Reviewer ID: Janice Eng, Franny Fan, Carlos L. Cano

Last updated: January 29th, 2024

Research Summary – Graded Redefined Assessment of Strength, Sensibility and Prehension (GRASSP) – Upper Limb

Author Year Research Design Setting (country)	Demographics and Injury Characteristics of Sample	Validity	Reliability	Responsiveness Interpretability
Voss et al. 2023 Psychometric study to assess the psychometric properties of remote version of the GRASSP (r-GRASSP) Shirley Ryan Ability Lab, IL, USA; Hines VA Hospital, IL, USA; and Kessler Institute for Rehabilitation, NJ, USA	Participants with tetraplegia (n = 61): Mean age: 49 ± 15 yr Gender: males = 43, females: 18 Level of injury: C1-T1 Mean time since injury: 0.6 ± 43.3 yrs AIS scale: A=6, B=7, C=12, D=35.	**Concurrent validity:** Overall, the r-GRASSP demonstrated excellent concurrent validity with the GRASSP. Table 1.	**Inter-rater reliability:** Comparison r-GRASSP total scores for Examiner 1 vs. Examiner 2 demonstrated high inter-rater reliability, with ICC = 0.99 for both the right and left sides (95% CI [0.98, 0.99] for both sides) Table 2.	

Table 1. Intraclass Correlation and 95% Confidence Interval Comparing the GRASSP and Remote GRASSP (Validity) for Both the Left and Right Hand.

Scale	ICC_left	CI_left	ICC_right	CI_right
Total	0.96	(0.94–0.97)	0.96	(0.94–0.98)

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Strength	0.96	(0.93–0.97)	0.95	(0.92–0.97)
Sensibility	0.59	(0.41–0.73)	0.68	(0.47–0.8)
Prehension ability	0.94	(0.91–0.96)	0.95	(0.92–0.97)
Prehension performance	0.92	(0.82–0.96)	0.93	(0.88–0.96)

Table 2. Intraclass Correlation and 95% Confidence Interval Comparing the Remote GRASSP Examiner 1 and Remote GRASSP Examiner 2 (Reliability) for Both the Left and Right Hand.

Scale	**ICC_left**	**CI_left**	**ICC_right**	**CI_right**
Total	0.99	(0.98–0.99)	0.99	(0.98–0.99)
Strength	0.99	(0.99-1)	0.99	(0.99–0.99)
Sensibility	1.00	(0.99-1)	1.00	(1-1)
Prehension ability	0.95	(0.92–0.97)	0.97	(0.95–0.98)
Prehension performance	0.95	(0.92–0.97)	0.94	(0.9–0.96)

Kalsi-Ryan et al. 2022	Acute cervical SCI (n = 147): Mean age: 49.3 ± 23.8			**MCID:** Tables 1 and 2 define the MCID values for all

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Multi-centre, observational, longitudinal cohort study to establish the MCID of all subtests of the GRASSP v1 for cervical SCI 7 sites in Canada (London Health Sciences [2 sites], ON; Hamilton Health Sciences [2 sites], ON; St. Michael's Hospital, ON; Toronto Western Hospital, ON; and Toronto Rehabilitation Institute, ON) and 5 sites in Europe (Klinik Hohe Warte	yr. Gender: males = 99, females = 28. Level of injury: C1=6, C2=12, C3=20, C4=41, C5=29, C6=11, C7=3, C8=2, T1=3 Mean time since injury: NR. AIS scale: A=29, B=17, C=26, D=55.			subtests of the GRASSP v1 at six months.

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Author Year Research Design Setting (country)	Demographics and Injury Characteristics of Sample	Validity	Reliability	Responsiveness Interpretability
Bayreuth, D; Unfallklinik Murnau, D; Orthopädische Universitätsklinik Heidelberg, D; Balgrist University Hospital Zurich, CH; and Swiss Paraplegic Center, CH)				
	Table 1. Minimum Clinically Important Difference Values for the Graded Redefined Assessment of Strength, Sensation, and Prehension Version Subtests, Spinal Cord Independence Measure, and the Upper Extremity Motor Score Using the Anchor Based Approach for Patients Reporting "Better" or "Much Better" Functional Outcome from Their One Month to Six Month Follow-Up Post-Injury			

	Better (n = 58) **Mean (95% CI)**	**Much Better (n = 30)** **Mean (95% CI)**
GRASSP v1 Strength	13 (4.1-16.7)	19 (11.4-26.6)
GRASSP v1 Sensation	0 (-7.7-7.7)	0 (-7.6-7.6)
GRASSP v1 PA	2 (-3.9-7.9)	3 (-2.5-8.5)
GRASSP v1 PP	23 (14.8-31.2)	30 (20.8-39.2)

CI, confidence interval; GRASSP v1, Graded Redefined Assessment of Strength, Sensation, and Prehension Version 1; PA, prehension ability; PP, prehension performance.

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<table>
<tr><th>Author Year Research Design Setting (country)</th><th>Demographics and Injury Characteristics of Sample</th><th>Validity</th><th>Reliability</th><th>Responsiveness Interpretability</th></tr>
<tr><td></td><td colspan="4">Table 2. Minimum Clinically Important Difference Values for the Graded Redefined Assessment of Strength, Sensation, and Prehension Version 1 Subtests, Spinal Cord Independence Measure, and the Upper Extremity Motor Score Using the Anchor Based Approach for Patients Dichotomized Based on Their Initial American Spinal Injury Association Classification into "A+B" and "C+D"
<table>
<tr><th></th><th>ASIA A + B (n = 369
Mean (95% CI)</th><th>ASIA C + D (n = 52)
Mean (95% CI)</th></tr>
<tr><td>GRASSP v1 Strength</td><td>12 (6.3-17.7)</td><td>17 (11.4-26.6)</td></tr>
<tr><td>GRASSP v1 Sensation</td><td>0 (-5.5-5.5)</td><td>0 (-6.3-6.3)</td></tr>
<tr><td>GRASSP v1 PA</td><td>2 (-3.5-7.5)</td><td>1 (-5.0-6.0)</td></tr>
<tr><td>GRASSP v1 PP</td><td>6 (-2.3-14.3)</td><td>12 (2-22)</td></tr>
</table>
CI, confidence interval; GRASSP v1, Graded Redefined Assessment of Strength, Sensation, and Prehension Version 1, PA, prehension ability; PP, prehension performance.</td></tr>
<tr><td>Kalsi-Ryan et al. 2020

Observational and cross-sectional study to develop and validate GRASSP-Myelopathy</td><td>- Degenerative cervical myelopathy (DCM) (n = 148).
Mean age: 56.89 ± 10.67 yr; Gender: males = 84, females = 64; Level of injury: cervical = 148; Mean duration of symptoms = 45.5 ± 60.4 months;</td><td>Concurrent validity: All GRASSP-M subtests showed a positive, moderate correlation with the upper limb motor, upper limb sensory, and total upper limb mJOA scores. Dexterity time showed a negative, moderate correlation with these scores. All correlations</td><td>The ICC – Cronbach's alpha for inter-rater reliability was 0.869 (95% CI: 0.759-0.928) in the dominant hand and 0.862 (95% CI: 0.748-0.925) in the non-dominant hand.

The ICC – Cronbach's alpha for intra-rater reliability was 0.868</td><td>Discriminative Qualities of GRASSP-M Domains:
Table 3.</td></tr>
</table>

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Author Year Research Design Setting (country)	Demographics and Injury Characteristics of Sample	Validity	Reliability	Responsiveness Interpretability
Toronto Western Hospital, Canada	Severity: Mild (modified Japanese Orthopaedic Association [mJOA] 15.85 ± 0.748) (n = 75), moderate (mJOA 13.20 ± 0.782) (n = 41), and severe (mJOA 9.94 ± 1.110) (n = 32). - Healthy participants (n = 21). Mean age: 53.67 ± 16.81 yr; Gender: males = 11, females = 10.	were significant except for the correlation between dexterity time in the dominant hand and the mJOA upper limb sensation score. Table 1. **Known groups' validity:** The prehension/dexterity score was the most discriminative subtest of the GRASSP-M, followed by the strength subscore. Table 2.	(95% CI: 0.727- 0.936) in the dominant hand and 0.790 (95% CI: 0.565-0.899) in the non-dominant hand.	

Table 1. Concurrent validity:

Subtest		**UL mJOA**	**UL motor mJOA**	**Sensation mJOA**
GRASSP-M strength	**Dominant**	0.431*	0.373*	0.323*
	Non-dominant	0.406*	0.384*	0.251*
GRASSP-M sensation	**Dominant**	0.412*	0.374*	0.280*
	Non-dominant	0.488*	0.448*	0.323*
	Dominant	0.502*	0.511*	0.250*

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GRASSP-M prehension/dexterity	**Non-dominant**	0.533	0.524	0.301
GRASSP-M prehension/dexterity time	**Dominant**	-0.407*	−0.455*	−0.138*
	Non-dominant	-0.439*	− 0.469*	− 0.186*

*Indicates statistical significance (P ≤ 0.05)

Table 2. Discriminative Qualities of GRASSP-M Domains:

Subtest		**P-value**		
		Mild vs moderate	**Moderate vs severe**	**Mild vs severe**
GRASSP-M strength	**Dominant**	0.019	0.028	0.001
	Non-dominant	0.028	0.079	0.001
GRASSP-M sensation	**Dominant**	0.883	0.001	0.001
	Non-dominant	0.567	0.000	0.000
GRASSP-M prehension/dexterity	**Dominant**	0.000	0.004	0.000
	Non-dominant	0.001	0.002	0.000
GRASSP-M prehension/dexterity time	**Dominant**	0.002	0.062	0.001
	Non-dominant	0.005	0.019	0.000

(*P* ≤ .016) refers to a significant difference between groups and the *P*-value reflects a Bonferroni Correction.

Table 3. GRASSP-M Discriminative Values for Assessment of Degenerative Cervical Myelopathy:

GRASSP-M	**Control**	**Mild**	**Moderate**	**Severe**
GRASSP-Str (0-50)	50	48-46 note which muscles	45-40	Less than 40
GRASSP-Sens (0-12)	11-12	10	9-8	Less than 8

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	GRASSP-PD (0-9) | 8-9 | 8-7 | 6-5 | Less than 5			
Kalsi-Ryan et al. 2019 Post-hoc analysis of datasets for the GRASSP cross-sectional and longitudinal studies to calculate the psychometric properties of the GRASSP V2 Five clinics in Canada (Toronto Rehabilitation Institute, ON; GF Strong, BC; Hamilton Health Sciences-2 sites,	**Cross sectional study:** Chronic and traumatic tetraplegia (n = 72). Mean age: 39.7 ± 10.7 yr. Gender: NR. Level of injury: C6=38. Mean time since injury: NR. AIS scale: A=28, B=18, C=14, D=12. **Longitudinal study:** Traumatic cervical SCI (n = 127). Mean age: 49.3 ± 23.8 yr. Gender: NR. Level of injury: C1-C2=18, C3=20, C4=41, C5=29, C6=11, C7=3, C8=2, T1=3.	**Concurrent validity:** All associations between GRASSP subscores, SCIM, SCIM-SS, and CUE-Q were positive and of moderate strength with P < 0.001. Table 1.	**Inter rater and test retest reliability:** The reliability values re-calculated for the modified subtests actually indicate improved reliability for both inter rater and test retest reliability. Table 2.	**Responsiveness:** The modified subtests rendered values that show the GV2 to be responsive, however, not as sensitive to the GV1 when considering the GR-PP subtest alone. Table 3. **MDD:** The re-calculated values for the modified subtests are also decreased from the GV1. Table 4.

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ON; St. Michael's Hospital, ON; and Toronto Western Hospital, ON), two clinics in USA (Rehab Institute of Chicago, IL and Thomas Jefferson University, PA), and five in Europe (Klinik Hohe Warte Bayreuth, D; Unfallklinik Murnau, D; University Hospital Balgrist, CH; Universitätsklinik Heidelberg, D; and Swiss Paraplegic Center, CH)	Mean time since injury: NR. AIS scale: A=29, B=17, C=26, D=55.			
	Table 1. Concurrent validity values for GV2 subscores:			

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	SCIM	SCIM-SS	CUE-Q
GRASSP Sensibility	0.53	0.72	0.79
GRASSP Strength	0.59	0.74	0.76
GRASSP Prehension	0.71	0.82	0.83

Table 2. Reliability values of subtest scores within GV2:

Subtest	Inter-rater reliability		Test-retest reliability	
	ICC	CI	ICC	CI
GR-Palmar Sensation Right	0.84	0.75-0.90	0.95	0.90-0.97
GR-Palmar Sensation Left	0.93	0.89-0.95	0.97	0.94-0.98
GR-Strength Right	0.95	0.93-0.97	0.98	0.98-0.99
GR-Strength left	0.95	0.92-0.97	0.98	0.96-0.98
GR-Prehension ability right	0.95	0.92-0.97	0.98	0.96-0.99
GR-Prehension ability left	0.95	0.92-0.97	0.98	0.97-0.99
GR-Prehension performance right	0.97	0.92-0.98	0.96	0.92-0.97

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GR-Prehension performance left	0.96	0.95-0.98	0.97	0.94-0.98

Table 3. Descriptive statistics and responsiveness values for GV2 new subtests

Group	GV2 Subtest	N	Baseline	1 month	6 month	12 month
Whole	GR-Sens	71	13.6 (7.7)	14.3 (8.3)	18.1 (6.7)	18.4 (6.4)
AB	GR-Sens	17	11 (8.5)	10.1 (7.9)	14.8 (8.8)	15.4 (8.6)
CD	GR-Sens	47	14.2 (7.2)	16.3 (7.8)	19.1 (5.5)	19.5 (4.9)
Whole	GR-PP	108		16.4 (14.9)	23.5 (14.5)	25.9 (13.2)
AB	GR-PP	33		5.1 (8.7)	13.4 (13.6)	14.7 (12.7)
CD	GR-PP	64		26.8 (14.1)	32.1 (12.3)	31.3 (9.8)
Group	GV2 Subtest	N	Mean Diff	SRM	ES	SE
Whole BL-6mo	GR-Sens	102	3.41 (3.97)	.84	.41	.39
AB BL-6mo	GR-Sens	17	3.89 (4.65)	.86	.45	1.13
CD BL-6mo	GR-Sens	43	3.15 (3.56)	.88	.41	.54
Whole BL-12mo	GR-Sens	60	5.8 (4.5)	1.28	.77	.58
AB BL-12mo	GR-Sens	17	5.65 (5.1)	1.11	.69	1.24
CD BL-12mo	GR-Sens	42	5.8 (4.3)	1.35	.81	.67
Whole 1mo-	GR-PP	99	8.7 (9.4)	.93	.62	.94

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6mo						
AB 1mo-6mo	GR-PP	33	8.5 (9.7)	.88	.97	1.7
CD 1mo-6mo	GR-PP	64	5.76 (8.6)	.67	.41	1.1
Whole 1mo-12mo	GR-PP	89	9.7 (8.6)	1.12	.66	.91
AB 1mo-12mo	GR-PP	31	9.9 (8.1)	1.22	1.11	1.47
CD 1mo-12mo	GR-PP	58	9.6 (8.8)	1.10	.69	1.15

GR-Sens = GRASSP Sensation; GR-PP = GRASSP Prehension Performance; Mean Diff = Mean Difference; SRM = Standardized Response Mean; ES = Effect Size; SE = Standard Error of Mean.

Table 4. MDD values for subtest scores within GV2

	SEM	SRD	# of items	SRD/ items	Change in Scores
GR-Palmar Sensation Right (0–12)	1.41	3.27	3	1.09	4 pts or more
GR-Palmar Sensation Left (0–12)	0.93	2.68	3	0.89	4 pts or more
GR-Strength Right (0–50)	3.34	9.23	10	0.92	5 pts or more
GR-Strength Left (0–50)	3.47	9.59	10	0.95	5 pts or more
GR-Prehension Ability Right (0–12)	0.99	2.76	3	0.92	4 pts or more

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	<table><tr><td>GR-Prehension Ability Left (0–12)</td><td>0.98</td><td>2.76</td><td>3</td><td>0.92</td><td>4 pts or more</td></tr><tr><td>GR-Prehension Performance Right (0–20)</td><td>1.08</td><td>2.89</td><td>4</td><td>0.75</td><td>3 pts or more</td></tr><tr><td>GR-Prehension Performance Left (0–20)</td><td>1.12</td><td>2.94</td><td>4</td><td>0.74</td><td>3 pts or more</td></tr><tr><td>GR-Strength (0–100) R + L</td><td>5.51</td><td>15.20</td><td>20</td><td>6.71</td><td>7 pts or more</td></tr><tr><td>GR-Palmar Sensation (0–24) R + L</td><td>2.31</td><td>4.21</td><td>6</td><td>0.70</td><td>3 pts or more</td></tr><tr><td>GR-Prehension Ability (0–24) R + L</td><td>1.81</td><td>4.90</td><td>6</td><td>0.81</td><td>4 pts or more</td></tr><tr><td>GR-Prehension Performance (0–40) R + L</td><td>2.48</td><td>4.36</td><td>8</td><td>0.55</td><td>3 pts or more</td></tr></table>GR-GRASSP; SEM-Standard Error of Measure; SRD-Smallest Real Difference.			
Velstra et al. 2018 Psychometric study using	Patients with acute, traumatic and nontraumatic, tetraplegia due to an SCI (n = 77). Mean age: 50.61 ±		Table 2 includes the item and person targeting (without the extremes), the reliability of the models as well as	**Robustness of the subscales over time:**

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<table>
<tr>
<th>Author Year
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<th>Validity</th>
<th>Reliability</th>
<th>Responsiveness
Interpretability</th>
</tr>
<tr>
<td>data from a prospective cohort study to reveal interval level scales of the GRASSP subtests and reduce subtest items if redundant (GRASSP Version 2)

Three SCI-specific clinics in Germany (Spinal Cord Injury Center, Hohe Warte, Bayreuth; Orthopädische Universitätsklinik, Heidelberg; and Unfallklinik Murnau) and two SCI-specific clinics in Switzerland</td>
<td>20.24 yr.
Gender: males = 52, females = 25.
Level of injury: cervical = 77.
Mean time since injury: Acute*.
AIS scale: NR.
*Data for the side (left and right) resulted in total of 614 observations, which were based on the repeated measurements (0 days, and at 1, 3, 6, and 12 months after SCI).</td>
<td></td>
<td>presence of floor or ceiling effects, local item dependencies (LID), and differential item functioning (DIF) before and after remedies were applied to each of the GRASSP subtests.
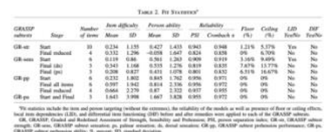
TABLE 2. FIT STATISTICS[a]
<table>
<tr><th>GRASSP subtests</th><th>Stage</th><th>Number of items</th><th>Item difficulty Mean</th><th>Item difficulty SD</th><th>Person ability Mean</th><th>Person ability SD</th><th>Reliability PSI</th><th>Reliability Cronbach α</th><th>Floor (%)</th><th>Ceiling (%)</th><th>LID Yes/No</th><th>DIF Yes/No</th></tr>
<tr><td>GR-str</td><td>Start</td><td>10</td><td>0.234</td><td>1.155</td><td>0.427</td><td>1.433</td><td>0.943</td><td>0.948</td><td>1.21%</td><td>5.37%</td><td>Yes</td><td>No</td></tr>
<tr><td></td><td>Final reduced</td><td>4</td><td>0.332</td><td>1.296</td><td>−0.058</td><td>1.647</td><td>0.824</td><td>0.858</td><td>0%</td><td>6.70%</td><td>No</td><td>No</td></tr>
<tr><td>GR-sens</td><td>Start</td><td>6</td><td>0.119</td><td>0.86</td><td>0.561</td><td>1.263</td><td>0.909</td><td>0.919</td><td>3.16%</td><td>9.49%</td><td>Yes</td><td>No</td></tr>
<tr><td></td><td>Final (ds)</td><td>3</td><td>0.343</td><td>1.168</td><td>0.535</td><td>1.276</td><td>0.819</td><td>0.835</td><td>7.87%</td><td>13.77%</td><td>No</td><td>No</td></tr>
<tr><td></td><td>Final (ps)</td><td>3</td><td>0.208</td><td>0.827</td><td>0.431</td><td>1.078</td><td>0.801</td><td>0.832</td><td>6.31%</td><td>16.67%</td><td>No</td><td>No</td></tr>
<tr><td>GR-pp</td><td>Start</td><td>6</td><td>0.232</td><td>1.802</td><td>0.845</td><td>1.762</td><td>0.956</td><td>0.971</td><td>0%</td><td>0%</td><td>No</td><td>No</td></tr>
<tr><td></td><td>Final all items</td><td>6</td><td>0.597</td><td>1.942</td><td>0.814</td><td>2.336</td><td>0.956</td><td>0.972</td><td>0%</td><td>0%</td><td>No</td><td>No</td></tr>
<tr><td></td><td>Final reduced</td><td>4</td><td>0.664</td><td>2.279</td><td>0.87</td><td>2.322</td><td>0.937</td><td>0.955</td><td>0%</td><td>0%</td><td>No</td><td>No</td></tr>
<tr><td>GR-pa</td><td>Start and Final</td><td>3</td><td>1.643</td><td>3.998</td><td>1.667</td><td>3.828</td><td>0.955</td><td>0.972</td><td>0%</td><td>0%</td><td>No</td><td>No</td></tr>
</table>
[a]Fit statistics include the item and person targeting (without the extremes), the reliability of the models as well as presence of floor or ceiling effects, local item dependencies (LID), and differential item functioning (DIF) before and after remedies were applied to each of the GRASSP subtests.
GR, GRASSP, Graded and Redefined Assessment of Strength, Sensibility and Prehension; PSI, person separation index; GR-str, GRASSP subtest strength; GR-sens, GRASSP subtest sensation; ps, palmar sensation; ds, dorsal sensation; GR-pp, GRASSP subtest prehension performance; GR-pa, GRASSP subtest prehension ability; %, percent; SD, standard deviation.

• GR-pa subtest (reduction was not undertaken): It was the only subtest that did not require any adjustment to fit the Rasch model. The PSI of 0.995 indicated high reliability for individual measurement. The GR-pa</td>
<td></td>
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(Balgrist University Hospital, Zurich and the Swiss Paraplegic Center, Nottwil).			subtest presented good subscale targeting with no floor and ceiling effects, no LID, unidimensionality, and ordered thresholds with the original scale response categories. However, the infit and outfit statistics were <0.5 for the later key pinch item point on a high discrimination of this item. • **GR-str subtest (reduction from 10 items to 4 items was undertaken):** The final recoded and reduced GR-str subtest has good	

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			reliability for use as measurement tool (PSI: 0.824), a slight ceiling effect, absence of LID, good item fit, and ordered thresholds. • **GR-sens subtest (reduction from five response categories [0–4] of GR-ps and GR-ds were collapsed into three recoded categories [range 0–3] for each one):** The collapsing strategy worked well for GR-ps and GR-ds. • **GR-pp subtest (collapsing of the six response categories [0–5] into four**	

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			recoded categories [range 0–3]): The collapsing intervention improved the item fit and did not impact the reliability of the subscale (PSI = 0.937).	
Marino et al. 2018 Cross-sectional	N=69 (tetraplegic) 60 acute, 9 chronic injuries Mean age: 41.9±18.1 years 25 motor complete AIS: 8A, 17B, 22C, 22D			**Interpretability:** Standardized Response Mean (SRM)=0.88 Minimum Detectable Difference (MDD)=9.7 for the combined score and 6.0/5.3 points for the right/left side scores.
Mulcahey et al. 2017 Psychometric study to validate the GRASSP in	N=47 children with tetraplegia 28 Male, 19 Female AIS: 14A, 4B, 10C, 8D, 11 Unknown Age groups:	Correlation between GRASSP and SCIM r=0.33-0.66 Correlation between GRASSP and SCIM-SC	**Test-retest, inter-rater, intra-rater:** Test-retest reliability ICC=0.99	

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pediatric SCI populations and establish the lower age of test administration US, Pennsylvania, Maryland, Illinois, Michigan, California, Texas	- 5, 3-5 years - 15, 6-12 years - 12, 13-15 years - 15, 16-17 years	r=0.37-0.70 Correlation between GRASSP and CUE-Q r=0.40-0.84		
Kalsi-Ryan et al. 2016 Multicenter, observational, longitudinal, cohort study 5 centers (7 sites) in Ontario, Canada	N=53 (48M, 5F) Mean (SD) age 49.6 (15.6) All acute SCI, 0-10 days post-injury AIS-A/B/C/D: 11/5/16/21 51 cervical, 2 thoracic	Table 1.		**Responsiveness:** Mean Difference, Std Error, Std Response Mean and Effect Sizes (Mean diff; SE; SRM; ES) at different post-injury intervals: GRASSP Strength: - 1 month -> 3 month: 11.55; 1.62; 1.02; 0.45 - 1 month -> 6 month: 16.24; 2.13; 1.16; 0.62

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				- 1 month -> 12 month: 21.64; 2.50; 1.46; 0.83 GRASSP Sensation: - 1 month -> 3 month: 5.10; 0.76; 0.96; 0.36 - 1 month -> 6 month: 6.28; 1.07; 0.90; 0.45 - 1 month -> 12 month: 7.41; 1.26; 0.95; 0.53 GRASSP Prehension Ability: - 1 month -> 3 month: 3.73; 0.69; 0.77; 0.47 - 1 month -> 6 month: 4.16; 0.79; 0.80; 0.52 - 1 month -> 12 month: 5.79; 1.02; 0.91; 0.72 GRASSP Prehension Performance:

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				- 1 month -> 3 month: 9.22; 0.90; 1.46; 0.42 - 1 month -> 6 month: 11.00; 0.96; 1.73; 0.50 - 1 month -> 12 month: 14.60; 1.11; 2.11; 0.69 Breakdown by motor completeness and other time intervals available in article **Interpretability:** Table 2.
	Table 1. Pearson Correlations (p≤0.001):			

	1 month	3 months	6 months	12 months
UEMS/GR-st	0.89	0.952	0.963	0.955
UEMS/GR-sen	0.608	0.651	0.736	0.571
ISNCSCI-LT/GR-st	0.532	0.304	0.415	0.368
ISNCSCI-LT/GR-sen	0.640	0.307	0.658	0.479
GR-st/SCIM-SS	0.942	0.784	0.854	0.836
GR-st/CUE-Q	0.820	0.771	0.859	0.815
GR-sen/SCIM-SS	0.574	0.643	0.684	0.577

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GR-sen/CUE-Q	0.715	0.657	0.695	0.518
GR-pa/SCIM-SS	0.766	0.740	0.839	0.770
GR-pa/CUE-Q	0.798	0.698	0.804	0.719
GR-pp/SCIM-SS	0.866	0.740	0.911	0.844
GR-pp/CUE-Q	0.858	0.817	0.903	0.805

GR-st = GRASSP Strength
GR-sen = GRASSP Sensation
GR-pa = GRASSP prehension ability
GR-pp = GRASSP prehension performance
ISNCSCI-LT = ISNCSCI Light Touch Score (see also ASIA-LT)
UEMS = ASIA Upper Extremity Motor Score

Table 2. Minimal Detectable Values:

	SEM	SRD	# of Items	Score Change
Sensation right (0–24)	2.88	7.96	1.5	More than 2 pts
Sensation left (0–24)	2.32	6.41	0.5	More than 2 pts
Strength right (0–50)	3.34	9.23	1	More than 5 pts
Strength left (0–50)	3.47	9.59	1	More than 5 pts
Prehension ability right (0–12)	0.99	2.76	0.5	More than 2 pts

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<table>
<tr><th>Author Year
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Setting (country)</th><th>Demographics and Injury Characteristics of Sample</th><th>Validity</th><th>Reliability</th><th>Responsiveness
Interpretability</th></tr>
<tr><td></td><td colspan="4">
<table>
<tr><td>Prehension ability left (0–12)</td><td>0.98</td><td>2.76</td><td>0.5</td><td>More than 2 pts</td></tr>
<tr><td>Prehension performance right (0–30)</td><td>2.16</td><td>5.97</td><td>0.5</td><td>More than 3 pts</td></tr>
<tr><td>Prehension performance left (0–30)</td><td>1.93</td><td>5.33</td><td>0.5</td><td>More than 3 pts</td></tr>
<tr><td>Bilateral strength (0–100)</td><td>5.5</td><td>15.2</td><td>6.7</td><td>More than 7 pts</td></tr>
<tr><td>Bilateral dorsal sensation (0-–4)</td><td>2.4</td><td>6.6</td><td>3.6</td><td>More than 4 pts</td></tr>
<tr><td>Bilateral palmar sensation (0–24)</td><td>2.4</td><td>6.6</td><td>3.6</td><td>More than 4 pts</td></tr>
<tr><td>Bilateral prehension ability (0–24)</td><td>1.8</td><td>4.9</td><td>4.8</td><td>More than 5 pts</td></tr>
<tr><td>Bilateral prehension performance (0–24)</td><td>3.5</td><td>9.7</td><td>6.2</td><td>More than 6 pts</td></tr>
</table>
</td></tr>
<tr><td>Velstra et al.
2016
prospective longitudinal multicenter study
5 European SCI centers; Recruitment</td><td>N = 61, 45 male
Mean age 47, SD = 19
Acute (16-40 days after injury) tetraplegia at recruitment
58/61 traumatic SCI
AIS at 1 month: A=16, B=10, C=7, D=28</td><td>Backward multiple binary logistic regression reveals that combinations of select predictors have similar predictive accuracy as that of 10 predictors:</td><td></td><td></td></tr>
</table>

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between 2009 ~ 2012		Combination of FDP & Delto predicting GRASSP-QtG at 6 months: - Sensitivity = 86.4% (74.7-93.3%), Specificity = 86.5% (75.5-93.0%) All 10* unilateral muscle predictors predicting GRASSP-QtG at 6 months: - Sensitivity = 86.4% (74.7-93.3%), Specificity = 86.5% (75.5-93.0%) Combination of ElbowFlex, WristExt, EDC & FPL predicting SCIM-Self-care at 6 months:		

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		- Sensitivity = 81.8% (61.5-92.7%), Specificity = 89.2% (75.7-97.2%) All 10* bilateral muscle predictors predicting SCIM-Self-care at 6 months: - Sensitivity = 86.4% (66.7-95.3%), Specificity = 89.2% (75.3-95.7%) Combination of WristExt, FDP, Delto & FPL predicting SCIM-Mobility at 6 months: - Sensitivity = 96% (80.5-99.3%), Specificity = 91.2% (77.0-96.7%)		

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		All 10* bilateral strength predictors predicting SCIM-Mobility at 6 months: - Sensitivity = 92% (75.0-97.8%), Specificity = 91.2% (77.0-96.7%) UEMS = Upper extremity motor score GRASSP-MMT = GRASSP Manual muscle testing *Predictors included: - ElbowFlex = Elbow flexors (UEMS) - WristExt = Wrist extensors (UEMS) - Triceps = Elbow extensors (UEMS) - FDP = Long finger flexors (UEMS)		

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		- AbdDigV = Small finger abductors (UEMS) - Delto = M. anterior deltoid (GRASSP-MMT) - EDC = M. extensor digitorum communis (GRASSP-MMT) - OPP = M. opponens pollicis (GRASSP-MMT) - FPL = M. flexor pollicis longus (GRASSP-MMT) - DI1 = M. first dorsal interosseus (GRASSP-MMT) URP-CTREE analysis revealed that GRASSP-QIG subtest** can accurately predicted upper-limb function: - "The combination of proximal and		

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		distal upper limb muscles as well as the early ability to initiate simplified grasp movements (ie, CylGrasp, LatPinch, and TTPinch), predicted upper limb function very well" (p300) **Predictors included: - CylGrasp = Cylindrical grasp - LatPinch = Lateral key pinch TTPinch = Tip-to-tip pinch		
Velstra et al. 2015 Prospective longitudinal	N = 74, (23F, 51M) Age: 49 ± 18	Spearman Correlations ($p<0.0001$): At 1 month postinjury:		**Responsiveness:** Responsiveness between first month

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multicenter study 5 European SCI Rehab centers	SCI patients <= 10 days post-injury at enrollment AIS at 1 month: A=18, B=12, C=10, D=34 69/74 traumatic SCI	- GRASSP-MMT subscale & SCIM-selfcare = 0.78 - GRASSP-MMT subscale & ASIA UEMS = 0.95 - GRASSP-SWM subscale & SCIM-selfcare = 0.63 - GRASSP-QtG subscale & SCIM-selfcare = 0.85 At 12 month postinjury: - GRASSP-MMT subscale & SCIM-selfcare = 0.82 - GRASSP-MMT subscale & ASIA UEMS = 0.88 - GRASSP-SWM subscale & SCIM-selfcare = 0.56		and 1 year postinjury (measured by SRM): AIS A-D (For AIS A-B, or C-D specific data, refer to article) GRASSP-MMT: 1.48 (large) GRASSP-SWM: 0.64 (moderate) GRASSP-QlG: 0.99 (large) GRASSP-QtG: 1.03 (large) SRMs with respect to 1~3, 1~6, 1~12, 3~12, 3~6, 6~12 months post-injury: In all patients: GRASSP-MMT subtest: 0.79-1.48 GRASSP-SWM subtest: 0.14-0.93 GRASSP-QlG subtest: 0.34-0.99

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		- GRASSP-QtG subscale & SCIM-selfcare = 0.82 Data at 3 & 6 month also available in article Predictive validity: ROC analysis (AUC & 95%CI): Btwn 1-3 month postinjury: - Change in GRASSP-MMT: 0.81 (0.71~0.91) ($p<0.001$) - Change in GRASSP-SWM: 0.77 (0.65~0.89) ($p<0.001$) - Change in GRASSP-QtG: 0.71 (0.57~0.85) ($p<0.001$) Btwn 3-6 month postinjury:		GRASSP-QtG subtest: 0.50-1.03 In AIS-A/B patients: GRASSP-MMT subtest: 0.82 -1.56 GRASSP-SWM subtest: 0.31-0.94 GRASSP-QlG subtest: 0.22-1.02 GRASSP-QtG subtest: 0.42-1.10 In AIS-C/D patients: GRASSP-MMT subtest: 0.68-1.50 GRASSP-SWM subtest: 0.02-0.54 GRASSP-QlG subtest: 0.41-1.02 GRASSP-QtG subtest: 0.55-1.17

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		- Change in GRASSP-MMT: 0.87 (0.77~0.97) ($p<0.001$) - Change in GRASSP-SWM: 0.68 (0.53~0.82) ($p<0.05$) - Change in GRASSP-QtG: 0.81 (0.70~0.93) ($p<0.001$) Btwn 6-12 month postinjury: - Change in GRASSP-MMT: 0.71 (0.58~0.85) ($p<0.01$) - Change in GRASSP-SWM: 0.86 (0.76~0.96) ($p<0.001$) - Change in GRASSP-QtG: 0.82 (0.70~0.94) ($p<0.001$)		

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		(GRASSP-MMT = Manual Muscle Testing subscale – based on Daniels and Worthington, 1995)		
Velstra et al. 2014 Prospective longitudinal multicenter study	N=61 (16F, 45M) Age: 46 ± 19 All acute (16-40 days after injury) tetraplegia patients from cervical SCI 56/61 traumatic SCI AIS at 1 month: A=16, B=9, C=7, D=29	Spearman correlations with SCIM: MMT (1 month) subscale and SCIM self-care subscale: - at 6 months (r=0.821, p<0.001) - at 12 months (r= 0.820, (p<0.001) SWM subscale (1 month) and SCIM self-care subscale: - At 6 months: r=0.781, p<0.001; - At 12 months, r= 0.643, p<0.001 Predictive validity: Area Under Curve (95%CI) (p<0.001),		

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		Sensitivity/specificity (95%CI): GRASSP-MMT subtest (@1mth) as predictor of: - SCIM-self-care (@6mth): AUC = 0.917(0.680-0.926); Sens = 81.8%(70.1-89.4); Spec = 92.1%(81.9-96.4) - SCIM-self-care (@12mth): 0.917(0.849-0.984); Sens = 82.8%(67.2-87.8); Spec = 72.4%(59.8-82.2) GRASSP-SWM subtest (@1mth) as predictor of: - SCIM-self-care (@6mth): 0.803(0.680-0.926); Sens = 68.2%(55.7-78.7);		

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		Spec = 78.9%(66.4-86.9) SCIM-self-care (@12mth): 0.842(0.737-0.947); Sens =79.3%(67.2-87.8); Spec = 75.9%(63.5-85)		
Kalsi-Ryan et al. 2012 Cross-sectional multi-center trial focused on establishing the reliability and validity of GRASSP Test-retest reliability study: N=45 (North American centers) Inter-rater reliability study & Construct	Study site: (total N=72) Toronto Rehabilitation Institute, Canada (N=15) Vancouver Coastal Health, Canada (N=10) Rehabilitation Institute of Chicago, USA (N=10) Thomas Jefferson University, USA (N=10) Balgrist University Hospital, Switzerland (N=9) Krakenhaus Hohe Worte, Germany (N=8) Traumacenter Murnau, Germany (N=10)	Construct validity: precision of GRASSP was established by comparing the sensation and strength subtest items to the sensory and motor upper limb items in the ISNCSCI. On average, 54% of the sample showed discordance in sensory innervation when assessed with the GRASSP due to the additional test locations of sensory testing included (added palmar	**Test-retest, inter-rater, intra-rater:** All ICC values had a significance level of p<.001. Table 4. ICC = intra-class correlation coefficient CI = confidence interval ICC for inter-rater reliability ranged between 0.84 – 0.96. ICC for test-retest reliability ranged between 0.86 - 0.98.	**Interpretability:** Table 5.

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validity study: N=72 Seven centers collected data: Rehabilitation Institute of Chicago, Chicago, Illinois; Toronto Rehabilitation Institute, Toronto, Ontario; Vancouver Coastal Health, Vancouver, British Columbia; Thomas Jefferson University, Philadelphia, Pennsylvania; Balgrist University Hospital, Switzerland;	Sample description: Mean age (years): 39.7 (10.7) Time post-injury (years): 7.6 (6.1) AIS complete: n=28 (39%) AIS incomplete: n=44 (61%) C6-C7 AIS motor level: 52.5% C4-C6 AIS sensory level: 66.0% Chronic tetraplegia AIS grades: A: 38.8% B: 25.2% C: 16.6% D: 19.4% Each site engaged two examiners who were either occupational or	locations and increased response levels of the SWM). Table 1. On average, 53% of the sample showed a different degree of motor innervation when assessed with the GRASSP due to the added muscles in the GRASSP, and the designation of the most caudal level in the ISNCSCI. Table 2. Concurrent validity: Spearman correlation coefficients were used to establish the association between GRASSP subtests and the CUE, SCIM-total and SCIM-SS (self-care subscale).		

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Krakenhaus Hohe Worte, Germany; Traumacenter Murnau, Germany.	physical therapists who had expertise with SCI. In total 14 examiners were involved in the study, 12 of whom were occupational therapists and two of whom were physical therapists. Two workshops (one in Europe and one in North America) were conducted to train the examiners on the study protocol and appropriate use of all study measures. Inclusion and exclusion criteria: Individuals with chronic (more than 6 months after injury) traumatic tetraplegia who were neurologically and medically stable, between the ages of	All associations were positive and significant (P<.0001). Table 3. *Right and left data were combined for the analyses SCIM-SS showed stronger association than SCIM-total with GRASSP subtests. CUE showed the strongest associations with GRASSP, indicating strong association between self-perceived function and tested impairment.		

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	16 and 65 and able to provide informed consent were included in the study. Individuals with moderate brain injury who were neurologically unstable or individuals with any other pathology causing upper limb impairment were excluded.			

Table 1.

	Agreement		Discordance	
ISNCSCI sensory level:	**n**	**n (%)**	**1* n (%)**	**2* n (%)**
Total sample (R)	72	32 (44)	16 (22)	24 (33)
Total sample (L)	72	34 (47)	13 (18)	25 (35)
C2-C4 (R)	29	14 (19)	7 (10)	8 (11)
C2-C4 (L)	29	12 (17)	6 (8)	11 (15)
C5 (R)	11	5 (7)	4 (6)	2 (3)
C5 (L)	9	5 (7)	3 (4)	1 (1)
C6 (R)	17	6 (8)	5 (7)	6 (8)
C6 (L)	19	8 (11)	4 (6)	7 (10)
C7 (R)	8	4 (6)	0 (0)	4 (6)

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C7 (L)	6	3 (4)	0 (0)	3 (4)
C8 and below (R)	7	3 (4)	0 (0)	4 (6)
C8 and below (L)	9	6 (8)	0 (0)	3 (4)

1* = discordance due to added palmar test locations in GRASSP

2* = discordance due to increased response levels (SWM) used in GRASSP

Table 2.

	Agreement		Discordance	
ISNCSCI motor level:	**n**	**n (%)**	**1* n (%)**	**2* n (%)**
Total sample (R)	72	36 (50)	19 (26)	17 (24)
Total sample (L)	72	34 (47)	20 (28)	17 (24)
C2-C4 (R)	10	1 (1)	6 (8)	3 (4)
C2-C4 (L)	14	6 (8)	6 (8)	1 (1)
C5 (R)	10	3 (4)	2 (3)	5 (7)
C5 (L)	9	3 (4)	1 (1)	5 (7)
C6 (R)	23	13 (18)	3 (4)	7 (10)
C6 (L)	21	11 (15)	5 (7)	4 (6)
C7 (R)	17	9 (12)	6 (8)	2 (3)
C7 (L)	16	6 (8)	7 (10)	3 (4)
C8 (R)	4	2 (3)	2 (3)	0 (0)
C8 (L)	5	1 (1)	1 (1)	3 (4)
T1 and below (R)	8	8 (11)	0 (0)	0 (0)
T1 and below (L)	7	7 (10)	0 (0)	0 (0)

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Table 3.

Subtest score	SCIM	SCIM-SS	CUE
Sensation total (R+L)	0.57	0.74	0.77
Strength total (R+L)	0.59	0.74	0.76
Prehension performance total (R+L)	0.68	0.79	0.83

Table 4.

GRASSP Subtest:	Inter-rater reliability		Test-retest reliability	
	ICC	CI	ICC	CI
Sensation right	0.84	0.75-0.89	0.95	0.91-0.97
Sensation left	0.91	0.86-0.94	0.86	0.76-0.92
Strength right	0.95	0.93-0.97	0.98	0.98-0.99
Strength left	0.95	0.92-0.97	0.98	0.96-0.98
Prehension ability right	0.95	0.92-0.97	0.98	0.96-0.99
Prehension ability left	0.95	0.92-0.97	0.98	0.97-0.99
Prehension performance right	0.95	0.92-0.97	0.93	0.88-0.96

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Prehension performance left	0.96	0.93-0.97	0.96	0.93-0.98

Table 5. Mean (SD) scores for GRASSP items and SEM, MDC (calculated from data in Kalsi-Ryan et al. 2012):

GRASSP items:	Mean		SD		SEM		MDC	
	R	L	R	L	R	L	R	L
Strength (0-50)	24.3	25.1	13.0	13.5	1.8	1.9	5.1	5.3
Dorsal sensation (0-12)	6.5	6.7	3.2	3.1	--	--	--	--
Palmar sensation (0-12)	7.1	7.2	3.6	3.3	--	--	--	--
Prehension ability (0-12)	4.9	5.1	4.5	4.3	0.6	0.6	1.8	1.7
Prehension performance (0-30)	15.6	14.7	9.6	8.9	2.5	1.8	7.0	4.9

R=right, L=left

Table 6. GRASSP subtest scores of four representative examples (right side data only):

	GRASSP subtest scores				
ISNCSCI sensory/motor AIS	**Dorsal sensation (0-12)**	**Palmar sensation (0-12)**	**Strength (0-50)**	**Prehension ability (0-12)**	**Prehension performance (0-30)**
C5/C4/A	4	3	5	0	0
C7/C6/A	6	9	23	10	21
C5/C6/D	10	10	26	5	16
C4/T1/D	12	12	45	12	27

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Author Year Research Design Setting (country)	**Demographics and Injury Characteristics of Sample**	**Validity**	**Reliability**	**Responsiveness Interpretability**
Kalsi-Ryan et al. 2013 Cross-sectional multi-center trial focused on determining the association between the impairment domains (sensation, motor, and prehension) and the construct of "sensorimotor upper limb function" by testing the hypothetical model (based on the theoretical framework)	Same sample as Kalsi-Ryan et al. 2012 above.	Structural equation modeling rendered the strength of association between impairment, function and the latent trait variable of sensorimotor upper limb function. The SEM results show a very good fit of the model to the data; the model explained 72% of the variance in "sensorimotor upper limb function." The very high value of R^2 was substantiated by the goodness-of-fit indices. The goodness-of-fit indices were greater than the accepted thresholds (χ^2 = 14.3, P = .11; CFI =		

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Same sample as Kalsi-Ryan et al. 2012 above.		.99, TLI = .97, and RMSEA = .09, SRMR = .02), which implies that the R^2 value is reliable and the relationship among variables are also reliable. Prehension has a significant positive effect on upper limb function and strength and palmar sensation both have a direct and indirect effect through prehension on upper limb function. Based on the SEM, palmar sensation showed a direct and indirect relationship to upper limb function. The relationship mediated through prehension is larger (0.19 + 0.32) than the direct relationship		

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		(0.31); but both direct and indirect relationships are statistically significant. Strength also showed a direct and indirect relationship to upper limb function. The relationship mediated through prehension is larger (0.68 + 0.31) than the direct relationship to upper limb function, but both direct and indirect relationships are statistically significant. Therefore, sensorimotor upper limb function can be predicted by palmar sensation and strength through prehension. The values on the right of the latent trait 0.89, 0.80, 0.92, 0.93) simply confirm that		

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		sensorimotor upper limb function is adequately estimated by the variables used. The values are very high and significant, which would be expected as the SCIM and CUE are functionally relevant tests and the construct of "sensorimotor upper limb function" is well defined by impairments that are functionally relevant. Essentially, changes in strength and sensation are most likely to have an effect on upper limb function when associated with improvement in prehension.		
Kalsi-Ryan et al. 2009	Study site: (total N=72)	Strength of observed relationships between	**Test-retest, inter-rater, intra-rater:**	

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Cross-sectional study assessed a cohort of neurologically stable patients with tetraplegia using a preliminary version of the GRASSP Seven centers collected data: Rehabilitation Institute of Chicago, Chicago, Illinois; Toronto Rehabilitation Institute, Toronto, Ontario; Vancouver Coastal Health, Vancouver, British Columbia;	Toronto Rehabilitation Institute, Canada (N=15) Vancouver Coastal Health, Canada (N=10) Rehabilitation Institute of Chicago, USA (N=10) Thomas Jefferson University, USA (N=10) Balgrist University Hospital, Switzerland (N=9) Krakenhaus Hohe Worte, Germany (N=8) Traumacenter Murnau, Germany (N=10) Sample description: C6-C7 AIS motor level: 52.5% C4-C6 AIS sensory level: 66.0% AIS grades:	GRASSP impairment components and functional measures (SCIM, SCIM self-care subscore, and prehension) were used to exclude items and tests from the final GRASSP. A similar method was used to determine which individual items from the MMT should be retained based on the strength of association to function. Out of 11 muscles, 10 were included into the GRASSP; only the muscle abductor policis brevis failed to demonstrate significant association between impairment and function, and was excluded.	Kalsi-Ryan et al. 2009 reports inter/intra-rater reliability for components of the GRASSP, as found in other articles (referenced). Components of the GRASSP and inter / intra reliability: Sensibility domain: - Light touch / Semmes Weinstein monofilament (SMW): inter/intra = 0.965 - Static 2 point disc: inter/intra = 0.989 Strength and tone domain:	

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Thomas Jefferson University, Philadelphia, Pennsylvania; Balgrist University Hospital, Switzerland; Krakenhaus Hohe Worte, Germany; Traumacenter Murnau, Germany.	A: 38.8% B: 25.2% C: 16.6% D: 19.4%	The final GRASSP consisted of: strength, Semmes Weinstein monofilaments (SWM) and grasp function (quantitative grasp = Qn-Grasp). Items eliminated were: tone (Ashworth) and static two-point discrimination (S2PD). The final GRASSP (version I) consists of SWM, Manual Muscle Test (MMT) – 10 muscles and prehension testing.	- strength: inter-rater = 0.880 - tone: inter-rater: 0.750 Prehension domain: - quantitative (performance) – adapted from Sollerman: inter-rater = 0.980	