children with hemiplegia secondary to injury of the brain (body structure) in this population (ICF: s110) [28]; (4) have some published clinimetric data from any population available for review.

Assessments were excluded if they: (1) were published before 1950; (2) were not published in English; (3) assessed other aspects of seeing and related functions (ICF b210 – b229, e.g. visual acuity; visual field; quality of vision; sensing light and colour, distant and near vision, monocular and binocular vision; visual picture quality; impairments such as myopia, hypermetropia, astigmatism, hemianopia, colour-blindness, tunnel vision, central and peripheral scotoma, diplopia, night blindness and

impaired adaptability to light; functions of external and internal muscles of the eye, eyelid, external muscles of the eye, including voluntary and tracking movements and fixation of the eye, lachrymal glands, accommodation, pupillary reflex; impairments such as nystagmus, xerophthalmia and ptosis); (4) assessed visual-motor integration, reading ability or USN and (5) did not have published clinimetric data available to the assessors.

Data extraction

A data extraction sheet was adapted from the CanChild Outcome Measures Rating Form [29], which assesses the validity, reliability, responsiveness and clinical utility of each test. An assessment is considered valid if it measures exactly what it claims to measure [30]. This includes content, construct and criterion validity. Reliability is the degree to which an assessment achieves the same score when measured on different occasions, regardless of the time of administration (test-retest), or tester (intra-rater, inter-rater) [30]. In this review, clinical utility was rated according to ease of administration, cost, meaningfulness of scores and acceptability of measure for assessors and participants. Time for administration, manual availability and clarity of instructions, assessment format and training required for administration were considered.

Criterion validity can be measured using Pearson product moment correlations. For factor loadings, if an unidimensional factor adequately describes each subscale, the factor loadings for the observed construct would be large (>0.35) [31,32]. For item analysis and inclusion, Kline (1986) recommends that items scoring lower than a correlation of 0.2 with the subtest should not be included in the assessment [33]. Statistics considered most appropriate for measuring inter- and intra-rater reliability are intra-class correlation coefficients (ICCs) or kappa coefficients (κ), not Pearson's correlation or percentage of agreement between rater [30,34]. ICCs are more appropriate for measuring reliability than Pearson's correlations as they incorporate error and are therefore a true measure of agreement [35]. For ICCs, measures of 0.8 or above were considered excellent, measures of 0.6–0.79 as adequate and measures less than 0.6 poor [29]. For kappa statistics, measures of 0.41–0.6 were considered moderate, 0.61–0.8 substantial and 0.81–1 almost perfect [36]. For internal consistency, Cronbach's α coefficients should be above 0.7 [33]. Correlations between 0.0 and 0.25 exhibit little relationship, values between 0.26 and 0.49 exhibit a low relationship, values between 0.5 and 0.69 exhibit a moderate relationship and values >0.7 exhibit a high relationship[33,37]. Internal consistency can also be measured by the split-half technique with Spearman Brown formula correlates or the Kuder-Richardson technique (KR-20), which allows the analysis of all possible splits and may be used to increase the support of internal consistency measures.

Results

Initial search of databases yielded 112 papers. Ninety-three were excluded because they contained no reference to visual assessments in children with hemiplegia in the title or abstract. Nineteen papers contained information about a total of 44 different visual assessments that had been utilised in the target population. Paper selection was confirmed by two independent raters (MA and LJ), who were clinicians and researchers with experience in the study topic area.

Of the 44 assessments identified, three met the inclusion criteria: the MVPT, TVPS and Developmental Test of Visual Perception (DTVP). Although some papers referred to revised test versions, as revisions were minor and limited new clinimetric data were reported, all tests will be referred to by their original names.

Forty-one (41) assessments were excluded. Thirty-three did not measure visual perception and related to either registration or visual response generation [3,4,6,7,38–46]. Four tests were excluded due to either not having any clinimetric data available [47–49] or being published in a language other than English [40]. Two assessments were excluded as they are part of much larger batteries of assessments and only have a small section of their test dedicated to visual perception [50,51]. The Visual Motor Integration test (VMI) [44,52] was excluded as the visual perception content comprised less than 30% of the total test battery. The Star Cancellation test was excluded as it primarily assesses visual spatial neglect [38].

Assessment characteristics

Characteristics of the three assessments meeting criteria are shown in Table II. All have a defined age range in children. Each has clinimetric data available from normative studies; however none have data from studies of children with hemiplegia. There is considerable overlap in content between the subtests of the examined assessments. There is, however, substantial variation in the manner in which these subtests are applied.

The MVPT is a discriminative and evaluative assessment tool used in children aged 4–11 years

Table II. Description of visual perception assessments used in children with hemiplegia.

Assessment tool	Purpose	Age range (years)	Normative sample	Scale/items/description
Motor-free Visual Perceptual test (MVPT) [19,24,44]	Discriminative/ evaluative	4–11 years (can be used to adulthood)	1856 (2001–2002) – representative of US population –age 4 years to elderly MVPT-R uses norms from original MVPT, except for additional children in the 9–11 year age group [10].	Spatial relationships, visual discrimination, figure-ground, visual closure, visual memory.
Test of Visual Perceptual Skills revised (TVPS-R) [44]	Discriminative/ evaluative	4–13 years, with upper level assessment available (12–19) years	1032 children aged 4–13 representative of 1990 USA census. 1826 US sample age 4 years to older adult	Visual discrimination, visual memory, visual spatial-relationships, visual form-constancy, visual sequential memory, visual figure ground, visual closure.
Developmental Test of Visual Perception (DTVP) [25]	Descriptive	4–10 years	1972 children across 12 states of USA 1992	Eight subtests measuring various aspects of visual perception. Measures visual perception in 'motor reduced' and 'motor enhanced' subtests

MVPT, Motor-free Visual Perceptual Test; TVPS, Test of Visual Perception Skills; DTVP, Developmental Test of Visual Perception.

[10]. It measures the subtests of spatial relationships, visual discrimination, figure-ground, visual closure and visual memory, all of which are aspects carried out by ventral stream processing. The MVPT subtests cannot be scored individually. The authors state that this test is intended as a quick and easy measure of visual perception and should not be used to determine specific areas of difficulty. The TVPS is a discriminative and evaluative tool designed for children aged 4–13 years with an upper level assessment available up to the age of 18 years [16]. It includes subtests of visual discrimination, visual memory, visual-spatial relationships, visual form constancy, visual sequential memory, visual figure ground and visual closure, which, similar to the MVPT, are also aspects of ventral stream function. The DTVP is a descriptive test for children aged 4–10 years [26]. It measures visual perception of spatial relations, position in space, form constancy and figure-ground in both 'motor-reduced' (i.e. requiring no motor output) and 'motor-enhanced' (i.e. requiring a motor task) subtests, thus assessing both dorsal and ventral stream function [14].

Validity

The DTVP and TVPS have some evidence of content validity. Factor analysis and confirmatory analysis have been completed for the TVPS, showing that two subtests (visual memory and visual form closure) do not load strongly for the first factor (motor-free visual perception) and are not related to the other tests, which suggests that they may be measuring something other than visual perception [31,32]. The subtests that do load significantly for the first factor are visual discrimination, visual-spatial relationships, visual-sequential memory, visual figure ground and visual closure [31]. Similarly, for the DTVP, factor analysis suggests that the subtests of position in space, visual closure and form constancy relate to the first factor, visual perception, while the subtests of eye–hand coordination, copying and visual motor speed relate to the second factor, visual motor integration. Figure ground and spatial relations are equally related to both the first and second factors in the DTVP [26]. All three assessments demonstrate evidence of construct validity, with the MVPT showing a moderate relationship with age, academic performance and ability to identify children and adults with difficulties [10]. The TVPS has had more extensive research completed on content validity, and demonstrates low to moderate intercorrelations of the subscales, which suggests that the scales are related, but that they assess different aspects of visual perception [16,31,32,53]. Rasch measurement model analysis has also been applied to the TVPS subtests: three scales (visual memory scale, visual-spatial relationships scale and visual form constancy scale) had an item that displayed

misfit and five scales (visual memory scale, visual spatial relationships scale, visual sequential memory scale, visual figure ground scale and visual closure scale) had an item that displayed differential item functioning (DIF) based on gender. Only the 'Visual discrimination' subscale did not have these flaws [54]. The TVPS does, however, show high ability to detect differences between client groups (e.g. children with cerebral palsy *versus* children with a history of preterm birth or CVA) [22,55,56]. The DTVP can accurately distinguish specific populations with visual perceptual difficulties, such as children with learning difficulties [57], but may not be suitable for use within other populations/cultures in which it has not yet been validated (for example, children from Hong Kong demonstrated ceiling effects in subtests 1, 2 and 5 [58]). The MVPT also recognises the differences between TDC and children with diplegia [20]. For criterion validity, MVPT and TVPS demonstrate variable results with several related assessments (see Table III). The DTVP shows moderate to high criterion validity relationships with several other related assessments [59,60,61–65].

Reliability

The MVPT displayed excellent inter-rater reliability in one study on children with learning disabilities and TDC [65], but this study used the less satisfactory Pearson Product Moment Correlation instead of the ICCs measure, which makes it difficult to interpret their report. Inter-rater reliability of the DTVP is moderate but lacks significant data [26]. Test-retest reliability completed on the whole MVPT seems to reveal high results for two age groups of TDC (4–10 and >11years) [10] and another group of TDC and children with learning disabilities (ICCs = 0.63–0.79) [65]. Using the same assessment in children with learning difficulties and TDC, adequate to high ICCs were achieved [65]. The TVPS shows high test-retest reliability for the test as a whole when tested in children with learning difficulties, but this reduces when the test-retest reliability of the individual tests is considered [67]. From the one study completed, DTVP reports high test-retest reliability in TDC [26]. The MVPT demonstrates high internal consistency with high Cronbach's α coefficient scores, Spearman Brown and Kuder-Richardson scores [10]. Internal consistency for the subtests of the TVPS varies between studies from low to excellent (see Table IV). According to one study, almost 50% of TVPS items had poor correlation with their respective tests and only three showed acceptable correlation [59]. Other studies report higher internal consistency. While the results show some variability, DTVP generally demonstrates high internal consistency [26,60].

Clinical utility

All three assessments have high clinical utility – they are of a similar cost, do not require training to implement and are relatively easy to administer and score (Table V).

Discussion

To our knowledge this is the first systematic review of visual perception assessments for children with cerebral palsy – hemiplegia. It identified three visual perception assessments: MVPT, TVPS and DTVP. There is consistency among the assessments in their subtest selection and the clinical utility of all the tests make them feasible for children and clinicians. Visual perception is a complex area of assessment and it should be acknowledged that these three assessments are a strong basis on which to begin the investigation into the best assessment tools for testing visual perception in children with hemiplegia. From available data, the MVPT and the DTVP show the strongest clinimetric properties and, while still requiring further assessment to confirm their reliability and validity, would be recommended for clinical practice. In terms of the neurobiological basis of visual perception, it could be argued that the DTVP subtests, which include both motor-enhanced and motor-reduced subsections, assess both the ventral and dorsal streams of visual processing as compared to those of the MVPT, which only assess ventral stream function. However, both show strong clinimetric properties and contribute important aspects to the assessment of visual perception.

The TVPS is the most rigorously investigated of the three assessments; however, this systematic review has uncovered significant flaws in both its validity and its reliability. In relation to internal consistency of items, if one was to adhere to the recommendation of only including subtests that have internal consistency α coefficients of >0.7 [32], only three of the subtests would remain in the assessment.

In examining construct validity, Klein et al. (2002) found that only 12 of the 16 items of the original TVPS test loaded significantly for the first factor in visual memory and visual form constancy subtests [32]. This suggests that these two subscales may be measuring something different to the other subtests of this assessment. These results are reinforced by Brown et al. (2003) who state that items with correlations less than 0.2 should be excluded, according to previous research standards [53]. For

Table III. Validity of visual perception assessments used in children with hemiplegia.

Assessment tool	Content	Construct	Criterion
MVPT-R		Age correlation 4–10 years: 0.72; 11–39 years: 0.37; Cognition: low $r = 0.22$–0.37; Academic achievement: moderate $r = 0.33$–0.51 [10]	Frostig subtests $r = 0.38$–0.73; DTVP-2 subtests $r = 0.27$–0.82; Metropolitan Readiness Tests copying subtest $r = 0.40$; Durell analysis of reading deficits $r = 0.46$ [10]
		Typically developing children *vs.* physically impaired: scanning time difference $p < 0.001$ [63]	Diplegia *vs* controls: PQ $p < 0.005$; PA $p < 0.05$. MVPT: PA $r = 0.888$; PQ $r = 0.868$ [20]
		Significant differences on scanning time $p < 0.025$ and errors $p < 0.05$ in adults with hemiplegia *vs* controls [64]	Frostig = 0.38–0.6; 0.27–0.74 with DTVP-2 ($p < 0.01$) [61]
TVPS	Mean ratings assigned by the panel on relevance and comprehensiveness of subtests: 3–3.67. At least 83.3% of all ratings were 3 or above [59]	Relationship between TVPS subscales and PQ score: (0.59–0.76) intersubscale (0.15–0.51) [32]	TVMS: 0.07–0.51, VMI: 0.06–0.27, TVMS-R, TAPS-R, TONI-2, TAAS®, TAAS (A), WPPSI-R (V), WPPSI-R (PC), WISC-III (V), WISC-III (PC), WRAT-3 (R): $r = 0.12$–0.45 [16]
		Total: $r = 0.69$–0.73; Between subscales $r = 0.34$ to 0.47 [16]	PQ: WISC-III performance standard score > WISC-III verbal standard score; PQ: WISC-III block design & object assembly > WICS-III digit span & vocabulary subtests; VMI $r = 0.15$–0.39 [32]
		TVPS: Item analysis varied for subscales(0.05–0.96) [16]	MVPT-R ($r = 0.6$); subtests $r = 0.19$–0.59 [59].
		TVPS-R: item analysis for subscales 0.08–0.65 [16]	
	TVPS-R: 5 subtests load for 1st factor (0.38–0.9) Confirmatory analysis Poor: chi square – 35.06; RMSEA 0.065. Good: RMR 0.177; CFI 0.990 [31]	TVPS-R: Item analysis for subscales (0.19–0.72) [53]; 0.01–0.72 – 4 items failed to meet criteria [31]	
		Children with CP *vs* typically developing PQ $p < 0.001$ [22]	
		Preterm significantly lower 5 subtests [55]	
		Discriminant analysis could not classify CP drivers better than random [68]	
	TVPS: 4 subtests load 1st factor. Confirmatory analysis: Poor fit χ^2 68.06, RMSEA 0.11, RMR 0.1, AGFI 0.85 [32].	Learning disabled *vs* controls. TVPS total ($p < 0.0005$) time scores total ($p < 0.000$); discriminant analysis for group membership: visual Short-term memory & visual closure (84.6%) [56].	
	Rasch Measurement Model: three scales of items with RMM misfit and five scales have items with DIF, only 1 subscale displays neither of these faults [54].		
DTVP	Single factor described 9/11 subtests accounting for 50–60% of variation [70].	In spastic diplegia correlated with volume white matter ($r = 0.64$–0.74; $p < 0.01$) [71]	VMI: 0.89 motor items only (0.87 total test); MVPT:0.72 non-motor items only (0.78 total test); WRAT-3 (R):(0.168–0.451) [61]
	DTVP-2: subtests with coefficients < 0.3 for item analysis not included [26].	Children in Hong Kong ceiling effects in subtests 1, 2 and 5. No gender differences except on copying ($p < 0.028$) and figure ground ($p < 0.01$) [58]	In epilepsy PQs with Verbal IQs ($p < 0.001$) ($r = 0.71$): subtests 1–5 (0.5–0.75) PQs with all WISC subtests ($p < 0.001$) ($r = 0.47$–0.65) [66]
	Loads strongly for 1st factor of motor-reduced (0.44–0.84) and 2nd factor of visual motor integration (0.51–0.79).	Learning difficulties different to controls two subtests: $p < 0.05$; 5 subtests: $p < 0.01$ [57].	DTVP-2: MVPT 0.78; VMI 0.87 [23]

(*continued*)

Table III. (*Continued*).

Assessment tool	Content	Construct	Criterion
	52% of items fulfilled requirements with regard to difficulty in preschool children [60]. Correlations to age (0.49–0.65); inter-relationships 0.1–0.57; cognitive test (0.1–0.31) [26]	DTVP-2: 6 basic constructs underlie test. Correlations of subtests to age (0.49–0.65). Inter-relationships among values 0.1–0.57 [26].	Relationship with cognitive test subtests (0.1–0.31). Relationship with WISC-R – 0.68 [26].

MVPT, Motor-free Visual Perceptual Test; TVPS, Test of Visual Perception Skills; DTVP, Developmental Test of Visual Perception; RMSEA, root mean square error of approximation; RMR, root mean square residual; CFI, comparative fit index; AGFI, goodness of fit index; RMM, Rasch measurement model; DIF, differential item functioning; TVMS, test of visual motor skills; VMI, visual motor integration; TAPS-R, Test of Auditory Perceptual Skills-Revised; TONI-2, Test of Non-Verbal Intelligence; TAAS (A), Texas Assessment of Academic Skills; WPPSI-R (V), Weschler Preschool and Primary Scale of Intelligence (Vocabulary); WPPSI-R (PC), Weschler Preschool and Primary Scale of Intelligence (Picture Completion); WISC-III (V), Wechsler Intelligence Scale for Children-3 (Vocabulary); WISC-III (PC), Wechsler Intelligence Scale for Children-3 (Picture Completion); WRAT-3, Wide Range Achievement Test 3.

the TVPS, this would mean that items visual memory 1, visual spatial memory 15 and visual closure 1 fail to meet the psychometric inclusion criteria and are probably measuring another construct [53]. It has been recommended that the TVPS-R not be used as an overall summary performance score for motor-free visual perception, but instead individual subscales should be used, excluding visual memory and visual form closure [53]. Using the Rasch Measurement Model, Brown and Rodger (2009) found that visual discrimination was the only subscale that had items that did not display either misfit or Differential Item Functioning with the model [54], further suggesting that the subscales should not be summed to calculate an overall score for visual perception. Instead, these excluded items would form an appropriate assessment for the memory and cognitive components of the sensory processing that significantly impact visual perception.

Within the framework of visual assessment, the subtests of the TVPS that do not load for the first factor of visual perception are those that examine aspects such as memory (visual spatial memory) or cognition (visual closure), rather than pure aspects of visual perception. That is, visual perception, memory and cognition together contribute to cognitive vision [12]. Those subtests that do, however, fit the factor analysis of visual perception, also closely fit the framework that defines visual perception (see Table I). Visual discrimination, visual-spatial relationships, visual orientation and visual figure ground all contribute to the ability to understand [9], interpret or give meaning to information from seen objects/environments [10], while visual memory and visual closure more closely represent the memory and cognitive aspects, respectively, that impact visual perception (but are not 'perceptual' in themselves). The outcomes of factor analysis for the TVPS in combination with considering the framework and definition of visual perception and cognitive vision [12], may suggest that subtests such as visual memory cannot be appropriately included in visual perception assessments. Although these items have traditionally been added as conventional subtests and visual perception is essential for success in these items, it is not the primary construct that is explored. We recommend that this framework for visual assessment be used for selecting assessment subtests.

Additional difficulties are presented when the test-retest reliability of the TVPS is considered. While the TVPS has high test-retest reliability for the test as a whole, its subtests have poor test-retest reliability [67]. This means that this assessment is unreliable as a series of subtests, and invalid as a complete test.

While all the reviews that have been completed on the TVPS have uncovered significant issues with the assessment that need to be rectified, some positive outcomes can be noted. First, careful examination of the clinimetric properties of the TVPS makes clinicians and researchers aware of the gaps and enables the appropriate, cautioned use of the assessment tool. Second, the issues identified with the TVPS may be resolved by making appropriate revisions to the test design and some authors have provided suggestions as to which items and subtests need to be revised. While this review highlights the need for another revision of the TVPS to address the lack of validity in some of its subtests, it also suggests a need for the other visual assessment tools to undergo the same rigorous evaluation to ensure that they do not have similar faults. It is also important to consider reliability in the context of the populations being tested, bearing in mind that it may be the population and not the test that demonstrates poor reliability. Time of testing, attention, arousal and many other factors individual to the children tested may result in more varied responses than those that

Table IV. Reliability of visual perception assessments used in children with hemiplegia.

Assessment tool	Inter-rater	Test-retest	Internal consistency
MVPT	Pearson product moment correlations = 99% [65].	34 day duration for 4–10 years $r = 0.87$; >11 years $r = 0.92$ [10]; 0.77–0.83 at 20 days; 0.81 total [10] 2.5 weeks apart. Learning disability: ICC PQ: 0.79; PA ICC 0.86. PPC PQ = 0.8 PA = 0.87. Controls: PQ ICC = 0.63; PA = 0.69; PPC PQ = 0.7; PA = 0.77 [65].	Cronbach's coefficient α 4–10 years: 0.69–0.87; >11 years 0.86–0.9; Spearman Brown = 0.81–0.84; 0.88 for total test; Kuder-Richardson = 0.71–0.82; 0.86 for total test [10].
TVPS		1–3 weeks whole test (ICC = 0.81) subtests 0.33–0.78 [67]	α Coefficients for individual age groups r: 0.42–0.89, subscales: 0.73–0.86. PQ reliability coefficient: 0.55–0.84
		Total PQ (ICC 0.88 for DCD and 0.83 for controls). Subtests, DCD (ICC = 0.58–0.75);controls (ICC = 0.5–0.82) [72]	KR-20 for dichotomous data and Cronbach's α total score (PQ) = 0.83–0.91 (composite) [32]
		Whole test ICC = 0.88; subtests ICC 0.38–0.77, individual items (mean $\kappa = 0.32$) [59]	Median for all ages: $r = 0.42$–0.61 Median for all subtests: $r = 0.27$–0.80. Total group: $r = 0.74$–0.85 (composite); SEM = 2 on subtests and 3 on total test [16] Cronbach's $\alpha = 0.9$. Subtest total score correlation $r = 0.53$–0.86. Item level $r = 0.72$–0.91. Only three subtests acceptable >0.7 [59]. Coefficients for subscales: 0.01–0.76; total group 0.74–0.84. PQ reliability coefficient for age = 0.79–0.91. PQ total group = 0.96. TVPS-R PQ and subscale scores = 0.44–0.71, intersubscale correlation = 0.3–0.54 [31]
DTVP	Whole test $t = 0.89$ DTVP-2: subtests 0.92–0.99, Motor-reduced: 0.98; motor-enhanced: 0.95; general visual perception; 0.98 [26].	Total test $r = 0.95$ [26] DTVP-2: subtests 0.83–0.92; Motor-reduced = 0.92, motor-enhanced = 0.93; General visual perception 0.95 [26].	Cronbach's α coefficients = 0.8–0.97 for subtests; 0.93 or above for composites [23]. DTVP-2subtests: coefficient α 0.77–0.96 [26]. Kuder-Richardson formula 20 reliability coefficients for subtests: 0.31–0.58. Full scale $r = 0.72$ [60].

MVPT, Motor-free Visual Perceptual Test; TVPS, Test of Visual Perception Skills; DTVP, Developmental Test of Visual Perception; DCD, developmental coordination disorder.

would be expected from the typically developing population.

The subtests of the TVPS, MVPT and DTVP measure the spatial domains of visual perception, according to the defined framework. However, temporal visual perception as shown in Table I (the perception of timing of visual stimuli) is not examined by any of these assessments. One way that temporal perception can be examined is through the use of temporal order judgment tasks (TOJs). Previously used in the adult stroke population, TOJs examine the processing of sensory stimuli from two different locations [62]. It involves pairs of stimuli being presented to the left and right sides of the body at various stimulus onset asynchronies (i.e. with either the left or the right stimulus preceding). Temporal order judgments have been used in the tactile, auditory and visual modality in the adult population.

The literature consistently reports that deficits in visual perception are relatively common in children with hemiplegia [19,20,23]. A major limitation at

Table V. Clinical utility of visual perception assessments for children with hemiplegia.

Assessment tool	Administration time	Manual/ equipment	Training	Scoring	Interpretation
MVPT	20–30 min/10 min to score	$144 US from Western Psychological Services	Not required, recommended for some professions	Easy	Easy
TVPS	9–25 min	Manual, test plates and 25 record forms $150 US from Psychological and Educational Publications	Not required recommended for some professions	Easy	Easy
DTVP	30–60 min 45 min–1 h [73]	Kit: examiner's manual, 1 reusable picture book, 25 profile examiner record forms, 25 response booklets – $225US from Western Psychological Services.	Not required	Easy	Easy

MVPT, Motor-free Visual Perceptual Test; TVPS, Test of Visual Perception Skills; DTVP, Developmental Test of Visual Perception.

this point, however, is that none of the identified assessments have clinimetric data available for children with hemiplegia. Further work is required to (a) identify exactly which domains are valid factors for visual perception (e.g. size, shape, orientation, colour, intensity/gradient) (b) determine which available subtests address these domains and develop additional tests to create a comprehensive and valid test of visual perception, (c) revise testing procedures to increase reliability, and (d) evaluate these parameters in the hemiplegia population. To achieve this, appropriate changes need to be made to current tests (e.g. TVPS) and more reliability and validity data need to be collected on other tests (e.g. MVPT and DTVP) within the hemiplegia population. In addition, further work on other identified visual assessments and the development of new suitable tests for children with hemiplegia to fully assess the spatial, temporal and modality specific aspects of visual perception would broaden the range of assessments available. Completion of this research would better enable visual perception difficulties to be properly identified in children with hemiplegia.

Conclusion

Visual perception difficulties are common in children with hemiplegia. While several visual perception assessments are currently being used in this population, none have clinimetric data available for children with hemiplegia. Thorough search strategy has lead to the review of three assessments used in the hemiplegia population. The TVPS has some significant flaws in its test design, impacting both the validity and reliability of the test. At present the DTVP and MVPT demonstrate the strongest clinimetric properties and would, thus, be recommended for clinical practice. Further research is, however, required to improve current tests, ensure the validity and reliability of recommended tests and gather clinimetric data within the hemiplegia population for appropriate visual perception assessments. In addition, it is necessary for the subtests of current visual perception assessments to be examined within the context of the sensory processing framework for their suitability for inclusion in assessments, as well as developing new tests that thoroughly assess all aspects of visual perception.

Declaration of interest

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