Annals of Physical and Rehabilitation Medicine 62 (2019) 35–42

Available online at ScienceDirect www.sciencedirect.com

Elsevier Masson France EM|consulte www.em-consulte.com

Original article

# Validation of French upper limb Erasmus modified Nottingham Sensory Assessment in stroke

Claire Villepinte [a,b,c,*], Emilie Catella [d], Magali Martin [d], Sylvie Hidalgo [d], Sabrina Téchené [b], Claire Lebely [e], Evelyne Castel-Lacanal [d,f], Xavier de Boissezon [d,f], HuiJun Chih [c], David Gasq [a,f]

[a] Department of Physiological Functional Exploration, University Hospital of Toulouse, 31059 Toulouse, France
[b] School of Occupational Therapy, PREFMS, University Hospital of Toulouse, 31059 Toulouse, France
[c] School of Public Health, Faculty of Health Sciences, Curtin University, 6102 Perth, Australia
[d] Department of Neurorehabilitation, University Hospital of Toulouse, 31059 Toulouse, France
[e] Clinical Investigation Center, University Hospital of Toulouse, University of Toulouse 3 and Inserm, 31059 Toulouse, France
[f] ToNIC, Toulouse NeuroImaging Center, Université de Toulouse, Inserm, UPS, 31024 Toulouse, France

ARTICLE INFO

*Article history:*
Received 2 December 2017
Accepted 28 March 2018

*Keywords:*
Stroke
Upper extremity
Outcome assessment
Somatosensory disorders
Reproducibility of results

ABSTRACT

*Background:* Somatosensory impairment of the upper limb (UL) occurs in approximately 50% of adults post-stroke, associated with loss of hand motor function, activity and participation. Measurement of UL sensory impairment is a component of rehabilitation contributing to the selection of sensorimotor techniques optimizing recovery and providing a prognostic estimate of UL function. To date, no standardized official French version of a measure of somatosensory impairment has been established.
*Objective:* To develop and validate a French version of the Erasmus modified Nottingham Sensory Assessment somatosensory (EmNSA-SS) and stereognosis (EmNSA-ST) component for evaluating the UL among adults with stroke.
*Methods:* This study is a single-center observational cross-sectional study. A French version of the EmNSA for UL was developed by forward-backward translation and cross-cultural adaptation. Fifty stroke patients were recruited to establish concurrent-criterion-related validity, internal consistency, intra- and inter-rater reproducibility with intracorrelation coefficients (ICCs) for reliability and the minimal detectable change with 95% confidence interval (MDC95) for agreement, as well as ceiling and floor effects. Criterion validity was assessed against the Fugl-Meyer Assessment-Sensory (FMA-S) for the UL.
*Results:* The median (range) EmNSA-SS score was 41.5 (1–44). The Spearman rank correlation coefficient between EmNSA-SS and FMA-S total scores was moderate (rho = 0.74, $P < 0.001$). The EmNSA-SS/ST internal consistency was adequate across subscales; with Cronbach $\alpha$ ranging from 0.82–0.96. For the EmNSA-SS total score, intra- and inter-rater reliability was excellent (ICC = 0.92 in both cases), with MDC95 of 12.3 and 14.6, respectively. EmNSA-SS/ST total scores demonstrated no ceiling or floor effects.
*Conclusions:* The French EmNSA is a valid and reproducible scale that can be used for comprehensive and accurate assessment of somatosensory modalities in adults post-stroke. Taking less than 30 min to administer, the instrument has clinical utility for use in patients with cognitive comorbidities and at various stages of recovery in multidisciplinary clinical practice and research settings.


## 1. Introduction

Somatosensory impairment occurs in 60% to 89% of adults with stroke [1,2]. Impaired tactile capacity of the paretic hand, due to cerebral lesions altering somatosensory processing, is common in half of the patients with stroke [1–5]. Sensory processing is a component of normal movement because input is processed via somatosensory modalities producing sensorimotor output necessary for hand motor function and control [3,6,7]. Somatosensory feedback allows manipulation, coordination and strength skills to be adapted to tasks and the environment [2,3,8,9]. Sensory damage after stroke affects performance due to loss of arm movement impacting activity, participation and consequently quality of life in individuals post-stroke [2,10–12].

* Corresponding author. School of Occupational Therapy, PREFMS, University Hospital of Toulouse, 74, voie du TOEC, TSA 40031, 31059 Toulouse cedex 9, France.
*E-mail address:* villepinte.c@chu-toulouse.fr (C. Villepinte).

https://doi.org/10.1016/j.rehab.2018.03.004
1877-0657/

Integration of sensory modalities in clinical sensorimotor rehabilitation should be based on quantitative evaluation to optimize selection and implementation of appropriate techniques contributing to improved outcomes [1,2,13]. Measures with established psychometric properties contribute to prognostic estimates of loss of movement and function [4,5]. Somatosensory impairment is associated with longer hospital stays, which illustrates the prognostic utility of assessment for recovery post-stroke [2,4,14]. Clinical practice should include relevant measures to assess sensory impairment; however, measures of sensory impairment warrant further development to contribute to evidence-based practice and facilitate professional communication throughout the rehabilitation process [2,15,16].

The current literature reveals few standardized sensory assessments for stroke with established validity and reliability [16]. The development of sensory assessments evaluating exteroceptive, proprioceptive and cortical sensory functions is recommended for stroke, warranting attention from research and clinical practice [16,17]. Exteroceptive sensation, also termed superficial sensation, refers to tactile or touch, pain, temperature sensations and sensory perversions [17]. Limitations arise from issues including lack of generalizability, subjectivity of assessment, and lack of standardized protocols [18,19]. Evaluations may not consider the impact of neurological comorbidities on results (such as cognitive deficits and aphasia) due to strict inclusion and exclusion criteria, so the measures are best suited for use with musculoskeletal, rheumatic and/or peripheral nerve disorders [19–21].

The Nottingham Sensory Assessment (NSA), Fugl-Meyer Assessment-Sensory Section (FMA-S) and the Rivermead Assessment of Sensory Processing are standardized tools showing clinical relevance for the stroke population [21–23]. The FMA-S does not provide a comprehensive assessment of somatosensory capacity post-stroke but does provide a standardized assessment of tactile and proprioception in French. The tactile light touch subscale demonstrates poor to moderate reliability (weighted kappa from 0.3–0.55) and low to moderate validity (rho from 0.29–0.53) with the Barthel Index, as well as a significant ceiling effect, which explains its decreased use in clinical trials [18,19,24]. Lack of published protocols contribute to low reliability and weak face validity, thus indicating a need for further testing of psychometric qualities [16,18,24]. The Rivermead Assessment of Sensory Processing demonstrates good intra- and inter-reliability; however, its restricted heterogeneity, with cognitive impairment and comprehension difficulties excluded, and non-probability sampling limit generalizability of its use among the general stroke population [21].

The original NSA is a standardized measure created specifically for adults with stroke, demonstrating good intra-rater reliability but poor inter-rater reliability [15,19,23]. The tool, now known as the Revised NSA, was shortened, and a hierarchized protocol established reducing testing time [15]. This version demonstrates good intra-rater reliability and acceptable inter-rater reliability in English [15,19]. The standardized tool is time- and cost-effective, demonstrating clinical utility among adults post-stroke [9,15].

The Revised NSA was modified as the Erasmus modification of the NSA (EmNSA), demonstrating good to excellent ($k > 0.75$) intra- and inter-reliability kappa coefficients among 18 adults with intracranial disorders [7]. Modifications included removal of the temperature test due to poor psychometric qualities, the addition of sharp-blunt discrimination, modification of two-point discrimination testing, standardization and cartography of defined points of testing, as well as standardization of a uniform scoring system [7]. The stereognosis component of the NSA can be used as an accompanying scale to the EmNSA. The 10-item scale is an established measure demonstrating reliability between assessors; however, the small sample size ($n = 20$), strict exclusion criteria and non-probability sampling techniques limit its generalizability [6].

At present, there are no standardized tools in the French language for somatosensory assessment of UL specific to adults with stroke. Furthermore, validity and reliability testing of such a measure is needed before it can be adopted in clinical practice and research.

The objectives of this study were to translate and cross-culturally adapt the EmNSA in French and to examine and report criterion-related validity, internal consistency, floor and ceiling effects, intra/inter-rater reliability and minimal detectable change for UL in adults with stroke.

## 2. Methods

The study consisted of 2 phases, defined as instrument translation and validation, to examine the psychometric properties of the EmNSA.

### 2.1. Instrument translation and cross-cultural adaptation

Only the UL component of the EmNSA was translated, cross-culturally adapted and validated in accordance with study objectives and identified gaps in the literature. Translation was conducted in accordance with guidelines, with outcome measures objectively assessed to ensure culturally specific clinical tools contributing to evidence-based practice [25]. An eight-step translation procedure for self-reported outcome measures, modified for objective-outcome measures, ensured appropriate professional vocabulary of administration procedures relevant for clinical use in a foreign language and face validity [25].

Forward-backwards translation and cross-cultural adaptation were ensured by involving native-speaking professionals and was reviewed by a multidisciplinary group of medical professionals to check for comprehensiveness and linguistic issues [25,26]. The final version was approved by the original authors. Consensus meetings were carried out to review testing equipment, clarify procedures and scoring to ensure validity [25].

Health professionals with clinical experience in neurological rehabilitation studied whether the EmNSA-SS was representative of somatosensory evaluation for patients with stroke. Procedures and scoring were critiqued by focus groups influencing the inclusion of a stereognosis component (EmNSA-ST) ensuring a comprehensive assessment of somatosensation of the UL in patients with stroke [17]. Lawshe's method describing inter-rater agreement for scale items reflecting the construct of scale measurement as a content validity ratio supported the inclusion of EmNSA items for the development of the instrument [27]. A panel of 9 subject-matter experts rated item relevance as "not necessary; useful but not essential; and essential" to the construct of the measurement of somatosensory capacity. Items included were found to be above the threshold of content validity ratio critical values congruent with number of matter experts ($> 0.78$) [27].

### 2.2. Validation phase

An observational cross-sectional design study was implemented to determine the psychometric properties of the French EmNSA-SS and EmNSA-ST. The single-center study took place in the Neurological Rehabilitation Department of the University Hospital of Toulouse from May 2015 to September 2016. The hospital's ethical committee approved the study (no. 02-0415 on May 18, 2015) and all participants provided informed consent before data collection.

#### 2.2.1. Participants

Participants were recruited by occupational therapy staff from a convenience sample of inpatients with stroke. Eligibility criteria were (1) age > 18 years with principle diagnosis of first-time ischemic or hemorrhagic stroke at least 1 month since onset and confirmed by MRI or CT; (2) subscale of aphasia severity from the Boston Diagnostic Aphasia Examination ≥ 2 indicating sufficient comprehension and expression for testing [28]; and (3) motivation to participate and informed written consent. Individuals were excluded if they presented peripheral neuropathy disease, additional central neurological disease or diabetes mellitus. Sample size was determined in accordance with recommendations for reliability studies design [29].

*2.2.2. Testing procedure*

EmNSA was administered on 3 separate occasions by 2 assessors. The principal assessor administered the Fugl-Meyer Assessment–Motor scale (FMA-M), EmNSA and FMA-S for concurrent-criterion validity. The same principal assessor conducted a second EmNSA within 7 to 14 days of the first evaluation to establish test–retest intra-rater reliability. Other assessors administered the EmNSA within 3 days for test–retest inter-rater reliability. Random allocation to testing of the second assessor was ensured. Assessors were 3 certified occupational therapists having undergone training for tool use, further contributing to the study's internal validity.

Blinding of participants and assessors was not possible due to the rehabilitation context, but assessors were blinded to previous results and specifically instructed not to discuss results throughout the study [30]. Pilot testing was conducted by all assessors, and data collection commenced when all assessors established good inter-rater reliability (intraclass correlation coefficient [ICC] > 0.75) to reduce measurement bias [31].

*2.2.3. Measurement tools*

The EmNSA was the main outcome measure for UL sensory capacity [7,15,23]. The UL components of the French-Canadian version of the FMA-S and FMA-M subscales were other outcome measures administered to establish criterion validity and illustrate demographic characteristics of participants, respectively [32]. Two-point discrimination was included on the scoring sheet regardless of low reproducibility contributing to a comprehensive assessment of somatosensation [7,17]. Inclusion of stereognosis and its items was also agreed upon in consensus meetings for cross-cultural adaptation and supported by the literature [14,17,23,33].

The EmNSA-SS comprises 22 items of somatosensory functions across 3 subscales including (1) tactile sensation, (2) two-point discrimination, and (3) proprioception. Tactile sensation includes 4 components corresponding to light touch, pressure, pinprick and sharp-blunt discrimination. A maximal score of 44 points on a three-point scale (0 = absent, 1 = impaired, 2 = normal) demonstrates somatosensory capacity [6,7]. The EmNSA-ST comprises 10 items on stereognosis function, with a maximal score of 20 indicating normal function. The complete version of the French EmNSA testing guidelines is in Appendix A, and its score sheet is in supplementary material. Testing is conducted at the shoulder, elbow, wrist and hand, standardized by instructions and a visual chart presented in Appendix A.

The FMA-S subscale was used to collect data regarding light touch and proprioceptive data for patients with stroke [22,24]. Assessment is conducted by bilateral light touch of anterior and posterior regions, and proprioception [22,24,32]. Scoring is conducted with an ordinal three-point scale (0 = absent, 1 = impaired, 2 = normal).

The FMA-M domain of UL was used to collect UL motor scores. A maximal score of 66 points indicates minimal motor impairment severity correlated with functional ability [9,22].

*2.2.4. Data analysis*

Normal distribution of data was assessed by examining graphical interpretations and the Shapiro-Wilk statistic. Quantitative measures for normally distributed variables were described with mean (SD) and skewed variables were described with median (minimum and maximum). Statistical analyses involved using SPSS v22.0 (IBM SPSS Statistics for Windows) and Matlab (Release 2012a, The MathWorks, Inc., Natick).

*2.2.5. Verification of hierarchical aspect of the scale*

Hierarchized testing procedures were developed for EmNSA, with the aim to reduce the length of administration if some items could be predictable from the score of other items [7,20]. EmNSA hierarchized testing procedures state that (1) when a score of 2 is assigned for each item (total score is 8 for the whole UL) of light touch modality of the tactile sensation subscale, a score of 2 can be assigned for each pressure and pinprick item (scores of 8 for the whole UL); (2) when a score of 0 or 1 is assigned to an item of at least one of light touch, pressure and pinprick, a score of 0 can be assigned for the same sharp-blunt item; and (3) two-point discrimination is only tested if a maximal score of 24 was obtained with the additional score of light touch, pressure and pinprick [7]. Verification of the hierarchical aspect of the scale was carried out on data collected by the principal assessor from the first assessment. This was done by recording the number of discrepancies between the scores obtained from hierarchized testing procedures and comparing them to the testing of all items. The number of errors was expressed in percentages of all EmNSA scoring, and the average loss of points was computed.

*2.2.6. Concurrent-criterion validity*

Concurrent-criterion validity was examined by comparing the association between the light touch component, proprioception and total scores of EmNSA-SS with the FMA-S collected by the principal assessor. Spearman coefficient (rho) was used because of skewed data in conjunction with visual interpretation of scatter-plots. Correlation was classified as poor (< 0.5), moderate (0.5–0.75) and good (> 0.75) [31].

*2.2.7. Internal consistency*

Cronbach $\alpha$ coefficient was used to analyze the internal consistency of the EmNSA. Values 0.7 to 0.9 were interpreted as excellent (> 0.8), acceptable (0.7–0.8) or low (< 0.7) [34,35]. Internal consistency was calculated for the total number of items of each subscale measuring the same type of sensation for the EmNSA-SS and EmNSA-ST, as well as the total number of items of 3 subscales representing the total score of the EmNSA-SS UL. Floor and ceiling effects, assessed by frequency analyses were defined as significant if more than 20% of the participants had the lowest or highest possible score, respectively [35].

*2.2.8. Reproducibility*

Reproducibility concerns the degree to which intra- and inter-rater test–retest measurements provide similar results [36]. ICCs with 95% confidence intervals (CIs) were used to assess the intra- and inter-rater test–retest reliability of the EmNSA subscale and total scores (i.e., the measurement error related to the variability between subjects) [36]. Intra-rater reliability using the $ICC_{2,1}$ (two-way random model with absolute agreement) was determined from scores collected by the principal assessor on 2 testing sessions. Inter-rater reliability using the $ICC_{1,1}$ (one-way random model with absolute agreement) was determined from scores of the principal assessor in comparison to 2 other assessors [37]. ICC estimates were ranked according to values and interpreted as excellent (> 0.75), moderate to good (0.5 > 0.75), fair (0.25–0.5) or low (0.2) [9,31].

The minimal detectable change with 95% level of confidence (MDC95) was used to assess the intra- and inter-rater test–retest agreement of the EmNSA subscale and total scores (i.e., the measurement error in repeated measurements expressed in the actual scale of the measurement) [36]. MDC95 reflects the smallest detectable change between 2 repeated measures for a given individual, ensuring that this minimum amount of change is not the result of measurement error [31,36]. MDC95 was calculated from the standard error of measurement taking into account systematic differences between the test and retest, suitable for use in clinical evaluation at different times (SEM agreement): $SEM = \sqrt{\sigma^2_{intra} + \sigma^2_{residual}}$, where $\sigma^2_{intra}$ is the variance of the individual differences between the test–retest measurements, and $\sigma^2_{residual}$ is the residual variance of the interaction between intra and inter-individual differences obtained from a repeated-measures ANOVA [36]; and $MDC95 = 1.96 \times SEM \times \sqrt{2}$ [31].

Bland-Altman plot analysis was used to plot differences in test–retest scores against the mean of the 2 test scores for each participant for visual examination of distribution [38]. When zero was included within the 95% CI for the test–retest mean differences, no systematic bias was assumed [38].

## 3. Results

### 3.1. Participants

The flow of participants in the study is shown in Fig. 1. Data were collected from 50 participants who gave informed consent. Characteristics and clinical scores of participants are in Table 1. Score distribution for EmNSA and FMA-S are illustrated in Fig. 2. The mean delay for the test–retest intra-rater was 7.1 days (range 4 to 14) and inter-rater delay 2.1 days (range 1 to 7).

### 3.2. Protocol and hierarchical aspect of the scale

Administration time was influenced by hierarchized testing procedures, ranging from 15 to 30 min. No errors were found from testing the hierarchical scoring aspect of tactile sensation associated with the shortened testing method. In other words, a score of 8 for light touch indicates a score of 8 for pressure and pinprick subscales. Hierarchical scoring of the sharp-blunt items was incorrect in 24%, 24%, 16% and 12% of cases for fingers, hand, forearm and arm, respectively. In other words, when a score of 0 or 1 is assigned to an item of at least one of light touch, pressure and pinprick, a score of $> 0$ was found for the corresponding sharp-blunt item, which resulted an average loss of 3.5 points (range 1 to 8). Hierarchical scoring aspect of two-point discrimination subscale score was incorrect in 20% of cases. In other words, a score of $> 0$ on two-point discrimination subscale was found for scores less than 24 in light touch, pressure and pinprick, which resulted in an average loss of 2.6 points (range 1 to 4). A score $< 11$ for light touch, pressure and pinprick was associated in all cases with a two-point discrimination score of 0.

### 3.3. Concurrent-criterion validity

Significant and moderate to good positive correlations were observed between the EmNSA-SS and FMA-S UL for total, tactile and proprioception subscales. The scores ranged from 0.74 to 0.77, as demonstrated in Table 2.

### 3.4. Internal consistency

As stated in Table 3, the Cronbach's alpha coefficients suggested acceptable to excellent consistency for EmNSA-SS and EmNSA-ST

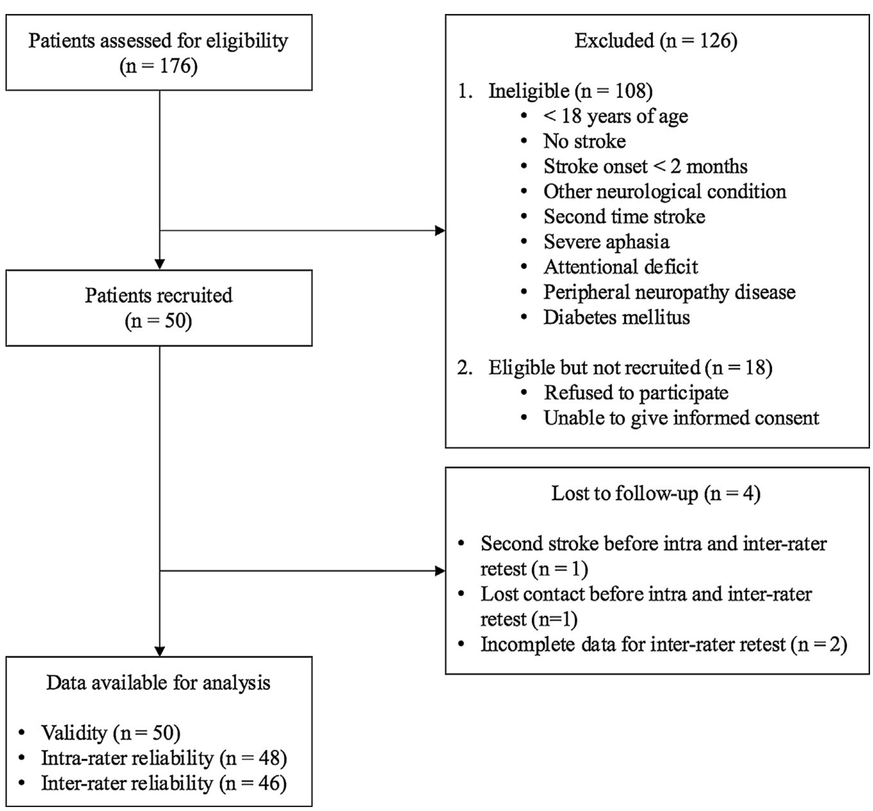


**Fig. 1.** Flow of participants in the study.

**Table 1**
Characteristics and clinical scores ($n = 50$).

| Characteristics | Scores |
|---|---|
| Age (years), median (min–max) | 61.7 (22–77) |
| Sex (male; female), *n* (%) | 35 (70); 15 (30) |
| Type of stroke (ischemic; hemorrhagic), *n* (%) | 37 (74); 13 (26) |
| Time since stroke onset (m), median (min–max) | 3.1 (1.1–319.1) |
| Side of paresis (right; left), *n* (%) | 26 (52); 24 (48) |
| Dominant hand[a] (right; left), *n* (%) | 48 (96); 2 (4) |
| Aphasia[b], *n* (%) | 14 (28) |
| FMA-M UL scale, median (min–max) | 33.5 (4–66) |
| Motor impairment[c], *n* (%) | |
| Severe (score ≤ 27) | 22 (42) |
| Moderate (score 28–57) | 18 (36) |
| Mild (score 58–66) | 11 (22) |
| FMA-S UL scale (/28), median (min–max) | 25.5 (0–28) |
| Light touch subscale (/20) | 18 (0–20) |
| Proprioception subscale (/8) | 8 (0–8) |
| EmNSA-SS UL scale (/44), median (min–max) | 41.5 (1–44) |
| Tactile sensation subscale (/32) | 30 (0–32) |
| Discrimination subscale (/4) | 3 (0–4) |
| Proprioception subscale (/8) | 8 (0–8) |
| EmNSA-ST UL scale (/20), median (min–max) | 11.5 (0–20) |

FMA-M UL: motor subscale of the Fugl-Meyer Assessment for the upper limb (0–66); FMA-S UL: sensory subscale of the Fugl-Meyer Assessment for the upper limb; EmNSA-SS/ST UL: Erasmus modified Nottingham Sensory Assessment Somatosensory/Stereognosis components for the upper limb.
[a] Dominant hand was defined as the writing hand before onset of stroke.
[b] Aphasia was classified using the subscale of aphasia severity from the Boston Diagnostic Aphasia Examination [28].
[c] Motor impairment was classified by FMA-M UL levels [40].

total scale, and individual EmNSA-SS subscales, with scores ranging from 0.82 to 0.96. A significant floor effect was found for the two-point discrimination subscale. Significant ceiling effects were found for tactile sensation, two-point discrimination and proprioception subscales of the EmNSA-SS UL. The FMA-S demonstrated significant ceiling effects for its total score, tactile sensation and proprioception subscales (Table 3).

### 3.5. Reproducibility

Reproducibility scores are reported in Table 4, with data distribution illustrated in supplemental Fig. S1. Intra-rater reliability of the EmNSA subscales and total score demonstrated excellent values, with $ICC_{2,1}$ values ranging from 0.86 to 0.92. Inter-rater reliability was also excellent with the exception of proprioception and discrimination of two-point subscales, which were both found to be moderate, with $ICC_{1,1}$ values of 0.71. Intra- and inter-rater MDC95 values for the total score of EmNSA-SS were 12.3 and 14.6, respectively. The EmNSA-ST showed a systematic increase of scores, which suggests systematic bias, likely due to a learning effect between the test–retest measurements (see supplemental material, Fig. S1B and S1D).

## 4. Discussion

This study supports the use of the French EmNSA for comprehensive UL somatosensory assessment in adults with

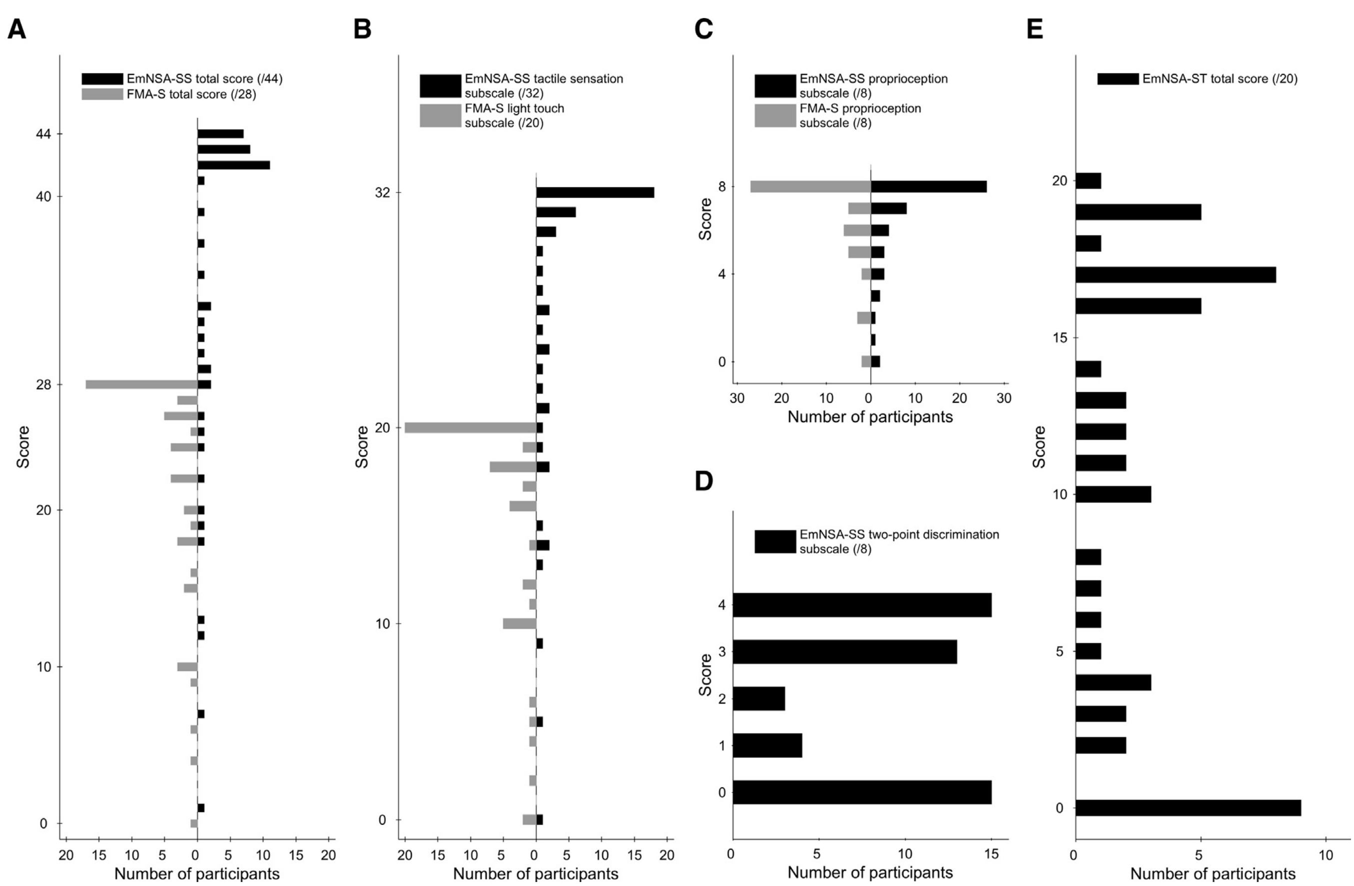


**Fig. 2.** Score frequencies for (A) Erasmus modified Nottingham Sensory Assessment–somatosensory component (EmNSA-SS) and sensory subscale of the Fugl-Meyer Assessment (FMA-S) for upper limb, (B) EmNSA-SS tactile sensation and FMA-S light touch subscales, (C) EmNSA-SS proprioception and FMA-S proprioception subscales, (D) EmNSA-SS two-point discrimination subscale, and (E) EmNSA–stereognosis component (EmNSA-ST).

**Table 2**
Concurrent-criterion validity assessed by Spearman's rank correlation coefficient between EmNSA-SS UL and the FMA-S UL ($n=50$).

| EmNSA-SS UL | FMA-S UL | | |
|---|---|---|---|
| | Light touch subscale | Proprioception subscale | Total score |
| Tactile sensation subscale | 0.75* | – | – |
| Proprioception subscale | – | 0.77* | – |
| Total score | – | – | 0.74* |

EmNSA-SS UL: Erasmus modified Nottingham Sensory Assessment Somatosensory component for the upper limb; FMA-S UL: Fugl-Meyer Assessment-Sensory component for the upper limb.
* $P<0.001$ (two tailed).

**Table 3**
Internal consistency, floor and ceiling effect of the EmNSA UL and the FMA-S UL ($n=50$).

| | Internal consistency[a] | Floor effect (%) | | Ceiling effect (%) | |
|---|---|---|---|---|---|
| | EmNSA UL | EmNSA UL | FMA-S UL | EmNSA UL | FMA-S UL |
| Total score | | | | | |
| Somatosensory component ($n=22$) | 0.961 | 0 | 2 | 14 | 34 |
| Stereognosis component ($n=10$) | 0.941 | 18 | – | 2 | – |
| Subscales of EmNSA-SS | | | | | |
| Tactile sensation ($n=16$) | 0.954 | 2 | 4 | 36 | 40 |
| Two-point discrimination ($n=2$) | 0.852 | 30 | – | 30 | – |
| Proprioception ($n=4$) | 0.821 | 4 | 4 | 52 | 54 |

EmNSA-SS/ST UL: Erasmus modified Nottingham Sensory Assessment Somatosensory/Stereognosis component for the upper limb; FMA-S UL: Fugl-Meyer Assessment-Sensory component for the upper limb.
[a] Internal consistency was reported as Cronbach $\alpha$ coefficient.

**Table 4**
Intra- ($n=48$) and inter-rater ($n=46$) reproducibility of the EmNSA UL scale and subscales.

| | ICC (95% CI) | MDC95 | mDiff (95% CI) |
|---|---|---|---|
| EmNSA-SS total score (/44) | | | |
| Intra-rater | 0.92 (0.86–0.95) | 12.3 | 0.65 (−0.63–1.93) |
| Inter-rater | 0.92 (0.87–0.96) | 14.6 | 0.91 (−0.31–2.14) |
| Tactile sensation (/32) | | | |
| Intra-rater | 0.88 (0.79–0.93) | 8.6 | 0.27 (−0.89–1.43) |
| Inter-rater | 0.90 (0.83–0.95) | 14.1 | 0.93 (−0.07–1.94) |
| Discrimination of two-point (/4) | | | |
| Intra-rater | 0.89 (0.82–0.94) | 1.9 | 0.08 (−1.14–0.31) |
| Inter-rater | 0.71 (0.53–0.83) | 2.5 | −0.07 (−0.42–0.29) |
| Proprioception (/8) | | | |
| Intra-rater | 0.86 (0.77–0.92) | 4.4 | 0.29 (−0.01–0.60) |
| Inter-rater | 0.71 (0.53–0.83) | 3.5 | 0.04 (−0.48–0.57) |
| EmNSA-ST (/20) | | | |
| Intra-rater | 0.92 (0.76–0.97) | 23.1 | 1.67 (0.97–2.37)[a] |
| Inter-rater | 0.84 (0.74–0.91) | 27.5 | 2.00 (0.94–3.06)[a] |

EmNSA-SS/ST UL: Erasmus modified Nottingham Sensory Assessment for Somatosensory/Stereognosis component for the upper limb; ICC: intraclass correlation coefficient; MDC95: minimal detectable change with 95% confidence interval.
[a] Bias present for EmNSA-ST due to 95% confidence interval (95% CI) of the mean difference (mDiff) not including zero, indicating systematic bias from recall of items.

stroke. Validation of the tool for adults with stroke demonstrated acceptable psychometric properties in terms of validity and reproducibility of EmNSA-SS, thereby suggesting its use in evidence-based clinical practice and research trials. Meanwhile, findings identify limitations of the EmNSA-ST in comparison to the EmNSA-SS, which suggests that the stereognosis component is more suited for screening purposes [6,15,19].

### 4.1. Validity, ceiling and floor effects

The good concurrent-criterion validity of the EmNSA-SS is consistent with previous studies describing moderate to excellent validity of the Brazilian NSA and English Revised NSA in adults post-stroke appropriate for clinician professionals across populations [9,11,14]. Our results indicate advantages of the use of the EmNSA-SS over the FMA-S in terms of better floor and ceiling effects. The FMA-S demonstrated a significant ceiling effect of 34% for the total score, as compared with 14% for the EmNSA-SS. Similar results for adults with stroke demonstrated ceiling effects ranging from 44% to 72% for the FMA-S associated with time since stroke onset, which indicates limited discrimination of the measure for somatosensory recovery in adults with stroke [24]. Ceiling effects for the EmNSA-SS were significant for tactile sensation, two-point discrimination and proprioception but remained less than the FMA-S, demonstrating effects for tactile sensation and proprioception, as shown in previous studies on similar populations [11]. Our study indicates less ceiling and floor effects for the EmNSA-SS as compared with the Brazilian NSA, which demonstrated ceiling effects for tactile sensation (66%) and stereognosis (38%) as well as two-point discrimination floor effects (42%) identified as limitations of this version. However, the small sample size ($n=21$) and chronic phase of stroke among participants (onset > 6 months) associated with lower recovery should be noted as potential factors of floor and ceiling effects [11]. Our study identified floor effects of 30% of two-point discrimination; however, no other significant floor effects were found for other EmNSA subscales, congruent with findings of the FMA-S.

*4.2. Internal consistency and hierarchical scoring*

The EmNSA demonstrates efficient internal consistency for total and subscale scores. EmNSA-SS total score, tactile sensation and stereognosis components revealed values > 0.9, thereby indicating redundancy of content across items [39], which could be influenced by the number of items [20]. Analysis of the hierarchical testing procedure supports its use for light touch pressure and pinprick scores, which is consistent with previous studies regarding the redundancy of similar-site testing to reduce testing time [7,20]. However, errors associated with sharp-blunt items should be considered to minimize loss of points. The two-point discrimination procedure tested for scores of > 24 in light touch, pressure, pinprick indicates discrepancies and loss of points of total score. Comprehensive testing of all items is recommended for evaluation in recovery clinical practice and/or testing when a score of > 11 is detected for light touch, pressure and pinprick items for screening purposes.

*4.3. Reproducibility*

The EmNSA-SS presents excellent intra- and inter-reliability properties with the exception of proprioception and two-point discrimination that demonstrates moderate to good reliability in a population of adults post-stroke. Findings are consistent with previous studies that reported high inter- and intra-rater reliability coefficients of the measure and limited discriminative touch reliability, not present in our study with a larger stroke population [13,24]. The MDC95 results address a gap in the current literature because it could be used to interpret modifications of an individual's score over time in relation to the measurement error.

Our results support previous findings from smaller samples ($n = 20$) that identified the stereognosis component as moderately appropriate for somatosensory evaluation of recovery among assessors [6,11]. The MDC95 for EmNSA-ST was associated with a systematic increase in score between test–retest, thus indicating that the EmNSA-ST is not suitable for monitoring stereognosis impairment over time because learning and recall might have influenced the score [33]. Our findings illustrate the limitations of the psychometric properties of the EmNSA-ST in contrast to the EmNSA-SS, thereby suggesting inclusion of the stereognosis in the final measure because exclusion would not provide a comprehensive somatosensory assessment [6,7,19,33]. The influence of learning and memory associated with cortical sensory function on stereognosis scores supports its use for screening purposes and/or modification of the testing procedure to 2 sets of 5 paired items [7,14,33].

*4.4. Limitations, strengths and future research*

Although the use of standardized validated assessments for data collection limited information bias, the associated subjectivity of responses of sensory evaluation should not be ignored [23]. Blinding of assessors was impossible, but training, pre-pilot design and blinding of previous scores minimized the influence of information bias. Generalization of results to national and/or international populations is limited because of the single-center design and sample size, thus indicating the potential perspective of testing with a larger sample size. Responsiveness of the French version of EmNSA was not studied; however, this is a potential perspective of research to establish the ability of this scale to identify changes that are clinically meaningful [35]. Participants were representative of stroke characteristics, such as experiencing communication and cognitive deficits, which were previously overlooked in other studies [6,7,11,15]. This study also demonstrates application to a wider stroke population including various times since stroke onset with regard to recovery phases. A Rasch analysis regarding the separate use of two sets of items to minimize associated learning effects may reduce systematic bias of the subscale [16]. Additional Guttman scale analysis would contribute to improve the hierarchical procedure of tactile sensation and the related two-point discrimination subscale enhancing its use in clinical practice [7].

## 5. Conclusion

The French version of the EmNSA demonstrates good concurrent validity and reproducibility for UL evaluation of somatosensory impairment in adults post-stroke, thus providing a comprehensive measure of somatosensory function with inclusion of the stereognosis component. The tool, which takes between 15 and 30 min to administer, demonstrates clinical utility for use across the general stroke population with cognitive comorbidities, at various stages of recovery, in clinical practice and research. The EmNSA-SS can be used for screening purposes and monitoring of recovery, whereas the EmNSA-ST has application for screening purposes. This study highlights the potential use of the French EmNSA in evidence-based practice and research trials.

## Authors' contributions

Concept, idea and research design: CV, DG, HC.
Instrument development: CV, CL, DG, EC, EC-L, MM, SH, ST.
Providing participants and facilities/equipment: SH, ST, EC, MM, CL, EC-L, XdB.
Data collection: CV, EC, MM, CL.
Project management, data analysis, writing manuscript and final review of manuscript: CV, DG, HC.

## Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

## Data statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

## Disclosure of interest

The authors declare that they have no competing interest.

## Acknowledgment

The authors thank Lesley Crow, Erasmus MC University Hospital for Rotterdam, and Nadia Lincoln, University of Nottingham, who provided expertise and collaboration throughout the study; Baptiste Gentilhomme, for assistance with participants; Jean-Michel Caire for support; and Mireille Coste, Marie-Odile Peters and Pierre Carette for assistance with the concept.

## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.rehab.2018.03.004.

## References


[1] Borstad A, Schmalbrock P, Choi S, Nichols-Larsen DS. Neural correlates supporting sensory discrimination after left hemisphere stroke. Brain Res 2012;1460:78–87.
[2] Doyle SD, Bennett S, Dudgeon B. Upper limb post-stroke sensory impairments: the survivor's experience. Disabil Rehabil 2014;36:993–1000.
[3] Turville M, Carey LM, Matyas TA, Blennerhassett J. Change in functional arm use is associated with somatosensory skills after sensory retraining poststroke. Am J Occup Ther 2017;71:1–9.
[4] Tyson SF, Hanley M, Chillala J, Selley AB, Tallis RC. Sensory loss in hospital-admitted people with stroke: characteristics, associated factors, and relationship with function. Neurorehabil Neural Repair 2008;22:166–72.
[5] Carey LM, Matyas TA. Frequency of discriminative sensory loss in the hand after stroke in a rehabilitation setting. J Rehabil Med 2011;43:257–63.
[6] Gaubert CS, Mockett SP. Inter-rater reliability of the Nottingham method of stereognosis assessment. Clin Rehabil 2000;14:153–9.
[7] Stolk-Hornsveld F, Crow JL, Hendriks EP, van der Baan R, Harmeling-van der Wel BC. The Erasmus MC modifications to the (revised) Nottingham Sensory Assessment: a reliable somatosensory assessment measure for patients with intracranial disorders. Clin Rehabil 2006;20:160–72.
[8] Dannenbaum RM, Michaelsen SM, Desrosiers J, Levin MF. Development and validation of two new sensory tests of the hand for patients with stroke. Clin Rehabil 2002;16:630–9.
[9] Wu CY, Chuang IC, Ma HI, Lin KC, Chen CL. Validity and responsiveness of the revised nottingham sensation assessment for outcome evaluation in stroke rehabilitation. Am J Occup Ther 2016;70:1–8.
[10] World Health Organization. ICF: international classification of functioning, disability and health. World Health Organization; 2001.
[11] Lima DHF, Queiroz AP, De Salvo G, Yoneyama SM, Oberg TD, Lima NMFV. Brazilian version of the Nottingham Sensory Assessment: validity, agreement and reliability. Rev Bras Fisioter 2010;14:166–74.
[12] Lang CE, Bland MD, Bailey RR, Schaefer SY, Birkenmeier RL. Assessment of upper extremity impairment, function, and activity after stroke: foundations for clinical decision making. J Hand Ther 2013;26:104–14.
[13] Langhorne P, Coupar F, Pollock A. Motor recovery after stroke: a systematic review. Lancet Neurol 2009;8:741–54.
[14] Connell LA, Lincoln NB, Radford KA. Somatosensory impairment after stroke: frequency of different deficits and their recovery. Clin Rehabil 2008;22:758–67.
[15] Lincoln N, Jackson J, Adams S. Reliability and revision of the Nottingham sensory assessment for stroke patients. Physiotherapy 1998;84:358–65.
[16] Connell LA, Tyson SF. Measures of sensation in neurological conditions: a systematic review. Clin Rehabil 2012;26:68–80.
[17] Bigley GK. Sensation. In: Walker HK, Hall WD, Hurst JW, editors. Clinical Methods: The History, Physical and Laboratory Examinations. 3rd ed., Boston: Butterworths; 1990. p. 343–50.
[18] Gladstone DJ, Danells CJ, Black SE. The Fugl-Meyer assessment of motor recovery after stroke: a critical review of its measurement properties. Neurorehabil Neural Repair 2002;16:232–40.
[19] Connell LA, Tyson SF. Clinical reality of measuring upper-limb ability in neurologic conditions: a systematic review. Arch Phys Med Rehabil 2012;93:221–8.
[20] Busse M, Tyson SF. How many body locations need to be tested when assessing sensation after stroke? An investigation of redundancy in the Rivermead Assessment of Somatosensory Performance. Clin Rehabil 2009;23:91–5.
[21] Winward CE, Halligan PW, Wade DT. The Rivermead Assessment of Somatosensory Performance (RASP): standardization and reliability data. Clin Rehabil 2002;16:523–33.
[22] Fugl-Meyer AR, Jääskö L, Leyman I, Olsson S, Steglind S. The post-stroke hemiplegic patient. 1. A method for evaluation of physical performance. Scand J Rehabil Med 1975;7:13–31.
[23] Lincoln NB, Crow JL, Jackson JM, Waters GR, Adams SA, Hodgson P. The unreliability of sensory assessments. Clin Rehabil 1991;5:273–82.
[24] Lin J-H, Hsueh I-P, Sheu C-F, Hsieh C-L. Psychometric properties of the sensory scale of the Fugl-Meyer Assessment in stroke patients. Clin Rehabil 2004;18:391–7.
[25] Schuster C, Hahn S, Ettlin T. Objectively-assessed outcome measures: a translation and cross-cultural adaptation procedure applied to the Chedoke McMaster Arm and Hand Activity Inventory (CAHAI). BMC Med Res Methodol 2010;10:1–9.
[26] Epstein J, Santo RM, Guillemin F. A review of guidelines for cross-cultural adaptation of questionnaires could not bring out a consensus. J Clin Epidemiol 2015;68:435–41.
[27] Ayre C, Scally AJ. Critical values for Lawshe's content validity ratio: revisiting the original methods of calculation. Meas Eval Couns Dev 2014;47:79–86.
[28] Goodglss H, Kaplan, Edith. The assessment of aphasia and related disorders. Philadelphia: Lea & Febiger; 1972.
[29] Terwee CB, Mokkink LB, Knol DL, Ostelo RWJG, Bouter LM, de Vet HCW. Rating the methodological quality in systematic reviews of studies on measurement properties: a scoring system for the COSMIN checklist. Qual Life Res 2012;21:651–7.
[30] Villamar MF, Contreras VS, Kuntz RE, Fregni F. The reporting of blinding in physical medicine and rehabilitation randomized controlled trials: a systematic review. J Rehabil Med 2013;45:6–13.
[31] Portney LG, Watkins MP. Foundations of clinical research: applications to practice. Pearson/Prentice Hall; 2009.
[32] Dutil É, Duncan PW, Propst M, Nelson SG, Burglund K, Kusoffsky A, et al. Test de Fugl-Meyer: protocole d'évaluation de la fonction sensori-motrice. Ottawa: École des sciences de la réadaptation, Sciences de la santé, Université d'Ottawa; 2004.
[33] Irving B. Stereognosis. J R Soc Med 1968;VI:25–7.
[34] Cronbach LJ. Coefficient alpha and the internal structure of tests. Psychometrika 1951;16:297–334.
[35] Andresen EM. Criteria for assessing the tools of disability outcomes research. Arch Phys Med Rehabil 2000;81:S15–20.
[36] de Vet HCW, Terwee CB, Knol DL, Bouter LM. When to use agreement versus reliability measures. J Clin Epidemiol 2006;59:1033–9.
[37] Shrout PE, Fleiss JL. Intraclass correlations: uses in assessing rater reliability. Psychol Bull 1979;86:420–8.
[38] Giavarina D. Understanding Bland Altman analysis. Biochem Medica 2015;25:141–51.
[39] Streiner DL. Starting at the beginning: an introduction to coefficient alpha and internal consistency. J Pers Assess 2003;80:99–103.
[40] Pang MY, Harris JE, Eng JJ. A community-based upper-extremity group exercise program improves motor function and performance of functional activities in chronic stroke: a randomized controlled trial. Arch Phys Med Rehabil 2006;87:1–9.