Accepted Manuscript

Preliminary psychometric evaluation of the Brachial Assessment Tool Part 2:
Construct validity and Responsiveness

Bridget Hill, PhD, Gavin Williams, PhD, John Olver, MBBS, Scott Ferris, MBBS,
Andrea Bialocerkowski, PhD

PII: S0003-9993(17)31399-0

DOI: [10.1016/j.apmr.2017.11.004](https://doi.org/10.1016/j.apmr.2017.11.004)

Reference: YAPMR 57084

To appear in: *ARCHIVES OF PHYSICAL MEDICINE AND REHABILITATION*

Received Date: 28 November 2016

Revised Date: 29 October 2017

Accepted Date: 6 November 2017

Please cite this article as: Hill B, Williams G, Olver J, Ferris S, Bialocerkowski A, Preliminary psychometric evaluation of the Brachial Assessment Tool Part 2: Construct validity and Responsiveness, *ARCHIVES OF PHYSICAL MEDICINE AND REHABILITATION* (2018), doi: 10.1016/j.apmr.2017.11.004.

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Title Page

Running head: Validity and responsiveness of the BrAT

Title: Preliminary psychometric evaluation of the Brachial Assessment Tool Part 2: Construct validity and Responsiveness

Authors

Corresponding author:

Bridget Hill PhD

Menzies Health Institute, Queensland, Australia

Epworth Monash Rehabilitation Medicine Unit Epworth HealthCare, Melbourne, Victoria,
Australia

The Alfred, Melbourne, Australia

Gavin Williams, PhD

Epworth Monash Rehabilitation Medicine Unit Epworth HealthCare, Melbourne, Victoria,
Australia

John Olver MBBS

Epworth Monash Rehabilitation Medicine Unit Epworth HealthCare, Melbourne, Victoria,
Australia

Scott Ferris MBBS

The Alfred, Melbourne, Australia

Andrea Bialocerkowski PhD

Menzies Health Institute, Queensland, Australia

Acknowledgements

The authors wish to acknowledge the assistance of Jaslyn Gibson, Occupational Therapist, Perth, Australia; Mr. David McCombe, Victorian Hand Surgery Associates and St Vincent's Hospital, 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.

No financial support was provided for this project

There are no conflicts of interest

Corresponding author

Bridget Hill, Grad Dip (Physio)

Griffith Health Institute, Griffith University, Gold Coast, Queensland, Australia

Epworth Monash Rehabilitation Medicine Unit Epworth HealthCare, Melbourne, Victoria, Australia

89 Bridge Rd Richmond Vic 3122 Australia

Business Tel 61+ (03) 9426 8785

Email: bridget.hill@epworth.org.au

Reprints are not available

1 Preliminary psychometric evaluation of the Brachial Assessment Tool Part 2:

2 Construct validity and Responsiveness

3

4 Abstract

5

6 Objective: To evaluate construct validity and responsiveness of the Brachial
7 Assessment Tool (BrAT), a new patient-reported outcome measure for people with
8 traumatic Brachial Plexus Injury (BPI) and to compare it to the Disability of the Arm,
9 Shoulder and Hand (DASH) and the Upper Extremity Functional Index (UEFI)

10 Design: Cross sectional study

11 Setting: Outpatient clinics

12 Participants: Adults with confirmed traumatic BPI

13 Intervention: 29 people (aged 20 – 69 years) with BPI completed the BrAT three
14 times over an 18-month period together with sixteen DASH activity items and the
15 UEFI. Evaluations were undertaken of construct validity, known groups validity, one-
16 way repeated ANOVA and effect size.

17 Main outcome measures: The BrAT, DASH, UEFI

18 Results: The BrAT demonstrated a moderate to low correlation with the DASH
19 activity items (< 0.7) and a large correlation with the UEFI (> 0.7). According to
20 known groups validity only the BrAT was able to discriminate between people who
21 stated they could use their hand versus those who were unable to use their hand to
22 perform activities. All measures indicated a significant effect for time with the
23 exception of BrAT subscale 1. The effect size was highest for the BrAT but lower
24 than expected (BrAT 0.52 – 0.40. DASH 0.15. UEFI 0.36).

25

Conclusion: These preliminary findings support the BrAT as a valid and responsive patient-reported outcome measure for adults with traumatic BPI. The BrAT activity items appear to be more targeted than the DASH or UEFI particularly for people with more severe BPI. The BrAT also appears to be measuring a different activity construct to the DASH and the UEFI. Further work is required to confirm these results with larger sample sizes.

Key words: Brachial Plexus Injury; Outcome Assessment, Upper Extremity, Validation studies.

List of abbreviations

BrAT – Brachial Assessment Tool

BPI - Brachial Plexus Injury

SD - Standard deviation

DASH Disability of Arm Shoulder and hand

GPUS Global Perceived Use Scale

51 People with Brachial Plexus Injuries (BPI) demonstrate a wide spectrum of ability to
 52 use their arm to perform day-to-day activities. In recent years, microsurgical options
 53 have improved the outcome for people with this serious injury. For example, those
 54 with complete BPI should be able to stabilise or carry light objects with the affected
 55 arm freeing the unaffected limb to perform more complex activities. A person with a
 56 C5/6 injury may be expected to regain near normal use of their affected limb.⁽¹⁻³⁾
 57 However, the degree of heterogeneity seen in this population means that assessment
 58 of outcome is complex. Outcome measures must contain a wide range of items that
 59 truly reflect the abilities of all adults with a BPI including for those who may regain
 60 only limited but important ability to use their arm.⁽⁴⁾
 61
 62 Patient-reported outcome measures are increasingly being recognised as pivotal to
 63 understanding the impact of an injury on the individual and to have a direct influence
 64 on the clinical decision-making process.^(5, 6) While a few patient-reported outcome
 65 measures have been used to evaluate function following BPI, most do not contain
 66 items that assess the full range of ability of adults with a BPI.^(7, 8) Further, none have
 67 been psychometrically evaluated for this population.^(7, 9, 10)
 68
 69 The Brachial Assessment Tool (BrAT) is a new unidimensional, targeted, 31-item
 70 patient-reported outcome measure, with each item quantified on a 4-point scale.
 71 Experts, including people with BPI, generated items for inclusion in the BrAT based
 72 on the International Classification of Functioning Disability and Health (ICF)
 73 definition of activity 'execution of a task or action by an individual'.⁽¹¹⁾ Items are
 74 important to people with BPI, regularly performed and appear to represent the
 75 spectrum of ability of this population.^(8, 12) The BrAT is comprised of 3 subscales: i)

eight '*Dressing and grooming*' items, ii) 17 '*Whole arm and hand*' items, iii) six '*No hand*' items; or alternatively all 31-items may be added to produce a summed score.

Content validity and unidimensionality of the BrAT has been established using Rasch analysis.⁽¹²⁾ Reliability has been evaluated and a minimal detectable change score calculated for each subscale and the summed score. Further evaluation of construct validity and responsiveness is required to complete the initial psychometric testing.

Construct validity is an on-going iterative process that assesses how well a measure provides expected scores based on knowledge of the underlying construct.⁽¹³⁾ The underlying construct of a new outcome measure may be evaluated by comparing the how closely items are related to existing measure that assess similar (convergent validity) or dissimilar (divergent validity) constructs. There is no known gold standard to assess upper limb activity. The Upper Extremity Functional Index (UEFI) is a generic 20-item patient-reported outcome measure designed to assess upper extremity function in people with musculoskeletal disorders. It is thus appropriate for use in conditions that involve the whole upper limb and similar to the BrAT assesses primarily activity of the upper limb.⁽¹⁴⁾ The Disability of the Arm Shoulder and Hand (DASH)⁽¹⁵⁾ is the most frequently used patient-reported outcome measure following BPI. Comparison of the UEFI and the DASH to the BrAT is warranted.^(7, 9, 10)

In addition to ensuring an outcome measure is assessing what is intended (construct validity), outcome measures also need to be responsive,^(13, 16) i.e. able to detect change over time in the construct measured.⁽¹⁷⁾ Construct validity and responsiveness are related and considered by some to be the same measurement property.⁽¹³⁾ For this project, construct validity refers to the validity of a single score and responsiveness

refers to the validity of a change score.⁽¹⁷⁾ The purpose of this study was to investigate the preliminary construct validity and responsiveness of the BrAT.

Method

This project employed a multicentre, prospective repeated measure design. Ethical approval was gained from three Human Research and Ethics 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 project. The construct validity and responsiveness analyses were informed by the COSMIN checklist recommendations.⁽¹⁷⁾

Participants

Participants comprised a convenience sample recruited from the 106 people with BPI who participated in the Rasch analysis arm of a previously reported project. Data were collected concurrently for the Rasch analysis, a reliability project and this project.⁽¹²⁾ The primary inclusion criteria for all three projects was a diagnosis of traumatic BPI confirmed by MRI, nerve conduction studies, clinical assessment or intraoperative findings, and were over 18 years of age. In contrast to the reliability arm participants were only recruited if they had undergone microsurgery to reanimate the upper limb within the previous two years. Thus, it was biologically plausible that their ability to use their arm could improve over the course of this project. Exclusion criteria for all three projects included a diagnosis of brachial plexus birth injury, pre-existing upper limb conditions, inability to provide informed consent or evidence of spinal cord injury confirmed by MRI.⁽¹²⁾

Data collection

Once participants consented, they were posted a copy of the BrAT together with the DASH⁽¹⁵⁾ and the UEFI⁽¹⁴⁾ at recruitment, and again at 9 and 18 months with a reply paid envelope. A global perceived use score (GPUS) was completed at 9 and 18 months. Outcome measures were reordered at each time point to decrease possible survey bias.⁽¹⁸⁾

Measures

Two outcome measures were compared with the BrAT. The DASH contains 30 items and is known to be multidimensional,^(19, 20) with only 16 items specific to activity as defined by the ICF.^(7, 8, 21) These 16 items have been shown to contain two further dimensions, variously reported as ‘gross motor activities’ and ‘fine motor activities’⁽²⁰⁾ or ‘shoulder range of motion’ and ‘manual functioning’.⁽¹⁹⁾ Moreover, unlike the BrAT the DASH is not limb specific with respondents able to answer irrespective of the strategy they use to complete the activities, including compensatory mechanisms or altering hand dominance.^(22, 23) It is likely that the DASH may measure a different aspect of day-to-day arm use to the BrAT and demonstrate divergent validity. UEFI responses are attributed to the affected limb and as with the BrAT all but two of the 20 items (items 1 and 2) are specific to activity as defined by the ICF. The UEFI may assess a similar construct to the BrAT demonstrating convergent validity.^(14, 24) A *priori* hypotheses were formulated based on the expected relationship between the measures (Table 1).^(13, 25)

The five-point GPUS was used as a reference criterion to anchor arm use as perceived by people with BPI during the evaluation period.^(25, 26) Responses were attributed

specifically to use of the affected limb. Options ranged from 1 – ‘*Much less than last time*’, 2 – ‘*A little less than last time*’, 3 ‘*No change to last time*’, 4 – ‘*A little better than last time*’ 5 – ‘*Much better than last time*’. Table 2 outlines the key measurement properties of the four measures.

Data analyses

All statistical analyses were undertaken using SPSS version 22^a. Descriptive statistics were generated to describe the sample. Data were analysed separately for each of the three BrAT subscales and the summed score.⁽¹²⁾ Normality of the data was evaluated using visual inspection together with skewness and kurtosis statistics and Shapiro Wilk test. Construct validity was evaluated using Pearson correlations to test the association between the BrAT scores with the DASH activity items and the UEFI at three time points (recruitment, 9 and 18 months). Correlations coefficients were categorised as high if >0.70 , moderate between 0.51 and 0.70 and low below 0.50.⁽²⁷⁾ Floor and ceiling effects were considered present if $\geq 15\%$ of participants scored the lowest or highest scores.⁽²⁸⁾

Known groups or discriminant validity was assessed using independent t tests to establish whether score differences were similar for those who self-reported they could use their affected hand versus those who self-reported they could not use their affected hand to do any activity at the time of assessment.⁽¹³⁾ Responsiveness was assessed using one-way repeated measures ANOVAs for all measures to compare the scores on each outcome measure at recruitment, 9 and 18 months later for participants who stated their arm use had improved or deteriorated on the GPUS. In addition, the effect sizes or the magnitude of change was calculated by dividing the mean of

change in the score during the time period by the standard deviation of the baseline score.⁽²⁹⁾ The effect size was considered small if less than 0.20, moderate if greater than 0.50 and large if greater than 0.80.⁽²⁹⁾

Results

Twenty-nine participants, recruited from three outpatient clinics in Melbourne, Australia, commenced this study. Twenty-five completed all assessments at 9 months and twenty-eight at 18 months. There were no missing data for the BrAT or the UEFI. Seven DASH questionnaires were returned with up to 3 missing items. Results were inputted based on the DASH scoring manual. Table 3 outlines the participants demographics. Skewness statistics confirmed a normal distribution (range 0.811 for the BrAT subscale 1 at recruitment, to -0.67 for the UEFI at 18 months). Shapiro Wilk test was non significant for all but BrAT subscale 2.

Validity

There were no floor effect or ceiling effects for the total scores or subscales. (Table 4). The DASH activity scores showed greater disability at 9 months than at recruitment or 18 months (Table 4). The correlations between the BrAT scores and DASH activity items at recruitment and 18 months were moderate (range 0.48 to 0.69) indicating they were assessing a different construct, supporting hypothesis 1 (Table 1). In contrast correlations between the BrAT and UEFI were large (range 0.6 to 0.8), indicating they were measuring similar constructs and lending support to, but not confirming hypothesis 2. Based on known groups validity, all BrAT scores discriminated between people who self-reported hand use (with the exception of

subscale 1 at 9 and 18 months) indicating that the BrAT activities are targeted to this population. The DASH did not discriminate between the two groups at any time point. The UEFI only discriminated between the groups at recruitment (Table 5) indicating the items contained in these outcome measures may not be targeted to people with BPI. Hypothesis 3 was confirmed for the BrAT total score and subscales 2 and 3 only (Table 5).

Responsiveness

Change, as measured by one-way repeated measures ANOVAs, (Table 6) indicated a significant effect for time for all outcome measures with the exception of BrAT subscale 1 (dressing and grooming items). This supported hypothesis 4. Only subscale 3 (no hand items) achieved an effect size greater than .50 indicating the magnitude of change over time was small for all the outcome measures. Hypothesis 5 that effect sizes would be greater than .50 was not supported (Table 7). The magnitude of change as measured by the effect size was larger for the BrAT than the DASH and the UEFI, indicating the BrAT is more responsive to change, supporting hypothesis 6.

Discussion

This project presents preliminary psychometric evaluation of the construct validity and responsiveness of the BrAT, a new patient-reported outcome measure for the assessment of activity following adult traumatic BPI. As hypothesised, divergent validity was confirmed between the BrAT and DASH with only a moderate

correlation (< 0.7) with the DASH activity items at recruitment and the 18-month time point. This indicates that the BrAT is measuring a different aspect of upper limb use compared to the DASH.⁽²¹⁾ One reason for the higher correlation found between the BrAT and the UEFI compared to the BrAT and the DASH may be the way people respond to the three outcome measures. The BrAT and the UEFI are limb specific, with responses attributed directly to the affected limb. In contrast, the DASH does not differentiate between the two limbs, with responses based on the ability to perform the activity regardless of which hand, arm or part of the body is used, i.e. people can use a variety of compensatory techniques. Mancuso et al. (2016) investigated the influence of compensation on outcome as measured by the DASH for people with BPI.⁽²²⁾ Participants were requested to respond to the DASH in one of two ways - unqualified responses (usual instructions) and qualified instructions (using the affected limb as they would have before their injury with no compensatory techniques). A difference was found between the two scores, with people reporting they would be unable to do 46% of the tasks when not using compensatory techniques, compared to only 18% when using compensatory techniques. It is clear from Mancos's study that people can differentiate between compensatory techniques and use of the affected limb following BPI. Compensatory techniques are very important to people with BPI. However, we would argue that to fully assess day-to-day use of the affected limb, it is important that responses are related directly to the affected limb if we are to measure the actual impact of expensive surgery and on-going rehabilitation. The results of this study, in particular the inability of the DASH to discriminate between those who could use their affected hand and those who could not, lends further support to this argument.

It is unclear why the DASH score increased at the 9-month time point, i.e. participants described themselves as more disabled than at recruitment. One possibility is that at nine-months participants may not be showing much improvement post injury and they view themselves as less able to use their affected limb. It is clear from the literature that people with BPI experience a wide range of emotional states including depression and anxiety linked to their arm use.^(4, 30-34) More work in this area is required to explain what may be occurring, particularly in the extended period before people can begin to expect some recovery post-surgery.

Using a known groups comparison, only the BrAT was able to differentiate between those participants who stated they could use their affected hand to perform any activities and those who could not. Further, the BrAT demonstrated the greatest magnitude of change and the greatest effect size of the three measures. These results may reflect the inclusion of activities specifically targeted towards people with less ability to use their affected limb.⁽¹²⁾ For example the six activities that make up subscale 3 include controlling the arm without using a sling, stabilising objects, carrying objects against the chest wall or over the forearm none of which require any hand use. For people with complete plexus injury these may be the only activities that improve over time, however, none are assessed by the DASH or UEFI. It is vital that outcome measures contain a range of activities that cover the spectrum of ability of the target group in order to assess change over time. By establishing the psychometric properties of each of the three subscales and the total summed score clinicians may tailor the BrAT for individual clients. For example, using only subscale 3 for people with more severe injury and less use of their limb. The BrAT has been shown to be well targeted to people with BPI with a range of activities for all ability levels.⁽¹²⁾ To

the best of our knowledge this is one of only two patient-reported outcome measure that specifically addresses this type of arm and hand use.⁽³⁵⁾

The eight items that comprise subscale 1 ('dressing and grooming') demonstrated the greatest disparity with the *a priori* hypotheses. These activities are performed on a daily basis usually from the day of injury and are some of the most important for people with BPI.⁽⁸⁾ As a consequence, people with BPI may use compensatory skills that are not used to perform other items. On-going evaluation is required to determine the relationship of these activities to the others.

Limitations

To the best of our knowledge this is one of only two studies that have used only the DASH activity items to evaluate construct validity.⁽³⁶⁾ We acknowledge that the DASH is not designed to be used in this way. However, the retained DASH activity items allowed a closer comparison between the two outcome measures and eliminated the difficulties related to summing and interpreting the score of a multidimensional measure. Further, as the most commonly used patient-reported outcome measure for BPI the direct comparison has highlighted the differences between the two measures.

The sample size used in this project, while within accepted boundaries, was small. However, while BPI injury is a devastating injury it is relatively uncommon, recovery is slow and recruitment is challenging particularly for a project that spanned an 18-month commitment. To the best of our knowledge this is the largest BPI cohort that has been used to investigate the psychometric properties of outcome measures at

multiple time points. On-going research is required to confirm the results of this study in larger cohorts from multiple centres. Further investigation of the minimal important change scores for the four BrAT scores is still required.

Conclusions

This preliminary study appears to indicate that the BrAT is a valid and responsive patient-reported outcome measure for people with BPI. The BrAT appears to measure different activities to the DASH activity items and the UEFI and better represent the BPI population, particularly those with limited use of their arm. These results support the use of the BrAT for people with BPI, however on-going investigation is required to confirm these findings with larger sample sizes. As a unidimensional measure solely of activity, it is recommended that the BrAT be used as part of a suit of outcome measures that evaluate BPI from multiple perspectives.

Suppliers

a. IBM

References

1. Dodakundi C, Doi K, Hattori Y, Sakamoto S, Fujihara Y, Takagi T, et al. Outcome of surgical reconstruction after traumatic total brachial plexus palsy. *J Bone Joint Surg.* 2013;95:1505-12.
2. Seal A, Stevanovic M. Free Functional Muscle Transfer for the Upper Extremity. *Clin Plast Surg* 2011;38:561-75.

- 325 3. Ahmed-Labib M, Golan JD, Jacques L. Functional outcome of brachial plexus
326 reconstruction after trauma. *Neurosurg.* 2007;61:1016-22;
- 327 4. Mancuso CA, Lee SK, Dy CJ, Landers ZA, Model Z, Wolfe SW. Expectations
328 and limitations due to brachial plexus injury: a qualitative study. *Hand.* 2015;10:741-
329 9.
- 330 5. Rolfson O, Eresian Chenok K, Bohm E, Lübbecke A, Denissen G, Dunn J, et
331 al. Patient-reported outcome measures in arthroplasty registries: Report of the Patient-
332 Reported Outcome Measures Working Group of the International Society of
333 Arthroplasty Registries: Part I. Overview and rationale for patient-reported outcome
334 measures. *Acta Orthop.* 2016;87:3-8.
- 335 6. Black N. Patient reported outcome measures could help transform healthcare.
336 *BMJ (Online).* 2013;346(7896).
- 337 7. Hill B, Williams G, Bialocerkowski A. Clinimetric Evaluation of
338 Questionnaires Used to Assess Activity After Traumatic Brachial Plexus Injury in
339 Adults: A Systematic Review. *Arch Phys Med Rehabil.* 2011;92:2082-9.
- 340 8. Hill B, Williams G, Olver J, Bialocerkowski A. Do existing patient-report
341 activity outcome measures accurately reflect day-to-day arm use following adult
342 traumatic brachial plexus injury? *J Rehabil Med.* 2015;47:438-44.
- 343 9. Bengtson KA, Spinner RJ, Bishop AT, Kaufman KR, Coleman-Wood K,
344 Kircher MF, et al. Measuring outcomes in adult brachial plexus reconstruction. *Hand*
345 *Clin.* 2008;24:401-15.
- 346 10. Dy CJ, Garg R, Lee SK, Tow P, Mancuso CA, Wolfe SW. A systematic
347 review of outcomes reporting for brachial plexus reconstruction. *J Hand Surg.*
348 2015;40:308-13.

- 349 11. WHO. International Classification of Functioning, Disability and Health.
350 Geneva.2001.
- 351 12. Hill B, Pallant J, Williams G, Olver J, Ferris S, Bialocerkowski A. Evaluation
352 of Internal Construct Validity and Unidimensionality of the Brachial Assessment
353 Tool, A Patient-Reported Outcome Measure for Brachial Plexus Injury. Arch Phys
354 Med Rehabil. 2016;97:2146-56.
- 355 13. De Vet HCW, Terwee CB, Mokkink LB, Knol DL. Measurement in medicine:
356 A practical guide. Cambridge: Cambridge University Press.; 2011..
- 357 14. Stratford PW, Binkley JM, Stratford DM. Development and initial validation
358 of Upper Extremity Functional Index. Physio Can. 2001;53:259.
- 359 15. Hudak PL, Amadio PC, Bombardier C. Development of an upper extremity
360 outcome measure: The DASH (disabilities of the arm, shoulder, and head). Am J
361 Indust Med. 1996;29:602-8.
- 362 16. Portney L, G. Watkins. M,P Foundations of Clinical Research Applications to
363 Practice. Third Edition ed: Pearson Prentice Hall; 2009.
- 364 17. Mokkink LB, Terwee CB, Patrick DL, Alonso J, Stratford PW, Knol DL, et al.
365 The COSMIN study reached international consensus on taxonomy, terminology, and
366 definitions of measurement properties for health-related patient-reported outcomes. J
367 Clin Epidemiol. 2010;63:737-45.
- 368 18. Polit DF. Getting serious about test-retest reliability: A critique of retest
369 research and some recommendations. Qual Life Res. 2014;23:1713-20.
- 370 19. Franchignoni F, Giordano A, Ferriero G. On dimensionality of the DASH.
371 Multi Sclero. 2011;17:891-2.

- 372 20. Lehman LA, Woodbury M, Velozo CA. Examination of the factor structure of
373 the disabilities of the arm, shoulder, and hand questionnaire. *AmJ Occup Thera*.
374 2011;65:169-78.
- 375 21. Drummond AS, Sampaio RF, Mancini MC, Kirkwood RN, Stamm TA.
376 Linking the Disabilities of Arm, Shoulder, and Hand to the International
377 Classification of Functioning, Disability, and Health. *J Hand Thera*. 2007;20:336-44.
- 378 22. Mancuso CA, Lee SK, Dy CJ, Landers ZA, Model Z, Wolfe F. Compensation
379 by the injured arm after Brachial Plexus Injury. *Hand*. 2016;4:410-6.
- 380 23. Kachooei AR, Moradi A, Janssen SJ, Ring D. The influence of dominant limb
381 involvement on DASH and QuickDASH. *Hand*. 2015;10:512-5.
- 382 24. Forget NJ, Higgins J. Comparison of generic patient-reported outcome
383 measures used with upper extremity musculoskeletal disorders: Linking process using
384 the International Classification of Functioning, Disability, and Health (ICF). *J Rehabil*
385 *Med*. 2014;46:327-34.
- 386 25. Mokkink LB, Terwee CB, Patrick DL, Alonso J, Stratford PW, Knol DL, et al.
387 The COSMIN checklist for assessing the methodological quality of studies on
388 measurement properties of health status measurement instruments: An international
389 Delphi study. *Qual Life Res*. 2010;19:539-49.
- 390 26. Cleland JA, Childs JD, Whitman JM. Psychometric Properties of the Neck
391 Disability Index and Numeric Pain Rating Scale in Patients With Mechanical Neck
392 Pain. *Arch Phys Med Rehabil*. 2008;89:69-74.
- 393 27. Munro B. Statistical methods for health care research. Philadelphia (PA): JB
394 Lippincott; 2000.

- 395 28. Terwee CB, Bot SDM, de Boer MR, van der Windt DAWM, Knol DL,
 396 Dekker J, et al. Quality criteria were proposed for measurement properties of health
 397 status questionnaires. *J Clin Epidemiol*. 2007;60:34-42.
- 398 29. Cohen J. Statistical power analysis for the behavioral sciences. 2nd Edition ed:
 399 Lawrence Erlbaum, Hillsdale, NJ; 1988.
- 400 30. Wellington B. Quality of life issues for patients following traumatic brachial
 401 plexus injury - Part 2 research project. *Int J Orthop Trau Nurs*. 2010;14:5-11.
- 402 31. Gray B. Quality of life following traumatic brachial plexus injury: A
 403 questionnaire study. *Int J Orthop Trau Nurs*. 2016;22:29-35.
- 404 32. Wilson TJ, Chang KWC, Yang LJS. Depression and anxiety in traumatic
 405 brachial plexus injury patients are associated with reduced motor outcome after
 406 surgical intervention for restoration of elbow flexion. *Neurosurg*. 2016;78:844-9.
- 407 33. Franzblau L, Chung KC. Psychosocial outcomes and coping after complete
 408 avulsion traumatic brachial plexus injury. *Disabil Rehabil*. 2015;37:135-43.
- 409 34. Franzblau L, Shauver MJ, Chung KC. Patient satisfaction and self-reported
 410 outcomes after complete brachial plexus avulsion injury. *J Hand Surg*. 2014;39:948-
 411 55.e4.
- 412 35. Ashford S, Slade M, Turner-Stokes L. Conceptualisation and development of
 413 the arm activity measure (ArmA) for assessment of activity in the hemiparetic arm.
 414 *Disabil Rehabil*. 2013;35:1513-8.
- 415 36. Ashford S, Turner-Stokes L, Siegert R, Slade M. Initial psychometric
 416 evaluation of the Arm Activity Measure (ArmA): A measure of activity in the
 417 hemiparetic arm. *Clin Rehabil*. 2013;27:728-40.

418

419

420 Figure legend: There are no figures.

ACCEPTED MANUSCRIPT

Table 1: A priori hypotheses to assess construct validity and responsiveness of the BrAT

No.	Hypothesis and rational for hypothesis	Hypothesis accepted
1	A low to moderate association ($r = < 0.7$) between the BrAT and the DASH as they measure dissimilar activity constructs	Yes
2	A moderate association ($r = > 0.7$) between the BrAT and the UEFI as they measure similar activity constructs	Yes
3	Based on known groups validity, participants who indicated they are able to use their affected hand will have higher scores for all outcome measures than those who indicate they are unable to use their affected hand	For the BrAT only
4	All measures will demonstrate a significant effect for time as measured by a one way repeated ANOVA i.e., use of the affected limb will improve over time	Yes
5	The BRAT will have a moderate to large effect size of > 0.5 , for those participants who self-report improved hand use in activity	Yes
6	The BrAT will have a greater effect size than the DASH or UEFI	Yes

Key: BrAT: Brachial Assessment Tool. DASH: Disabilities of the Arm, Shoulder and hand.

UEFI: Upper extremity Functional Index

ACCEPTED MANUSCRIPT

Table 2 Outcome measure properties

Measure	Number of items	Score range	Response option	Attributed to affected limb	Interpretation	Reliable for BPI	Valid for BPI
BrAT summed score	31	0 - 93	5 point Likert scale (0	Y	Higher score = more ability	ICC .97, α .98	Local independence
			'Cannot do now' to 5 'Easy to do now')			SEM 4.5, MDC ₉₀ 10.3 PSI .86 ⁽⁷⁾	No DIF for age, TPI or hand dominance
BrAT subscale 1	8	0 - 24	5 point Likert scale (0	Y	Higher score = more ability	ICC .91, α .92	Local independence
			'Cannot do now' to 5 'Easy to do now')			SEM 1.8, MDC ₉₀ 4.1 PSI .88 ⁽⁷⁾	No DIF for age, TPI or hand dominance
BrAT subscale 2	17	0 - 51	5 point Likert scale (0	Y	Higher score = more ability	ICC .97, α .97	Local independence
			'Cannot do now' to 5 'Easy to do now')			SEM 2.8, MDC ₉₀ 6.5 PSI .94 ⁽⁷⁾	No DIF for age, TPI or hand dominance
BrAT subscale 3	6	0 - 18	5 point Likert scale (0	Y	Higher score = more ability	ICC .90, α .90	Local independence
			'Cannot do now' to 5 'Easy to do now')			SEM 1.6, MDC ₉₀ 3.7 PSI .80 ⁽⁷⁾	No DIF for age, TPI or hand dominance
DASH activity	16	16 - 80	5 point Likert scale (1 'No difficulty' to 5	N	Higher score = more disability	Not reported	Not reported

Unable)							
5 point Likert scale (0							
'Extreme difficulty or							
UEFI	20	0 - 80	unable to perform	Y	Higher score =	Not reported	Not reported
activity' to 4 'No							
difficulty')							
5 point Likert scale (1							
'Much less use than last							
GPUS	5	1 - 5	time to 3 'No change in	Y	NA	NA	NA
use' to 5 'Much better							
use than last time'							

Key: BrAT: brachial assessment tool. ICC: intraclass correlation coefficient, α , cronbach alpha. SEM standard error of measurement. PSI: person separation index. MDC, minimal detectable change. PSI person separation index. DASH disability of the arm shoulder and hand. UEFI: upper extremity functional index. GPUS: global perceived use scale.

Table 3. Participant demographics

Demographic		n = 29 (%)
Gender	Male	29 (100)
	Female	0 (0)
Injury level	C5/6	6 (21)
	C5 - C7	4 (13)
	C5 - C8	11 (38)
	C8/T1	2 (7)
	Complete avulsion	6 (21)
Mechanism of injury	Motor car	3 (10.3)
	Motor bike	15 (51.7)
	Bicycle	5 (17.2)
	Pedestrian	0 (0)
	Work injury	1 (3.4)
	Fall from height	2 (7.9)
	Sporting injury	2 (7.9)
	Gun shot	1 (3.4)
Pre injury dominance	Right	23 (79)
	Left	6 (21)
Injured limb	Right	13 (45)
	Left	16 (55)

Table 3 Mean, SD, floor and ceiling effects and Pearson correlations between measures

Recruitment	Mean	SD	Floor effect		Ceiling effect		Correlations	
			n	%	n	%	DASH	UEFI
BrAT Summed score	41.76	25.82	0	0	0	0	-0.55	0.78
BrAT Subscale 1	14.62	5.70	0	0	2	7	-0.58	0.67
BrAT Subscale 2	18.17	15.85	0	0	1	3	-0.48	0.76
BrAT Subscale 3	8.97	5.85	3	10	1	3	-0.57	0.76
DASH activity items	44.83	23.63	0	0	1	3		-0.76
UEFI	34.9	21.41	0	0	1	3		
9 months								
BrAT Summed score	46.20	24.92	0	0	1	3	-0.73	0.78
BrAT Subscale 1	14.84	5.81	0	0	2	7	-0.79	0.64
BrAT Subscale 2	21.08	15.43	0	0	1	4	-0.62	0.76

BrAT Subscale 3	10.28	5.58	2	8	4	14	-0.70	0.60
DASH activity items	45.40	23.31	0	0	0	0		-0.62
UEFI	37.48	20.23	0	0	1	3		
18 months								
BrAT Summed score	51.93	24.99	0	0	0	0	-0.62	0.81
BrAT Subscale 1	16.68	5.55	0	0	3	10	-0.69	0.63
BrAT Subscale 2	23.89	16.08	0	0	1	4	-0.52	0.78
BrAT Subscale 3	11.36	5.50	1	4	2	7	-0.61	0.73
DASH activity items	41.07	21.71	0	0	0	0		-0.85
UEFI	43.29	20.26	0	0	1	3		

Key SD standard deviation. DASH, disabilities of the arm shoulder and hand activity items. UEFI, upper extremity functional index

Table 5. Known group validity based on perceived hand use

		BrAT summed		BrAT subscale 1		BrAT subscale 2		BrAT subscale 3		DASH activity		UEFI	
	n	Diff (SD)	Sig.	Diff (SD)	Sig.	Diff (SD)	Sig.	Diff (SD)	Sig.	Diff (SD)	Sig.	Diff (SD)	Sig.
Initial													
Able use	19	51.21	0.01	16.26	0.03	24.06	0.01	10.37	0.05	38.32	0.17	40.68	0.04
hand		(26.15)		(5.46)		(15.99)		(6.06)		(14.28)		(20.40)	
Unable use	10	23.8		11.50		6.00 (4.32)		6.30		47.10		23.90	
hand		(12.63)		(4.99)		(4.59)		(18.59)		(19.73)			
9 months													
Able use	19	51.95	0.04	15.26	0.53	25.05	0.01	11.63	0.03	41.79	0.54	40.37	0.21
hand		(24.84)		(5.85)		(15.60)		(4.98)		(17.13)		(19.93)	
Unable use	6	28.00		13.50		8.50 (4.04)		6.00		46.83		28.33	
hand		(15.27)		(6.025)		(6.03)		(18.51)		(20.09)			
18 months													
Able use	23	56.26	0.05	17.30	0.21	26.61	0.01	12.35	0.04	37.04	0.45	44.61	0.20

hand	(24.85)	(5.56)	(16.33)	(5.30)	(15.16)	(22.00)
Unable use	32.00	13.80	11.40	6.80	42.60	37.20
5						
hand	(14.62)	(4.97)	(6.43)	(4.32)	(11.04)	(7.26)

Key: Diff. difference SD standard deviation. Sig, significant ($p < 0.05$) independent t tests

Table 6. Repeated measure ANOVA over time (18 months)

	Wilks Lambda	F	(df, error)	Sig	PTA
Time v BrAT summed	0.35	5.96	2, 22	0.01	0.35
Time v BrAT subscale 1	0.83	2.34	2, 22	0.12	0.18
Time v BrAT subscale 2	0.61	6.98	2, 22	0.01	0.39
Time v BrAT subscale 3	0.71	4.53	2, 22	0.02	0.29
Time v DASH activity	0.77	3.21	2, 22	0.06	0.23
Time v UEFI	0.75	3.71	2, 22	0.04	0.25

Key: Sig significance. PTA, partial eta squared

Table 7: Effect size

	Effect size
BrAT Summed score	0.43
BrAT Subscale 1	0.40
BrAT Subscale 2	0.40
BrAT Subscale 3	0.52
DASH activity	0.15
UEFI	0.36