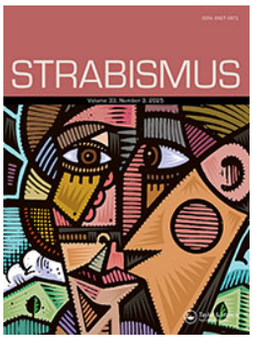

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Developing age-reference values for convergence and visual attention assessments

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ABSTRACT

Aim: Definitions and cutoff values for impaired near point of convergence, and for dominant/non-dominant hand completion of line bisection and cancellation tasks, in older adults are lacking. In this study, we investigate the measurements, response times, and accuracy in a non-clinical population with healthy eyes and cognition. *Methods:* This was a prospective cross-sectional study recruiting adults older than 50 years. Demographic data included hand dominance, sex, age, and ethnicity. The average of three near point of convergence measurements was recorded. Accuracy and speed of task completion were recorded for two-line bisection tasks (3 lines and 10 lines) and for the clock cancellation task, using dominant and non-dominant hands. *Results:* A total of 240 participants (161 female), with mean age of 61.23 years (SD8.71, range 50–97) were recruited. All participants had best corrected visual acuity of better than 0.1logMAR in each eye with no ocular pathology, and with no neurological disease. Overall mean near point of convergence was 9.22 cm (SD4.13), with slight decrease in convergence with increasing age (mean 11.71 cm in the 80th decade). Error cutoff for line bisection was determined as 6 mm with greater accuracy for the 10-line vs 3-line task. Error cutoff for the clock cancellation task was 42 with mean completion time of 1.5 minutes. *Conclusions:* We report normative ranges of older adults (>50 years) to which future clinical comparisons can be made when evaluating near point of convergence and visual inattention. Further research is required in acquired brain injury populations to take into consideration any additional impact on task completion due to co-morbidities/associated sequelae of the brain injury.

KEYWORDS

Acquired brain injury; cancellation; convergence; dominance; handedness; line bisection; normative values; stroke

Background

Visual impairment after acquired brain injury includes impaired central vision, visual field loss, disorders of eye movements and disorders of visual perception.[1,2] Assessments for these visual impairments involve a range of visual acuity charts, range and grading of eye movements, angle of ocular misalignment and binocular vision, perimetric quantitative visual field evaluation, and (in)attention tests.[1–3] Many tests have clearly defined values and cutoffs for what constitutes normal vs abnormal responses across wide age ranges. However, others do not have such clear reference values.

The near point of convergence is a routine clinical assessment for the measurement of vergence movement. The incidence of reduced convergence is estimated at between 2.5% and 13% in younger populations[4,5] and the definition of reduced convergence in the younger age group is a near point of convergence less than 6 to 7 cm.[6,7] Little is reported for the incidence of reduced convergence, or definition of impaired convergence, in older age groups.

Line bisection and cancellation tasks are two typical assessments of visual attention in clinical populations such as post acquired brain injury.[8] There are various versions of cancellation tasks available such as star cancellation, heart cancellation, balloons cancellation, and symbols cancellation.[9–13] Cutoff values are provided for these tasks to indicate potential presence of neglect, e.g. >6 mm displacement on line bisection crossing and <42 detection accuracy on cancellation tasks.[11] When assessing patients after brain injury it is not always possible for them to use their dominant hand due to paresis of the arm or hand. However, impact to line bisection positioning, cancellation task

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error rate, and completion time when completed using both dominant and non-dominant hands is not reported.

The above assessments of convergence, line bisection, and cancellation tasks are routinely conducted when screening patients following acquired brain injury and in the presence of other neurological conditions. The "normal" range for these assessments is not available for an older population and/or when using their non-dominant hand. The lack of this data makes it difficult to determine cutoff values and identify patients who may have impaired function following acquired brain injury.

The aim of this study was to evaluate the measurements, response times, and accuracy in a non-clinical population with healthy eyes and cognitive status, and report a normative range for older people to which future clinical comparisons can be made.

Methods

This cross-sectional cohort study had Institutional research ethics approval (reference UoL6440). Participants were required to have no known eye or neurological problems (with allowance for usual glasses or contact lens wear) and be aged 50 years or older. Participant information such as handedness, biological sex, age, and ethnicity was recorded. All assessments were conducted by qualified orthoptists.

Convergence was tested three times with any required near glasses correction. Participants were asked to look at a target held at a 33 cm distance and then follow the target as it was moved slowly toward their nose. The point at which convergence broke on each occasion was noted.

For line bisection, participants were asked to bisect each of three lines by placing a cross where they believed the middle was. The three lines varied in length on a landscape page. On a second page they were asked to bisect each of ten lines varying in length on a portrait page. The direction of error (left or right) was recorded as well as the length of error in millimeters from the actual center.

For the cancellation task, participants were asked to cross out as many large clocks as they could see on the sheet, and to ignore the small clocks and open circles. The task was on an A4 sheet containing 50 clocks, 25 smaller clocks and 26 open circles (12 large and 14 small). The number of large clocks found was recorded. The time taken to complete the task was recorded. Both inattention tests were repeated using both dominant and non-dominant hands.

For sample size calculation, to determine a range of test responses for each test, we allowed a margin of error of 5% and, assuming 95% confidence, 235 completed tests were required from 235 participants. Descriptive analysis reported the duration of assessment for each test, the means plus standard deviations of near point of convergence, position of line bisection cross and number of correctly canceled shapes and the time taken to complete this task. Non-parametric analysis was undertaken for values per age group and parametric analysis for values per dominant hand. The Pearson chi-square test was undertaken for correlation of handedness. To report normative values in this older age population, we took the upper 95% confidence interval value as indicative of the normal value maximum. Further, to determine a cutoff point indicative of abnormal responses, we calculated the 90th centile from collated responses.[14]

Results

In total, 240 participants were recruited: 161 female, 79 male, with mean age of 61.23 years (SD 8.71; median 60, range 50–97) – see Figure 1. Ethnicity was 96.7% White, 2.9% Asian/Asian British, and 0.4% Arab, with 90.8% right-handed and 9.2% left-handed.

Convergence

Breakpoint overall for all age groups was a mean of 9.22cm, SD 4.13 (95%CI 8.69–9.74cm; median 9, range 5 to 29). Table 1 shows the mean near point of convergence across age groups. Table 2 shows overall values for mean, median, confidence intervals (CI) and 90th centile. Despite limited numbers of participants in older age groups, there was a significant trend to reduced convergence in older ages ($p = .015$, independent Kruskal-Wallis test). The distribution of average near point of

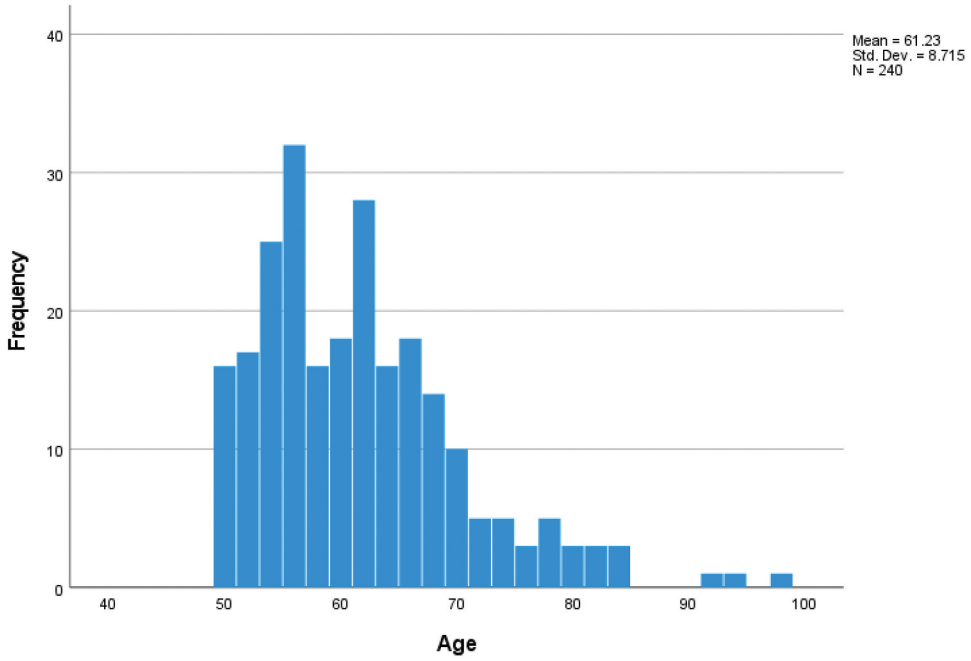

Figure 1. Age (in years) distribution of participants.

Table 1. Mean near point of convergence vs age.

Age Group	Mean (cm)	N	Std. Deviation
50–59	8.71	117	4.21
60–69	9.11	87	3.62
70–79	11.24	25	4.55
80–89	11.71	7	4.84
90–99	9.44	3	5.12
Total	9.23	239	4.13

convergence (Figure 2) was skewed toward low (i.e. better) convergence values. Cutoff values for normal vs abnormal near point of convergence are typically based on mean and median values from population samples. To report normative values for this sample of older adults, with a mean of 9.22cm and median of 9cm, we took the upper 95% confidence interval value of 9.74cm, rounded to 10cm for clinical practicality, as indicative of normal near point of convergence. However, to determine a cutoff point indicative of abnormal convergence near point for older adults, we calculated the 90th centile from collated responses: responses worse than 14cm for older adults >50 years of age.

Line bisection task

3-line task

When using the dominant hand, the mean line bisection displacement was 4.41 mm, SD2.75 (95%CI 4.05–4.76; median 3.67 mm, range 0.3 to 17.3) for the 3-line task (Table 2). Over half (52.5%) marked the center of the three lines inconsistently with marks placed centrally, or to the right or to the left of the center. Line bisections were marked consistently to the left side of center for 40.0% and to the right side of center for 7.5%; however, there was no association with dominant or non-dominant hand for consistent line bisections to the left or right of center ($p = .196$ Mann-Whitney test).

When using the non-dominant hand, the mean line bisection displacement was 5.01 mm, SD2.76 (95%CI 4.66–5.36; median 4.33 mm, range 0.3 to 20.0) for the 3-line task. The center of the three lines was marked inconsistently by 43.8% with marks placed centrally or to the right or to the left of the center. Line bisections were marked consistently to the left side of center for 50.8% and to the right side of center for 5.4%; however, there was no association with dominant/non-dominant hand for consistent line bisections to the left or right of center ($p = .232$ Mann-Whitney test).

To report normative values for this sample of older adults, with a mean of 4.41 mm and median of 3.67 mm completion for the dominant hand, we took the upper 95% confidence interval value of

Table 2. Test completion values for line bisection and clock cancellation.

Test	Mean (SD)	Median (Range)	95% confidence intervals	10th centile	90th centile
Near point of convergence (cm)					
	9.22 (4.13)	9(5-29)	8.69–9.74	–	14
3-line bisection (mm)					
Dominant hand	4.41 (2.75)	3.67 (6.3–17.3)	4.05–4.76	–	8
Non-dominant hand	5.01 (2.76)	4.33 (0.3–20)	4.66–5.36	–	8
10-line bisection (mm)					
Dominant hand	3.61 (1.99)	3.2 (0–18.6)	3.34–3.89	–	6
Non-dominant hand	3.71 (2.12)	3.3 (0.8–19.2)	3.42–3.99	–	6
Clock cancellation accuracy					
Dominant hand	49.52 (1.66)	50 (31–50)	49.31–49.76	42	–
Non-dominant hand	49.54 (1.05)	50 (44–50)	49.40–49.67	44	–
Clock cancellation duration (seconds)					
Dominant hand	36.48 (21.11)	32(14-239)	33.8–39.17	–	55
Non-dominant hand	44.00 (29.99)	38(15-303)	40.19–47.82	–	68

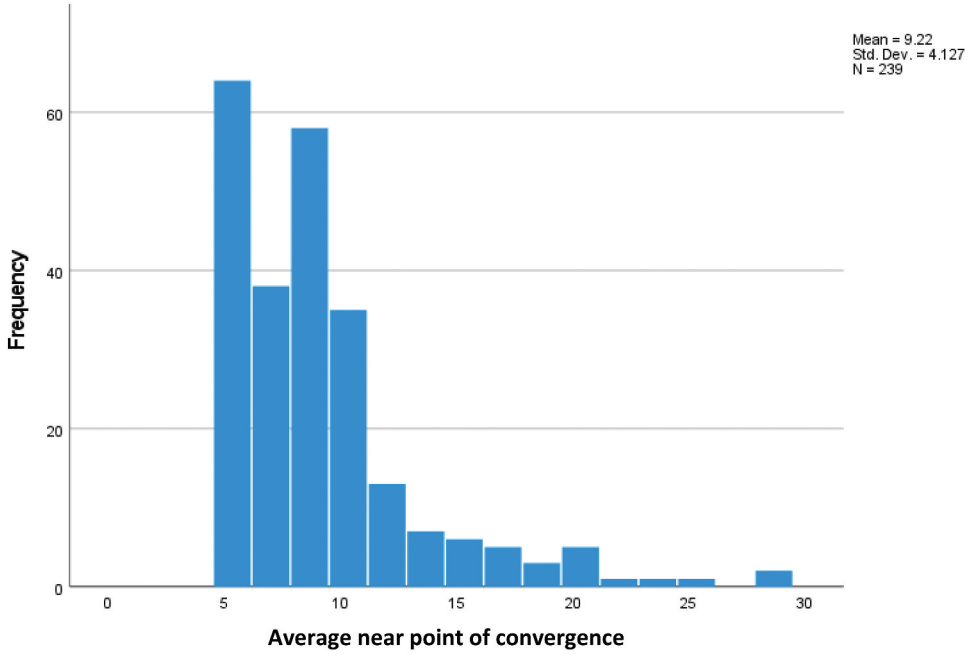

Figure 2. Distribution of average (in cm) near point of convergence.

4.76 mm, rounded to 5 mm for clinical practicality, as the normal line bisection completion with a 3-line task by older adults >50 years of age. For the non-dominant hand, with a mean of 5.01 mm and median of 4.33 mm completion for the dominant hand, we took the upper 95% confidence interval value of 5.36 mm, rounded to 6 mm for clinical practicality, as the normal for line bisection completion with a 3-line task by older adults >50 years of age. To determine cutoff points indicative of abnormal 3-line bisection for older adults, we calculated the 90th centile from collated responses: responses greater than 8mm for older adults >50 years of age regardless of whether using their dominant or non-dominant hand.

Mean line bisection displacement was significantly less for the 3-line task when completed by the dominant vs non-dominant hand indicating greater precision by the dominant hand ($p < .001$ paired t-test). There was significant correlation for consistency/inconsistency of line bisection displacement whether completed with right or left hand ($p = .006$ Pearson x^2). With increasing line length, mean displacement increased (Figure 3).

10-line task

When using the dominant hand, the mean line bisection displacement was 3.61 mm, SD1.99 (95%CI 3.34–3.89; median 3.20 mm, range 0.0 to 18.60) for the 10-line task (Table 2). Most (91.9%)

A: 3-line task

Left hand		Right hand
Mean 3.78, SD3.17		Mean 2.93, SD2.61
Mean 5.93, SD4.15		Mean 5.27, SD3.96
Mean 5.37, SD4.28		Mean 5.01, SD4.76

B: 10-line task

Left hand		Right hand
Mean 3.39, SD2.84		Mean 2.25, SD2.25
Mean 3.32, SD2.95		Mean 3.59, SD3.14
Mean 3.59, SD3.42		Mean 3.70, SD2.89
Mean 4.45, SD3.97		Mean 4.38, SD3.79
Mean 4.91, SD4.17		Mean 4.74, SD4.30
Mean 3.59, SD3.42		Mean 3.81, SD3.63
Mean 3.06, SD2.80		Mean 3.23, SD2.83
Mean 4.47, SD3.51		Mean 3.82, SD3.44
Mean 4.28, SD3.55		Mean 4.82, SD3.94
Mean 2.41, SD2.03		Mean 2.66, SD2.29

Figure 3. Mean (in mm) line bisection displacements per line.

marked the center of the ten lines inconsistently with marks placed centrally, to the right or to the left side. Line bisections were marked consistently to the left side of center for 7.1% and to the right side of center for 0.9%; however, there was no association with dominant/non-dominant hand for consistent line bisections to the left or right of center ($p = .593$ Mann-Whitney test). Mean line bisection displacement was significantly less for the 10-line vs 3-line task ($p < .001$ paired t-test).

When using the non-dominant hand, the mean line bisection displacement was 3.71 mm, SD2.12, (95%CI 3.42–3.99; median 3.30 mm, range 0.80 to 19.20) for the 10-line task. Most (90.0%) marked the center of the ten lines inconsistently with marks placed centrally, to the right or to the left side. Line bisections were marked consistently to the left side of center for 9.5% and to the right side of center for 0.5%; however, there was no association with dominant/non-dominant hand for consistent line bisections to the left or right of center ($p = .483$ Mann-Whitney test).

To report normative values for this sample of older adults, with a mean of 3.61 mm and median

of 3.20 mm completion for the dominant hand, we took the upper 95% confidence interval value of 3.89 mm, rounded to 4 mm for clinical practicality, as the normal line bisection completion with a 10-line task by older adults >50 years of age. For the non-dominant hand with a mean of 3.71 mm and median of 3.30 mm completion for the dominant hand, we took the upper 95% confidence interval value of 3.99 mm, rounded to 4 mm for clinical practicality, as the normal for line bisection completion with a 10-line task by older adults >50 years of age. To determine cutoff points indicative of abnormal 10-line bisection for older adults, we calculated the 90th centile from collated responses: responses worse than 6mm for older adults >50 years of age regardless of handedness.

Mean line bisection displacement was not significantly different for the 10-line task when completed by the right vs left hand ($p = .689$ paired t-test). There was significant correlation for consistency/inconsistency (i.e. no difference) of line bisection displacement whether completed with right or left hand ($p = .006$ Pearson x^2). With increasing line length, mean displacement increased (Figure 2).

Cancellation task

The number of clocks canceled was a mean of 49.52, SD 1.66 (95%CI 49.31–49.73; median 50, range 31 to 50) and 49.54, SD1.05 (95%CI 49.40–49.67; median 50, range 44 to 50) for dominant and non-dominant hand completion, respectively, with significant similarity ($p < .001$, paired t-test: Table 2).

Mean duration to complete the cancellation task was 36.48 seconds, SD21.11 (95%CI 33.81–39.17: median 32 seconds, range 14 to 239) and 44.00 seconds, SD29.99 (95%CI 40.19–47.82: median 38 seconds, range 16 to 303) for dominant and non-dominant hand completion, respectively. Although it took slightly longer to complete with the non-dominant left hand, the mean durations per hand were significantly similar ($p < .001$, paired t-test).

To report normative clock cancellation values for this sample of older adults, with a mean of 49.52 and median of 50 completion for the dominant hand, and mean of 49.54 and median of 50 completion for the non-dominant hand, we took the rounded upper 95% confidence interval value ($n = 49$) as the normal clock cancellation completion by older adults >50 years of age. To determine cutoff points indicative of abnormal clock cancellation for older adults, we calculated the 10th centile from collated responses: less than 42 clock cancellation responses regardless of handedness.

To report normative clock cancellation test duration values for this sample of older adults, with a mean of 36.48 and median of 32 seconds duration for the dominant hand, and mean of 44.00 and median of 38 seconds duration for the non-dominant hand, we took the upper 95% confidence interval values of 40 and 48 seconds as the normal duration limits to complete the clock cancellation task by older adults >50 years of age. To determine cutoff points indicative of abnormal clock cancellation time durations for older adults, we calculated the 90th centile from collated responses (55 and 68 seconds respectively) and rounded to the nearest half minute: one minute when completed by the dominant hand and 1.5 minutes when completed by the non-dominant hand.

Discussion

Vergence is one of five eye movement systems with a normal near point of convergence reported as from 6cm in younger age populations to 8cm in older age populations.[6,7,15,16] In older age convergence is particularly influenced by onset of presbyopia, extraocular muscle and innervation aspects[17,18] and is reported as a common sign of neurological disease.[19] We sought to evaluate the near point of convergence in older adults >50 years of age to determine changes in convergence with increasing age. We found a mean near point of convergence of 9cm and with slight further reduction of convergence with increasing age up to a mean of 12cm.

In the assessment of visual neglect, both the line bisection test and cancellation tasks are commonly used. The line bisection test is a quick screening assessment in which the patient places a mark through the center of a series of horizontal lines. When the patient marks the line with consistent displacement away from the affected side (typically toward the side of the brain lesion) visual neglect is suspected.[20] Because the line bisection results can be influenced by other conditions such as

hemianopia,[21] the test should be used in conjunction with other assessments of visual neglect, and not as a single assessment.[3] Line bisection tests range from bisecting a series of three up to 18 horizontal lines on an A4 page, and a deviation of greater than 6 mm from the central point and/or omission of two or more lines on one half of the page are considered to indicate visual neglect.[22] Cancellation tasks are most frequently used in the assessment of visual neglect and there are a range of options to choose from with typical cutoff of 42 indicating abnormality.[3,23–25]

There is little information about completion of such tasks by dominant vs non-dominant hands. Hemiplegia and monoplegia are common after acquired brain injury.[26] As such, patients may have to use their non-dominant hand to complete these pen and paper tasks. When completing the line bisection task, participants were marginally closer to central bisection for dominant hand (5 mm) than dominant hand (6 mm) completion for the 3-line test, indicating greater precision using the dominant hand, but with no difference for handedness with the 10-line test (4 mm). Given the simplicity of the task – marking the center of each line – dexterity with the non-dominant hand did not cause issue with task completion. In either the 3- or 10-line bisection task, there was greater displacement error for longer horizontal lines. Cutoffs depicting an abnormal response were > 8 mm and >6 mm for the 3- and 10-line tests. Overall, there was a tendency to mark to the left of center if right-handed, but this was not significant for the 10-line task. However, this was a significant finding for the 3-line task. These results indicate more consistency of response with use of more lines, hence a recommendation to use multiple lines with a mix of long and short lengths. The cutoff of 6 mm is in agreement with other studies.[22]

For clock cancellation, there was little difference in accuracy for dominant vs non-dominant hand completion with cutoff calculated as 42. Test duration was slightly longer when using the non-dominant hand with a cutoff of up to 1.5 minutes being allowed. Whilst the cutoff for accuracy is similar to other cancellation tests,[12] other studies report an extended time allowance for completion of the task of 3–5 minutes.[23,24] Our study was in a normal older age population sample (without ocular or neurological disease). However, for acquired brain injury patients, it is important to consider the additional sequelae of brain injury which may likely influence task completion with the non-dominant hand and/or needing to spend longer doing the task, such as cognitive impairment and fatigue.[26,27]

Limitations

Whilst we reached the target sample size for this study, we did not have an equal spread across different age groups above the age of 50 years. We had less numbers for older ages in the 80th and 90th decades. Hence, our one overall cutoff value was calculated for convergence for those >50 years of age in the absence of sufficient numbers within age groups to calculate cutoffs per increasing decade.

Conclusions

Convergence near point values have typically been reported for young age groups, but it is important to be aware of decreasing convergence near point in older adults as a normal functional decline. For assessment of visual neglect using line bisection and clock cancellation tasks, greater precision was found using multiple (ten) lines for displacement error and handedness. In acquired brain injury it is important to consider the impact of completion of tasks using the non-dominant hand (for many, their left hand where hemiplegia is present and impacting use of their dominant right hand). Further research is now warranted whereby these tests are completed by patients with acquired brain injury to compare results by dominant vs non-dominant hands and taking into account the added complexity of physical and mental sequelae such as fatigue, cognitive impairment, and upper limb weakness.

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Author contributions

CRediT: **Nicola Gavin BSc(Hons)Orth:** Data curation, Formal analysis, Funding acquisition, Writing – review & editing; **Lauren R. Hepworth PhD:** Supervision, Writing – review & editing; **Fiona J. Rowe PhD:** Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Supervision, Writing – original draft.

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