The Oxford Visual Perception Screen: development and normative data of a standardised assessment for visual perception difficulties

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Abstract

Objective: We aimed to develop and standardise a practical systematic screening tool for visual perception impairments after a stroke to replace current subjective methods.

Study design: A mixed methods study including test development, a cross-sectional study, and a case series.

Methods: Development of the Oxford Visual Perception Screening tool (OxVPS) follows a published Delphi, a survey and performance data on visual perception tasks. Stakeholder feedback from patients and health professionals improved iterative prototypes. Subsequently, we collected normative data from community dwelling older volunteers without a neurological history. Our case series included patients with ocular conditions or a stroke. For each task of OxVPS, we determined 5th centile cut-off scores. We further explored effects of age, visual acuity, and gender on visual perception through Generalised Linear Models.

Results: OxVPS is a 15-minute paper-and-pen assessment comprising 10 tasks including picture naming, star counting, and reading. Normative data of 107 participants demonstrated persistent high performance with most cut-offs near ceiling. Apart from the Figure Copy ($p<0.001$) and Global Shape Perception task ($p=0.009$) we found no evidence for an effect of visual acuity on OxVPS. An effect of age was only observed in the Face Recognition ($p<0.001$) and Reading task ($p<0.001$). No effects of gender were observed. A series of eight cases illustrates the interpretation of OxVPS.

Conclusion: We present the Oxford Visual Perception Screen, a standardised visual perception screening tool alongside normative data and illustrative cases. OxVPS can potentially change screening for visual perception impairments in clinical practice and is available at https://oxvps.webspace.durham.ac.uk/.

Introduction

Diagnosis of visual perception problems after a stroke mostly relies on subjective methods like observations because current standardised assessment instruments are time consuming, require considerable training, and are not suitable for stroke survivors with communication and concentration difficulties (Colwell et al., 2022; Vancleef et al., 2022). Visual perception is the dynamic process of perceiving the environment through sensory inputs and translating the sensory input into meaningful concepts (Bouska et al., 1990). Visual perception deficits are therefore distinct from sensory visual impairments such as reduced visual acuity, visual field and eye movements (Intercollegiate Stroke Working Party, 2023). Examples of visual perceptual deficits include apperceptive and associative agnosia (object recognition difficulties), prosopagnosia (face recognition difficulties), akinetopsia (difficulties in perceiving motion), achromatopsia (difficulties in perceiving motion), problems in visual memory (remembering what you have seen before), and in visuospatial abilities (e.g. judging distances or spatial relations between objects) (Kolb & Whishaw, 2003). Visual inattention or hemispatial neglect is sometimes considered to be part of visual perception deficits (Bouska et al., 1990; Rowe et al., 2019), though neuropsychology research considers this an attentional deficit (Làdavas, 1994).

Edmans and Lincoln found that 76% of stroke survivors within one month post stroke presented with visual perceptual problems as identified by the Rivermead Perceptual Assessment Battery (RPAB) (Edmans & Lincoln, 1987). However, because a 1h systematic assessment with the RPAB is not feasible in clinical practice, health professionals typically rely on patient self-reports and observations (Vancleef et al., 2022), and indeed self-report is the most common method of screening for visual perception problems (Colwell et al., 2022). A recent systematic review of screening instruments for vision and visual perception problems after stroke demonstrated that the sensitivity of any screening tool is significantly lowered when patients are unable to report their symptoms (Hanna et al., 2017). They concluded that many impairments may currently be missed (Hanna et al., 2017). Such under-diagnosis of visual perception problems can severely impact stroke survivors' quality of life, functional outcome, participation in the community, independence and pose substantial risk (Jehkonen et al., 2000; Kalra et al., 1993; Kerkhoff, 2000; Mercier et al., 2001; Plante et al., 2010). An objective diagnosis of visual perception difficulties with standardised instruments can allow better care planning and can positively impact stroke survivors' life and independence.

Assessment of visual perception problems after stroke is challenging. The aforementioned systematic review has demonstrated that there is no standardised tool for visual perception

problems after stroke (Hanna et al., 2017). The RPAB has long been considered to be the best practice test because of its extensive validation research (Barer et al., 1990; Friedman & Leong, 1992; N. B. Lincoln & Clarke, 1987; Matthey et al., 1993; Sloan et al., 1991), even though certain subtests require intact cognitive skills like reasoning and planning (e.g. Sequencing, Cube Copy). Another well-known test battery is the Visual Object and Space Perception battery (VOSP) (Warrington & James, 1991). Although it has strong theoretical underpinnings, VOSP is not suitable for patients with aphasia or dysphasia, common impairments after stroke (Rapport et al., 1998). In addition, the VOSP's nine subtests do not match specific visual perceptual functions or impairments. Also the Test of Visual Perceptual Skills (TVPS (Ted Brown et al., 2003)), Motor-Free Visual Perception Test (MVPT-4 (Brown & Peres, 2018)), and the Beery Developmental Test of Visual Motor Integration (VMI (Beery, 1993)) measure only one or two visual perceptual functions and have not been validated for use in adult stroke survivors (Cooke et al., 2005). The limited validation research or normative data also reduces the suitability of the VOSP (Annegarn, 2017; Bonello et al., 1997; Rapport et al., 1998), the Chessington Occupation Therapy Neurological Assessment Battery (COTNAB (Tyerman et al., 1986)) and the Birmingham Object Recognition Battery (BORB (Riddoch & Humphreys, 2022)) (Cooke et al., 2005; de Vries et al., 2018). Most importantly, all the existing visual perception test batteries take at least 45 minutes to complete (e.g. RPAB: 60-120 min; VOSP: 45 min) making them unsuitable for systematically screening all stroke survivors, who are typically in time- and resource-poor acute settings (Cooke et al., 2005), and who themselves often present with fatigue (Alghamdi et al., 2021) and impaired sustained attention (Varkanitsa et al., 2023) preventing them from taking part in lengthy assessments. Two attempts to shorten visual perception tests have been made: a short version of the RPAB(N. Lincoln & Edmans, 1989) and the Occupational Therapy Adult Perception Screening Test (Cooke, Deirdre, 2023). Both require a large set of materials and considerable training and practice in administration and interpretation, making them less suitable for assessment at bedside and less accessible to new staff.

In a recent qualitative study, 25 occupational therapists and orthoptists involved in visual perception screening after stroke indicated a need for a quick evidence-based screening tool that requires minimal training and is suitable for stroke survivors with communication and concentration difficulties (Colwell et al., 2022). These findings were confirmed in a survey carried out across the United Kingdom and Ireland with 214 occupational therapists and orthoptists. The survey showed that health professionals more often rely on observations (94%) and self-report (94%) than on standardised assessments (58%) in screening for visual perception problems after a stroke. If they used a standardised tool, this was often not appropriate for visual perception screening (e.g. screening for problems in attention or sensory vision). The key clinical needs identified were training

in visual perception screening and tools that were suitable for the physical and cognitive impairments of stroke survivors (Colwell et al., 2022).

Here, we introduce the Oxford Visual Perception Screen or OxVPS, a new screening tool that aims to provide an answer to some of the issues outlined above. We describe the development of OxVPS alongside a detailed description of the test. Subsequently, we report a normative study to establish cut-off scores for normal performance on OxVPS and illustrate the interpretation of OxVPS through a case series.

Development of Oxford Visual Perception Screen

Aim

The aim was to develop a tool that met the following requirements:

- can screen directly for a range of different visual perceptual impairments;
- can discriminate between problems in visual perceptual, cognitive, and sensory vision problems common in the elderly (cataract, glaucoma, macular degeneration);
- is suitable for stroke patients with expressive communication issues, concentration difficulties, visual neglect, and hand weakness;
- meets the clinical needs of being quick, portable, and easy to administer and interpret (Colwell et al., 2022; Vancleef et al., 2022);
- is informed by patients' feedback on user-friendliness such as the duration of the test, the text fonts and size used, the phrasing of the instructions, and the specific images included.

The results of OxVPS should provide pointers to which impairments might be likely for the patients. A formal diagnosis can then be confirmed through targeted follow-up assessments.

Development process

To support content and face validity, the selection of which visual perceptual impairments to screen for and which tasks to include was guided by the following criteria:

1) experts have identified the impairment or the task as essential in the measurement of visual perception;
2) tasks that differentiate well between healthy participants and participants who had a stroke.

Expert consensus on which impairments to screen for was based on a Delphi study with international multidisciplinary experts in visual perception (de Vries et al., 2018) and further

informed by a recent survey with occupational therapists and orthoptists (Colwell et al., 2022). De Vries et al. selected active and experienced international researchers and health professionals from a range of disciplines involved in the assessment of visual perception functions (de Vries et al., 2018). The visual perception impairments with the highest median ranks by the experts were visual inattention, visual search, simultanagnosia, visual processing speed, apperceptive agnosia and object agnosia (i.e. associative agnosia and optic aphasia). The 214 occupational therapists and orthoptists taking part in Colwell et al.'s survey were presented with eight common visual perception functions and asked how important it is to screen for each of these in stroke survivors. They most often listed visual inattention, object recognition difficulties, visuospatial perception, apperceptive agnosia, and visual memory as more important to screen for than word blindness, motion perception, and face perception.

With regards to studies investigating task differentiation between neurologically healthy and stroke participants, two previously reported samples of patients were compared with neurologically healthy controls on the Leuven Perceptual Organisation Screening Test (Robotham et al., 2023; Vancleef et al., 2015). The first sample included 64 stroke survivors and 46 neurological healthy control participants (Robotham et al., 2023). In the second study 13 stroke survivors and 355 neurologically healthy control participants took part (Vancleef et al., 2015). They all completed nine tasks measuring perceptual organisation like figure-ground segmentation, perceptual grouping, contour, and texture segregation. For a detailed description of the tasks, see Vancleef et al. (2015). The distribution of accuracy scores and reaction times between stroke survivors and neurologically healthy was compared on each task. Tasks that differentiated well between patients and neurologically healthy controls were Contour Integration with Radial Frequency Patterns, Texture Segregation with Radial Frequency Patterns, Kinetic Object Segmentation, and Dot Counting.

The ultimate decision on inclusion of impairments and tasks struck a balance between the two criteria used and the requirements of OxVPS listed under 'Aim' above with priority given to health professionals' opinions (to maximise adoption) and practicality of tasks. For example, because health professionals preferred a downloadable paper and pen tool, we could not include a standardised motion perception display (e.g. Kinetic Object Segmentation) and the colour calibration that is required for standardised test of colour perception was not feasible when the stimulus booklet will be printed on various printers. Instead, we opted for self-reported difficulties for these two impairments.

The format and layout of OxVPS was inspired by the successful Oxford Cognitive Screen (Demeyere et al., 2015) which is used internationally to assess cognitive functions in stroke survivors. As with

the Oxford Cognitive Screen, we maximised the accessibility of the tasks for stroke survivors to be inclusive for those with unilateral weakness affecting their hand, communication difficulties, visual neglect, and fatigue.

Iterative drafts of OxVPS were discussed with three internationally recognised experts in neuropsychology research, each with specific expertise in either instrument development, visual perceptual impairments after stroke, and/or cognitive neuroscience. A prototype version of OxVPS was then presented to four experts (a researcher specialised in alexia, a cognitive neuroscientist, a researcher specialised in assessment of visual perception difficulties after stroke, a researcher specialised in neglect dyslexia), three health professionals, 28 healthy volunteers and 49 stroke survivors. They were given the opportunity to try out the prototype and provide feedback on any aspect of OxVPS. We noted 620 comments including feedback on ambiguities in the instructions, unclear images, confusing answer options, size of stimuli, and other aspects of user-experience. All comments were reviewed by the team and improvements were made in subsequent versions of OxVPS. We completed a total of 30 iterations of gathering feedback and making improvements. We believe that the involvement of stroke survivors and end-users (health professionals and expert researchers) greatly improved the value of OxVPS as a practical and acceptable screening tool.

Data of 80 neurologically healthy older volunteers were collected with the prototype version. In a short health questionnaire, participants were asked to confirm they did not have a history of psychiatric or neurological conditions. Participants completed the prototype OxVPS and a visual acuity test while wearing their habitual correction. Data collection started in March 2020 with in-person appointments but switched to video-call appointments after nine participants due to the Covid-19 pandemic. We aimed for an average performance of 80% correct on each task. The distributions of the scores for each task were highly skewed. In line with OxVPS' design, healthy volunteers performed well on all tasks, with only occasional errors made. One task, Picture Naming, was too easy with over 95% of participants obtaining the maximum score. Two tasks, Face Recognition and Reading, were too difficult with most participants making one or more mistakes. Additionally, our expert panel and an Intellectual Property adviser reviewed the prototype and suggested some further clarification in the instructions, replacement of images, and adjustments for people with low vision. The stimuli in Picture Naming and Semantic Information tasks were replaced by more challenging images. The instructions for the Semantic Information task changed from 'Where would you most likely find this object?' to 'Which word goes best with the picture?'. In the self-evaluation task, we rephrased the questions to make it clear that we were asking about new visual perception difficulties since their stroke and not their existing visual impairments. The text in the Reading task was adjusted to replace a potentially insensitive word ('housewife') and a word

that was commonly mispronounced (‘conflagration’). The Face Recognition task changed from a delayed matching task to a matching task where all photos are presented simultaneously. The font size in the stimulus book was changed to size 14 in line with Clear Print guidance from the Royal National Institute of Blind People (Royal National Institute of Blind People, 2023) and the line thickness of the images in the drawing task was increased to improve accessibility for people with low vision.

This resulted in the finalised OxVPS, the version described in this paper. This version is available to download on https://oxvps.webspace.durham.ac.uk/ and is there listed as version 2.0.

Description of OxVPS

OxVPS is a 15-minute screening tool in paper format that screens for impairments in object recognition, face recognition, reading, eye-hand coordination (visuo-constructive skills), and neglect of the left or right side of space. Across ten disparate tasks, patients are asked to recognise drawings of objects, recognise faces, read a short paragraph, and draw a geometrical figure. Except for the drawing and reading task, all tasks are multiple choice (overcoming expressive communication issues), images are presented vertically (avoiding confounds due to visual neglect), and patients can respond with pointing gestures with their unaffected hand (in case of any upper-limb weakness). The test results indicate which visual perceptual problems are likely present in a patient. A total score indicates the extent of the visual perceptual problems.

An overview of the ten tasks of OxVPS is given in Table 1. Further details are available in the OxVPS manual (Vancleef & Demeyere, 2023). OxVPS is freely available to download for non-commercial use at https://oxvps.webspace.durham.ac.uk/.

Table 1 Description of tasks of OxVPS 2.0

Task name	Task description	Impairments screened for
Self-evaluation	This task records subjective visual complaints through three questions on whether the patients noticed any difficulties with perception in general, perception of motion, and perception of colours.	Blindsight: patient would answer they cannot see anything but their performance in other tasks of OxVPS is above chance Anton-Babinsky syndrome: patient would deny having any difficulties while performance in other tasks of OxVPS is lower than the cut-off for normal visual perception Achromatopsia Akinetopsia
Picture Naming	In this task, the patient is shown a black and white line drawing (e.g. bear) at the top of the page and is asked what it is a picture of. Five possible answers are given. One of the incorrect options is semantically related to the drawing but not visually (e.g. kangaroo), another is visually related but not semantically (e.g. table), another is visually and semantically related (e.g. dog), and the last one is unrelated (e.g. car). Four drawings are presented at different pages.	Optic aphasia Associative agnosia: patients would also have difficulties with Semantic Info Apperceptive agnosia: patients would also have difficulties with Semantic Info, Global Shape Perception Cortical blindness: patients would also have difficulties with any other task
Semantic Info	The patient is shown four black and white line drawings of objects alongside five words and is asked which word goes best with each image. The words are all associated with each other but only one is strongly associated with the image. For instance, a drawing of a rabbit will be shown alongside the words ‘carrot’, ‘pear’, ‘onion’, ‘tomato’, ‘potato’. All these are vegetables, but only one, ‘carrot’, is strongly associated with a rabbit.	Associative agnosia: patients would also have difficulties with Picture Naming Apperceptive agnosia: patients would also have difficulties with Picture Naming, Global Shape Perception Cortical blindness: patients would also have difficulties with any other task
Global Shape Perception	In this task, a fragmented outline of an irregular shape is shown at the top of each of the four pages of this task. Underneath, four other fragmented shapes are presented. Patients need to pick the shape that is most similar to the target shape at the top of the page. To ease the distinction between the target shape and the options to choose from, the target shape is made up of thicker line fragments.	Apperceptive agnosia: patients would also have difficulties with Picture Naming, Semantic Info Cortical blindness: patients would also have difficulties with any other task Simultanagnosia: patients would also have difficulties with Item Counting
Item Counting	In this task, patients are asked to count the number of stars presented on each of the four pages. Four options are given underneath each stimulus. Besides the correct number, the options include numbers in proximity to the correct number with at least one number smaller than the correct number.	Cortical blindness: patients would also have difficulties with any other task Simultanagnosia: patients would also have difficulties with Global Shape Perception

Simple Feature	The patient is shown four straight lines and for each of them is asked if the line is tilted.	Cortical blindness: patients would also have difficulties with any other task
Face Recognition	In each of the fur trials of this task, patients are shown five photographs of faces. One happy face at the top of the page and four neutral faces below. They are asked which of the four neutral face photographs is of the same person as the happy face photograph. All faces show a frontal view, have a white background, and cover a similar area in the image. All models wear a neutral black t-shirt and accessories such as jewellery were removed.	Prosopagnosia
Reading	In the reading task, the patient is asked to read a short paragraph. The paragraph consists of exactly 60 words including low frequency words (doughty, snappily), compound words (firefighters, overgrown, sunset, farmhouse, overnight), and a combination of low frequency and compound words (hitchhiker, woodshed, lean-to) evenly spread across the paragraph. The task is timed and any incorrect or omitted words are marked. The reading speed is calculated as the number of correctly read words per minute. An accuracy score is calculated for the low frequency and compound words.	Alexia Neglect dyslexia
Cancellation	In this task, the patient is presented with small heart shapes scattered over a page[1]. Some hearts are complete, others have a gap on the left or right side. They are asked to mark off the complete hearts. The page has to be presented at the body midline of the patient and cannot be moved (unless the patient moves their body midline).	Space-based or egocentric neglect Object-based or allocentric neglect
Figure Copy	Patients are asked to copy a complex geometric figure on a page. The figure shows a rectangle, divided in two halves, with smaller elements like star, circle or triangle placed on specific positions in the two halves[2]. These is no time limit to this task.	Visuo-constructive deficit Global attention deficit Simultanagnosia Apperceptive agnosia

[1] The task is adapted from the OCS cancellation task (Demeyere et al., 2015), by reducing the number of hearts targets (30 instead of 50), but keeps the same density of distribution by compressing the vertical search space on the page.

[2] The figure is identical to the one in the OCS-Plus (Webb et al., 2021).

The scores on each of the tasks are compared to cut-off scores for normal visual perception (see Normative data below). The total score is calculated as the total number of passed tasks (maximum 10) and gives an indication of the extent of the visual perceptual problems of a patient.

OxVPS does not include measures of sensory vision and users are advised to check their patient's sensory vision (visual acuity, visual fields, eye movements, double vision, etc.) by gaining orthoptic input or with a stroke vision screening tool such as Visual Impairment Screening Assessment (Rowe et al., 2018) in advance of completing OxVPS. Although OxVPS is designed so common ophthalmological conditions in elderly people (Martinez et al., 1982) lead to a different pattern of scores and mistakes compared to the visual perceptual impairments, a note should be made of any ophthalmological or sensory vision problems that might affect the interpretation of the OxVPS scores. Similarly, a note should be made about any cognitive (e.g. executive functions), communication (e.g. aphasia) or physical impairments (e.g. arm weakness, fatigue) that might have an influence on performance, and thus for OxVPS to be conducted following first-line screening on these aspects (e.g with the Oxford Cognitive Screen (Demeyere et al., 2015)). OxVPS also includes the option to report unusual testing conditions such as incomplete tasks, interruptions, or technical problems to aid interpretation.

Normative data and case series

To establish the normal range of scores on OxVPS, we conducted a descriptive cross-sectional study. We expect high average scores on OxVPS in a neurological healthy population. In addition, we report cases of patients without a stroke or other neurological conditions but with self-reported ocular conditions, and cases of stroke survivors with visual perceptual difficulties.

Methods

Participants

Inclusion criteria for the normative study were being neurologically healthy, adult, and English-speaking. Exclusion criteria for all participants were psychiatric conditions affecting their daily life and a history of neurological conditions with potential long-lasting effects (stroke, dementia, neurodegenerative diseases, etc.). People who reported mild depression or anxiety controlled by medication, who experienced a transient ischaemic attack in the past, and people who experienced headaches were not excluded. These inclusion and exclusion criteria were assessed through self-report.

To ensure our normative sample had a similar age distribution as stroke survivors in the UK we intended to recruit 15% of participants younger than 60 years old, 16% from 60 to 69 years old, 27%

from 70 to 79 years old, 31% from 80 to 89 years old, 11% older than 89 years old (Healthcare Quality Improvement Partnership, 2023).

For our case series, we invited stroke survivors who had demonstrated visual perceptual difficulties in the Rivermead Perceptual Assessment Battery (Friedman & Leong, 1992). In addition, we recruited participants without a stroke but with self-reported ocular conditions. Exclusion criteria were a history of other neurological conditions with potential long-lasting effects (dementia, neurodegenerative diseases, etc.) or psychiatric conditions affecting their daily life.

Participants were recruited through social media (Facebook and Twitter), our research group's participant pool of healthy older volunteers, care homes, through social groups for people of an older age (e.g. craft groups, fitness groups, friendship groups, church groups, etc.), and at stroke rehabilitation units.

All participants provided their informed consent. All procedures were reviewed by the Psychology Ethics Committee at Durham University or the Health Research Authority Derby Research Ethics Committee and were given a favourable opinion (reference numbers PSYCH-2022-01-19T13_53_52 and 23/EM/0086).

Sample size

Our key objective was to establish the normal range of score for OxVPS by calculating cut-off scores for each task. OxVPS was designed to be easy for healthy people, so we foresaw negatively skewed distributions with most healthy volunteers obtaining maximum scores. Given the non-normative distributions, we opted for calculating the 5th percentile scores and using these as our cut-off scores for normal performance. Following Crawford's recommendations, we established that a normative sample of 100 participants would enable us to calculate the 5th percentile with a 95% confidence interval ranging from the 2nd to 8th percentile (Crawford & Garthwaite, 2008).

Setting

Data were collected between May 2023 and January 2024 by student research assistants. Appointments took place in the participant's location of choice such as their home, their room in a care home, in a stroke rehabilitation unit, community halls, or at a research lab at Durham University. All locations were in County Durham, Surrey, and North Yorkshire, countries in England in the United Kingdom of Great Britain and Northern Ireland. Because glaucoma, cataract and age-related macular degeneration are common in older adults and such patients can be sensitive to light and glare, participants were allowed to adjust the lighting levels in the room to their preferred levels.

Instruments

Health questionnaire

In a short health questionnaire, participants were asked demographic information (date of birth, gender, handedness, number of years in education) and medical information (psychiatric and neurological history). We also ask participants to report eye conditions: glaucoma, cataract, macular degeneration, dry eye, or any other conditions. We subsequently asked how the conditions impacted their daily life and details about any surgery they might have had for their condition. We also asked whether they normally wear glasses or contact lenses and which type of glasses (reading, distance, varifocal or bifocal glasses). The information from the health questionnaire was used to check exclusion criteria and to describe the sample.

OxVPS

Participants were instructed to wear their habitual correction for a viewing distance of 30-40 cm. Participants could take as much time as needed for each task. They were encouraged to guess on multiple choice questions and were allowed to correct their answers. The tasks are described in detail above. For each task of OxVPS, a score is calculated as described in the manual. For most tasks, the score is the number of correct answers in the task. The two exceptions to this rule are the score for alexia and the asymmetry scores on the cancellation task. Alexia is scored by calculating the number of words read per minute. The asymmetry scores on the cancellation task are calculated by taking the difference between number of left versus right hearts crossed off.

Visual acuity

Participants' near visual acuity was assessed to screen for undiagnosed eye conditions such as age-related macular degeneration and cataract. Participants were asked to wear their habitual correction for the near distance. Acuity was assessed with the LogMar Double Sided Near Vision Card/EDTRS chart a standardised assessment for near visual acuity (*Logarithmic Near Visual Acuity Chart 2000 'New ETDRS'*, 2023). A comparison between different scoring terminations of visual acuity tests showed that acuity defined as the print size for which at least 50% of the letters can be read correctly, is the most appropriate (Mimouni et al., 2019). This variable is expressed in logMAR units.

Statistical methods

Descriptive statistics on demographic variables were calculated to characterise the sample. For the continuous variables age and visual acuity, we calculated the mean and standard deviation. For categorical variables like education level and eye conditions, we calculated the percentage of participants in each category. The performance on each task of OxVPS was summarised by the median, interquartile range, 5^{th}, and 10^{th} centile. Sensitivity analyses were performed to investigate

the effects of age, gender, and visual acuity on scores. For each of the tasks, we fitted a Generalised Linear Model to the scores with as predictors age (in years), gender (man as reference category), and visual acuity (in logMAR). For tasks with a negatively skewed distribution of scores (i.e. all scores but reading speed and asymmetry scores), the observed scores were transformed by subtracting them from the perfect score on the task. For instance, for the Picture Naming all observed scores were subtracted from the perfect score of 4. This transformation resulted in a positively skewed distribution. The positively skewed distribution could then be modeled with a Poisson link function in our Generalised Linear Model. For the other scores (i.e. reading speed and asymmetry scores) an identity link function was used. A Bonferroni correction for multiple comparisons was used and the significance level was adjusted to 0.0015 to reflect a family-wise error rate of 0.05. Missing data were not replaced, instead, a smaller sample was analysed (e.g. 105 instead of 107 participants for the reading task).

Results

All data and code for the analyses, figures, and tables below are available on Open Science Framework for replication and further statistical details: https://osf.io/hsf2r/?view_only=4e0505cfe9114a419077a5d2c0f3f59a .

All 108 participants completed OxVPS and a near visual acuity test in one visit; one participant was excluded because a neurological condition was declared shortly after completion of the tests. Data of all remaining 107 participants was included and analysed. The median duration of a session was 20 minutes with an interquartile range from 16 to 27 minutes. All participants were fluent in English. The distribution of ages in our normative sample is similar to the distribution of ages in stroke patients (Healthcare Quality Improvement Partnership, 2023) as can be viewed in Figure 1.

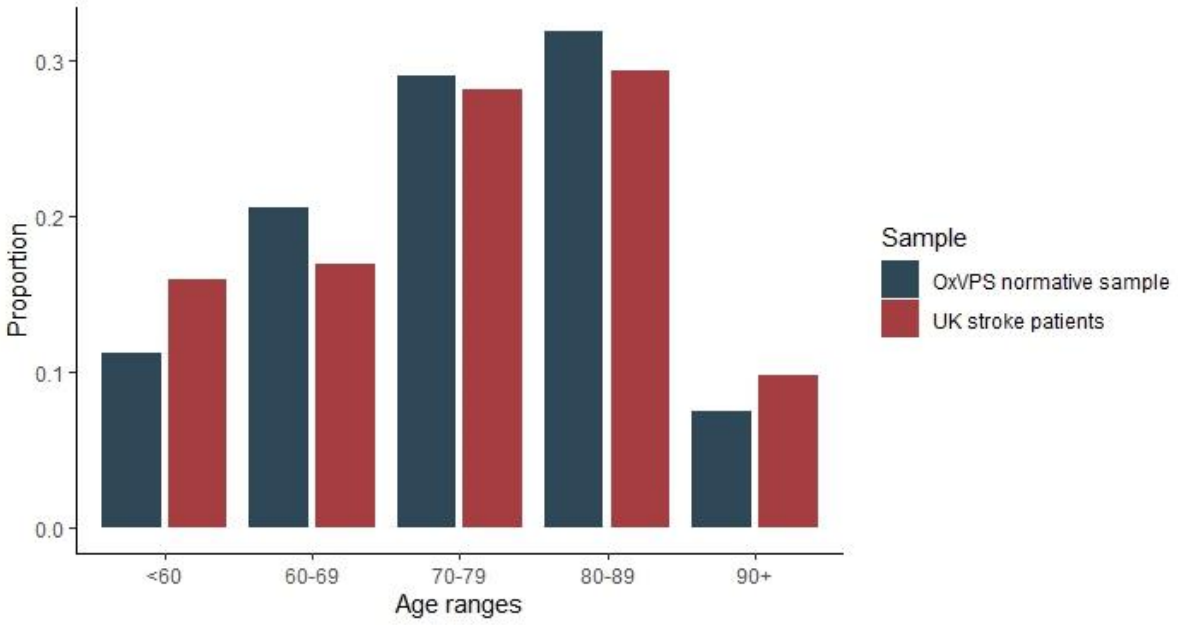

Figure 1. Distribution of age of the participants in our normative sample (in dark blue, N = 107) compared to the distribution of age of stroke patients admitted to hospital in the UK between April 2022 and March 2023 (in dark red, N = 91,162; source: (Healthcare Quality Improvement Partnership, 2023).

All but five participants had normal vision as defined by the World Health Organisation. Out of 95 participants who required glasses, four did not have them available for the tasks. Further details of all 107 participants are reported in Table 2. There were no missing demographic data.

Table 2 Demographic details of participants in our normative sample.

	Mean	SD	Count[1]	Percent
Age (years)	74.21	11.24		
Gender				
Man			36	34
Woman			71	66
Ethnic origin				
White			105	98
Unknown			2	2
Education				
No qualifications			3	3
Below secondary education			7	7
Secondary education			5	5
Upper secondary and advanced further education			9	8
Higher education			81	76
Unknown			2	2
Handedness				
Ambidextrous			3	3
Left-handed			8	7
Right-handed			96	90
Visual acuity (logMAR)	0.12	0.19		
Glasses				
None			12	11
Distance glasses			14	13
Reading glasses			40	37
Varifocal or bifocal glasses			49	46
Eye conditions				
None			64	60
Cataracts			23	21
Dry eye			3	3
Glaucoma			5	5
Macular Degeneration			5	5
Unsure			4	4
Other			9	8

[1] The count data in each category of glasses and eye conditions do not add up to 107 because some participants worn multiple type of glasses (e.g. reading and distance glasses) or had multiple eye conditions.

The distributions of the scores for each task of OxVPS were highly skewed (see Figure 2). In line with OxVPS' design, healthy volunteers performed well on all tasks, with only occasional errors made. In Table 3, we report the median, interquartile range and the 5th and 10th centile scores for each task. Two participants who had a visual acuity of only 0.8 logMAR were not able to complete the reading task, but completed all other tasks. For most tasks, the 5th centile score can be used as cut-off score when screening for visual perception impairments and can be taken as indicative for impairment (see last column in Table 3). The exceptions are the Self-evaluation task and the Strategy score of the Figure Copy task which are evaluated qualitatively. Any self-reported change in vision in the Self-evaluation task (answering 'Yes' to a question) is seen as indicative of an impairment. In addition, self-report is to be compared with performance in the subsequent tasks to screen for Anton-

Babinsky syndrome and Blindsight (see description of tasks and interpretation above). In the Figure Copy task, over 95% of healthy volunteers started their drawing with the large rectangle and then added details to the different areas in the rectangle. Drawings that started with any of the details instead of the large global shape of the rectangle should therefore be viewed as an indication of a global attention impairment.

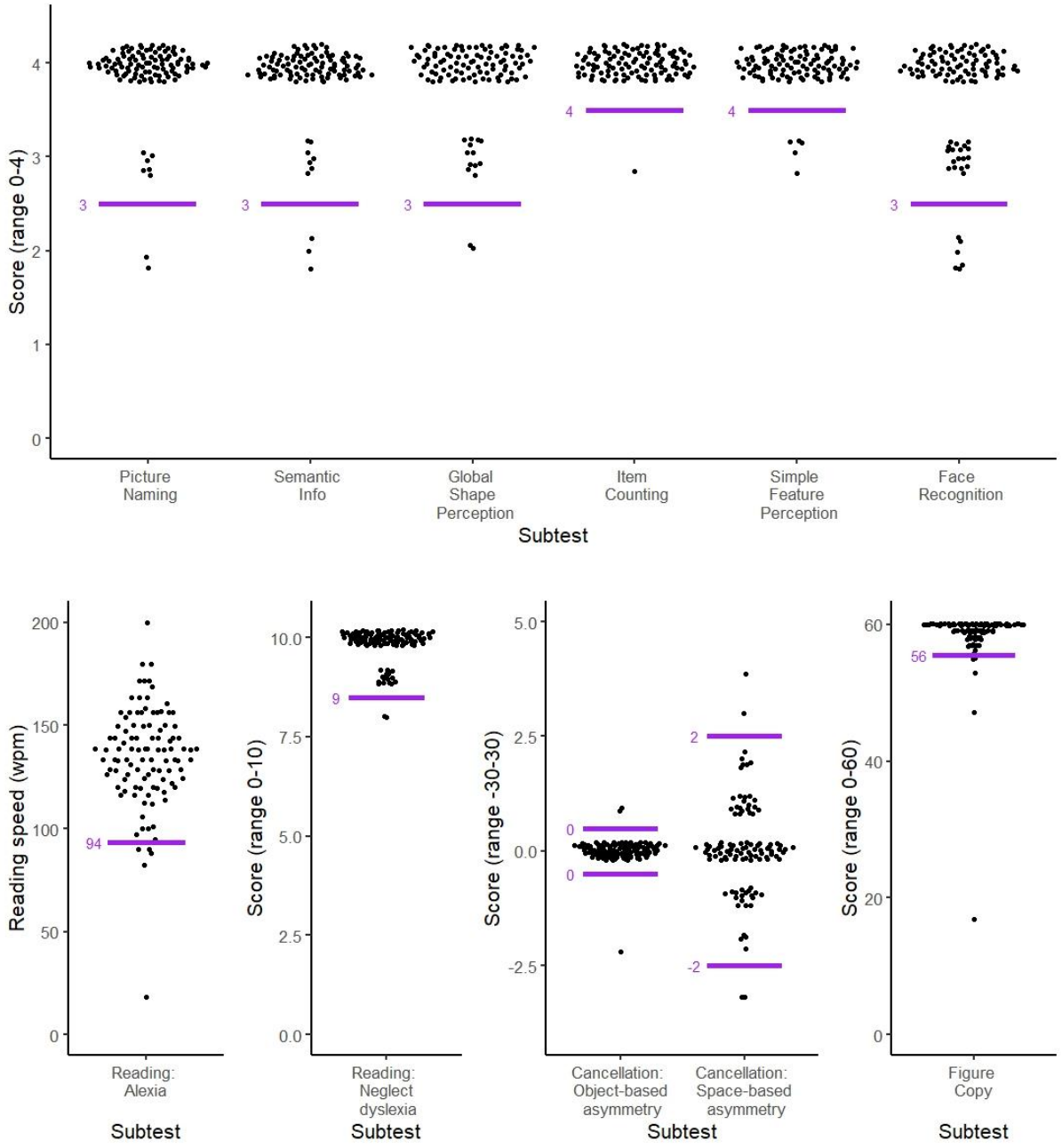

Figure 2. Distribution of scores for each task of OxVPS 2.0. The top graph shows the scores of all tasks with a range of scores between 0 and 4. The bottom row of graphs shows the reading speed in the Reading task in words per minute (no minimum or maximum), the number of correctly read complex words in the Reading task (maximum 10), the Object- and Space-based asymmetry scores (minimum possible score of -30 and

maximum of 30) and the score on the Figure Copy task (maximum 60). A small amount of vertical jitter was added to the scores to show overlapping data points and better reflect the distribution of the scores. For instance, the dots around the number 4 in the Picture Naming task all represent participants with a score of exactly 4 out of 4 on the task. The horizontal spread of the dots is proportionate to the number of data points at that value. The short purple horizontal lines indicate the cut-off scores for each task of OxVPS 2.0. For clarity, these lines were placed on the division line between 'impaired' and 'unimpaired' scores rather than at the location of the cut-off value. For instance, the cut-off value for the Picture Naming task is 3, but the short purple horizontal line is places slightly lower to show that a score of 3 is still within the normal range, while a score of 2 is only observed in less than 5% of our normative sample and therefore indicative for an impairment.

Table 3. Descriptive statistics for each task of OxVPS 2.0

Outcome measure per task	N[1]	Median	IQR	5th centile	10th centile	Indicative for 'impairment'
Self-evaluation						
Subjective complaints						'Yes'
Akinetopsia						'Yes'
Achromatopsia						'Yes'
Picture Naming	107	4	4 – 4	3	4	Lower than 3
Semantic Info	107	4	4 – 4	3	4	Lower than 3
Global Shape	107	4	4 – 4	3	3	Lower than 3
Item Counting	107	4	4 – 4	4	4	Lower than 4
Simple Feature	107	4	4 – 4	4	4	Lower than 4
Face Recognition	107	4	4 – 4	2.3	3	Lower than 3
Reading						
Neglect dyslexia	105	10	10 – 10	9	9	Lower than 9
Alexia (wpm)	105	138.5	122.1 – 150	93.5	103	Lower than 94
Cancellation						
Object asymmetry	107	0	0 – 0	0 and 0	0 and 0	Lower than 0 or higher than 0
Space asymmetry	107	0	0 – 0	-2 and 2	-1.7 and 2	Lower than -2 or higher than 2
Figure Copy						
Total	107	60	59 – 60	56	57	Lower than 56
Strategy	51					Not drawing big rectangle first

[1] Not all outcome measures are available for each participant. Two participants could not complete the reading task due to low visual acuity. The Figure Copy strategy was only recorded in 51 participants due to an administrative error.

The estimated coefficients of each Generalised Linear Model, Z statistics and p-values are reported in Table 4.

Table 4. Effect of age, gender, and visual acuity on OxVPS 2.0 performance

	Coefficient	Z	p	
Picture Naming				
Age	0.1518	2.5843	0.0098	
Gender	0.1373	0.1882	0.8507	
Visual acuity	1.6894	1.006	0.3144	
Semantic Info				
Age	0.033	1.0216	0.307	
Gender	-1.755	-2.6516	0.008	
Visual acuity	2.309	2.1668	0.0302	
Global Shape				
Age	0.007	0.3016	0.7629	
Gender	-0.328	-0.6386	0.5231	
Visual acuity	3.102	3.3215	0.0009	*
Item Counting				
Age	0.2294	0.7416	0.4584	
Gender	-19.323	-0.0027	0.9979	
Visual acuity	-7.5032	-0.8299	0.4066	
Simple Feature				
Age	0.0448	0.8868	0.3752	
Gender	-0.8603	-0.9282	0.3533	
Visual acuity	3.2349	1.9398	0.0524	
Face Recognition				
Age	0.0945	3.605	0.0003	*
Gender	-0.7307	-1.9722	0.0486	
Visual acuity	1.2644	1.5236	0.1276	
Reading: Alexia (wpm)				
Age	-0.6921	-3.5019	0.0007	*
Gender	2.0869	0.4575	0.6483	
Visual acuity	-36.7893	-2.8486	0.0053	
Reading: Neglect dyslexia				
Age	-0.0141	-0.6954	0.4868	
Gender	0.051	0.1022	0.9186	
Visual acuity	1.0431	0.9561	0.339	
Cancellation: Object asymmetry				
Age	0.0172	1.822	0.0714	
Gender	-0.1166	-0.5392	0.5909	
Visual acuity	-0.0256	-0.0474	0.9623	
Cancellation: Space asymmetry				
Age	-0.0032	-1.4771	0.1427	
Gender	-0.0511	-1.0412	0.3002	
Visual acuity	-0.0038	-0.0309	0.9754	
Figure Copy: Total				
Age	0.0241	3.1046	0.0019	
Gender	0.2535	1.4083	0.159	
Visual acuity	2.238	6.5682	<0.0001	*

* refers to p-values below 0.0015

The observed decrease in performance with increasing age provided supporting evidence that in the population there is an effect of age on performance in the Face Recognition task ($p = 0.0003$) and in reading speed of the Reading task ($p = 0.0007$). In addition, we observed evidence that visual acuity

negatively affects performance in the Global Shape ($p = 0.009$) and the Figure Copy task ($p < 0.0001$). Although it has been repeatedly demonstrated that visual acuity decreases with age (Erdinest et al., 2021; Gittings & Fozard, 1986), the correlation between visual acuity and age in our sample was low ($r = 0.25$) likely because we measured visual acuity while participants were wearing their habitual correction. Therefore, age will have unlikely mediated the effect of visual acuity on OxVPS performance in our sample.

The cases' scores on each of the tasks are reported in Table 5. Patients with Macular Degeneration that severely impacted their daily life (Case 1-2) failed several tasks of OxVPS but their profile of scores is not indicative of any visual perceptual impairment that OxVPS screens for and can therefore not be mistaken for a visual perception issue. Patients with cataract, glaucoma, or dry eye with no to little reduction in near visual acuity and only a mild effect on daily life (Case 3-5) performed well on all tasks of OxVPS. Cases 6-8 have been diagnosed with visual perceptual difficulties following an extensive neuropsychological assessment. Case 6 failed across all tasks of OxVPS and had no subjective complaints about their vision. This profile is indicative of severe cortical blindness. However, their performance in the cancellation task is better than would be expected from a blind patient: they crossed out most complete hearts but made number of false positive errors. Case 7's scoring profile show signs of prosopagnosia by failing the Face Recognition task, a visuo-constructive deficit as indicated by a low score on Figure Copy task, alexia, and neglect dyslexia (low score on both measures in the Reading task). When asked about their subjective experience, they reported that naming colours was difficult and when objects are moving fast "their brain can't keep up", which is indicative of akinetopsia and achromatopsia. Case 8's scoring profile is indicative of optic aphasia (failure on Picture Naming, but not on Semantic Info, Shape Perception, Item Counting, or Simple Feature), and alexia and neglect dyslexia (low score on both measures in the Reading task).

Table 5. OxVPS profile of nine cases with either sensory vision problems or with a stroke

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
	HCG011	HRC012	HCG015	HMC001	HRC011	SBA021	SQE012	SQE025
Neurological Condition	None	None	None	None	None	Stroke	Stroke	Stroke
Eye Condition	MD, C	MD	G, C	C	DE	None	C, Blind in left eye	None
Near visual acuity (logMAR)	0.7	0.8	0.0	0.3	0.3	0.4	0.0	0.4
Effect of eye condition on daily life	Severe	Severe	Mild	Mild	Mild	NA	NR	NA
OxVPS total score	6	8	10	10	10	1	6	8
Self-evaluation								
Subjective complaints	NA	NA	NA	NA	NA	No	Yes	No
Akinetopsia	NA	NA	NA	NA	NA	No	Yes	No
Achromatopsia	NA	NA	NA	NA	NA	No	Yes	No
Picture Naming	3	4	4	4	4	1	4	2
Semantic Info	2	4	4	4	4	1	3	3
Global Shape	2	4	4	4	3	2	4	4
Item Counting	4	4	4	4	4	0	4	4
Simple Feature	3	4	4	4	4	3	4	4
Face Recognition	3	3	4	3	4	0	2	3
Reading								
Alexia (wpm)	18	UR	157	150	122	50	87	92
Neglect dyslexia	8	UR	10	10	10	2	8	8
Cancellation								
Object asymmetry	0	0	0	0	0	2	0	0
Space asymmetry	1	4	0	0	-2	-1	-1	1
Time (sec)	356	73	68	40	39	265	93	100
Figure Copy								
Total	57	53	60	60	57	28	55	59
Strategy	1	NR	1	1	NR	0	1	1

MD = Macular Degeneration, C = Cataract, G = Glaucoma, DE = Dry eye, NR = not recorded, NA = not applicable, UR = unable to read.

Discussion

With input from health professionals, stroke survivors, older people, and vision scientists, we have developed the Oxford Visual Perception Screen (OxVPS). In ten short tasks, stroke survivors can be screened for 15 impairments. Our normative data of 107 healthy older volunteers provide a

standardised benchmark for normal performance on OxVPS. The scores on the tasks were highly skewed with many healthy volunteers obtaining the maximum score on each task. Based on our normative data, we have calculated 5th centile cut-off scores for normal performance on each task. The results of OxVPS could provide pointers to which perceptual difficulties might be likely for the patients to support referral for in-depth assessment and decide on interim rehabilitation advice.

OxVPS aims to fill the gap in existing visual perception assessments for a quick and easy to use screening tool that is accessible for stroke survivors. The three key tests screening for a range of visual perception difficulties currently available are RPAB (Whiting et al., 1985), VOSP (Warrington & James, 1991) and OT-APST (Cooke et al., 2005). Although some tests like RPAB and OT-APST have excellent psychometric properties, they are not always feasible to complete with stroke survivors at the acute stage because of their length (e.g. RPAB takes 60-90 minutes, VOSP takes 45 minutes), because of reliance on verbal communication (e.g. naming tasks are common in VOSP), or because cumbersome testing materials that make it difficult to complete at bedside (e.g. RPAB and OT-APST). These practical barriers mean existing screening tests are not often used in clinical settings (Colwell et al., 2022). With the development of OxVPS, we focused on practicality and key requirements identified by health professionals. OxVPS is a screening test that takes 15 minutes, making it feasible for stroke survivors with limited concentration in the first few days after a stroke. Health professionals can learn to administer, score, and interpret OxVPS by watching a 20-minute video. In addition, OxVPS is portable (only one stimulus book and five scoring pages), making it feasible to be completed at bedside. Central to the design process was accessibility for patients with expressive aphasia, hand weakness, and with hemispatial neglect, but also for patients with sensory vision impairments like cataract or glaucoma and a mild cognitive impairment (i.e., easy-to-understand instructions). The resulting tool aims to screen for 15 different visual perception impairments in ten tasks. OxVPS has the potential to change the screening for visual perception impairments in clinical practice.

A strength of the study is the age range of our normative sample: 45% of our volunteers were above 80 years old and the average age was 74.2 years old (SD = 11.2). In comparison, normative data for other visual perceptual tests have been collected from healthy volunteers of average age of 64-68 years old which is much younger than the typical stroke survivor (Bonello et al., 1997; Cooke et al., 2006), with the exception of one sample of normative data for older people for the RPAB in which participants were on average 76 years old (N. B. Lincoln & Clarke, 1987).

The first limitation of our study is the education level and ethnicity in our normative sample. Seventy-three percent of our volunteers completed higher education compared to only 28% in the

general UK population (Office for National Statistics (ONS), 2023). The effect of education or intelligence on performance in visual perception tasks is debatable with some authors reporting an effect of intelligence on RPAB (N. B. Lincoln & Clarke, 1987) but no effect of education on OT-APST (Cooke et al., 2006). In addition, nearly all our participants were of white ethnicity. Previous work has also highlighted the need for ethnicity specific normative data for neuropsychological tests, especially for non-verbal tests (Berry et al., 2019; Rivera Mindt et al., 2010). However, studies in visual perception difficulties after brain injury have largely achieved similar results in American, British, Estonian, German, Italian, and Spanish normative samples (Della Sala et al., 1995; Herrera-Guzmán et al., 2004; Merten, 2005; Sells & Larner, 2011; Tammik & Toomela, 2013). In future, the effect of education and ethnicity on performance in OxVPS should be further explored. Inviting a random sample from the population, for instance through the electoral register, has been shown to result in a more representative sample. However, this is a time- and labour-intensive process (Ganguli et al., 1998). Because further work is required on these matters, we should be careful in interpreting results for stroke survivors without higher education or of non-white ethnicity.

A second limitation is that OxVPS is currently only available in English and patients need to have a good understanding of the language to comprehend the instructions and understand the answer options. In addition, a basic education with literacy is a prerequisite for the Reading task. Our normative data showed that a minimum near visual acuity of 0.7 logMAR with habitual correction (equivalent to 6/30 or 20/100 Snellen and 0.20 decimal acuity) is required for the Reading task. The other tasks of OxVPS have not been tested in people with poorer near vision than 0.8 logMAR (equivalent to 6/38 or 20/125 Snellen and 0.16 decimal acuity).

As a third limitation, the current study does not evaluate the reliability and validity of OxVPS, for which work is ongoing. Although the design choices provide some initial evidence of validity this is only preliminary. The number of participants in our sample who declared any ocular pathology was too low to conduct any meaningful analysis on. The case series suggest that although patients with severe ocular conditions can fail some of the tasks in OxVPS, their mistakes can usually be explained by their ocular condition and/or their profile of failed tasks does not correspond to any of visual perceptual impairments that OxVPS screens for. In the future, the effect of common sensory vision conditions like cataracts, glaucoma, and macular degeneration could be systematically evaluated in a sample for which detailed optometric and ophthalmological information is available. In addition, research into test-retest reliability and inter-rater reliability will show if OxVPS test scores are stable across test sessions and examiners. A sufficiently powered validation study with stroke survivors assessing convergent and divergent validity is essential to develop the evidence-base to support the use of OxVPS in clinical practice.

With the case series we illustrated the interpretation and potential clinician use of OxVPS. The suggested clinical uses are speculative and depend on successful validation research in stroke patients. Following a low overall score on OxVPS or an indication for a specific impairment in a task, a stroke survivor can be referred for in-depth assessment with an orthoptist, neuropsychologist, occupational therapist, or other qualified health care professional for a formal diagnosis. The results from OxVPS can inform the choice of their follow-up assessments. For instance, the Cambridge Face Memory Test (Duchaine & Nakayama, 2006), might be a useful assessment to complete with a stroke survivor who failed the Face Recognition test of OxVPS. While awaiting referral, preliminary support can be offered to the stroke survivor based on their results on OxVPS. Indeed, an increased understanding of the consequences of their stroke can give patients a sense of control and agency (Hobden et al., 2023). Moreover, simple changes to their environment or compensatory strategies can be offered (Heutink et al., 2019). For instance, for the patient with potential prosopagnosia (Case 7)), the family can be given the advice to wear easily recognisable clothing. For patients with apperceptive agnosia or difficulties in visual attention, simple changes to their environment like decluttering might be beneficial. Following demonstrated test-retest reliability, OxVPS might be useful in a rehabilitation setting to evaluate progress and the effect of interventions. In sum, following future validation research, OxVPS has the potential to improve the detection of visual perception difficulties after stroke and support the planning of subsequent in-depth assessment and decisions on interim rehabilitation advice until a diagnosis is confirmed. OxVPS is available to download at https://oxvps.webspace.durham.ac.uk/.

Clinical Messages

- The Oxford Visual Perception Screen (OxVPS) screens stroke survivors for 15 different visual perception impairments in 10 short tasks.
- Normative data of 107 healthy older volunteers provide a benchmark for normal performance on OxVPS through cut-off scores for each task.

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Author Contributions

KV: Conceptualisation, Funding acquisition, Methodology, Resources, Supervision, Project administration, Data Curation, Formal analysis, Visualisation, Validation, Writing – Original Draft. **RC**: Investigation, Project administration, Writing – Review & Editing. **RS**: Investigation, Writing – Review & Editing. **CG**: Investigation, Writing – Review & Editing. **MFC**: Investigation, Writing – Review & Editing. **FG**: Investigation, Project administration, Writing – Review & Editing. **ND**: Conceptualisation, Funding acquisition, Methodology, Resources, Supervision, Validation, Writing – Review & Editing.

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Competing Interests

ND is a developer of the Oxford Cognitive Screen but does not receive any remuneration from its use. KV is a developer of the Oxford Visual Perception Screen but does not receive any remuneration from its use. KV occasionally receives reimbursements for travel expenses when invited to present the work described in this manuscript or deliver training on visual perception difficulties after a brain injury.

The authors had full access to all of the data in this study and take complete responsibility for the integrity of the data and the accuracy of the data analysis.

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