The Allen Martin Research Scholarship
Developing a gold-standard, ecologically valid assessment of associated reactions and demystifying the contributing impairments

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PhD Candidate, USC

Co-Investigators:
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Outline

• Define associated reactions
• Issues in the field
• Systematic review
• Project outline and aims
• Methods of assessing associated reactions
• Determining the contributing impairments
• Testing timeframes
• Achievements
• Expected outcomes
• Questions
What is an associated reaction?

‘Associated reactions are an unwanted, effort dependent limb movement that occurs following cerebral damage, where there may be sensorimotor dysfunction or insufficient postural control, so that when a stimulus is applied that goes beyond the individual’s level of inhibitory or modulatory control, it results in intermittent or sustained involuntary, heterogeneous muscle activation with abnormal limb posturing, most visible in the hemiplegic upper limb.’
Terminology

Motor Overflow

Normal
- Mirror movements & imitative synkineses
- Associated Movements

Pathological
- Mirror movements & imitative synkineses
- Associated Reactions
- Global Synkineses
What is an associated reaction?
What is an associated reaction?
What is an associated reaction?
What is an associated reaction?
What is the effect of ARs on the individual?

- Large variability in the range of incidence
- TBI not reported

Associated reactions can lead to: (Davies 2000, Bhkata et al 2001, Bobath 1990)
- Contractures
- Limited arm function
- Increased energy requirements of walking
- Reduced dynamic balance and increased risk of falling
- Aesthetic implications

Reducing the ARs that occur during functional activities is a major focus of neurological rehabilitation.
Problems in the field of ARs

1. No consensus on contributing factors

- **SPASTICITY**
- **REDUCED MOTOR CONTROL**
- **WEAKNESS**
- **FEAR OF FALLING**
- **HYPERTONICITY**
- **POOR GAIT QUALITY**
- **ANXIETY**
- **TRUNK INSTABILITY**
Problems in the field of ARs

2. Diverse treatment strategies
Problems in the field of ARs

3. Inconsistencies with terminology
Problems in the field of ARs

4. Lack of a gold standard clinical assessment tool
Differentiating Spasticity from an Associated Reaction

• Assessment of ARs commonly performed passively at the bedside
• ARs are poorly distinguished from spasticity in the arm
• ARs are often assessed using Tardieu spasticity measure
• The Modified Tardieu Scale is an assessment of the velocity dependent stretch reflex in a muscle
Differentiating Spasticity from an Associated Reaction

Example of true spasticity in elbow flexors
Differentiating Spasticity from an Associated Reaction

Patient - BEDSIDE UPPER LIMB ASSESSMENT
Differentiating Spasticity from an Associated Reaction

Patient – FUNCTIONAL ASSESSMENT
Methods of assessing associated reactions of the upper limb in stroke and traumatic brain injury: A systematic review

KAHN M, Mentiplay B, Clark R, Bower K and Williams G

Methods of assessing associated reactions of the upper limb in stroke and traumatic brain injury: A systematic review

Michelle B. Kahn1,2, Benjamin F. Mentiplay1, Ross A. Clark2, Kelly J. Bower3, & Gavin Williams4

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Abstract

Objective To determine the assessment methods for upper limb (UL) associated reactions (ARs) in people with acquired brain injury (ABI). Methods A systematic search of 10 databases was performed for Stage 1 to identify methods that quantify ARs of the hemiplegic UL. Stage 2 searched four databases to examine the clinimetric properties and clinical utility of these methods. Two independent reviewers identified relevant articles, assigned data, assessed study methodological quality and rated the clinimetric properties and clinical utility. Results Eighteen articles were included. The methods used to evaluate ARs were surface electromyography (1), goniometry (5), dynamometry (5), electoanography/EMG (1), subjective clinimetric (2) and patient testing (3). Electromyography, electromyography and dynamometry implemented stationary, unattended positions. Conversely, methods were diverse in the upper limb, including using a mobility task to examine the AR. There was a limited clinimetric data available. Only half of the assessment methods were deemed technically feasible. Most common methods were laboratory-based. Conclusion There were a limited number of methods used to assess ARs in people with ABI and the measurement properties of these outcomes were largely unreported. No gold standard was identified.

Introduction

Associated reactions (ARs) of the upper limb (UL) are a common phenomenon in people with acquired brain injury (ABI). The upper limb may experience involuntary UL movements that cause awkward and uncomfortable postures. Associated reactions are pathological and occur due to damaged supraspinal structures as a result of neurological injury. Associated involuntary movements occur globally and are patient-specific. These involuntary movements occur in the hemiplegic side, coinciding or following effort exerted at another body side [1-3]. Incidence rates of ARs in people with stroke have been reported to range from 20-80% [4-6]. There is no current estimate in the literature of prevalence in individuals with traumatic brain injury (TBI), however, it is likely to be similar.

Associated reactions may have a substantial impact on functional ability and quality-of-life for people with ABI. These pathological arm movements affect a diverse range of people with ABI, including individuals with relatively good UL function. Long-term abnormal UL posturing can lead to contractures [7], entrenched abnormal movement patters and limited UL function, particularly when standing and walking [8,9]. Associated reactions can also increase the energy requirements of walking and interfere with a person's dynamic balance, therefore increasing the risk of falling [7]. Furthermore, visible associated UL postures have obvious aesthetic implications, adding to the stigma of disability. The various nature of these reactions, i.e. being 'associated', means they happen dynamically and unintentionally in conjunction with other movements and effort [10,11]. For example, a person's UL may exhibit an AR during effort-dependent activities such as rising from sitting and walking [10,12]. Reducing the ARs that occur during functional activities is, therefore, often a major focus of neurological rehabilitation.

Effective treatment of ARs is important to clinicians and people with ABI. Associated reactions are commonly present for treatment and their presence and severity during walking is often examined as a means of monitoring patient progress or effectiveness of interventions [9,13]. Despite this, ARs remain poorly defined and consensus is lacking in relation to the contributing factors. For example, some authors suggest that ARs co-occur with spasticity [10,12,14,15] and others believe that ARs can occur independently of spasticity [16,17]. This confusion leads to a diverse range of treatment strategies.
Aims

1. Identify methods used to evaluate ARs in people with ABI

2. Determine their clinimetric properties

3. Assess the clinical utility of these methods
Methods

Stage 1 (Aim 1) - Identifying the AR assessment methods

<table>
<thead>
<tr>
<th>Inclusion Criteria</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Diagnosis of acquired brain injury (stroke or traumatic brain injury)</td>
<td>Focus on Children (&lt; 18 years of age)</td>
</tr>
<tr>
<td>Adult or adolescent onset &gt; 18 years of age</td>
<td>Grey literature, conference abstracts and review articles</td>
</tr>
<tr>
<td>An outcome measure of ARs, Motor Overflow or Global Synkinesis in the hemiplegic upper limb</td>
<td>Single Case studies</td>
</tr>
<tr>
<td></td>
<td>Published in languages other than English</td>
</tr>
<tr>
<td></td>
<td>Focus on Mirror Movements</td>
</tr>
</tbody>
</table>

Stage 2 (Aims 2 and 3) – To determine the clinimetric properties and clinical utility of existing methods of assessing ARs.
What is clinimetrics?

“Clinimetrics is the evaluation of a measurement tool’s properties, it includes the psychometrics such as reliability, validity and responsiveness, but also takes into consideration the clinical utility”.

- Reliability
- Validity
- Responsiveness
- Clinical utility
Methods

• Systematic search of 10 databases until October 2014
• Clinimetric evaluation
• Clinimetric rating system by with two independent reviewers (Terwee et al 2007)
• Rating of clinical utility with a score out of 10 (Tyson and Connell 2009)
  o Time
  o Cost
  o Training
  o Equipment
  o Portability
Results

Flow chart of study selection
Results
Study Characteristics

STUDY TYPES
- 13 observational
  - 6 case–control
- 2 RCTs
- 3 pre- and post-test case control series

PARTICIPANTS
- Middle aged adults
- Predominantly male
- Chronic
- 89% stroke
Results

The methods used to assess ARs were:

- Standard Goniometry (5)
- Electrogoniometry (1)
- Dynamometry or Load Cells (5)
- Subjective Clinician Rating Form (2)
- Subjective Patient Rating Form (2)
- Surface Electromyography (11)
Results

SURFACE ELECTROMYOGRAPHY

Figure 1  Arm posture and instrumentation for measuring AR (wrist supported).

Bhakta et al 2001  Ada et al 2001
Results

STANDARD GONIOMETRY
Results

ELECTROGONIOMETRY

Ada et al 2001
Results

DYNAMOMETRY & LOAD CELLS

Boissy et al 1997

Ada et al 2001
# Results

## CLINICIAN RATING FORM

<table>
<thead>
<tr>
<th></th>
<th>Excursion and duration of associated reaction</th>
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<tbody>
<tr>
<td>A</td>
<td></td>
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<td>B</td>
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<tr>
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<th>Release of associated reaction</th>
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<tbody>
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<td>C</td>
<td></td>
</tr>
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<th>Effect of upper limb associated reaction on functional task (sit-to-stand, stand to sit)</th>
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<tr>
<td>D</td>
<td></td>
</tr>
<tr>
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<td>No limb reaction. Task unaffected.</td>
</tr>
<tr>
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<td>2</td>
<td>Obvious interference with task, but able to complete task</td>
</tr>
<tr>
<td>3</td>
<td>Significantly affects ability to complete task or task not completed.</td>
</tr>
</tbody>
</table>

Macfarlane et al 2002
Results

PATIENT RATING FORM

Task

Date ___________ Start _______ End _______
Results Clinimetrics

- Use of COSMIN checklist not possible
- Stage 2 searches yielded no additional clinimetric information
- All authors contacted
<table>
<thead>
<tr>
<th>Method</th>
<th>Stationary or dynamic test</th>
<th>Reliability</th>
<th>Face Validity</th>
<th>Construct Validity - known groups</th>
<th>Construct Validity - Discriminant/convergent Validity</th>
<th>Ecological Validity</th>
<th>Responsiveness</th>
<th>Interpretability</th>
<th>Floor and ceiling effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Electromyography</td>
<td>Stationary&lt;sup&gt;4&lt;/sup&gt; 15, 17, 31-33, 35, 36, 39</td>
<td>0</td>
<td>0</td>
<td>[-]&lt;sup&gt;17&lt;/sup&gt;</td>
<td>[-]&lt;sup&gt;31&lt;/sup&gt;</td>
<td>[-]&lt;sup&gt;4&lt;/sup&gt;, 15, 17, 31-33, 35, 36, 39</td>
<td>[-]&lt;sup&gt;4&lt;/sup&gt;, 15, 17, 31-33, 35, 36, 39</td>
<td>[-]&lt;sup&gt;4&lt;/sup&gt;, 17</td>
<td>[-]&lt;sup&gt;4&lt;/sup&gt;, 17</td>
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<tr>
<td></td>
<td>Dynamic&lt;sup&gt;14&lt;/sup&gt; 38</td>
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<td>0</td>
<td>[+]&lt;sup&gt;14&lt;/sup&gt;</td>
<td>[+]&lt;sup&gt;31&lt;/sup&gt;</td>
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<td>0</td>
<td>[-]&lt;sup&gt;14&lt;/sup&gt;, 38</td>
<td>0</td>
</tr>
<tr>
<td>Standard Goniometry</td>
<td>Stationary&lt;sup&gt;10&lt;/sup&gt; 10</td>
<td>[-]&lt;sup&gt;10&lt;/sup&gt;</td>
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<td>0</td>
<td>0</td>
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<td>Dynamic&lt;sup&gt;3&lt;/sup&gt;, 12, 14, 38</td>
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<td>0</td>
<td>[+]&lt;sup&gt;14&lt;/sup&gt;</td>
<td>[+]&lt;sup&gt;31&lt;/sup&gt;</td>
<td>[+]&lt;sup&gt;3&lt;/sup&gt;, 12, 14, 38</td>
<td>0</td>
<td>[±]&lt;sup&gt;3&lt;/sup&gt;, 12, 14</td>
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<tr>
<td>Dynamometry</td>
<td>Stationary&lt;sup&gt;4&lt;/sup&gt; 17, 31, 37, 39</td>
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<td>[-]&lt;sup&gt;17&lt;/sup&gt;, 37, 31</td>
<td>[+]&lt;sup&gt;31&lt;/sup&gt;</td>
<td>[-]&lt;sup&gt;4&lt;/sup&gt;, 17, 31, 37, 39</td>
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<td>[-]&lt;sup&gt;4&lt;/sup&gt;</td>
</tr>
<tr>
<td>Electrogoniometry</td>
<td>Stationary&lt;sup&gt;17&lt;/sup&gt; 17</td>
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<td>0</td>
<td>[-]&lt;sup&gt;17&lt;/sup&gt;</td>
<td>[±]&lt;sup&gt;17&lt;/sup&gt;</td>
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<td>0</td>
<td>[±]&lt;sup&gt;17&lt;/sup&gt;</td>
<td>0</td>
</tr>
<tr>
<td>Clinician rating form</td>
<td>Stationary&lt;sup&gt;6&lt;/sup&gt; 6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>[-]&lt;sup&gt;6&lt;/sup&gt;</td>
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<td>0</td>
<td>[-]&lt;sup&gt;6&lt;/sup&gt;</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Dynamic&lt;sup&gt;18&lt;/sup&gt; 18</td>
<td>[+]&lt;sup&gt;18&lt;/sup&gt;</td>
<td>0</td>
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<td>[±]&lt;sup&gt;18&lt;/sup&gt;</td>
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<td>[±]&lt;sup&gt;18&lt;/sup&gt;</td>
<td>[+]&lt;sup&gt;18&lt;/sup&gt;</td>
</tr>
<tr>
<td>Patient rating form</td>
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<td>0</td>
<td>0</td>
<td>[+]&lt;sup&gt;5&lt;/sup&gt;, 39</td>
<td>[-]&lt;sup&gt;5&lt;/sup&gt;, 39</td>
<td>0</td>
<td>[-]&lt;sup&gt;5&lt;/sup&gt;, 39</td>
<td>0</td>
</tr>
</tbody>
</table>

(+) = met criteria; (±) = information unclear; (-) = did not meet criteria; (0) = no information available
## Clinical Utility Rating

<table>
<thead>
<tr>
<th>Method</th>
<th>Time to complete</th>
<th>Costs</th>
<th>Specialist equipment and training</th>
<th>Portability</th>
<th>Total (max = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Electromyography</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Standard Goniometry</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Dynamometry</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Electrogoniometry</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Clinician Rating Form</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Patient Rating Form</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>10</td>
</tr>
</tbody>
</table>
Discussion

- A few methods used to assess ARs
- No gold standard
- Measurement properties unreported
- Stationary testing positions with MVC intact arm to induce AR
- Unlikely to reflect what occurs day-to-day
- ARs are a multifactorial problem with dynamic contributing factors → Poor ecological validity
Limitations

- Terminology
- Mixed neurological cohort
- Exclusion of paediatric or juvenile onset disorders
Future Research

- Motion analysis systems for the upper limb ARs as a criterion reference
- Quantify ARs in dynamic and ecologically valid context as gold standard comparator
- Establish contributing factors
- Develop comparable clinical methods
Conclusion

- No gold standard, robust, objective, functional assessment method
- No strong clinimetric information
- Few have good clinical utility
- Most do not assess entire upper limb
- Existing methods may not detect ARs and contributing factors
The dream to find a cure came crashing down… by 2 words…
Project Outline

• Adult onset upper motor neuron injury (stroke, TBI, stable neurosurgical)

• 60 participants
  - 30 Chronic > 1 year post injury
  - 30 Subacute < 1 year post injury

• ARs in their hemiplegic upper limb during walking

• Observational study
Aims Specific to Summer Foundation Scholarship

- Develop normative dataset of arm movement during walking in healthy controls with 3DMA and Microsoft Kinect
- Develop a gold-standard, ecologically valid, dynamic assessment of ARs in people with ABI using the criterion reference 3DMA
- Determine the test-retest reliability of the 3DMA and Kinect for measuring ARs in a group of people with chronic ABI.
Aims

Additional Overall PhD Project Aims

Investigate:

- Concurrent validity

- Further test-retest reliability - chronic ABI (> 1 year post injury)

- Responsiveness - subacute ABI (< 1 year post injury)

- The main contributing impairments related to ARs of the arm
Measurements of ARs

1. Three Dimensional Motion Analysis (3DMA)
2. Microsoft Kinect (skeleton & depth sensor)
3. 2D elbow angle during walking
4. Dynamic biceps muscle surface electromyography (SEMG) during walking
5. Stationary seated maximal voluntary contraction tests (goniometer and SEMG)
6. Subjective Associated Reaction Rating Scale
“Technology empowers people to do what they want to do. It lets people be creative. It lets people be productive. It lets people learn things they didn't think they could learn before”

Steve Ballmer
Assessment of Associated Reactions
1. Three Dimensional Motion Analysis
Three Dimensional Motion Analysis
Three Dimensional Motion Analysis
Three Dimensional Motion Analysis
Three Dimensional Motion Analysis

- Normal Band
- Hemiplegic arm
- Unaffected arm
Three Dimensional Motion Analysis

Gait Profile Score  Arm Posture Score
Assessment of Associated Reactions

2. Microsoft Kinect
Microsoft Kinect
Assessment of Associated Reactions

3. Dynamic Surface Electromyography
Assessment of Associated Reactions

4. 2-Dimensional Elbow Angle (degrees)
# Assessment of Associated Reactions

## 5. Associated Reaction Rating Scale

<table>
<thead>
<tr>
<th></th>
<th>Excursion and duration of associated reaction</th>
<th>Number of joints in the affected upper limb involved in associated reaction</th>
<th>Release of associated reaction</th>
<th>Effect of upper limb associated reaction on functional task (sit-to-stand, stand to sit).</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>No involuntary movement/excursion of the limb</td>
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<td></td>
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</table>
Assessment of Associated Reactions

6. Stationary Seated Maximal Voluntary Contraction Tests – SEMG and goniometer
Stationary Seated Maximal Voluntary Contraction Tests – SEMG trace
We have an outcome measure – so what?

MY MIND SAYS, "WHO CARES?"

BUT THEN MY HEART WHISPERS, "YOU DO, STUPID..."

DespicableMeMinions.org
We have an outcome measure – THEN what…!

• Dynamic, ecologically valid measure of ARs using 3DMA – the APS
• Then we need to consider clinical utility – The Microsoft Kinect!
We have an outcome measure – **THEN** what…!

- Define nature and extent of ARs
- Establish the main contributing clinical impairments
- Guide clinical decision making and provision of therapy
Impairment Testing

• Questionnaires:
  - Short falls efficacy Scale
  - ArMA
  - Hospital Anxiety and Depression Scale
  - Arm pain/discomfort VAS

• Spasticity – hemiplegic upper and lower limb
  - Modified Tardieu Scale
  - Modified Ashworth Scale

• Hemiplegic upper limb hand held dynamometry strength
• Hemiplegic lower limb isometric leg press force
• Short Form Berg Balance Scale
• 3DMA outcome measures
  - GPS
  - Lateral COM displacement
  - Width of BOS
Testing Procedures

GROUP

TEST 1
Initial Ax

TEST 2
< 7 days post
Initial Assessment

TEST 3
> 90 days post
Initial Assessment

VALIDITY

- 3DMA
- Kinect
- Development of normative dataset
- Development of Arm Profile Score for ARs

RESPONSIVENESS AND SENSITIVITY

- 3DMA
- Kinect
- Dynamic EMG
- 2D Elbow angle
- ARRS
- SSMVCT

VALIDITY

- Baseline Clinical Assessment
- 3DMA
- Kinect
- Dynamic EMG
- 2D Elbow angle
- ARRS
- SSMVCT

RELIABILITY

- 3DMA
- Kinect
- Dynamic EMG
- 2D Elbow angle
- ARRS
- SSMVCT

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Progress so far for this grant…

- Ethics Approval HREC # 648-14
- 35 healthy controls tested & normative dataset of arm movement during walking developed
- Development of patient testing protocol
- Recruitment of 22 chronic participants
- Tested 15 chronic participants at baseline and 1 week
- Allen Martin Research Scholarship provided seeding funding for preliminary data to then be awarded a number of competitive external research grants
  - Pat Cosh Research Grant – education tool development
  - Physiotherapy Research Fund
  - Epworth Research Institute Grant
  - RACV Sir Edmund Herring Memorial Scholarship
Outcomes

• Development of user-friendly assessment tools to Ax ARs
• Improved patient care
• Creation of webpage for dissemination
  • Freely available and simply downloadable
  • Clinical translation
  • Widely accessible
  • Applicable for use in other populations
• Educational resource
• Doctoral thesis
• Publications in peer-reviewed journals
• National and international conference presentations
• Inform future studies
THANK YOU!

Any Questions?