Evaluation of Internal Construct Validity and Unidimensionality of the Brachial Assessment Tool, A Patient-Reported Outcome Measure for Brachial Plexus Injury

Author

Hill, B, Pallant, J, Williams, G, Olver, J, Ferris, S, Bialocerkowski, A

Published

2016

Journal Title

Archives of Physical Medicine and Rehabilitation

Version

Accepted Manuscript (AM)

DOI

10.1016/j.apmr.2016.06.021

Evaluation of internal construct validity and unidimensionality of the Brachial Assessment Tool (BrAT), a patient-reported outcome measure for Brachial Plexus Injury.

Abstract
Objective: To evaluate the internal construct validity and dimensionality of a new patient-reported outcome measure for people with traumatic Brachial Plexus Injury (BPI) based on the ICF definition of activity.
Design: Cross sectional study
Setting: Five outpatient clinics across Australia
Participants: Adults (range 18-82) with a traumatic BPI
Intervention: 106 people with BPI completed a 51 item 5-response questionnaire. Responses were analyzed in 4 phases: missing responses, item correlations, Exploratory Factor Analysis and Rasch analysis to evaluate the properties of fit to the Rasch model, threshold response, local dependency, dimensionality, Differential Item Functioning and targeting.
Results: Six items were deleted for missing responses, 10 for high inter-item correlations >0.81. The remaining 35 items, while demonstrating fit to the Rasch model, showed evidence of local dependency and multidimensionality. Items were divided into three subscales, 'Dressing and grooming' (8 items); 'Arm and Hand' (17 items) and 'No hand' (6 items). All subscales demonstrated fit to the model with no local dependency, minimal disordered thresholds, no unidimensionality or DIF for age, time post injury or self-selected dominance. Subscales were combined into 3-testlets and demonstrated fit to the model, no misfit and unidimensionality allowing calculation of a summary score.
Conclusion: This preliminary analysis of the BrAT supports the internal construct validity of the BrAT a unidimensional targeted 4-response patient-reported outcome measure designed to solely assess activity following traumatic BPI regardless of level of injury, age at recruitment, premorbid limb dominance and time post injury. Further examination is required to determine test-retest reliability and responsiveness.

Key words: Brachial Plexus Injury; Outcome measurement; Rasch analysis

List of abbreviations
BPI - Brachial Plexus Injury
BrAT - Brachial Assessment Tool
PROM - Patient-Reported Outcome Measures
DASH - Disability of the Arm, Shoulder and Hand
ICF -The International Classification of Functioning, Disability and Health
CCS-HC - Comprehensive Core set for Hand Conditions
DIF - Differential Item Functioning
PSI - Person Separation Index

Brachial Plexus Injury (BPI) typically occurs after severe trauma including motor vehicle accidents, work accidents or falls from a height. [1] The impact of BPI is dependent on the level and severity of the injury to the nerves within the plexus. In recent years a number of new microsurgical techniques and methods have been developed to repair injuries to the brachial plexus. [2-4] Individuals may undergo repeated surgeries and ongoing rehabilitation over many months or years, therefore determining the most cost effective form of treatment and the impact of BPI on the individual and community is paramount.

Historically, the primary focus of assessment has been to determine the change in status over time in terms of impairments, more specifically individual upper limb muscle strength, active range of motion or sensation. [5, 6] While it is important to measure the direct result of nerve repair to a specific muscle or reinnervation of a sensory nerve, assessment of impairment alone is unable to provide an understanding of how people with BPI use their limb to perform day-to-day activities. [5-7] Further, a paucity of evidence exists which supports increases in strength or range of motion equating with better ability to use the arm and hand to perform day-to-day activities. [8, 9]

In recent years there has been an increasing emphasis on the use of Patient-Reported Outcome Measures (PROM) to evaluate outcome over time from the perspective of the individual. [10] The most commonly reported PROM for this demographic is the Disability of the Arm, Shoulder and Hand (DASH). [7, 11] Designed as a measure of physical function and symptoms, the DASH has been shown to be multidimensional. [12, 13] Summed scores from multi-dimensional tools have been reported to be ambiguous and recommendations suggest that they be viewed with caution due to uncertainty regarding the dimensions being assessed. [14] In addition, the DASH does not attribute responses directly to the affected limb; rather answers are based on the ability to perform the task irrespective of the limb used. As a consequence, the DASH may be measuring compensatory techniques or strategies over time, not improvement in use of the affected limb.

Empirical evidence of validity and reliability is required to ensure a measure is assessing what it intends to, is responsive to change, produces reproducible scores in a stable population and as free of error as possible. [15] In addition all items must relate to an underlying construct. The International Classification of Functioning, Disability and Health (ICF) is being increasingly used as a framework to define items that may reflect a specific construct, for example, items that pertain solely to body functions, activity or participation. On a conceptual level, the new measure evaluated in this study was conceived as a PROM of solely upper limb activities based on the ICF definition of activity, an ‘execution of a task or action by an individual’. The purpose of this paper was to evaluate the internal construct validity and unidimensionality of a new PROM, designed specifically for BPI using the latest evidence based psychometric techniques.

Methods

This was a cross sectional study. Ethical approval was gained from three Human Resources Committees, (Griffith University PES_12_13_HREC, Alfred Health 425/11, Melbourne Health 2011.220) and all participants provided signed informed consent prior to commencement of the study.

Inclusion and exclusion criteria

A convenience sample of people with a traumatic BPI was recruited from 5 centres in Australia. Participants were included if they had a diagnosis of traumatic BPI confirmed by MRI, nerve conduction studies, intraoperative findings or clinical assessment, and were over 18 years of age at the time of recruitment. Participants were excluded if they were unable to provide informed consent, had a pre-existing upper limb condition that affected day-to-day activity, had evidence of spinal cord injury confirmed by MRI, were non-weight bearing on the affected limb, or were diagnosed with brachial plexus birth palsy.

Item generation

The 51 items evaluated in this project were developed in a qualitative study [16] using the 29 ICF Comprehensive Core set for Hand Conditions (CCS-HC) activity categories. [17] To reduce the generated 522 items, similar items were grouped by CCS-HC category and task (for example open a medicine bottle, open a water bottle) and people with BPI rated both the importance and difficulty of each item. Items deemed to be less importance were deleted in an iterative process designed to retain a spread of item importance and difficulty to people with BPI and a cross section of CCS-HC categories. The 51 items retained were representative of 21 CCS-HC activity categories. [17]

Data Collection

All participants independently completed the 51-item 5-response PROM consisting of 2 sections, on one occasion. Section 1 consisted of 20 unilateral day-to-day activities including activities that are dominant limb-specific e.g. *'Cleaning your teeth'* or *'Doing your hair'* attributed to the affected arm only. Section 2 consisted of 31 day-to-day activities that required the use of both arms. Five category responses options were provided: '*Easy to do now'*, '*A little hard to do now'*, '*Very hard to do now'*, '*Cannot do now'* and '*Never did with affected arm / Never did this activity' scored from 5 to 1 with higher scoring reflecting greater ability*. This final category was included at this stage to allow identification of any items that were not routinely undertaken by all with this injury. Response to this category was managed as a missing response during data analyses.

Data analyses

Data were first entered into SPSS (version 22) and analysed in four phases. Items that remained after phase 3 were assessed for unidimensionality and scaling properties using the Rasch Unidimensional Measurement Model (RUMM 2030) partial credit model software. [18]

Phase 1: Items with missing responses were removed. The response category '*Never did with affected arm / Never did this activity'* was removed from all further analysis as this response did not inform actual day-to-day use of the limb. Items were rescored to 3 'Easy to do now' to 0 'Cannot do now'.

Phase 2: Items that correlate highly with each other are repeatedly measuring the same construct. While this may result in high internal consistency, it may artificially inflate reliability and lower the breadth of measurement. Items should be selected that load maximally to the underlying construct but exhibit low inter-item correlations. [19] Therefore, items with inter-item correlations (> 0.8) were eliminated in an iterative process using the following decision rules: a) number of inter-item correlations >0.8, b) importance and spread of difficulty to people with traumatic BPI, c) clinically-based justification as determined by experts, d) maintain the spread of CCS-HC activity categories and e) items with highest correlation values.

Phase 3: Exploratory factor analysis was used to assess dimensionality and identify the presence of any subsets of items. Factorability of the data was assessed using the Kaiser-Meyer Olkin Measure of sampling adequacy and Bartlett's Test of Sphericity.

Phase 4: The analysis followed the published criteria by Tennant and Conaghan. [20] Overall fit to the Rasch model was assessed with deviations from the model indicating problems with the tool and items. Appendix 1 provides a detailed description of the expectations of fit to the measurement model including summary fit statistics, ordering of response categories, individual person and item fit, local dependency, unidimensionality, internal consistency, Differential Item Functioning (DIF) and targeting. Items were systematically evaluated and where data did not fit the model items were sequentially removed and data reanalyzed. Where items were removed the same decision rules outlined above in Phase 2 were implemented. Sample size for Rasch analysis is influenced by scale targeting. A planned sample size of 108 participants provided accurate estimations of person and item locations within 0.5 logits (99% confidence interval). [21]

Results

One hundred and six adults with a traumatic BPI were recruited. Participants' mean age was 40 years (range 18-82) and the mean time post injury was 124 weeks (range 10 - 740 weeks). Injury severity covered the full range of BPI presentation from pan plexus to those with partial brachial plexus lesions.

Phase 1: Six items were removed because of missing responses (~10%) due to dominance dependence leaving 45 items (Table 1).

Phase 2: Ten items were removed based on high (> 0.80) inter-item correlations, leaving 35 items (Table 1). Following removal of these 10 items, no item correlated with another greater than 0.81

Phase 3: The remaining 35 items were analyzed using exploratory factor analysis as the Kaiser-Meyer Olkin Measure of sampling adequacy was 0.941 and Bartlett's Test of Sphericity was highly significant (p=0.000) indicating the factorability of the data file. Principal Component Analysis revealed 4 Eigen values greater than 1, suggesting a 4-factor solution, explaining 61%, 6.3%, 4.5% and 3.3% of the variance respectively. The scree plot and parallel analysis identified a possible 2-factor solution with 2 components exceeding the corresponding criterion values for a randomly generated data matrix of 35 items. However, items loaded very strongly onto the first component (range 0.87 - 0.64), therefore all 35 items were uploaded to RUMM 2030 for analysis as a single data set.

Phase 4: Rasch analysis.
Overall fit statistics for the 35 items revealed no deviation from the Rasch model (Table 2 analysis 1) with non-significant chi square (*p* 0.03 Bonferroni adjusted), item and person fit residuals standard deviation close to 1, and a high Person Separation Index (PSI) of 0.96. One item *'roll over while sleeping'* was misfitting. In total, three people were misfitting. Deletion of their data and subsequent reanalysis showed minimal change to overall model fit therefore all participants' data were retained. Thirteen items displayed disordered thresholds despite overall fit statistics matching the Rasch model. Multiple items correlated with one or more items >0.2 showing evidence of local dependency. Analysis of the PCA revealed multidimensionality with a set of items clustering into a similar group to that identified in EFA i.e. all the dressing items plus two additional items. Given the identification of multi-dimensionality that coincided with the EFA analysis the items were divided into subscales for further analyses.

Subscale 1: Nine dressing and grooming items. Analysis of fit statistics showed good match to the Rasch model (Table 2 analysis 2), with no disordered thresholds. One pair of items demonstrated local dependency, *'Put toothpaste on a toothbrush'* and *'Tear toilet paper from a toilet roll'*. There was no evidence of multidimensionality. Due to the local dependency one item '*Tear toilet paper from toilet roll'* was removed (Table 1). Following removal of this item, all fit statistics were satisfactory. Items were well targeted for those with limited use of their arm however there was a ceiling effect for those with more ability to perform day-to-day activities (Figure 1).

Table 1 Rationale for item deletion

	Item	Rational for removal
Phase 1	Writing	25 missing responses
	Iron a shirt	22 missing responses
	Use computer mouse	21missing responses
	Shake hands	18 missing responses
	Wipe yourself after toilet	13 missing responses
	Brush teeth	12 missing responses
Phase 2	Texting (using a mobile phone)	Correlate above 0.9 with nails, easier to perform than nails
	Eat finger food	Correlates with 3 items > 0.85 and least important to participants
	Push up from chair	Correlates with 13 items > 0.8
	Turn a knob	Correlates with 7 items > 0.8
	Open a cereal packet	Correlates with 4 items > 0.8 and least important to participants
	Receive change	Correlates with 5 items > 0.8 and least important to participants
	Chop raw vegetables	Correlates with 3 other items > 0.8 and least important to participants
	Carry a bag	Correlates with 3 items > 0.8 and least important to participants
	Do your hair	Correlates with 3 items > 0.8 and clinically based justification - not performed by all
	Turn a Key	Correlates with 8 items > 0.8 and least important to participants
Phase 3	No items deleted	
Phase 4		
Subscale 1	Tear toilet paper from a toilet roll	Less important to item spread and least important to participants
Subscale 2	Cut nails	Correlates with 2 items > 0.2 and least important of items
	Carry a tray	Correlate with shelf, easier task based on item map
	Open a Jar	Correlate with jam on bread, easier task, same CCS-HC category as others

Table 2 Summary of fit statistics

Action	Analysis	n items	Item fit residual		Person fit residual		Item trait interaction		Unidimensionality	PSI
			Mean	SD	Mean	SD	Chi square (DF)	*p*	95% CI	
Initial	1	35	-0.087	1.264	-0.121	1.335	93.430 (70)	0.030	19 - 27%	0.96
Subtest 1: Dressing items										
Initial	2	9	0.109	1.048	0.304	1.260	26.399 (20)	0.090	1% - 9%	0.90
Final	3	8	0.135	1.268	-0.284	1.187	27.688 (16)	0.030	1% - 7%	0.88
Remaining 26 items										
Initial	4	26	-0.207	1.263	-0.116	1.124	75.241 (52)	0.020	13-22%	0.95
Subtest 2: Whole arm and hand items										
Initial	5	20	-0.291	1.084	-0.206	1.027	58.584 (40)	0.030	7% - 10%	0.95
Final	6	17	-0.243	1.138	-0.177	0.923	45.683 (34)	0.090	4% - 12%	0.94
Subtest 3: No hand use items										
Initial	7	6	-0.152	0.762	-0.749	0.990	5.861 (12)	0.920	0 - 0%	0.80
Summary scale										
Initial	8	31	-0.088	1.274	-0.115	1.27	86.841 (62)	0.020	14% - 23%	0.96
Final	9	31	0.130	1.306	-0.365	0.915	3.262 (6)	0.770	1% to 9%	0.86

Key: n: Number of items, SD: Standard deviation, DF: Degrees of freedom, PSI: Person Separation Index

Table 3 Individual item fit statistics (subscale categorization indicated by font style)

Item	Location	SE	FitResd	ChiSq	df	Prob	Imp	Diff
Put on a T shirt	-2.40	0.19	-0.03	2.03	2	0.362	3	57
Put on a pair of trousers	-1.52	0.17	-0.76	2.77	2	0.250	12	54
Put on socks	-1.48	0.16	-0.02	1.86	2	0.395	21	48
Put toothpaste on a toothbrush	-0.81	0.14	1.38	2.15	2	0.341	40	46
Maintain control of your affected arm so you don't need to wear a sling	-0.72	0.13	0.95	2.93	2	0.232	1	62
Do up belt buckle	-0.71	0.15	-0.71	0.16	2	0.922	15	17
Tuck your shirt in	-0.67	0.17	0.50	0.95	2	0.623	23	52
Wash both hands at same time	-0.55	0.13	-0.17	5.12	2	0.077	16	53
Hold an object between your affected upper arm and your chest wall	-0.42	0.14	0.39	1.24	2	0.538	32	58
Push a pram, lawnmower or shopping trolley	-0.35	0.14	0.01	1.07	2	0.695	30	50
Hold an object draped over your affected forearm	-0.33	0.13	1.40	5.36	2	0.069	51	61
Stabilize an object with your affected arm while you manipulate it with your other hand	-0.30	0.14	-0.75	1.07	2	0.585	4	43
Do up shirt buttons	-0.30	0.16	2.11	5.69	2	0.058	9	9
Do up zip including putting ends together	-0.30	0.15	-0.99	1.94	2	0.379	14	16
Spread butter or jam on a piece of bread	0.00	0.15	-1.23	0.73	2	0.960	33	22
Do up tight trouser buttons	0.09	0.15	1.34	1.05	2	0.591	17	10
Lift your affected arm to feed it through the sleeve of a shirt	0.10	0.14	1.02	2.63	2	0.269	5	56
Roll over when sleeping without having to wake to move your arm	0.10	0.13	2.43	3.15	2	0.207	10	55
Tie up a rubbish bag and put in bin	0.21	0.14	-1.63	1.24	2	0.005	31	42
Do up shoe laces	0.48	0.14	-1.32	2.42	2	0.298	13	25
Use a knife and fork	0.62	0.14	-0.56	6.36	2	0.210	7	41
Carry an object only using your affected arm	0.65	0.15	-1.89	3.12	2	0.538	2	39
Pick up a small object with the fingers of your affected arm	0.68	0.14	2.66	4.53	2	0.104	20	37
Hold a pot of food with 1 hand and stir it with the other	0.69	0.14	-1.06	0.27	2	0.042	35	44
Change the sheet on a bed	0.71	0.16	-2.01	10.68	2	0.873	29	32

Wash your face with 2 hands	0.75	0.14	-1.33	2.64	2	0.267	39	33
Peg clothes on the washing line	0.88	0.15	0.01	2.23	2	0.585	36	11
Type on a keyboard, using 2 hands	0.89	0.15	0.80	0.08	2	0.023	27	13
Turn on a light switch using only your affected arm	1.06	0.15	-1.29	7.57	2	0.327	38	40
Use your affected hand to wash your other armpit	1.21	0.15	-1.05	1.55	2	0.460	19	21
Use both arms to lift a box or bag onto a shelf at eye level	1.73	0.17	-0.90	2.26	2	0.323	-	-

Key: Subscale 1 in italics, Subscale 2 in normal font, Subscale 3 in bold. SE: Standard error, FitResd: Fit residual, ChiSq: Chi Square, df: Degrees of freedom. Prob: Probability value. Imp: Importance of item as determined by people with BPI during item identification. Diff: Difficulty of item as determined by people with BPI during item evaluation

Overall fit statistics for the remaining 26 items revealed no deviation from the Rasch model (Table 2 analysis 4). However, twenty pairs of items correlated >0.2 showing evidence of local dependency, and analysis of the PCA revealed multi-dimensionality. Items clustered into two sets: those that require use of the whole arm and hand and those that require solely placement of the arm from the shoulder and elbow with no hand use (Table 3). The 26 items were therefore sub divided into two further subscales.

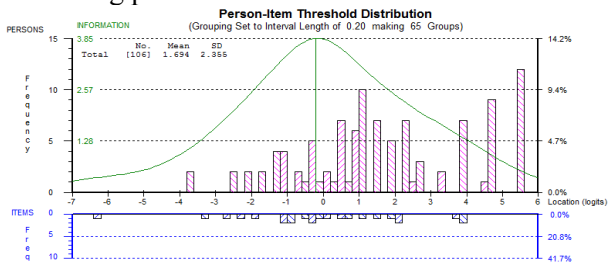
Subscale 2: Arm and Hand items: 20 items that required placement of the arm and hand to perform activities. Analysis of fit statistics showed a good match to the Rasch model (Table 2 analysis 5). No items were misfitting, five items demonstrated disordered thresholds, however the disorder was minor and did not affect the fit of the items or overall fit to the scale. Six pairs of items demonstrated local dependency. Three items were sequentially removed based on the Phase 2 criteria while maintaining fit to the Rasch model (Table 1). The final 17-item solution for subscale 2 showed adequate fit to the model (Table 2 analysis 6) with no evidence of dependency; multidimensionality or DIF. Items were targeted across the spectrum of ability with no floor or ceiling effect (Figure 1).

Subscale 3: No hand items: six items that required no hand use, only stabilising and/or holding by the affected limb. Analysis of fit showed a good match to the Rasch model (Table 2 analysis 7). No items or persons were misfitting. One pair of items *'Arm into sleeve'* and *'Not wearing a sling',* demonstrated some minor local dependency correlating at 0.214. There was no multidimensionality. The PSI value was 0.80 indicating adequate internal consistency. Targeting was reasonable despite the small number of items (Figure 1) with a ceiling effect for those with greater ability to use their hand to perform day-to-day tasks.

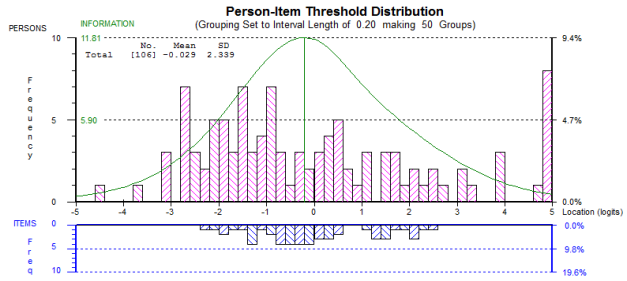
Summary scale

Given the strong correlation between all the items, the 31 items that remained were further analysed to assess the suitability of summing the total score (Table 2 analysis 8). While the overall data fitted the Rasch model, some evidence of multidimensionality remained. To further investigate this, a second order analysis was performed. The items from each subscale were combined to create three 'subtests' [(22)] allowing Rasch to analyse fit for the summary scale by treating the three subtests as three single 'super items'. The results (Table 2 analysis 9) showed good fit to the Rasch model with no local dependency, no dimensionality and no DIF. Figure 1 shows the 31 item 4-response option BrAT (total score 93, higher scores indicate greater ability) is well targeted across the sample. Individual item fit statistics for all 31 items are shown in Table 3. The person item map (Figure 2) shows the spread of item difficulty and person ability along a linear scale. The most difficult items required use of the whole arm and hand working above shoulder height for example *'Peg clothes on a line'* or *'place an object on a shelf above shoulder height'.* The

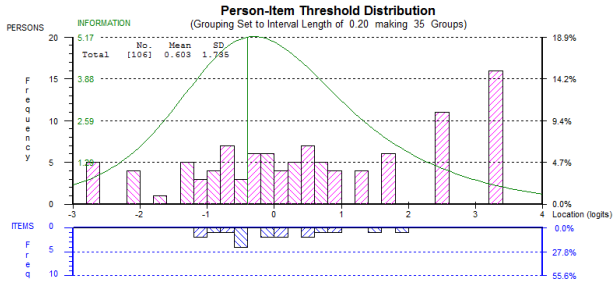
A) Subscale1: Dressing plus



B) Subscale 2: Whole arm and hand



C) Subscale 3: No hand use



D) Summary scale

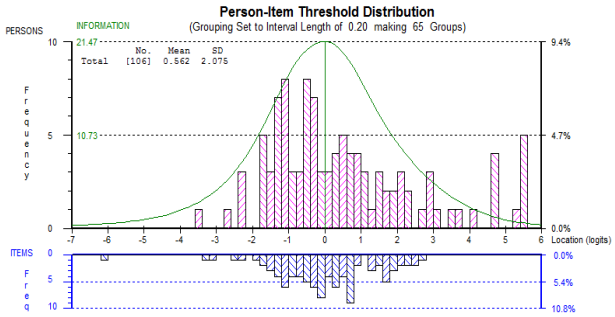


Figure 1. Targeting map for person and item thresholds.
Key: The upper section of the figure shows the distribution for the participants. The lower section of the figure shows the distribution of the items.

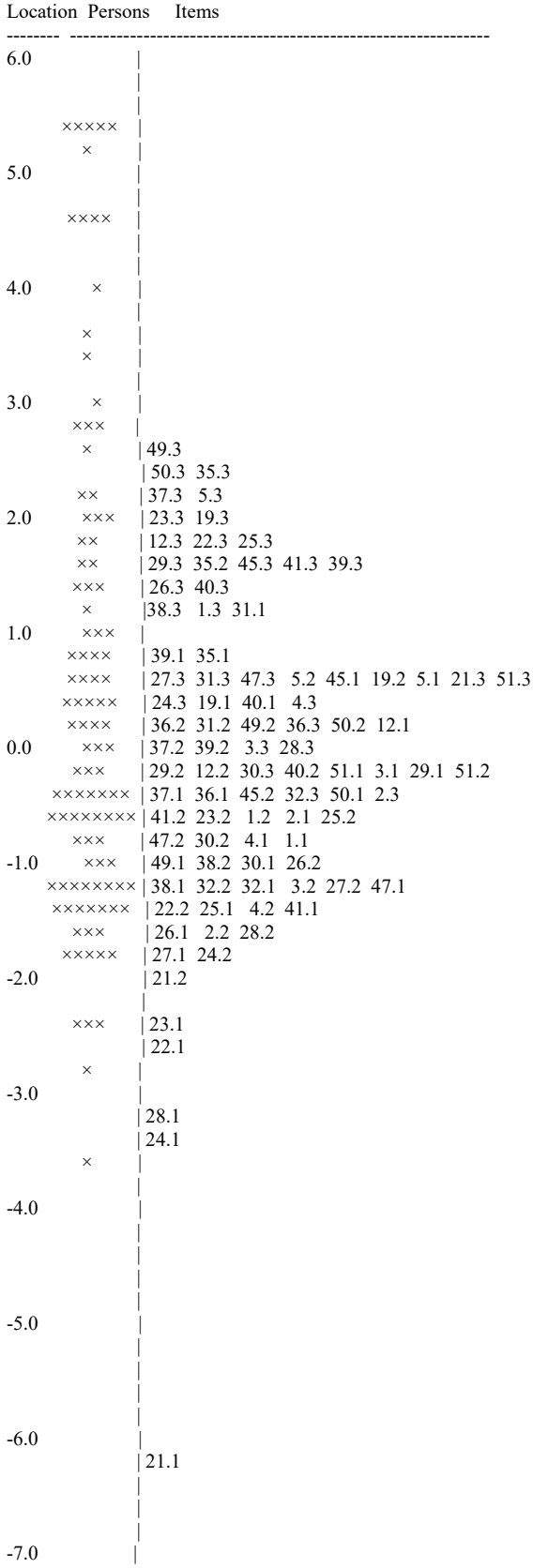


Figure 2 Item map of person abilities and item difficulties for all 31 items: Person ability measures are to the left of the scale. Item thresholds together with item numbers to the right (i.e. 21.1 means item 21 threshold 1). Higher scores indicate greater ability (-7.0 to 6.0) Key: × = 1 Person.

easiest items were all dressing activities. Items that were retained were classified to 13 CCS-HC activity categories (Appendix 2).

Discussion

The results of this preliminary validation of the psychometric properties of the 31-item Brachial Assessment Tool (BrAT) suggests that it is a unidimensional, targeted 4-response PROM designed to assess activity following traumatic BPI regardless of level of injury, age at recruitment, premorbid limb dominance and time post injury. Items were selected for inclusion based on importance and difficulty to people with BPI and this has been supported by statistical analyses using Rasch analysis (Table 3). The mean person ability for the 31 items was 0.562 indicating that on average the person ability was matched to the item difficulty, however, there is a small ceiling effect (18%) for those with higher levels of ability. This is not unexpected given the very wide spectrum of ability of people with BPI. We envisage the BrAT being part of a suite of outcome measures that addresses a range of domains including higher-level function, quality of life, pain, impairments and participation. From a clinical perspective, a number of the items retained in the BrAT, primarily those that require minimal to no use of the hand, are not present in existing PROMs but appear to be reflective of the demographic who sustain near complete loss of arm use.

While comprising three separate subscales, second order Rasch analysis empirically supports summing the scores across all 31 items. The presence of three separate subscales that address different aspects of upper limb use may offer some advantage in the clinical setting. People with a pan plexus injury could use subscale 3 ‘No Hand items’ with or without subscale 1 ‘Dressing and Grooming items’. Conversely someone with a C5/6/7 injury who maintains the ability to use their hand but minimal to no ability to place their limb in space could respond only to the Dressing and Grooming plus the Arm and Hand subscales. Further analysis is ongoing to determine whether the responsiveness of each subscale, or combination of subscales, is more suited to people with different injury and ability levels.

The results point to the complexity and diversity of the upper limb. Activities that are performed away from the body or require fine hand use seem to be a different dimension to those related to simple, commonly performed day-to-day tasks. This phenomenon has also been identified in a recent evaluation of existing scales, [12, 13, 23] Similar to Vincent et al (2015), we identified a subscale related to self-care; subscale 1 Dressing and Grooming. [24] It is unclear why these items are a separate subscale. They are all performed on a daily basis, usually from the day of injury, and most are reported as the easiest to perform (Figure 2) while being among the most important (Table 3). It maybe that participants have developed compensatory techniques that they do not use in other tasks and therefore their ability to perform these items is different to the others. [25]

Study limitations

A limitation of this study is the relatively small sample size; at the lower bounds of the minimum required for Rasch analysis. This means that the results may only be accurate estimations of person and item locations to within 0.5 logits. As a consequence raw score to interval scale transformations have not been produced at this stage. In addition, due to the low prevalence of BPI in Australia, participants were recruited over an extended period of time from five centres across two states. Different surgeons and therapists with somewhat different approaches, managed participants, however this has ensured that the people recruited to this project are representative of the heterogeneous BPI population.

Conclusion

The results of this study support the internal construct validity and dimensionality of the BrAT; a 31 item 4-respone PROM that assesses activity limitation in people with BPI. It is well targeted with no evidence of DIF for age, self-selected hand dominance or time post injury. The BrAT may be used equally well as three separate subscales or as a summed score. Further testing with participants from multiple sites is required to confirm these findings. In addition further work is ongoing to evaluate test-retest reliability and the responsiveness of the BrAT for people with different levels of brachial plexus injury.

Acknowledgments

The authors wish to acknowledge the assistance of Jaslyn Gibson, Occupational Therapist, Perth, Australia; Mr. David McCombe, Victorian Hand Surgery Associates, Melbourne, Australia and Melanie McCulloch, Re-wired Hand Therapy, Melbourne, Australia for their valuable contribution to this project during the recruitment and data collection phase.

References

1. Coene LNJEM. Mechanisms of brachial plexus lesions. Clinical Neurology and Neurosurgery. 1993;95.
2. Yang LJS, Chang KWC, Chung KC. A systematic review of nerve transfer and nerve repair for the treatment of adult upper brachial plexus injury. Neurosurgery. 2012;71:417-29.
3. Garg R, Merrell GA, Hillstrom HJ, Wolfe SW. Comparison of nerve transfers and nerve grafting for traumatic upper plexus palsy: A systematic review and analysis. Journal of Bone and Joint Surgery - Series A. 2011;93:819-29.
4. Ali ZS, Heuer GG, Faught RW, Kaneriya SH, Sheikh UA, Syed IS, et al. Upper brachial plexus injury in adults: comparative effectiveness of different repair techniques. Journal of neurosurgery. 2015;122:195-201.
5. Dy CJ, Garg R, Lee SK, Tow P, Mancuso CA, Wolfe SW. A systematic review of outcomes reporting for brachial plexus reconstruction. Journal of Hand Surgery. 2015;40:308-13.
6. Bengtson KA, Spinner RJ, Bishop AT, Kaufman KR, Coleman-Wood K, Kircher MF, et al. Measuring outcomes in adult brachial plexus reconstruction. Hand Clinics. 2008;24:401-15.
7. Hill BE, Williams G, Bialocerkowski AE. Clinimetric Evaluation of Questionnaires Used to Assess Activity After Traumatic Brachial Plexus Injury in Adults: A Systematic Review. Archives of Physical Medicine and Rehabilitation. 2011;92:2082-9.
8. Michielsen ME, de Niet M, Ribbers GM, Stam HJ, Bussman JB. Evidence of a logarithmic relationship between motor capacity and actual performance in daily life of the paretic arm following stroke. Journal of Rehabilitation Medicine. 2009;4:327-31.
9. Gates DH, Smurr Walters L, Cowley J, Wilken JM, Resnik L. Range of motion requirements for upper limb activities of daily living. American journal of occupational therpay. 2016;70:700-7013.
10. Devlin NJ, Appleby J. Getting the most out of PROMS: putting helath outcomes at th heart of NHS decision-making. The Kings Fund.2010.
11. Hudak PL, Amadio PC, Bombardier C. Development of an upper extremity outcome measure: The DASH (disabilities of the arm, shoulder, and head). American Journal of Industrial Medicine. 1996;29:602-8.
12. Franchignoni F, Giordano A, Sartorio F, Vercelli S, Pascariello B, Ferriero G. Suggestions for refinement of the disabilities of the arm, shoulder and hand outcome measure (DASH): A factor analysis and Rasch validation study. Archives of Physical Medicine and Rehabilitation. 2010;91:1370-7.
13. Lehman LA, Woodbury M, Velozo CA. Examination of the factor structure of the disabilities of the arm, shoulder, and hand questionnaire. American Journal of Occupational Therapy. 2011;65:169-78.
14. Hobart JC, Cano SJ, Zajicek JP, Thompson AJ. Rating scales as outcome measures for clinical trials in neurology: problems, solutions, and recommendations. Lancet Neurology. 2007;6:1094-105.
15. Streiner DN, GR. Health Measurement Scales a practical guide to their developent and use. Fourth Edition ed: Oxford University Press; 2008.
16. Hill B, Williams G, Olver J, Bialocerkowski A. Do existing patient-report activity outcome measures accurately reflect day-to-day arm use following adult traumatic brachial plexus injury? Journal of Rehabilitation Medicine. 2015;47:438-44.

17. Kus S, Dereskewitz C, Wickert M, Schwab M, Eisenschenk A, Steen M, et al. Validation of the Comprehensive International Classification of Functioning, Disability and Health (ICF) Core Set for Hand Conditions Hand Therapy. 2011;16:58-66.
18. Andrich C, Penta M, Sheridan B. RUMM2030. Perth: RUMM Laboratory Pty Ltd.2003.
19. Boyle GJ. Does item homogeneity indicate internal consistency or item redundancy in psychometric scales? Personality and Individual Differences. 1991;12:291-4.
20. Tennant A, Conaghan PG. The Rasch measurement model in rheumatology: What is it and why use it? When should it be applied, and what should one look for in a Rasch paper? Arthritis Care and Research. 2007;57:1358-62.
21. Linacre JM. Sample size and item callibration stability. Rasch Measurement Transactions. 1994;7:97-116.
22. Gibbons CJ, Thornton EW, Ealing J, Shaw PJ, Talbot K, Tennant A, et al. Assessing social isolation in motor neurone disease: A Rasch analysis of the MND Social Withdrawal Scale. Journal of the Neurological Sciences. 2013;334:112-8.
23. Arnould C, VanDervelDe L, Batcho CS, Penta M, Thonnard JL. Can manual ability be measured with a generic ABILHAND scale? A cross-sectional study conducted on six diagnostic groups. BMJ Open. 2012;2.
24. Vincent JI, MacDermid JC, King GJW, Grewal R. Rasch analysis of the Patient Rated Elbow Evaluation questionnaire. Health and Quality of Life Outcomes. 2015;13.
25. Bialocerkowski AE, Grimmer KA. Compensatory mechanism use during the first 6 months following distal radius fracture. International Journal of Therapy and Rehabilitation. 2004;11:467-74.
26. Pallant JF, Tennant A. An introduction to the Rasch measurement model: An example using the Hospital Anxiety and Depression Scale (HADS). British Journal of Clinical Psychology. 2007;46:1-18.
27. Kersten P, White PJ, Tennant A. Is the pain visual analogue scale linear and responsive to change? An exploration using rasch analysis. PLoS ONE. 2014;9(6).
28. Tennant A, Pallant J. Unidimensionality matters! (A tale of two Smith's). Rasch Measuremtns Tranasctions 2006;20:1048-51.
29. Fisher WP. Reliability, separation, strata statistics. Rasch Measurement Tranasctions 1992;6:238.
30. Tennant A, Pallant J. DIF matters: A practical approach to test if Differential Item Functioning make a difference Rasch Measuremant Transactions. 2007;20:1082-4.

Appendix 1 Plan for Rasch analysis

Summary fit

- Item fit: Non-significant chi-square interaction fit statistic Bonferroni adjusted for number of items

This supports the required property of invariance across the trait and indicating the scale does not deviate from the model assumptions. [20]

- Fit residual: Mean of zero and standard deviation (SD) less than 1.5.

This examines the summary level differences between the observed data and the model expectations for items and individuals. [26]

Item thresholds

Item responses were investigated for disordered thresholds, which signify whether respondents are using the options consistently. The presence of disordered thresholds indicates respondents have difficulty discriminating between response options. This may be related to too many response options, or confusion in labeling options.

Non-significant item and person fit residuals (SD ±2.5)

This assesses differences between the observed data and the model expectations for items and individuals at an individual level.

Local independency: Residual correlation matrix correlations >.2 [27]

Local dependency requires that items show no pattern of association once the Rasch factor or underlying characteristic being measured has been removed. The presence of local dependency indicates that items may be measuring the same concept, which may artificially inflate the PSI indicating higher internal consistency than is actually present. Individual items that correlated with others above 0.2 were removed in an iterative process using the same decision rules as in Phase 2 while maintaining overall fit to the Rasch model

Unidimensionality

Unidimensionality was assessed in a 2-stage process. First, Principal Component Analysis (PCA) of the residuals was used to identify all items that positively and negatively loaded onto the first component greater than 0.2. These 2 sets of items were then compared using a series of t tests. The scale was considered unidimensional if fewer than 5% of these tests were significantly different, or the lower bound of the confidence interval (CI) was below 5%. [28]

Internal Consistency the Person Separation Index (PSI, range 0 - 1)

The PSI reflects how items can distinguish between different levels of ability and therefore how many subgroups may be compared within the sample. A PSI > 0.7 allows for group comparison, > 0.85 for clinical use based on the sample of responders examined. [29] Where the distribution is considered normal, the PSI is equivalent to Cronbach's alpha.

Differential item function (DIF)

DIF occurs when different groups within the sample respond in a different manner to an item despite having an equal level of construct being measured. [30] We investigated whether there was evidence of DIF for age (< 40 years vs ≥ 40 years), BPI involving the pre injury self-selected dominant or non-dominant limb, and time post injury (124 vs ≥124 months).

Item Targeting

Items were reviewed for targeting to the sample, i.e. the spread of item difficulty matching the ability of the sample

Floor or ceiling effect present if >15% of the participants reported a total score that was the minimum or maximum available

Appendix 2: CCS-HC activity categories arranged by importance to people with BPI

Item	Category	CCSHC activity
Maintain control of your affected arm so you don't need to wear a sling	NA	NA
Carry an object only using your affected arm	d430	Lifting and carrying
Put on a T shirt	d540	Dressing
Stabilize an object with your affected arm while you manipulate it with your other hand	NA	NA
Lift your affected arm to feed it through the sleeve of a shirt	d540	Dressing
Use a knife and fork	d550	Eating
Do up shirt buttons	d540	Dressing
Roll over when sleeping without having to wake to move your arm	d410	Changing basic body position
Put on a pair of trousers	d540	Dressing
Do up shoe laces	d4402	Manipulating
Do up zip including putting ends together	d4402	Manipulating
Do up belt buckle	d540	Dressing
Wash both hands at same time	d520	Washing oneself
Do up tight trouser buttons	d540	Dressing
Use your affected hand to wash your other armpit	d510	Washing oneself
Pick up a small object with the fingers of your affected arm, eg tablet or coin	d4401	Pick up
Put on socks	d540	Dressing
Tuck your shirt in	d540	Dressing
Type on a keyboard, using 2 hands	d360	Using communication devices and techniques
Change the sheet on a bed	d640	Doing housework
Push a pram, lawnmower or shopping trolley	d4451	Pushing
Tie up a rubbish bag and put in bin	d640	Doing housework
Hold an object between your affected upper arm and your chest wall, e.g. a book	d430	Lifting and Carrying
Spread butter or jam on a piece of bread	d630	Preparing meal
Hold a pot of food with 1 hand and stir it with the other	d630	Preparing meal
Peg clothes on the washing line	d640	Doing housework

Turn on a light switch using only your affected arm	d445	Reaching
Wash your face with 2 hands	d520	Washing oneself
Put toothpaste on a toothbrush	d4401	Grasping
Hold an object draped over your affected forearm, e.g. an article of clothing	d430	Lifting and Carrying
Use both arms to lift a box or bag onto a shelf at eye level	d430	Lifting and carrying
Items that involve the dominant limb only to be further evaluated		
Brush your teeth with your affected arm	d520	Caring for body parts
Write with a pen or pencil with your affected arm	d170	Writing
Use a computer mouse with your affected hand	d360	Using communication devices and techniques
Wipe yourself after going to the toilet with your affected arm	d530	Toileting
Shake hands with somebody	d335	Producing non verbal messages

Key: Subscale 1 in italics, Subscale 2 in normal font, Subscale 3 in bold.