1 # Manual ability in hand surgery patients:

2 # validation of the ABILHAND scale in four

3 # diagnostic groups

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5 ## Short title: Validation of the ABILHAND scale for hand surgery

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Abstract

Background: Patients treated in hand surgery (HS) belong to different demographic groups and have varying impairments related to different pathologies. HS outcomes are measured to assess treatment results, complication risks and intervention reliability. A one-dimensional and linear measure would allow for unbiased comparisons of manual ability between patients and different treatment effects.

Objective: To adapt the ABILHAND questionnaire through Rasch analysis for specific use in HS patients and to examine its validity.

Methods: A preliminary 90-item questionnaire was presented to 216 patients representing the diagnoses most frequently encountered in HS, including distal radius fracture (n=74), basal thumb arthritis (n=66), carpal tunnel syndrome (n=53), and heavy wrist surgery (n=23). Patients were assessed during the early recovery and in the late follow-up period (0-3 months, 3-6 months and >6 months), leading to a total of 305 assessments. They rated their perceived difficulty with queried activities as impossible, difficult, or easy. Responses were analyzed using the RUMM2030 software. Items were refined based on item-patient targeting, fit statistics, differential item functioning, local independence and item redundancy. Patients also completed the QuickDASH, 12-item Short Form Survey (SF-12) and a numerical pain scale.

Results: The rating scale Rasch model was used to select 23 mostly bimanual items on a 3-level scale, which constitute a unidimensional, linear measure of manual ability with good reliability across all included diagnostic groups (Person-Separation Index = 0.90). The resulting scale was found to be invariant across demographic and clinical subgroups and over time. ABILHAND-HS

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36   patient measures correlated significantly (p<0.001) with the QuickDASH (r=-0.77), SF-12 Physical

37   Component Summary (r=0.56), SF-12 Mental Component Summary (r=0.31), and pain scale (r=-

38   0.49).

39   **Conclusion:** ABILHAND-HS is a robust person-centered measure of manual ability in HS patients.

Introduction

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41 In hand surgery (HS), as in other medical specialties, outcome evaluations are needed to assess

42 the effectiveness and reliability of the intervention, as well as to reinforce patient education

43 regarding the risks and outcomes of the procedure and, potentially, to justify therapeutic

44 practices to payers [1]. Physician-documented reports of HS outcomes based on clinical

45 examination and imaging should be complemented with patient reported outcomes assessed by

46 questionnaires designed to capture patients' perspectives with respect to the impact of their

47 conditions and interventions on their daily lives [2–4].

48 Current views of health and disability have been shaped by the World Health Organization's

49 International Classification of Functioning, Disability, and Health [5], which parses disease

50 consequences into three domains: impairment of anatomical structures (e.g. bones, muscles,

51 ligaments) or body functions (e.g. motor skills, sensitivity), activity limitations (e.g. manual

52 activities), and participation restrictions (e.g. in hobbies and work). The impact of a pathology or

53 a surgical intervention in these three domains is also conditioned by personal factors (motivation,

54 capacity to develop compensatory strategies) and environmental factors (social or professional

55 context). Although impairment measurements such as imaging can provide clues regarding

56 functional prognosis, it does not provide good information about performance in everyday life,

57 especially of the hands, which are important for a great variety of activities [6–8]. For example,

58 demonstration of a bone fracture union is insufficient to determine whether a patient is capable

59 of resuming their usual activities or returning to work [9–12].

60 The patient-reported questionnaires that have been most commonly used in HS [13] are the

61 Disability of the Arm, Shoulder and Hand questionnaire (DASH) [14], the Patient Rated Wrist

62 Evaluation (PRWE) [15], and the Carpal Tunnel Questionnaire (CTQ) [16]. Each of these

63 questionnaires has been reported to have good psychometric properties, but each has a

64 particular focus on its own area(s) of disablement. The DASH assesses body functions, activities,

65 and participation [17] and can be divided into 3 subscales based on dimensionality [18].

66 Meanwhile, the PRWE is specific to the wrist joint and the CTQ is specific to carpal tunnel

67 syndrome (CTS). The Michigan Hand Outcomes Questionnaire (MHQ) [19] is a multidimensional

68 hand-specific outcomes instrument consisting of six subscales, measuring overall hand function,

69 activities of daily living, pain, work performance, aesthetics, and satisfaction. It measures

70 impairment by hand (left and right separately), rather than overall disability. Interpretation of

71 total scores on multi-dimensional instruments can be less than straightforward given that

72 patients can show simultaneous improvement in one domain with deterioration in another

73 [20,21]. Assessment of functional recovery on a unidimensional [22] and linear [21] scale would

74 allow for quantitative comparisons of ability among different patients and treatments. Such a

75 scale can be developed with state-of-the-art psychometric methods, such as the Rasch model

76 [23,24].

77 The ABILHAND questionnaire is a Rasch-model built measure of manual ability [25] that provides

78 an invariant linear scale and allows for quantitative comparisons of manual ability between

79 patients and over time. The scale has been validated in populations with rheumatoid arthritis

80 [26], chronic stroke [8], pediatric cerebral palsy [27], systemic sclerosis [28] and neuromuscular

81 diseases [29]. These previous validations have shown that the difficulty of most manual activities

82 was diagnosis-dependent [30]. Therefore, the objective of this work was to adapt the ABILHAND

83 scale to the most frequent diagnoses treated in HS.

Methods

Questionnaire adaptation to HS patients

The ABILHAND is a measure of manual ability that assesses one's ability to manage daily activities requiring upper limb use, regardless of strategy [25]. The necessary permissions were obtained from the developer of the original questionnaire to modify it. To develop a HS-adapted ABILHAND, a preliminary item list was compiled from previous versions of the ABILHAND questionnaire, the DASH, PRWE, CTQ, and MHQ items together with some new items. This pool of items was submitted to nine HS experts (hand surgeons, physical medicine and rehabilitation physicians, physical therapists, and occupational therapists), who were asked to assess each item's relevance to hand surgery patients on a yes/no basis and propose additional items that might be affected by the relevant pathologies (e.g. sensation for CTS and wrist loading for distal radius fractures (DRF)). A final list of 90 items constituted the experimental ABILHAND-HS questionnaire (S4 Appendix).

Patients

A convenience sample of 216 patients was recruited from February 2018 to February 2019 at the HS consultation center at Cliniques Universitaires Saint-Luc, Belgium representing the following four diagnostic categories: CTS, DRF, basal thumb arthritis (BTA), and heavy wrist surgery (HWS, including 1st row carpectomy and partial or total wrist arthrodesis). The inclusion criteria for patients were being >18 years old and being able to read and understand French. The exclusion criteria included comorbidities that may impede manual ability substantially (i.e. tremor, paralysis and active rheumatologic disease) and any mental or cognitive dysfunction (i.e. dementia and

105   mental retardation). The patient characteristics are summarized in Table 1. Patients provided

106   written informed consent to participate. This study was approved by the ethical committee of

107   Cliniques Universitaires Saint-Luc-Université catholique de Louvain (N° B403201523492).

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109 **Table 1. Sample characteristics (n = 216).**

Characteristic	N (%)[a]
Gender	
Women	145 (67%)
Men	71 (33%)
Mean age (range), years	60.3 (19–93)
Education level	
Basic	109 (51%)
Postsecondary	107 (49%)
Work status	
Student	2 (1%)
Unemployed	22 (10%)
(Self-)Employed	83 (38%)
Retired	109 (51%)
Hand dominance	
Right	194 (90%)
Left	15 (7%)
Ambidextrous	7 (3%)
Involved dominant hand	
Yes	136 (63%)
No	80 (37%)
Diagnostic group	
Distal radius fracture (DRF)	74 (34%)
Basal thumb arthritis (BTA)	66 (31%)
Carpal tunnel syndrome (CTS)	53 (24%)
Heavy wrist surgery (HWS)	23 (11%)
Follow-up assessments (n = 305)	
0–3 months (57 DRF, 52 CTS, 22 BTA, 1 HWS)	132 (43%)
3–6 months (38 DRF, 16 CTS, 3 BTA, 1 HWS)	58 (19%)
>6 months (30 DRF, 18 CTS, 46 BTA, 21 HWS)	115 (38%)

[a]Except where otherwise indicated

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Procedures

111   The French-language experimental ABILHAND-HS items were presented in five random orders to

113   avoid a systematic item sequence bias. Patients were asked to indicate their perceived difficulty

114   associated with completing the activities without technical or human assistance, independent of

115   the hand used to perform the activity on a three-level scale: impossible (0), difficult (1), or easy

116   (2) [8]. Activities not attempted during the last week were treated as missing responses. Patients

117   also completed the QuickDASH [31], 12-item Short Form Survey (SF-12) questionnaire [32] and a

118   10-level numerical pain scale, for external validation purposes.

119   Patients were first assessed as soon as they presented to their hand surgery consultation

120   appointments and had experienced manual activities in their own environment: after hand

121   surgery and cast removal for DRF, BTA and HWS and at the first consultation for non-operated

122   CTS and BTA. For the first assessment, patients were interviewed by the principal investigator in

123   order to ensure clarity, obtain feedback from participants, and make sure instructions are

124   properly followed. Patients were also asked to suggest additional items they felt the

125   questionnaire was missing. However, these were either gender related (e.g. fastening a bra) or

126   very specific and were thus not retained. Follow-up assessments were completed in our

127   consulting office or returned by mail, leading to a total of 305 completed assessments, which

128   provides sufficient power to support the planned Rasch analysis [33].

Rasch analysis

130   The 90-item experimental ABILHAND-HS questionnaire responses were analyzed using the Rasch

131   model in RUMM2030 software (RUMM Laboratory Pty Ltd., Perth, Australia). The Rasch model

132 [24], a prescriptive model, requires that specified response probabilities depend on only item

133 difficulty and patient ability. Polytomous datasets with thresholds between successive response

134 categories can be analyzed with either a rating scale model that constrains all threshold locations

135 to be equal across items [34] or a partial credit model that allows threshold locations to vary

136 across items [35]. Patient abilities and item difficulties are located along a common linear,

137 unidimensional continuum that defines the latent variable of interest (i.e. manual ability). The

138 locations are expressed in logits, calculated as the logarithm of the pass/fail probability ratio of

139 an item or threshold. The logit locations were converted into centiles to facilitate clinical

140 interpretation on a linear scale ranging from 0% (smallest ability) to 100% (largest ability) [36].

141 Expected responses, determined based on the patient and item locations, were compared to the

142 responses actually reported to compute residual and fit statistics, which were then used to assess

143 the scale's unidimensionality [37]. A good fit of the data with the model affirms invariant locations

144 along the continuum and indicates that the measure can be used to compare manual ability

145 across patients and diagnoses.

Item selection

147 From the experimental version of the questionnaire, the ABILHAND-HS was refined through

148 successive analyses of 305 assessments with the goal of selecting items that define a

149 unidimensional and clinically relevant scale of manual ability. P values < 0.05 were considered

150 significant for each of the following analysis steps:

151   1) *Item-patient targeting.* Based on examination of patient distributions and item locations,

152   items that showed a floor effect (too easy) or did not target the patients sample ability were

153   removed.

154   2) *Rating scale*. Items with disordered thresholds and items with thresholds that were too

155   narrow (<1.4 logits) or too wide (>5 logits) were removed before applying the rating scale

156   model [38].

157   3) *Unidimensionality*. Only items that delineated a common manual ability construct according

158   to the following four criteria were retained: (1) standardized residuals obtained over three

159   class intervals had to be within ±2.5 with a non-significant χ^2 [37]; (2) no observable major

160   differential item functioning (DIF) [39], uniform or non-uniform, shown by a 2-way analysis of

161   variance of the residuals with Bonferroni correction [40], according to gender (male vs.

162   female), age (above vs. below the median age of 63 years), pathology (CTS vs. DRF vs. BTA vs.

163   HWS), involved hand (dominant vs. non-dominant), level of education (basic vs. superior), and

164   follow-up (0-3 months vs. 3–6 months vs. >6 months); (3) overall fit of the response set based

165   on a non-significant item-trait interaction χ^2 [37]; and (4) statistically similar patient locations,

166   according to paired t-tests, calculated with items that loaded either positively or negatively

167   on the first residuals principal component [41–43].

168   4) *Local independence.* When items were found to be querying redundant content [44],

169   demonstrated by a residual correlation > 0.3, the item with the poorer fit statistic was deleted

170   [45].

171   5) *Item redundancy*. To shorten the scale, when two or more items had similar locations on the

172   continuum, the one with the best fit was retained.

Scale reliability

The Person-Separation Index (PSI), i.e. the proportion of total variance (including error) that is
attributed to patient location variance, was used to determine the ABILHAND-HS scale's reliability
and its degree of precision with the dataset, and thus how many statistically different ability strata
can be distinguished along the scale [46].

Construct validity

The construct validity of the ABILHAND-HS was examined with a comparison of means for
associations with gender, involved hand, and diagnosis. The relationships of the ABILHAND-HS
with age, the QuickDASH scale, the numerical pain scale, the SF-12 Physical Component Summary
(PCS), and the SF-12 Mental Component Summary (MCS) were assessed with a correlation
analysis.

Patient perceptions were compared between ABILHAND-HS and QuickDASH items by adding the
six QuickDASH activity items to the anchored data matrix. The locations of similar items were then
compared between the scales.

Statistical analyses

Statistical analyses were completed in IBM SPSS Statistics for Windows, version 25 (IBM Corp.,
Armonk, N.Y., USA). Data normality was verified for statistical tests using the Shapiro-Wilk test
and Q-Q plots. Parametric tests were used for normal data and continuous variables, non-
parametric tests for non-normal data and ordinal variables. A Mann-Whitney u-test (two-tailed)
was used for gender differences, an independent-samples t-test (two-tailed) for association with

193   the involved hand, and an analysis of variance for diagnosis. Pearson correlation coefficient was

194   calculated for association with age, while relationships with the QuickDASH scale, the numerical

195   pain scale, the SF-12 Physical Component Summary (PCS), and the SF-12 Mental Component

196   Summary (MCS) were assessed with Spearman correlation coefficients. P values < 0.05 were

197   considered significant. Mean values are reported with standard deviations (SD). Chi-square and t

198   values are reported with degrees of freedom (df).

Results

Item selection for the ABILHAND-HS scale

201   Successive analyses led to the selection of 23 items defining a unidimensional manual ability scale

202   in HS. Of the 90 experimental items, 34 were removed because they were too easy (e.g. 'Drinking

203   a glass of water'), 3 items had too-narrow thresholds (e.g. 'Using a touch screen'), 4 items were

204   misfitting (e.g. 'Carrying a shopping bag'), and 26 items had a location redundant with another

205   better fitting item (e.g. 'Peeling onions' was deleted in favor of 'Peeling potatoes with a knife').

Metric properties

207   The calibration obtained for the 23 mostly bimanual activities retained for ABILHAND-HS is

208   reported in Table 2 in descending difficulty order. The standardized residuals obtained matched

209   the expected standard normal distribution for items [mean (SD), -0.30 (0.99)] and for patients

210   [0.31 (0.97)], indicating that the ABILHAND-HS scale is globally unidimensional. An invariant item

211   location was obtained for more- and less- able patients as shown by a nonsignificant item-trait

212   interaction (χ^2 = 57.76, 46 df, p = 0.11). An invariant patient ability was obtained with items with

213   different content as shown by a non significant t-test when using items that loaded positively or

214   negatively on the first principal residual component (t = 1.24, 304 df, p = 0.22).

215 **Table 2. Calibration of the 23 items of the ABILHAND-HS.**

Item	Bi-manual	Difficulty logits (centiles)	SE logits	Residual z	Fit χ²	P
a. Doing push-ups	x	3.54 (78)	0.21	0.61	0.46	0.79
b. Playing a racket sport	x	2.30 (68)	0.25	0.04	1.66	0.44
c. Cutting a hedge	x	2.00 (65)	0.18	0.05	3.83	0.15
d. Opening a screw-topped jar	x	1.30 (59)	0.12	0.48	6.19	0.05
e. Applauding vigorously	x	1.11 (58)	0.16	2.09	2.00	0.37
f. Lifting a full pan	x	0.96 (57)	0.12	-0.53	5.69	0.06
g. Wringing a towel	x	0.86 (56)	0.12	-2.00	0.14	0.93
h. Opening a can with a can opener	x	0.76 (55)	0.12	-1.83	0.49	0.78
i. Hammering a nail	x	0.45 (52)	0.16	-0.70	5.31	0.07
j. Shaking bed sheets	x	0.13 (50)	0.17	-1.95	3.49	0.17
k. Using a screwdriver	x	-0.05 (48)	0.14	-0.14	0.54	0.77
l. Peeling potatoes with a knife	x	-0.16 (47)	0.13	-0.75	5.75	0.06
m. Ironing	x	-0.38 (45)	0.15	-0.44	3.12	0.21
n. Taking the cap off a bottle	x	-0.52 (44)	0.13	-0.32	2.75	0.25
o. Cutting one's nails	x	-0.55 (44)	0.13	-0.05	0.33	0.85
p. Shuffling and dealing cards	x	-0.77 (42)	0.16	-1.21	6.18	0.05
q. Wiping windows		-0.77 (42)	0.15	0.01	1.29	0.52
r. Tying shoelaces	x	-0.96 (41)	0.14	-0.61	2.02	0.36
s. Tearing open a pack of chips	x	-1.16 (39)	0.15	1.70	1.31	0.52
t. Fastening the zipper of a jacket	x	-1.45 (37)	0.14	0.32	1.58	0.45
u. Turning a car steering wheel	x	-1.69 (35)	0.18	-0.26	0.78	0.68
v. Putting on gloves	x	-2.24 (30)	0.19	-0.80	1.99	0.37
w. Spreading butter on a slice of bread	x	-2.68 (26)	0.18	-0.60	0.86	0.65

216

217 Analysis of DIF of the ABILHAND-HS with six criteria yielded only four instances of uniform DIF

218 among the 23 items (Table 3). A small magnitude DIF was revealed among diagnoses (Fig 1) with

219 no substantial impact on scale invariance, as evidenced by a good overall fit. Note that items

220 were not specifically calibrated to the HWS group because of a limited sample size (n=23) [47].

221 No DIF was observed between the first and last assessments, showing satisfactory invariance to

222 support the scale follow-up stability. Likewise, an intraclass correlation coefficient across the first

223 and last assessments was 0.94, indicating excellent item-difficulty-hierarchy consistency and

224 providing confidence for data pooling over different time points [48]. The PSI in this sample was

225 equal to 0.90, indicating the distinguishability of four strata of manual ability [46].

226 **Table 3. Differential item functioning (DIF) summary.**

Label	Person factor	Magnitude (logits)	Type	Difficulty
Taking the cap off a bottle	Gender	1.36	Uniform	Women > Men
Opening a screw-topped jar	Gender	0.93	Uniform	Women > Men
Opening a screw-topped jar	Diagnosis	0.61	Uniform	BTA > CTS > DRF
Using a screwdriver	Involved hand	1.26	Uniform	Non-dominant > Dominant hand involved

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228 **Fig 1. Differential item functioning (DIF) plots comparing the item difficulty hierarchy between**

229 **subgroups.** In each plot, the lines represent the 95% confidence interval of an ideal invariance

230 between subgroups; the items are represented by the dots or by their letter if they display

231 significant DIF. The most difficult items (dots) are plotted in the top right part of each plot.

232 When comparing the item difficulty hierarchy between each diagnostic group relative to the

233 whole sample, most of the ABILHAND-HS items lie within 95% confidence interval of the ideal

234 invariance, indicating an invariant difficulty across diagnostic groups. When comparing the item

235 difficulty hierarchy between the first and last assessment, all items fall within the 95%

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236   confidence interval of an ideal invariance, affirming invariance of item difficulties between the

237   assessments.

Scale description

239   The ABILHAND-HS structure and targeting of HS patients are illustrated in Fig 2, showing an

240   average patients' manual ability of 1.17 logits (SD = 1.85 logits; i.e. 58 (15) centiles). Twenty-four

241   patients (7.9%) were able to perform all 23 activities easily, and were thus identified as extreme

242   patients. Extreme patients tended to be younger men evaluated more than 6 months after

243   treatment, and were more likely to have a CTS rather than a HWS. The three response categories

244   were well distinguished in HS patients, with an inter-threshold distance of 2.93 logits (24 centiles),

245   indicating that, regardless of patient ability, rating an item as 'easy' is about 20 (i.e. $e^{2.93}$=18.7)

246   times more difficult than rating it as 'impossible'. Although the threshold distribution (range, -

247   4.15 to 5 logits) was well targeted to the range of patient abilities, the patients' ability levels

248   skewed high, indicating that the scale could measure patients that are more severely disabled

249   than in this sample.

250   **Fig 2. Structure of the ABILHAND-HS scale.** Top: distribution of manual ability measures for the

251   whole sample expressed in logits (log of the pass/fail probability ratio) and centiles (fraction of

252   the measurement range). Twenty-four patients (7.9%) were able to perform all 23 activities

253   easily, and were thus identified as extreme patients. None of the participants reported that they

254   could not perform any of the 23 activities. Middle: most probable patient response to each item

255   based on the patient manual ability and on the difficulty of the item's response category. The

256   average item difficulty was set to 0 logits and the items are ordered from most (top) to least

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257 (bottom) difficult. The distance between thresholds (middle bar) is constant for all items (2.93

258 logits or 24 centiles). A patient with a manual ability measure of 0 logits would be expected to

259 perform the first 3 activities easily, to have some difficulty with the following 17 activities, and

260 to be unable to perform the 3 most difficult activities. A patient with a measure of 2.1 logits

261 should be able to perform all activities easily or with some difficulty. Bottom: conversion of

262 ordinal raw scores into a linear continuum of manual ability for complete response sets. The raw

263 scores ranged from 0 to 46 (sum of scores of 0–2 for 23 items). This curve is linear in its central

264 (30th~70th percentile) range, with sigmoid flattening outside the central range, highlighting a

265 non-linear relationship, especially at the extremities of the score range.

Construct validity

267 ABILHAND-HS measures were normally distributed across the whole sample and subgroups,

268 except for men (W = 0.97; 100 df; p = 0.038). An effect of gender on ABILHAND-HS manual ability

269 measures was observed, with men [1.88 (2.39) logits; median 1.74 logits] reporting a significantly

270 higher mean manual ability than women [1.32 (1.93) logits; median 1.4 logits; U = 8642; p =

271 0.026]. Manual ability was not found to be significantly associated with age (R = -0.04; p = 0.47),

272 the hand involved (t = 0.96; 303 df; p = 0.37), or the patient's diagnosis (F = 1.92; 3 df; p = 0.12).

273 Although variance across diagnosis groups was not significant, we did observe a broad spectrum

274 of manual ability. Patients with CTS reported the highest manual ability [1.9 (2.0) logits], followed

275 by patients with BTA [1.5 (2.3) logits], DRF [1.4 (2.1) logits], and HWS [0.9 (1.8) logits].

276 The relationships between ABILHAND-HS measures and scores obtained with other instruments

277 are shown in Fig 3. Briefly, ABILHAND-HS correlated strongly with QuickDASH scores, moderately

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278   with SF-12 PCS scores and pain scale scores, and weakly with SF-12 MCS scores. We observed

279   substantial similarity with respect to manual ability scale locations between the ABLHAND-HS and

280   QuickDASH activity items (Fig 4).

281   **Fig 3. Correlations of ABILHAND-HS scores with QuickDASH, PCS, MCS, and numerical pain**

282   **scale scores.** Spearman correlation coefficients are indicated in the top right of each graph. All

283   correlations were statistically significant ($p < 0.001$).

284   **Fig 4. Comparison of difficulty levels (vertical axis) between similar items of the ABILHAND-HS**

285   **(left) and QuickDASH (right) scales.** QuickDASH item responses were added to the anchored data

286   matrix of ABILHAND-HS responses to equate both measures.

Discussion

288   Here, we report the adaptation and validation of an ABILHAND-HS questionnaire for use with HS

289   patients. Impairments present in our study cohort included weakness (e.g. following DRF), loss of

290   sensation (e.g. in CTS), and stiffness (e.g. in BTA), with some patients presenting with a

291   combination of these impairments. The ABILHAND-HS was constructed to measure manual ability

292   on a common, linear, and unidimensional scale wherein the 23 activities retained delineate an

293   invariant item difficulty hierarchy independent of patient diagnosis. All ABILHAND-HS activities

294   with the exception of one involve both hands and, consistent with our clinical experience, the

295   most difficult ones require high levels of force (e.g. 'doing push-ups' loads the wrist in extension).

296   Of the experimental 90 items, those that could be interpreted in different ways, for instance using

297   the injured or uninjured hand, were misfitting and thus omitted (e.g. 'carrying a shopping bag').

298   The sample size was adequate for the statistical interpretation of fit statistics [33], and was within

299   the same range of studies dealing with the development of outcome measures [14,15,19,31]. The

300   fit statistics for the 23 retained items support the item hierarchy invariance across the latent trait

301   [49]. A few instances of minor DIF were retained to maintain the scale's construct validity [50].

302   The resulting scale is well targeted to the studied HS population, despite a small persistent ceiling

303   effect, most likely due to missing responses for the most difficult activities. This observation of

304   apparent ceiling effect involves 7.9% (24/305) of the records, which is well below the maximum

305   recommended allowance of 15% [51].

306   Although reliability indices should be compared with caution across potentially different study

307   conditions, it is noteworthy that the PSI obtained for the ABILHAND-HS (0.90) was higher than

308   prior values obtained for the activities subscales of the PRWE [52] (0.78 and 0.81 for the usual

309   and specific activities subscales, respectively, in DRF patients), for the Patient-Rated Wrist and

310   Hand Evaluation [53] (0.83 in HS patients), for the QuickDASH scale [54] (0.84 in patients with

311   various upper limb dysfunctions) and for the Manual Ability Measure [55] (MAM-16; 0.83 for HS

312   patients), while being equal to that for the DASH manual functioning subscale [18]. PSI values

313   reflect sensitivity to clinical evolution over time, with greater values indicating a greater number

314   of distinguishable ability strata. We obtained person separation among patients using three

315   response levels (impossible, difficult, and easy), consistent with previous studies showing patients

316   unable to discriminate more than three levels of difficulty (ABILHAND [8], DASH activity items

317   [18] and QuickDASH activity items [54]).

318   Accurate communication of scale administration instructions is critical for targeting patient

319   manual ability as defined by the ABILHAND-HS. Generally, patients focus on their ability to

320   perform the queried activities with their injured hand; likewise, the PRWE explores use of the

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321   affected hand explicitly [15]. The ABILHAND-HS, like the QuickDASH, is oriented towards real daily

322   life behaviors and is intended to be independent of the limb(s) or strategy used and unbiased by

323   activities that are never performed with the affected hand or avoided during recovery [8]. Our

324   findings of stable item calibrations and lack of DIF across the assessments indicate that the

325   ABILHAND-HS can be used confidently to assess the patient recovery at different time points

326   during follow-up. Moreover, the stability of items hierarchy between the first and last evaluation

327   indicate that the results were not influenced by the method of administration (interview with the

328   investigator versus self-reported).

329   ABILHAND-HS construct validation results fit well with our clinical observations. The patients with

330   the highest manual ability scores on the ABILHAND-HS also had the highest SF-12 PCS and SF-12

331   MCS scores as well as the lowest QuickDASH and numerical pain scale scores, which was also

332   observed in other validation studies [15,19]. Correlations of ABILHAND-HS with other

333   instruments, including the QuickDASH, SF-12 and a pain scale are also consistent with prior

334   findings suggesting that generic instruments are less sensitive than specific ones [56]. The present

335   ABILHAND-HS manual ability scores were not related significantly to age, consistent with other

336   versions of the ABILHAND [8,26,29]. Our findings of a small, but significant gender effect, with

337   men tending to report a higher manual ability than women (mean difference, 0.56 logits), varied

338   across HS diagnoses but, generally, were consistent with previous reports in patients with DRFs

339   and wrist arthrodesis [57–59]. A possible explanation is that manual ability is related to grip

340   strength, which is more important in men compared to women [8,60]. The construct validity of

341   the ABILHAND-HS was further supported by our confirmation of a similar item difficulty hierarchy

342   for QuickDASH items in our patients sample. Notably, those ABILHAND-HS activities that require

21

343   a great amount of force (e.g. 'Opening a screw-topped jar') have been reported to likewise be

344   among the most difficult items in the DASH and QuickDASH [18,54] and in the MAM-16 [55].

345   The ABILHAND-HS, developed using Rasch methodology, has several advantages over

346   questionnaires developed using classical test theory. These are summarized in Table 4. Firstly, the

347   ABILHAND-HS can tolerate missing responses, which enables it to remain valid even in patients

348   who scarcely perform some of the queried activities. Secondly, the ability to analyze response

349   patterns can identify those patients whose responses do not fit the model due to random or

350   careless answers, a particular injury or comorbidities. Finally, the high precision of the ABILHAND-

351   HS items minimizes the need for interpretation, thereby allowing more reliable comparisons

352   between patients (e.g. recreational activities involving force or impact are broken down into the

353   items 'doing push-ups', 'practicing a racket sport').

354

355   **Table 4. Pros and cons of the ABILHAND-HS.**

	Feature	Benefit
Pros	Unidimensional and linear scale	Quantitative comparisons of manual ability can be made between patients, between treatments and along follow up
	Invariant scale calibration validated in four diagnostic groups	Unbiased comparisons of manual ability can be made within and between clinical subgroups (different HS diagnostics, stage of recovery)
	Precise item definition	Inaccurate responses and guessing are avoided
	Amenable to incomplete responses	The test is specific to activities really performed by the patient
	Capacity to analyze response patterns	The test can identify unexpected patient responses linked to patient specific behaviors, random or careless answers or comorbidities
	Precision of the measure	The standard error of measurement is specific to each patient measure allowing statistical assessment during follow-up

	Feature	Compensation
Cons	Yet another test for hand surgery outcomes evaluation	Takes five minutes to complete
	Complex statistical background	Necessary for the analyst, but not for routine clinical use
	Use of dedicated computer programs	A free web service (www.rehab-scales.org) can be used to interpret patient responses
	Ceiling effect of 7.9% of records	Well below the maximum recommended allowance of 15%

356

357   Limitations of this research include a sample of patients with hand and wrist disabilities from one

358   hand surgery outpatient clinic. The unbalanced diagnostic groups and genders might have

359   influenced the item calibrations. However, the gender distribution is similar in studies involving

360   DRF and CTS [15,16,31] and the DIF analysis allowed us to select items where the diagnosis and

361   gender effects were absent. Future studies with a larger sample size should confirm or refine our

23

362 findings. Furthermore, the way participants responded to the 90 items in the questionnaire may

363 not be the same as responses to the final 23-item instrument. One limitation to the availability of

364 Rasch model-based questionnaires is that they have a complex statistical background and require

365 the use of dedicated computer programs that are not easy to learn and implement. To facilitate

366 and spread the use of the ABILHAND-HS, a website (www.rehab-scales.org) developed by

367 Université catholique de Louvain and Arsalis, a spin-off of the ABILHAND authors' laboratory, can

368 be used to convert the questionnaire raw scores into manual ability measures. The web service is

369 free-to-use for daily practice in clinical and research applications although a license is required

370 for commercial applications and for clinical trials.

Conclusion

372 ABILHAND-HS was demonstrated to be a successful adaptation for application in HS patients. The

373 resulting scale was shown to be a valid, patient-oriented, clinically meaningful and precise

374 instrument. It targets commonly performed manual activities and allows stable and linear

375 measurement of manual ability over multiple time points in patients treated for DRF, BTA, CTS,

376 or HWS. The scale reveals unexpected responses that may provide clues regarding the patient's

377 clinical state, as summarized at www.rehab-scales.org. The questionnaire is available online, and

378 the web service is free-to-use for daily practice in clinical and research applications although a

379 license is required for commercial applications and for clinical trials. Future research should

380 include more patients with HWS, as well as other diagnoses such as tendinopathies, ligamentous

381 injuries and complex hand injuries, and an assessment of scale responsiveness.

24

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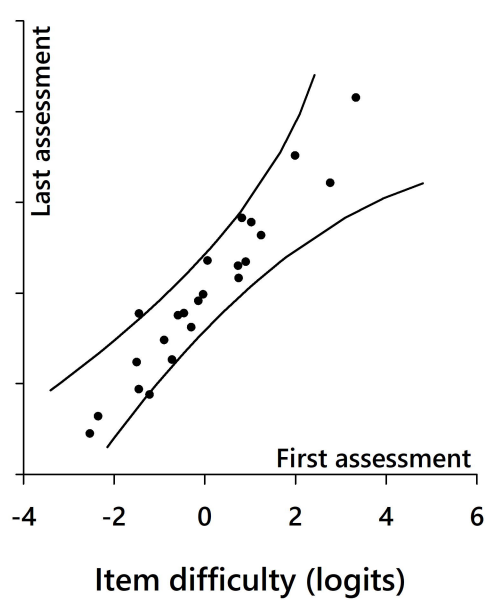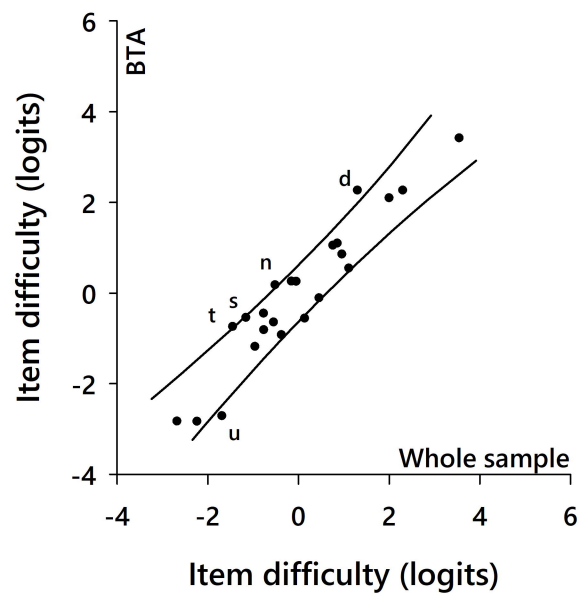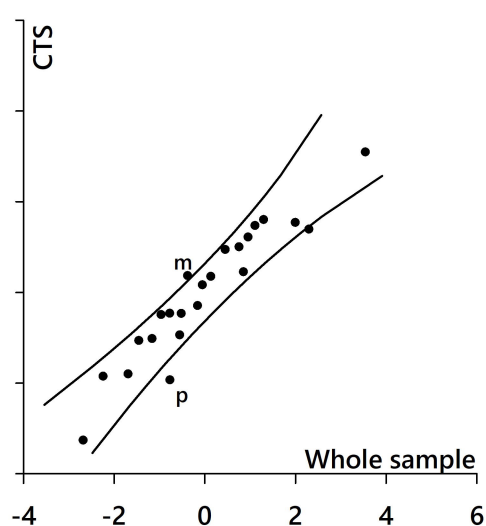517   children with cerebral palsy. Journal of Rehabilitation Medicine. 2007;39: 708–714.
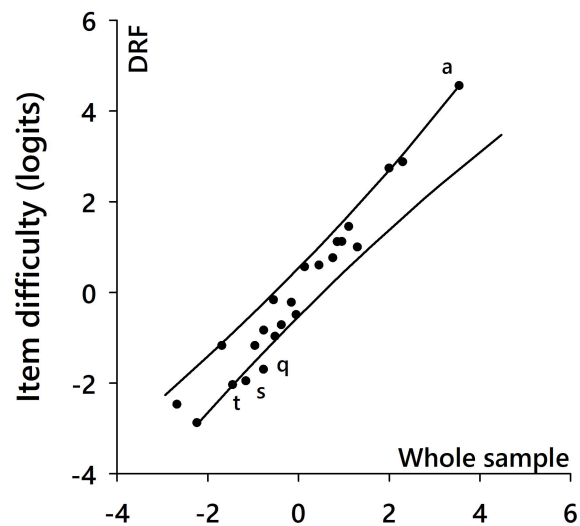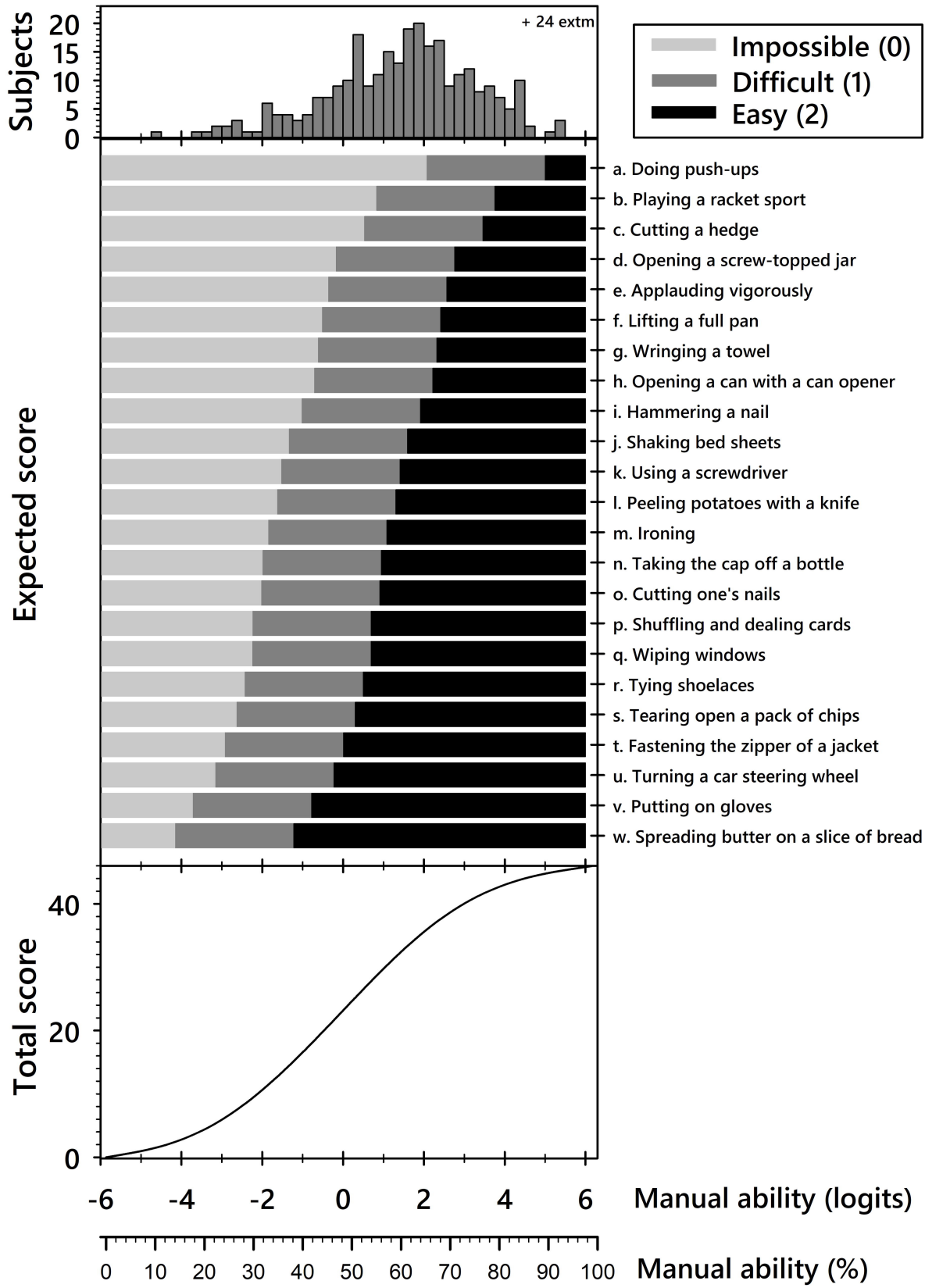
Supporting information

S1 Text. Common versus specific scales.

S2 Text. The ABILHAND-HS questionnaire (English version) instructions and scoring sheets. The scoring sheets are available in 10 different randomizations, as found on www.rehab-scales.org.
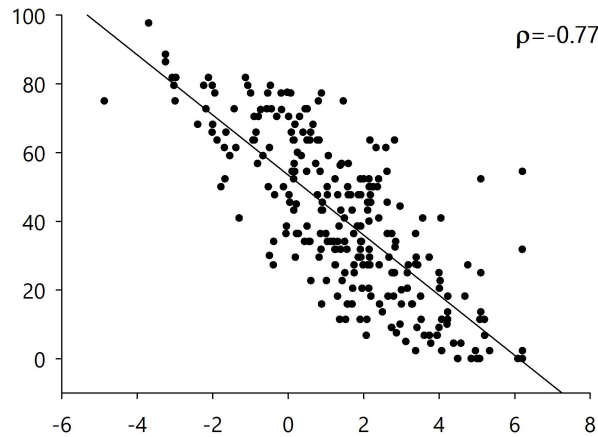
S3 Text. The ABILHAND-HS questionnaire (French version) instructions and scoring sheets. The scoring sheets are available in 10 different randomizations, as found on www.rehab-scales.org.

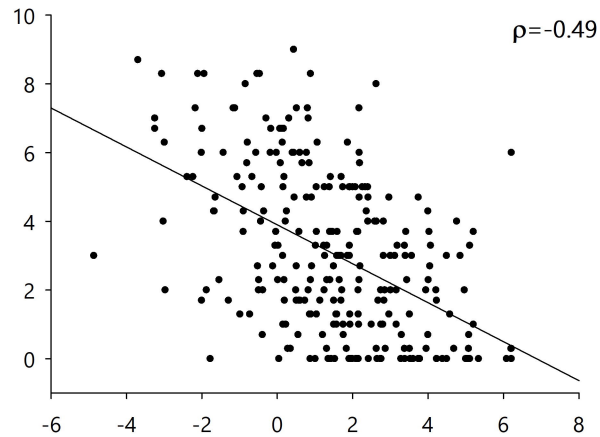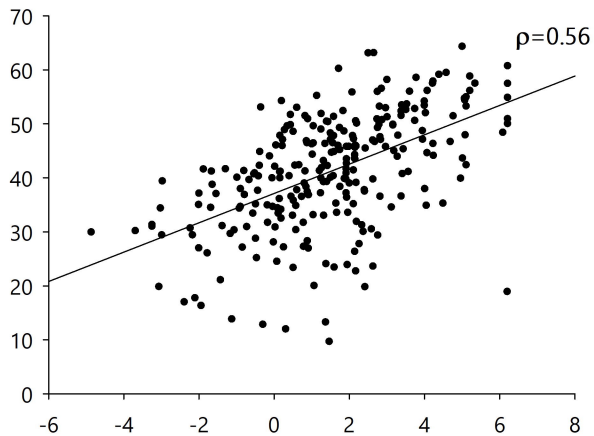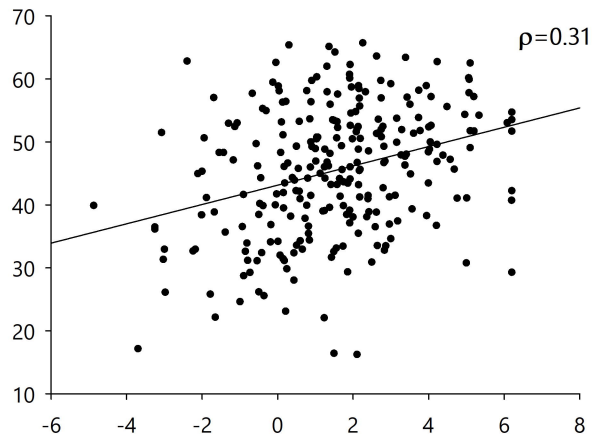**S4 Appendix. The experimental 90-item ABILHAND questionnaire.**

Figure legend:
- Impossible (0)
- Difficult (1)
- Easy (2)

+ 24 extm

Top panel y-axis: Subjects (0, 5, 10, 15, 20)

Expected score items:
a. Doing push-ups
b. Playing a racket sport
c. Cutting a hedge
d. Opening a screw-topped jar
e. Applauding vigorously
f. Lifting a full pan
g. Wringing a towel
h. Opening a can with a can opener
i. Hammering a nail
j. Shaking bed sheets
k. Using a screwdriver
l. Peeling potatoes with a knife
m. Ironing
n. Taking the cap off a bottle
o. Cutting one's nails
p. Shuffling and dealing cards
q. Wiping windows
r. Tying shoelaces
s. Tearing open a pack of chips
t. Fastening the zipper of a jacket
u. Turning a car steering wheel
v. Putting on gloves
w. Spreading butter on a slice of bread

Bottom panel y-axis: Total score (0, 20, 40)

x-axis: Manual ability (logits): -6, -4, -2, 0, 2, 4, 6

x-axis: Manual ability (%): 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100

ABILHAND-HS **QuickDASH**

3	
Playing a racket sport ——————— 2	Recreational activities
Opening a screw-topped jar ————————	Open a tight or new jar
Lifting a full pan ——————— 1	Carry shopping bag
Peeling potatoes with a knife ——————— 0	Use knife to cut food
-1	

Item difficulty (logits)