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# Clinimetric properties of relevant criteria for assessing writing and drawing orientation after right hemisphere stroke

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## ABSTRACT

**Background:** Writing and drawing orientation is rarely assessed in clinical routine, although it might have a potential value in detecting impaired verticality perception after right hemispheric stroke (RHS). Assessment tools and criteria must be conceived and validated. We therefore explored the clinimetric properties of a set of quantitative writing and drawing orientation criteria, their ranges of normality, and their tilt prevalence in RHS individuals.

**New methods:** We asked 69 individuals with subacute RHS and 64 matched healthy controls to write three lines and to copy the Gainotti Figure (house and trees). We determined six criteria referring to the orientation of writing and drawing main axes: for writing, the line and margin orientations, and for drawing, the tree, groundline, wall, and roofline orientations. Orientations were measured by using an electronic protractor from specific landmarks positioned by independent evaluators.

**Results:** The set of criteria fulfilling all clinimetric properties (feasibility, measurability, reliability) comprised the line orientation of the writing and the wall and roofline orientations of the drawing. Writing and drawing tilts were frequent after RHS (about 30% by criterion).

**Comparison with existing methods:** So far, graphomotor orientation was mostly tested qualitatively and could not be objectively appreciated in absence of validated tools and criteria, and without ranges of normality. Writing and drawing tilts may now be assessed both in routine clinical practice and research.

**Conclusions:** Our study paves the way for investigating the clinical determinants of graphomotor tilts, including impaired verticality perception, to better understand their underlying mechanisms.

## 1. Introduction

The spatial organization of handwriting and drawing predominantly involves the right hemisphere in right-handers (Ardila and Rosselli, 1993; Gainotti and Tiacci, 1970; Gainotti and Trojano, 2018; Hécaen et al., 1963; Lebrun, 1985; Raimo et al., 2021; Van der Stigchel et al., 2018), and right hemispheric stroke (RHS) often disturbs the spatial layout of writing (spatial dysgraphia) and drawing (constructional apraxia). Writing errors typically consist of an excessively large left margin, overwriting, word compression, letter omission and iteration, and sloping lines (Ardila and Rosselli, 1993; Cubelli et al., 2000; Hécaen et al., 1963; Lebrun, 1985). In parallel, drawing errors typically

consist of line omission, line iteration, loss of perspective, incorrect proportions and globally wrong orientation, alignment, and placement (Gainotti and Tiacci, 1970; Gainotti and Trojano, 2018; Trojano, 2020).

These writing and drawing spatial errors observed after RHS have been viewed as signs of spatial neglect (Ardila and Rosselli, 1993; Gainotti and Tiacci, 1970), feedback-related error (Cubelli et al., 2000; Lebrun, 1985), or impaired spatial remapping (Bai et al., 2021; Pisella and Mattingley, 2004; Rode et al., 2006). A recent single-case study (Jolly et al., 2020) suggested that the tilt of writing and drawing after RHS might be due to a tilted representation of the main visual axes transposed to the sheet of paper, referring to its top and bottom (vertical axis) and its left and right (horizontal axis). Such orientation deficits

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referring both to the vertical and the horizontal have been well documented in series of individuals with hemispheric stroke, with specific tasks consisting of adjusting visual and haptic stimuli to the vertical and to the horizontal (Kerkhoff and Zoelch, 1998; Kerkhoff, 1999). In this respect, one could determine whether individuals showing horizontal/vertical tilts in “gold-standard” orientation tests also show similar tilts in *graphomotor* tests.

However, before evaluating the orientation of graphomotor productions in a series of individuals tested after stroke and because the orientation is not a characteristic commonly assessed when evaluating their graphomotor productions, the first step is to conceive and validate an assessment tool as well as criteria for assessing orientation in writing and drawing tests. We hypothesized that extracting orientation criteria from writing and drawing productions obtained in routine clinical practice should be feasible, and that among eligible criteria, some should be reliable.

For this methodological study, we planned to analyse data of about 60 healthy controls matched to about 70 individuals tested in the subacute phase after RHS. These sample sizes are considered adequate ( $n > 50$ ) for reliability studies according to COSMIN recommendations (Mokkink et al., 2018, 2020). Our first objective was to explore the clinimetric properties of criteria, which might yield relevant information on writing and drawing orientation. To facilitate measurements, we used an electronic device whose reliability had been tested. Each criterion was investigated in terms of feasibility, measurability, and reliability. Our second objective was to determine the ranges of normality of these criteria with a series of healthy controls and determine their cut-offs to routinely diagnose abnormal writing and drawing orientations in individuals with RHS. Our third objective was to give a first indication of the prevalence of writing and drawing tilts observed after RHS. The reporting follows the STROBE (von Elm et al., 2007) and COSMIN statements.

## 2. Materials and methods

Data and analysis codes of this study are available from the corresponding author on reasonable request.

### 2.1. Study design and regulatory considerations

This study was performed in compliance with the Declaration of Helsinki and regulatory rules for human research in France. It was registered at the national committee for informatics and freedom (Commission Internationale Informatique et Liberté, no. 2014874 v1). All individuals were informed orally and in writing about the study and gave their informed consent. Graphomotor productions of individuals with RHS were analysed from data of the DOBRAS cohort (Determinants of Balance Recovery After Stroke). Then, we asked and obtained a specific ethical agreement to test controls, selected to be matched to individuals with RHS.

The DOBRAS cohort (see in Dai et al., 2021b, 2021a, 2022) was approved by our institutional review board (CHU Grenoble Alpes), which validated the ClinicalTrials.gov registration (NCT03203109). According to French law, eligible individuals were informed about the DOBRAS study (orally and in writing) and use of their data; those who did not want to participate signed an opposition form. Studies of the DOBRAS cohort focus on balance and gait disorders after stroke and recovery, in particular in relation to disorders of spatial cognition. Writing and drawing were part of the routine assessment of spatial neglect. In the current ancillary study, we focused on writing and drawing orientation, which were never before examined except in a single case study (Jolly et al., 2020).

The recruitment of healthy controls was approved by the ethical review board of Grenoble-Alpes University (CERGA-2019-04-09-1).

They were recruited from the environment of the authors and from relatives of patients hospitalized in our ward.

### 2.2. Participants

Observations of the DOBRAS cohort analyzed in the current study were limited to right-handed individuals (Edinburgh questionnaire score  $\geq 0.4$ ) with RHS, given that they are the most concerned by writing and drawing spatial errors (Ardila and Rosselli, 1993; Gainotti and Trojano, 2018; Lebrun, 1985) and usually have preserved language abilities, including writing. In addition, they could write and draw with their sound right upper limb. Among systematic assessments performed on day 30, 60, and 90 post-stroke, we extracted the first complete writing and drawing data along with sociodemographic and stroke features. Common exclusion criteria for the DOBRAS cohort included recurrent or complicated stroke, unstable medical condition, previous disability interfering with balance and verticality perception, psychiatric problems, or dementia (Dai et al., 2021a). For this study, we added several other exclusion criteria, dealing with language (altered French language, mainly because it was not the native language, or aphasia even if rare after RHS in right-handers), limb apraxia (Test of Upper Limb Apraxia score  $< 9$ ; Vanbellingen et al., 2011), and altered ability to remain seated (Postural Assessment Scale for Stroke Patients score  $< 8$ ; Benaim et al., 1999) for keeping the trunk relatively aligned with the sheet of paper when writing and drawing.

Healthy controls were recruited to be matched to stroke individuals in terms of age, sex ratio, manual laterality (right-handers) and education level (1 = primary school certificate, 2 = ninth-grade certificate [“brevet”], 3 = bachelor’s degree). They were asked about their medical history, had to not have neurological disorders, and had to have preserved abilities to draw and write legibly. No specific clinical examination or complementary investigation was performed.

All individuals, with RHS and controls, were blinded to the study hypotheses.

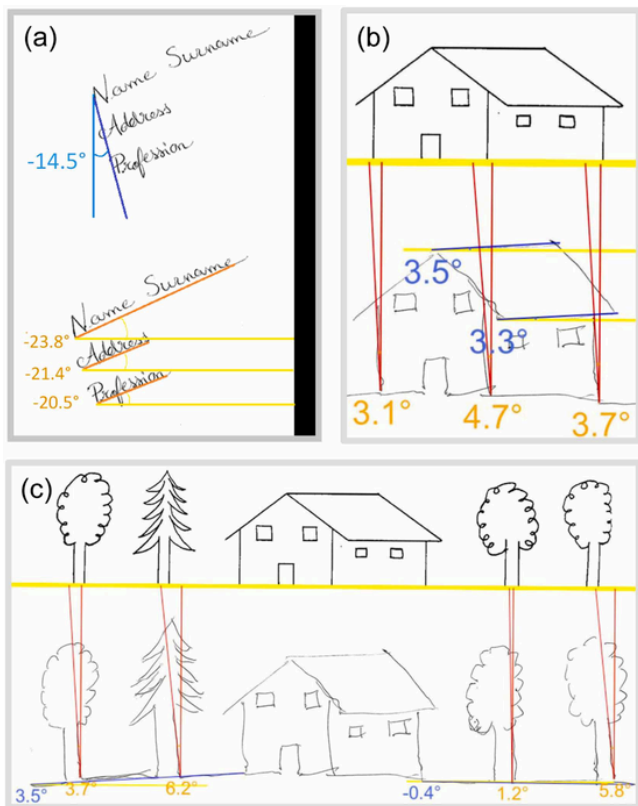
### 2.3. Setting of the writing and drawing tasks

Individuals were seated with the head and trunk in the same coronal plane, parallel to the narrow edge of a table, at an adjusted distance to be comfortable to write and draw on two different sheets of paper, placed flat on the table with the narrow border parallel to the table’s edge. Before the task, the examiner checked that the sheet of paper was centred on the individual’s head/trunk. No instruction was given on the disposition, orientation, and execution speed of the writing and drawing.

For writing, the material was that of the French battery for neglect assessment (*Batterie d’évaluation de la négligence*; Azouvi, 2002). Individuals were asked to manually write their name, surname, address, and profession on three lines on the blank sheet of paper in portrait format (see Fig. 1a). For drawing, the material was the Gainotti Figure that detects spatial neglect. It represents a landscape with four trees and one house oriented vertically and horizontally (Gainotti et al., 1972; see Fig. 1b and c). The Gainotti Figure was printed on the top of a page in landscape format. Individuals were instructed to manually copy the Gainotti Figure just below the model on the same page.

### 2.4. Orientation criteria extracted from writing and drawing tests

Graphomotor productions were first qualitatively analysed in a sample of individuals with RHS, to search for interesting criteria that might support the assessment of writing and drawing orientations. We determined six criteria: three referred to the vertical and three to the horizontal; two were obtained from writing materials and four from drawing materials. Then graphomotor productions of all individuals of this study were digitalized for measurements.



**Fig. 1.** Measures of writing and drawing orientation. All measurement procedures are described in Supplementary Materials. See also videos 1–3 for dynamic illustrations. (a) Criteria used for the *Batterie d'évaluation de la négligence* writing test (Azouvi, 2002): orientation of the left margin from the vertical and orientation of the three lines from the horizontal. (b) Criteria used for the drawing test (Gainotti Figure, Gainotti et al., 1972): orientation of three walls from the vertical and orientation of the two rooflines from the horizontal. (c) Criteria used for the drawing test: orientation of the four trees from the vertical and orientation of the two groundlines from the horizontal.

For writing, we decided to measure the orientation of the left margin with respect to the vertical (criterion 1 [C1]) and the mean orientation of the first three written lines with respect to the horizontal (C2). For drawing, verticality criteria were the mean orientation of the four trees (C3) and mean orientation of the three house walls (C4); horizontality criteria were the mean orientation of the two groundlines (left and right parts) (C5) and mean orientation of the two house rooflines from the horizontal (C6). For criteria with several items (C2–C6), at least one item was required to obtain a value for each criterion, so that these criteria could be assessed despite omissions linked to spatial neglect or visual field defect. All criteria were measured with respect to vertical and horizontal reference axes that were determined on the basis of the side edge of the sheet for writing and on the horizontal main axis (groundline) of the Gainotti Figure (see Fig. 1) for drawing.

These six criteria were measured on the productions for all individuals by several operators. Data measured by a principal operator were used for the whole study. Data measured by secondary operators served to assess the reliability of measurements. All operators were blinded to other data. All measures were performed with a home-made electronic protractor (developed in a software designed by Olivier Carré), which calculated the orientation of segments defined from landmarks positioned by the operator. Electronic rather than manual measures were used to speed up and better standardize orientation measurements as well as limit data entry errors. Full details about the measurement procedure are in Fig. 1 and videos 1–3. By convention, negative signs indi-

cated counter-clockwise orientations, corresponding to contralesional orientations in individuals with RHS. The accuracy was set at  $0.1^\circ$ .

Supplementary material related to this article can be found online at [doi:10.1016/j.jneumeth.2023.109900](https://doi.org/10.1016/j.jneumeth.2023.109900).

## 2.5. Validation of the measurement tool and reliability of the writing and drawing criteria

To validate our tool measurement, some criteria were also measured manually with a real manual protractor. Both methods yielded similar results (see Supplementary Materials for analyses).

To estimate the inter-rater reliability and measurement error for each criterion obtained with the electronic protractor, all writing and drawing criteria were measured twice for all participants: by a principal operator (RL) and by second operator (FD or SD). Each operator independently positioned their own landmarks.

## 2.6. Clinical deficits

We especially analysed two deficits that could interact with writing and drawing assessments. Spatial neglect was diagnosed with two abnormal test results from a battery of eight tests detailed in previous papers (Dai et al., 2021a; Lafitte et al., 2022) and in Supplementary Materials. The presence of hemianopia was manually evaluated by trained physicians. We also reported disability, assessed with the Functional Independence Measure (Dodds et al., 1993), ranging from 18 (very severe disability) to 126 (total independence).

## 2.7. Statistics

First, we explored three clinimetric properties — feasibility, measurability, and reliability — of the six writing and drawing criteria. Feasibility was quantified by the frequency of missing data due to non-written or non-drawn items, and measurability was quantified by the frequency of missing measurements due to missing landmarks. Feasibility and measurability were finally classified according to COSMIN terminology (Mokkink et al., 2018, 2020): very good (0 % of missing items), adequate (0–5 %), doubtful (5–10 %), and inadequate (> 10 %). The reliability of each criterion was investigated according to COSMIN recommendations (Mokkink et al., 2018, 2020).

Inter-rater reliability was assessed with the intraclass correlation coefficient (ICC) of type (2,1) according to the terminology of Shrout and Fleiss (1979). Raters were specified as random in the ANOVA model to better generalize the results to any future raters (Shrout and Fleiss, 1979). Inter-rater reliability was considered very good (or excellent) if the lower limit of the ICC confidence interval (CI) was > 0.90, adequate (or good) if > 0.75, doubtful (or moderate) if > 0.50, and inadequate (or poor) otherwise (Koo and Li, 2016). Measurement error was analyzed by the Bland-Altman method with 95 % CIs (Bland and Altman, 1986) and by the standard error of measurement (SEM). The SEM was calculated from the ANOVA model of the ICC as  $\sqrt{(\sigma_{\text{rater}}^2 + \sigma_{\text{residuals}}^2)}$ , where  $\sigma_{\text{rater}}^2$  is the mean squared error due to raters, and  $\sigma_{\text{residuals}}^2$  is the mean squared error due to unexplained variations (de Vet et al., 2006, 2011). The SEM was then used to calculate the minimal detectable change, with 95% CIs ( $\text{MDC} = 1.96 \times \text{SEM} \times \sqrt{2}$ ). Because of the lack of cut-offs in the literature, the MDC could not be considered “very good” or “doubtful”, as for other clinimetric properties. Instead we simply categorized the MDC as adequate or not. A threshold  $\leq 3^\circ$  was considered as conservative as possible and avoided misclassifying criteria as having inadequate MDC. This value of  $3^\circ$  was obtained by adding  $1^\circ$  (to account for the observational nature of the study and the novelty of our writing and drawing criteria) to the MDC for the visual vertical orientation ( $\approx 2^\circ$ , see Piscicelli et al., 2015).

Second, we determined the ranges of normality [5th–95th percentiles] for each criterion from control data, which allowed for diag-



nosing contralesional and ipsilesional tilts (i.e., abnormal orientations) in individuals with RHS. In addition, to better characterize these contralesional and ipsilesional tilts, we compared them in terms of absolute magnitude, calculated with respect to the median orientation of controls.

Finally, supplementary analyses were performed to test the effect of sociodemographic factors on writing and drawing orientation and to test for differences between writing/drawing items (e.g., the first, second, and third writing lines) within an orientation criterion (e.g., line criterion).

Because most data did not follow Gaussian distributions and sometimes contained extreme values, continuous data are presented as median [Q1; Q3] and were analysed by non-parametric tests (Wilcoxon-signed rank, Mann-Whitney, Friedman, Kruskal-Wallis). All effect sizes (Wilcoxon  $r$ , Cramer's  $w$ , Spearman  $\rho$ ) were considered small, medium, or large if  $> 0.1, 0.3, \text{ or } 0.5$ , respectively (Cohen, 1988). Categorical data are presented as number (%). The significance level was set at  $p < .05$  and was Bonferroni-corrected when needed. Statistical analyses were performed with R 4.0.3 (R Core Team, 2020). ICC, SEM, and MDC values were calculated from the outputs of the function `psych:ICC(lmer = F)` in the R package "psych" (Revell, 2023).

### 3. Results

#### 3.1. Participants

We analyzed data for 133 individuals (see flowchart in Fig. 2): 69 with RHS were compared to 64 healthy controls, matched in age (median 68 years [62; 73] vs 63 years [59; 71]; Mann-Whitney,  $p = .24$ ,  $r = 0.1$ ), sex ratio ( $n = 43/69$  [62.3%] vs  $35/64$  [54.7%] males;  $\chi^2$ ,  $p = .47$ ,  $w = 0.06$ ), and education level ( $\chi^2$ ,  $p = .10$ ,  $w = 0.19$ ). Individuals with RHS were mostly assessed in the early subacute phase: 48 (70%) were assessed at day 30 post-stroke, 13 (19%) at day 60 post-stroke, and 8 (12%) at day 90 post-stroke. Stroke was mostly an infarct ( $n = 61, 88\%$ ). Disability was moderate, with median Functional Independence Measure score 102 [75; 114]. Overall, 41/69 (59%) individuals with RHS exhibited left spatial neglect and 23/69 (33%) left hemianopia.

There were no missing data on main outcomes, all 133 individuals having produced writing and drawing material of sufficient quality for

the study. Missing data mainly concerned spatial neglect, as detailed in Supplementary Materials.

#### 3.2. Feasibility and measurability of writing and drawing criteria

##### 3.2.1. Writing material

All individuals correctly followed the instructions and wrote three lines (or more, except one who wrote two lines). Landmarks defined to measure the margin and line orientations were easy to identify, except for 6/69 (9%) individuals with very small writing. Hence, the feasibility and measurability of the writing criteria were very good.

##### 3.2.2. Drawing material

We obtained a criterion for most individuals (by averaging item orientations or keeping the orientation value of a unique item), although in some cases some drawing items could not be objectively assessed (see Table S1 for details). Individuals with RHS showing spatial neglect or hemianopia frequently omitted drawing items, in general those positioned on the left side of the landscape or the house. Therefore, some individuals did not draw at least one item, so the criterion was missing: 15/69 (22 %) individuals for the groundline, 2/69 (3%) for the roofline, and 1/69 (1%) for the wall. In addition, for some drawn items, landmarks were difficult to identify because of complex spatial alterations, as explained in additional material (see Figure S1 for example). Thus, the feasibility and measurability were less satisfactory for drawing than writing.

#### 3.3. Writing and drawing orientations

Table 1 presents the writing and drawing orientations for controls and individuals with RHS as compared with the horizontal or vertical reference axes of the sheet of paper (see also Fig. 3).

For controls, all verticality criteria (margin, tree, wall) were approximately upright (all Wilcoxon  $r \leq 0.28$ ; all  $p$ -values  $\geq .029$ ,  $\alpha$  cutoff = .003; Table 1), with nearly symmetrical ranges of normality for the margin [ $-18.1^\circ; 17.4^\circ$ ], tree [ $-5^\circ; 3.2^\circ$ ], and wall [ $-3.8^\circ; 2.9^\circ$ ]. For the margin, the range of normality was very wide because of great inter-individual differences in how to perform the line break. In contrast, all horizontality criteria (line, groundline, roofline) were tilted counterclockwise (all Wilcoxon  $r \geq 0.76$ ; all  $p$ -values  $\leq 10^{-6}$ ; Table 1), which led to asymmetrical ranges of normality for the line [ $-4.9^\circ; 0.6^\circ$ ], groundline [ $-4.3^\circ; 0^\circ$ ] and roofline [ $-7.5^\circ; 0.1^\circ$ ]. We checked the potential effects of socio-demographics (age, sex, education level) for all criteria, but all effects were small, and none were significant (see Table S2).

Similar patterns were found for individuals with RHS. All verticality criteria were approximately upright (all Wilcoxon  $r \leq 0.29$ ; all  $p$ -values  $\geq .014$ ,  $\alpha$  cutoff = .003), whereas all horizontality criteria were tilted counterclockwise (all Wilcoxon  $r \geq 0.55$ ; all  $p$ -values  $\leq 10^{-4}$ ). Controls and individuals with RHS had comparable writing and drawing orientations (all Wilcoxon  $r \leq 0.14$ ; all  $p$ -values  $\geq .10$ ; Table 1), except for the roofline, which was tilted more counterclockwise for RHS individuals ( $p < .001$ ,  $r = 0.33$ ). Finally, we explored possible different orientations between items of a same criterion (e.g., upper and lower lines of the line criterion). These data are in Table S3. We found a gradient effect in writing from the first to the third line for RHS individuals, with the writing tilting increasingly counterclockwise.

#### 3.4. Reliability

Table 2 presents the ICC and MDC values for the six criteria obtained with the electronic protractor for the whole sample. The mean differences between both operators were always small ( $< 0.5^\circ$ ), with few differences outside the limits of agreements ( $\leq 8\%$ ; see Figure S2 for the corresponding Bland-Altman plots). ICC values were always

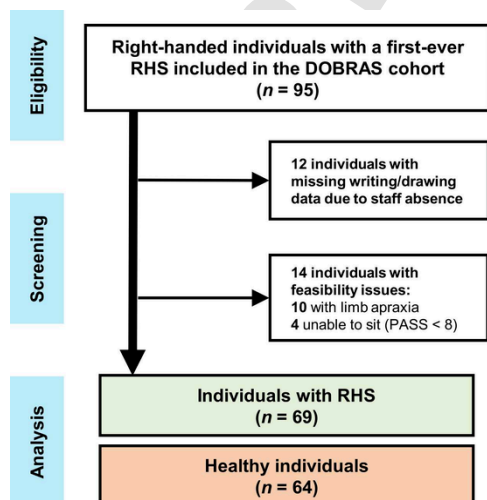


Fig. 2. Flow chart of the study. Limb apraxia was assessed with the Apraxia Screen of Test of Upper Limb Apraxia (Vanbellingen et al., 2011) and seating ability with the Postural Assessment Scale for Stroke Patients (PASS; Benaim et al., 1999). DOBRAS: Determinants of balance and recovery after stroke; RHS: right hemispheric stroke.

**Table 1**

Writing and drawing orientations for controls and individuals with right hemispheric stroke (RHS) extracted from the *Batterie d'évaluation de la négligence* writing test (Azouvi, 2002) and drawing test (Gainotti Figure, Gainotti et al., 1972).

Criterion	Task	Controls (n = 64)			Individuals with RHS			Controls vs individuals with RHS		
		median* [Q1; Q3]	<i>p</i> *	<i>r</i>	median* [Q1; Q3]	<i>p</i>	<i>r</i>	<i>n</i>	<i>p</i> **	<i>r</i>
Margin	writing	-1 [- 5.2; 4.4]	.48	0.09	-2.4 [- 12.1; 4.4]	.014 (ns)	0.30	69	.12	0.13
Line	writing	-1.7 [- 3; - 0.7]	< <b>10<sup>-6</sup></b>	0.77	-1.8 [- 4.5; - 0.6]	< <b>10<sup>-6</sup></b>	0.72	69	.19	0.11
Tree	drawing	-0.6 [- 2.3; 0.9]	.025 (ns)	0.28	0.5 [- 2.1; 1.9]	1	0	68	.14	0.13
Groundline	drawing	-1.2 [- 2; - 0.4]	< <b>10<sup>-6</sup></b>	0.80	-1.1 [- 2.6; 0.1]	< <b>10<sup>-6</sup></b>	0.55	54	.83	0.02
Wall	drawing	-0.5 [- 2; 1.2]	.05	0.24	-0.8 [- 2.7; 1.6]	.09	0.20	68	.81	0.02
Roofline	drawing	-2.3 [- 3.8; - 1.4]	< <b>10<sup>-6</sup></b>	0.85	-4.4 [-8.3; -2.5]	< <b>10<sup>-6</sup></b>	0.85	67	< <b>.001</b>	0.33

Note.

\*: One-sample Wilcoxon-signed rank tests, where 0° represent the true vertical for the margin, tree, and wall criteria and the true horizontal for the line, groundline, and roofline criteria.

\*\* : Mann-Whitney tests.

The  $\alpha$  rate accounting for multiple tests was .003 (.05/18[6 criteria \* 3 comparisons]). Significant *p* values are shown in bold. By convention, Wilcoxon *r* values  $\geq$  0.1, 0.3, or 0.5 were considered small, medium, or large, respectively.

ns: non-significant after Bonferroni correction

very good. MDC values were adequate for the groundline, wall, and roofline ( $< 2^\circ$ ) and for the line and tree ( $< 3^\circ$ ). Only the MDC value for the margin was inadequate ( $4.2^\circ$ ). Limits of agreements and ICC and MDC values calculated separately for controls and RHS individuals were quite similar (see Table 2, Figure S2).

### 3.5. Prevalence of abnormal writing or drawing orientation in RHS individuals

For all criteria, we identified three patterns of orientation: normal orientation, contralesional (counter-clockwise) tilt, and ipsilesional (clockwise) tilt (Table 3). The prevalence of tilt by criterion, regardless of direction, ranged from 26 % to 37 %. The prevalence ranged from 10% to 30% for contralesional tilts and from 6 % to 26 % for ipsilesional tilts. Contralesional tilts were predominant for the roofline, line, and margin criteria, whereas ipsilesional tilts were predominant for the groundline criterion. Contralesional and ipsilesional tilts had a similar frequency for the tree and wall criteria (Table 3). In considering only the three criteria found adequate in all clinimetric properties (line, roofline, wall), the frequency of individuals with at least one contralesional tilt was 51% ( $n = 35/69$ ), whereas the frequency of individuals with at least one ipsilesional tilt was half that (25 %,  $n = 17/69$ ). Frequencies were comparable in all possible combinations obtained with two criteria, most individuals showing normal orientations or a mix of normal and tilted orientations (contralesional or ipsilesional; Table 4). Associations of congruent contralesional tilts reached 13% when writing and drawing were considered together. This frequency was 6% when the three criteria were required. The frequency of congruent ipsilesional tilts was much lower, with no ipsilesional tilt found for the three criteria in any individuals. Finally, a few individuals also showed a combination of contralesional and ipsilesional tilts, ranging from 3% to 6% across all combinations of criteria. Further details are given in Supplementary Materials.

Table 3 compares magnitudes of contralesional and ipsilesional tilts for each criterion. The magnitudes of contralesional tilts were four and two times greater than those of ipsilesional tilts for the roofline and line, respectively (*p*-values  $\leq$ .002, Wilcoxon  $r > 0.62$ ). The magnitudes of contralesional and ipsilesional tilts were comparable for other criteria.

Altogether, these findings strengthen the idea that writing and drawing tilts are frequent after RHS, with a possible greater magnitude in contralesional tilts.

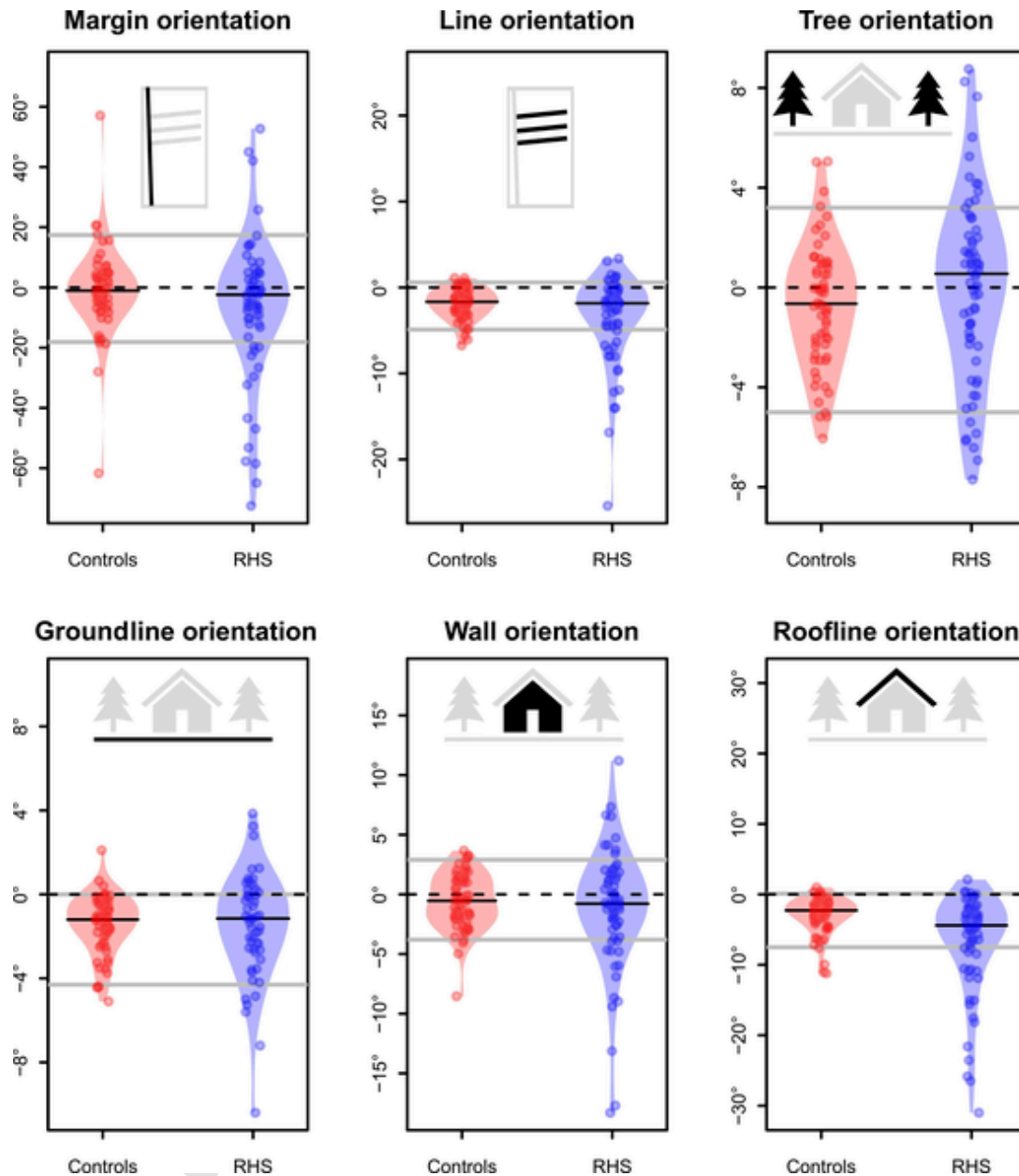
## 4. Discussion

Up to now, the orientation of writing and drawing production is rarely assessed in routine clinical practice in individuals with right

hemispheric stroke (RHS). Our first objective was to determine a set of feasible, measurable, and reliable criteria to assess writing and drawing orientations, from clinical routine tests. Our second objective was to set the ranges of normality of the criteria, to diagnose writing and drawing tilts in individuals with RHS. For this aim, we enrolled 64 controls matched to 69 individuals with subacute RHS. Participants were asked to write three lines and to copy the Gainotti Figure (Gainotti et al., 1972). From careful qualitative analysis, we extracted the orientation of six writing and drawing main axes: the margin and line of the writing, and the tree, groundline, wall, and roofline of the drawing. A home-made electronic protractor was designed for this purpose, to speed up and standardize orientation measurements. Then, each criterion was investigated in terms of feasibility, measurability, and reliability (see Table 5 for a synthesis). The set of criteria we recommend from our analyses includes the line orientation of the writing as well as the roofline and wall orientations of the drawing (house of the Gainotti Figure), found adequate for all clinimetric properties. These criteria can be quickly extracted by using electronic protractors applied on graphomotor productions obtained in clinical routine practice and digitalized for measurements. In contrast, the three other criteria had at least one doubtful or inadequate clinimetric property, concerning feasibility (groundline), measurability (tree, groundline), or excessive measurement error (margin). Our third objective was to give a first estimation of the prevalence of writing and drawing tilts in individuals with RHS. We found that these tilts are frequent, overall contralesional tilts, the magnitude of which is large in some individuals.

### 4.1. Clinimetrics of writing and drawing orientation: What makes a good criterion?

The line, roofline, and wall criteria satisfactorily met all clinimetric properties, whereas the margin, tree, and groundline criteria had one or two downsides. These results provide some hints about the features that characterized the most adequate criteria. (1) For adequate feasibility, the criterion to be drawn must be positioned not too far on the left side of the material, otherwise it may be omitted in individuals with spatial neglect and hemianopia after RHS. (2) For adequate measurability, the criterion to be drawn must be simple. Complex (tree) or very long (groundline) shapes were often distorted, with missing or unclear landmarks (Figure S1). Even more annoying is the frequent loss of canonical orientation of some items, drawn convex or in a piece-meal fashion (Figure S1). In comparison, the line, roofline, and wall criteria are short segments, with meaningful orientation values. (3) For adequate inter-rater reproducibility, the nature of the criterion (shape, materials) does not matter. Inadequate measurement error of the margin criterion may be due in part to its very wide distribution.



**Fig. 3.** Writing and drawing orientations for healthy controls ( $n = 64$ ) and individuals with right hemispheric stroke (RHS,  $n = 69$ ) extracted from the *Batterie d'évaluation de la négligence* writing test (Azouvi, 2002) and drawing test (Gainotti Figure, Gainotti et al., 1972). The solid black lines represent the median for each group. The solid grey lines represent ranges of normality calculated from control data.

#### 4.2. Writing and drawing orientations in controls

Writing and drawing orientations have been mainly assessed qualitatively and only in the field of clinical neurosciences (Ardila and Rosselli, 1993; Gainotti and Tiacci, 1970; Hécaen et al., 1963; Lebrun, 1985). To our knowledge, only three clinical studies provided quantitative measures of writing orientation, from words (Cubelli et al., 2000) and lines (Rode et al., 2006; Jolly et al., 2020), but only one compared clinical data to those from a small group of controls (Jolly et al., 2020).

Our study is the first to investigate the orientation of writing and drawing material in a series of healthy individuals. It confirms results reported by Jolly et al. (2020) in a few individuals included to serve as controls in a single case study. All three criteria referring to horizontality (line, groundline, and roofline) were congruently tilted counter-clockwise, with comparable magnitude of about 1–2°. This tilt might result from biomechanical constraints involved in the upper-limb joint

movements or the need to reduce degrees of freedom for optimal motor control. These interpretations may involve the absence of spatial bias in controls for criteria referring to the verticality, for which there is no lateral displacement of the hand (tree, wall).

#### 4.3. Writing and drawing orientations in RHS individuals

All writing and drawing criteria could be tilted in individuals with RHS, with a prevalence (about 30 %) comparable to that of spatial neglect (Bowen et al., 1999; Esposito et al., 2021) and impaired verticality perception (Brandt et al., 1994; Pérennou et al., 2008). This result extends the knowledge that RHS involves visuo-constructive deficits and more peculiarly disorientations in the spatial organization of the writing and drawing materials (Ardila and Rosselli, 1993; Gainotti and Trojano, 2018; Hécaen et al., 1963; Lebrun, 1985; Trojano, 2020). For two criteria fully meeting adequate clinimetric properties, the writing



**Table 2**

Reliability of the writing and drawing criteria for controls and individuals with RHS.

Criterion	Task	Inter-rater agreement		Measurement error		
		ICC [95% CI]	interpretation*	SEM <sup>†</sup>	MDC <sup>‡</sup>	interpretation*
Controls and individuals with RHS						
Margin (n = 133)	writing	.99 [.99;.99]	++	1.5	4.2	(-)
Line (n = 133)	writing	.99 [.98;.99]	++	1	2.8	+
Tree (n = 132)	drawing	.92 [.90;.94]	++	0.9	2.4	+
Groundline (n = 118)	drawing	.96 [.94;.97]	++	0.4	1.2	+
Wall (n = 132)	drawing	.98 [.98;.99]	++	0.6	1.8	+
Roofline (n = 131)	drawing	.99 [.99;.99]	++	0.6	1.7	+
Controls (n = 64)						
Margin	writing	.99 [.99;.99]	++	1.4	3.7	(-)
Line	writing	.95 [.92;.97]	++	0.5	1.3	+
Tree	drawing	.85 [.77;.90]	+	1.3	3.6	(-)
Groundline	drawing	.90 [.86;.93]	+	0.5	1.4	+
Wall	drawing	.97 [.95;.98]	++	0.9	2.4	+
Roofline	drawing	.98 [.97;.99]	++	0.5	1.4	+
Individuals with RHS						
Margin (n = 69)	writing	.99 [.99;.99]	++	1.5	4.1	(-)
Line (n = 69)	writing	.99 [.98;.99]	++	1.1	3.1	(-)
Tree (n = 58)	drawing	.96 [.93;.97]	++	1	2.9	+
Groundline (n = 54)	drawing	.98 [.96;.99]	++	0.4	1.1	+
Wall (n = 68)	drawing	.99 [.98;.99]	++	0.6	1.7	+
Roofline (n = 67)	drawing	.99 [.99;.99]	++	0.5	1.4	+

Note.

\*: For ICC, ++ = very good, + = adequate. All ICC values had a  $p$ -value < 10<sup>-6</sup>.

\*\* : For MDC, + = adequate, (-) = inadequate.

RHS: right hemispheric stroke; ICC: intraclass correlation coefficient; SEM: standard error of measurement; MDC: minimal detectable change

**Table 3**

Patterns of writing and drawing orientation (%) and absolute magnitude of writing and drawing tilt for individuals with RHS.

Criterion	Task	Orientation			Absolute tilt magnitude (°)				
		Normal	Contralesional tilt	Ipsilesional tilt	Contralesional tilt	Ipsilesional tilt	$p$	$r$	$n$
Margin	writing	51 (74%)	14 (20%)	4 (6 %)	36.8 [22.6; 55.5]	44.6 [39.1; 48]	.72	0.08	18
Line	writing	45 (65%)	16 (23%)	8 (12 %)	7.1 [5.5; 11]	3 [2.7; 3.6]	< 10 <sup>-4</sup>	0.85	24
Tree	drawing	51 (74%)	7 (10%)	11 (16 %)	5.5 [5.3; 6]	5.1 [4.6; 7.5]	.79	0.06	18
Groundline	drawing	34 (63%)	6 (11%)	14 (26 %)	4.2 [3.9; 5.6]	1.9 [1.7; 2.4]	.009 (ns)	0.58	20
Wall	drawing	45 (66%)	14 (21%)	9 (13 %)	5.9 [4.2; 8.8]	5.3 [4.7; 7.2]	.71	0.08	23
Roofline	drawing	43 (64%)	20 (30%)	4 (6 %)	11.2 [8.3; 16.7]	2.6 [2.6; 3.1]	.002	0.62	24

Note. The term “tilt” refers to an orientation outside the ranges of normality calculated in controls. The absolute magnitude of the contralesional and ipsilesional tilts, calculated with respect to the median orientation of controls, were compared with Mann-Whitney tests. The  $\alpha$  rate accounting for multiple tests was .008 (.05/6 comparisons). Significant  $p$  values are shown in bold. By convention, Wilcoxon  $r$  values  $\geq 0.1$ , 0.3, or 0.5 were considered small, medium, or large, respectively.

ns: non-significant after Bonferroni correction; RHS: right hemispheric stroke

line and drawing roofline, contralesional tilts were more frequent and greater than ipsilesional tilts. By analogy, this situation is precisely what is observed for impaired verticality perception (Brandt et al., 1994; Dai et al., 2021b; Pérennou et al., 2008), and by extension, impaired horizontality perception (Kerkhoff, 1999; Kerkhoff and Zoelch, 1998). Future studies are now needed to investigate more deeply the clinical determinants of writing and drawing tilt. Although the study of Jolly et al. (2020) suggests a role of verticality perception, multivariate analyses are needed to further explore the role of other deficits (spatial neglect, hemianopia) as well as the association with other domains of verticality perception such as the postural vertical (Lafitte et al., 2022; Pérennou et al., 2008) and their behavioral consequences. This work should help unravel the mechanisms involved in spatial dysgraphia and constructional apraxia as well as the diagnostic value of writing and drawing tilts in impaired spatial cognition. In that respect, studies could investigate the clinical determinants of line writing and roofline drawing, the only criteria found more tilted in individuals with RHS than in controls.

Finally, our findings show the existence, in the same individuals, of writing and drawing tilts of opposite directions, contralesional or ipsilesional. This situation might result from different mechanisms contributing to tilts of graphomotor production after RHS, possibly involving disorders of sensorimotor integration, coordinate transformation (Bai et al., 2021; Cubelli et al., 2000; Lebrun, 1985; Russell et al., 2010), and verticality representation (Jolly et al., 2020). Further studies are needed to investigate the clinical profiles of individuals meeting a given pattern of graphomotor orientation.

#### 4.4. Study limitations

The main limitation of this study was the observational nature of the writing and drawing data collected in routine clinical practice for individuals with stroke. For this reason, the test-retest reliability of the writing and drawing criteria could not be assessed in individuals with RHS and thus was not assessed in controls either. For the same reason, we cannot exclude that the sheet of paper did not remain always perfectly centered on the participant’s trunk during the test, even if neuropsychologists carefully checked this and we discarded data for individuals with high postural imbalance who were unable to sit independently. Finally, our data are not generalizable to individuals with left hemisphere stroke, who were not tested here. The study of individuals with RHS provided the optimal conditions for the search for satisfactory graphomotor orientation criteria: On the one hand, these individuals are known to present frequent graphomotor tilts (Hécaen et al., 1963; Gainotti and Tiacci, 1970), and on the other, motor commands for writing and drawing with the right hand are generally preserved, this side being the non-paretic one in hemispheric strokes. Moreover, although graphomotor errors have been described after left hemispheric stroke, to the best of our knowledge, they do not comprise orientation errors (Ellis, 1988; Gainotti and Tiacci, 1970; Roeltgen and Heilman, 1985).

**Table 4**

Patterns of graphomotor orientations for all combinations of congruent and incongruent criteria.

Criteria	Congruent orientations			Incongruent orientations		Total
	Normal orientations	Contralesional tilts	Ipsilesional tilts	Normal + tilt	Contralesional + ipsilesional tilts	
Writing + Drawing	24 (38 %)	8 (13 %)	2 (3 %)	26 (41 %)	4 (6 %)	64 (100 %)
Line + Roofline	30 (45 %)	7 (10 %)	1 (1 %)	27 (40 %)	2 (3 %)	67 (100 %)
Line + Wall	33 (49 %)	7 (10 %)	1 (1 %)	23 (34 %)	4 (6 %)	68 (100 %)
Roofline + Wall	32 (48 %)	5 (7 %)	2 (3 %)	24 (36 %)	4 (6 %)	67 (100 %)
Line + Roofline + Wall	24 (36 %)	4 (6 %)	0 (0 %)	37 (55 %)	2 (3 %)	67 (100 %)

Note. Writing refers to the orientation of the line criterion, and drawing refers to the orientation of roofline or wall criteria. For clarity, the four individuals showing incongruent roofline and wall tilts were removed from this specific table row.

**Table 5**

Qualitative summary of the clinimetric properties of the writing and drawing criteria.

Criterion	Task	Feasibility	Measurability	Reliability	
				ICC	MDC
Margin	writing	++	++	++	(--)
Line	writing	++	++	++	+
Tree	drawing	+	+	++	+
Groundline	drawing	(-)	(-)	++	+
Wall	drawing	+	+	++	+
Roofline	drawing	+	+	++	+

Note. The feasibility and measurability were evaluated from the frequency of non-written and non-drawn items inside each criterion, as follows: very good (0% of missing items), adequate (0–5%), doubtful (5–10%), and inadequate (>10%). For reliability, inter-rater reliability was considered very good if the lower limit of the confidence interval (CI) of the ICC was > 0.90, adequate if > 0.75, doubtful if > 0.50, and inadequate otherwise (Koo and Li, 2016). The MDC was considered adequate if < 3° and inadequate otherwise.

++ = very good; + = adequate; (-) = doubtful; (--) = inadequate. ICC: intraclass correlation coefficient, MDC: minimal detectable change

Nevertheless, graphomotor orientations after left hemispheric stroke could be assessed in individuals who retained or recovered the capacity to write and draw, especially in relation to their possible spatial neglect or impaired verticality perception (although these disorders are less severe and frequent after left than right hemispheric stroke; e.g., Kerkhoff, 1999; Pérennou et al., 2008).

## 5. Conclusion

Measuring writing and drawing orientation might benefit the clinician or researcher interested in the diagnostic value of graphomotor tilts in impaired verticality perception and more generally impaired spatial cognition. This study aimed to conceive an easy-to-use measurement tool and feasible, measurable, and reliable criteria to quantitatively assess and diagnose writing and drawing orientation after RHS. We systematically examined the clinimetric properties of six writing and drawing criteria in a series of 64 healthy individuals matched to a series of 69 individuals with RHS. One writing criterion (line orienta-

tion of the *Batterie d'évaluation de la négligence*) and two drawing criteria (roofline and wall of the house in the Gainotti Figure) met all clinimetric properties to be confidently used in routine clinical practice and research. We also provide ranges of normality for these criteria and a first estimation of tilts (prevalence and magnitude) in individuals with RHS. The next step is to better understand the clinical profile of individuals who show writing and drawing tilts after RHS and the predictive values of these tilts for the existence of other spatial disorders, in particular a biased verticality representation.

## Declaration of Competing Interest

None.

## Data Availability

The data set belongs to Grenoble-Alpes CHU. We are waiting for their acceptance to share the data in a public repository, but it could take some extra days.

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## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.jneumeth.2023.109900](https://doi.org/10.1016/j.jneumeth.2023.109900).

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