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ASSESSMENT OF CAPACITY FOR MYOELECTRIC CONTROL: A NEW RASCH-BUILT MEASURE OF PROSTHETIC HAND CONTROL

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Objective: **To report the results from a Rasch rating scale analysis of the Assessment of Capacity for Myoelectric Control (ACMC) implemented to evaluate internal scale validity, person response validity, separation reliability, targeting and responsiveness of the measures over time.**

Design: **Longitudinal data (18 months) from a prospective study of development of capacity for myoelectric control in children and adults were used for the analysis.**

Patients: **A consecutive sample of 75 subjects (43 males, 32 females) with upper limb reduction deficiency or amputation and myoelectric prosthetic hands referred for occupational therapy from September 2000 to March 2002. Participants' ages ranged from 2 to 57 years.**

Methods: **Outcome measure was the ACMC. Occupational therapists completed 210 assessments at an arm prosthesis centre in Sweden. A two-faceted rating scale analysis of the data was performed.**

Results: **All 30 ACMC items and 96.2% of participants demonstrated goodness-of-fit to the rating scale model for the ACMC. Separation and SE values suggested adequate reliability of the item and person estimates.**

Conclusion: **The items demonstrated internal scale validity and the participants demonstrated person response validity. The ACMC was well targeted and sensitive enough to detect expected change in ability.**

Key words: psychometrics, measurement, arm prosthesis, occupational therapy.

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INTRODUCTION

Persons with upper limb amputations are often fitted with prostheses in order to enhance function and appearance, and to facilitate performance of activities of daily living (ADLs) (1). Besides the conventional, body-powered prosthesis, fitting of a myoelectrically controlled prosthesis is a well-established practice for persons with both acquired upper limb amputations (2) and limb deficiencies present at birth (3, 4). As part of the rehabilitation of these patients, occupational therapists provide training in natural contexts so that competence in prosthetic use in everyday life can be ensured. The overall aim is for these persons to use the artificial limbs in such a way that they realize unrestricted possibilities for age-relevant performance of ADLs and participation in society.

When fitted with a myoelectric prosthesis, an additional issue arises related to the person's capacity for myoelectric control. That is, if the person does not display good myoelectric control, he or she will probably have more difficulty in performing essential ADLs (5). Unlike conventional prostheses, myoelectrically controlled prostheses have motorized operation of the opening and closing of the terminal device. Electrodes, located inside the prosthetic socket over muscle bellies, allow detection of electrical activity in the muscles. The contracting muscle activates the motor of the terminal device, and adjustments in the force or speed of the contraction control the range of opening and closing in the hand or hook.

When the occupational therapist provides training in natural contexts, several additional qualitative aspects of myoelectric control must be considered. For example, especially for persons fitted for the first time, the myoelectric prosthetic arm is often heavy. This can result in difficulties in contracting the correct muscle and activating the motor in the desired direction when the arm is not supported, for example when it is resting on a table. Moreover, there is no positional feedback from the myoelectric prosthetic hand to inform the user whether the prosthetic hand is open or closed. Hence, most people need to look at their prosthetic hands to determine their positions. To be able spontaneously to use the myoelectric prosthetic hand in ADLs, new prosthetic users must, therefore, learn to operate the hand without visual feedback. Although improved myoelectric control is thought to enhance the person's ability to perform essential tasks, there is no standardized method for measuring qualitative aspects of myoelectric control in daily life in an individual subject.

In order to meet the need for a valid, reliable and sensitive evaluation, the Assessment of Capacity for Myoelectric Control (ACMC) was developed. The ACMC is administered and scored based on clinical observations of the myoelectric prosthesis user as he or she is gripping, holding and releasing daily life objects when, for example, preparing a chosen meal, or, in the case of a child, playing. The items comprising the ACMC (see Appendix) describe different levels of difficulty of control of the

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myoelectric hand. Each item is scored on a 4-point ordinal scale. To convert these ordinal ratings into linear measures of myoelectric control (6), the ACMC has been developed using Rasch analysis methods (7, 8). The family of Rasch measurement models (7) has been used increasingly in rehabilitation to develop linear measures of ability (9–12). The 30 items included in the current version of the ACMC were previously piloted and then revised based on an earlier Rasch analysis of the tool. Items in the earlier version found to be redundant or misfitting to the Rasch rating scale model of the ACMC were eliminated. The aim of the present study was to evaluate the revised tool for aspects of validity and reliability.

The specific research questions addressed were as follows: (i) Do the ACMC demonstrate internal scale validity as evidenced by goodness-of-fit to a Rasch rating scale model?; (ii) Do the people using myoelectric prostheses show person response validity as indicated by goodness-of-fit to the Rasch rating scale model?; (iii) Are the item difficulty and person ability measures associated with separation indices greater than 2.0?; (iv) Are the items on the ACMC targeted in terms of difficulty to the abilities of the persons tested?; and, (v) Are the person ability measures sensitive measures of expected change?

METHODS

Participants

In this study, data collected prospectively from September 2000 to March 2002 were analysed. Seventy-five persons participated (43 males, 32 females, aged 2–57 years, mean age 8 years, interquartile range 5–14 years); the final analysis was based on 210 assessments. More specifically, the participants were all persons who were tested 1–9 times (median 2) over an 18-month period as they were developing their overall capacity for myoelectric control both through normal growth and development, and ongoing treatment. All participants had a congenital upper limb deficiency ($n = 64$) or acquired amputation ($n = 11$) and had been fitted with a myoelectrically controlled prosthesis. They had been referred for fitting of artificial limbs by primary and secondary health care centres throughout Sweden.

The participants entered the study consecutively during the study period. For some of the participants ($n = 11$), this was the first myoelectric fitting. Other participants had had myoelectric prostheses for a period of between 3 months and 19 years prior to entering the study. Clinically, all participants had transverse upper limb deficiency, 30 participants had right-sided limb deficiencies (transhumeral = 2; transradial = 21; hand = 7), and 45 had left-sided limb deficiencies (transhumeral = 4; transradial = 31; hand = 10). Depending on their ages, the participants had been fitted with myoelectric prosthetic hands of different sizes; and depending on the level of their deficiency, they had been fitted with additional body-powered or friction-regulated prosthetic joints (i.e. wrist, elbow or shoulder joints). All participants exhibited developmentally typical physical and mental behaviour. The data were generated by assessments made by 3 occupational therapists and 2 occupational therapy students.

Instrumentation

A basic premise of the ACMC is that the evaluation is made during the performance of everyday tasks. In contrast to many other instruments, the ACMC does not require the use of specific tasks or tools. According to the ACMC manual (13), any task, easy or difficult, can be used to evaluate the capacity for control, as long as the task requires active use of both hands (i.e. the unaffected hand and the prosthetic hand). A person with a prosthetic hand would not naturally use the prosthesis as a dominant hand. Only the performance of simple actions requiring the use of the prosthesis is considered in the evaluations. Hence, any tasks chosen as purposeful and meaningful to the individual may be used for the assessment. For example, a person might be observed whilst preparing a simple meal, making a bed, doing crafts or playing with different toys. The persons are encouraged to accomplish the tasks spontaneously in their usual way (i.e. by using the prosthetic hand as they are used to, as an active assisting hand or as a passive support or stabilizer of objects). If they need help to be able to perform the task successfully, the occupational therapist adjusts the task (e.g. by helping a young child to read recipes and measure the ingredients for cooking). It is the person's capacity to control the myoelectric prosthesis that is evaluated, not the person's independence or quality of task performance.

As the persons perform chosen tasks and actively or passively use their prosthetic hand, the occupational therapist assesses their capacity for control of their myoelectric prosthesis by rating their performances on items representing different aspects of quality of myoelectric control. The 30 items in the ACMC are classified into 4 groups: (i) gripping (12 items), (ii) holding (6 items), (iii) releasing (10 items) and (iv) co-ordinating between hands (2 items) (Appendix). Each person's performance is rated with scores ranging from 0 to 3, where 0 = not capable, 1 = sometimes capable, capacity not established, 2 = capable on request and 3 = spontaneously capable (13).

Procedure

Before its initiation, this study was approved by the local county council ethics committee review board. Informed consent was also obtained from all participants and, when appropriate, their parents.

The 5 raters were initially trained in the administration of the ACMC by the first author and received an administration manual (13). When data collection was initiated, the participants were evaluated during regular visits to the occupational therapy clinic for planning, re-evaluation and/or training. The rater was to score each item of the ACMC after having observed the participant performing the task. If a particular item was not part of the task performed, the item was to be recorded as missing. That is, it occasionally is possible that a person can be observed performing a task where there is no opportunity to observe the person's relative level of myoelectric control. While this situation is most likely to arise with more difficult items on the ACMC, we felt that it was most appropriate to make no assumptions about level of control if the action was required by the task and therefore not observed. An advantage of using the family of Rasch models is that they allow for missing data (14).

Statistics

The data were entered into the computer by the first author and analysed using the FACETS Rasch measurement computer program (version 3.1) according to a 2-facet rating scale model with 4 response categories. Rasch analysis methods are discussed in detail elsewhere (7, 8, 11, 14). The goal was to construct a unidimensional scale that yields valid measures of person capacity to control myoelectric prostheses.

From the ACMC raw scores, the FACETS program estimates an ability measure for each person and a difficulty calibration for each item, locating both persons and items on the same common linear metric. Measures and calibrations are expressed in logits (log-odds probability units). The estimated measures and calibrations are accompanied by goodness-of-fit statistics that can be used to determine whether persons and items meet the expectations of the model. For items, fit statistics are used to determine whether each item fits a single underlying unidimensional construct; when at least 95% of the items demonstrate acceptable goodness-of-fit, the scale can be said to possess internal scale validity (7, 14). For persons, fit statistics are used to verify that the persons have responded to the items in an expected manner (14). That is, persons who have higher myoelectric control are expected to pass more difficult items than persons with less myoelectric control, and all persons are expected to be more likely to pass easy items than difficult items. When at least 95% of the persons demonstrate acceptable goodness-of-fit, the people can be said to have valid patterns of response or person response validity.

The acceptable range for item and person mean-square (*MnSq*) fit statistics in observational rating scales is 0.6 to 1.4 (15). The standardized fit statistic (z) is used to evaluate the significance of the *MnSq* values. The commonly accepted interpretation of z is that values greater than -2 or less than 2 indicate compatibility with the relevant Rasch model (8). The measures and calibrations are also accompanied by standard errors (SEs), which indicate the precision of each calibration and measure. Separation, an index of the spread of the person ability measures and item calibrations relative to their precision (16), is used to estimate the number of strata that are distinguished by the test (14). Both SE and separation are indices of reliability.

In order to ensure that repeated assessments of the same persons did not result in a violation of local independence, we initially obtained item difficulty estimates based on the first assessment ($n = 75$) for all persons. We then obtained item difficulty estimates for all 210 assessments. Calculation of the standardized difference (Z) revealed stable item calibration values ($Z < 2.0$, $p \leq 0.05$) (7, 14). These results were further confirmed by Pearson product moment correlations between the 2 sets of item calibrations, $r = 0.99$. Hence, all 210 assessments were analysed together.

Evaluation of change

To evaluate whether or not the ACMC myoelectric control ability measures are sensitive measures of expected change, the participants were divided into 2 clinical groups: (i) participants who had been using a myoelectric prosthesis prior to this study; the ability measures of these persons were expected to remain relatively constant over sessions (time); (ii) participants who were fitted for the first time with a myoelectric prosthesis; these participants were expected to display improvements in capacity for myoelectric control over time, with an increase in their ability measures by session. All participants from each group who had been assessed at least 6 times were selected. At least 6 assessments per subject were considered needed in order to see a clear pattern between and within individuals.

RESULTS

Internal scale validity

All 30 ACMC items demonstrated acceptable goodness-of-fit (*MnSq* ≥ 0.6 and ≤ 1.4 and/or $z > -2$ and < 2), indicating that the items met the model expectation of unidimensionality (8, 15).

Person response validity

Only 8 individual assessments (3.8%) failed to demonstrate acceptable goodness-of-fit (*MnSq* < 0.6 or > 1.4 and $z \leq -2$ or ≥ 2); 5% would be expected to misfit due to chance (8, 17). Thus 96.2% of the participant assessments showed valid response patterns across items as expected by the Rasch rating scale model of the ACMC. Further examination of the data revealed no consistent pattern of misfit associated with age, gender, aetiology, level or side of deficiency, or level of ability to control the prosthesis among the 3.8% who failed to exhibit acceptable goodness-of-fit. We concluded therefore, that the failure of those 3.8% of the participants to fit the model was due to random error.

Separation

The separation index for items was 11.59, indicating that the participants separated the items into 16 statistically distinct item strata. The associated mean SE for items was 0.17 logit (range 0.12–0.28 logit). The participant separation index was 3.79, indicating that the items separated the 210 assessments into 5 statistically distinct strata based on the persons' myoelectric control capacity. The associated mean SE for the person ability measures was 0.59 logit (range 0.30–1.87 logit).

Targeting

The map of the person ability measures in relation to the item difficulty calibrations (Fig. 1) shows that the items were well targeted to the abilities of the persons. Only 12 persons had ability measures of ≥ 4.0 logits. They also had overall higher SEs associated with the estimates of their ability measures. Seven persons had ability measures ≤ -4.0 logits. They also had overall higher SEs associated with the estimates of their ability measures.

```
|Measure|Persons   |Items          |Scale|
----------------------------------------------
+      7 +           +               +(3)   +
|        |           |               |      |
|        | .         |               |      |
+      6 + *         +               +      +
|        |           |               |      |
|        |           |               |      |
+      5 +           +               +      +
|        | *.        |               |      |
|        | **        |               |      |
+      4 + *         +               +      +
|        | ***       |               |      |
|        | ***       | 16            |      |
+      3 + ******    + 35            +      +
|        | ****      | 12 14         |      |
|        | *******   | 11 13         |      |
+      2 + ******.   + 32 33         + ---  +
|        | ******    | 31            |      |
|        | *****.    | 36            |      |
+      1 + ****      + 37            + 2    +
|        | ***       |               |      |
|        | ****.     | 30            |      |
*      0 * ****      * 10 28         * ---  *
|        | *******   | 8  9  19 22   |      |
|        | ****.     | 21 29 34      | 1    |
+     -1 + *****     + 20            +      +
|        | ***.      | 7             |      |
|        | **.       | 5  27         |      |
+     -2 + **        +               + ---  +
|        | ***       | 6  18         |      |
|        | **.       |               |      |
+     -3 + **.       +               +      +
|        | *****     | 17            |      |
|        | *.        | 4             |      |
+     -4 + .         + 26            +      +
|        | *         |               |      |
|        | .         |               |      |
+     -5 +           +               +      +
|        | .         |               |      |
|        | .         |               |      |
+     -6 +           +               +      +
|        |           |               |      |
|        | .         |               |      |
+     -7 +           +               +(0)   +
----------------------------------------------
|Measure| * = 2      |Items          |Scale |
----------------------------------------------
```

Fig. 1. Targeting of the Assessment of Myoelectric Control: persons ability measures in relation to item difficulty calibrations. Expected scores and thresholds for adjacent response categories on the rating scale. High measure indicates high persons ability and difficult item. Item numbers refer to numbers in the Appendix.

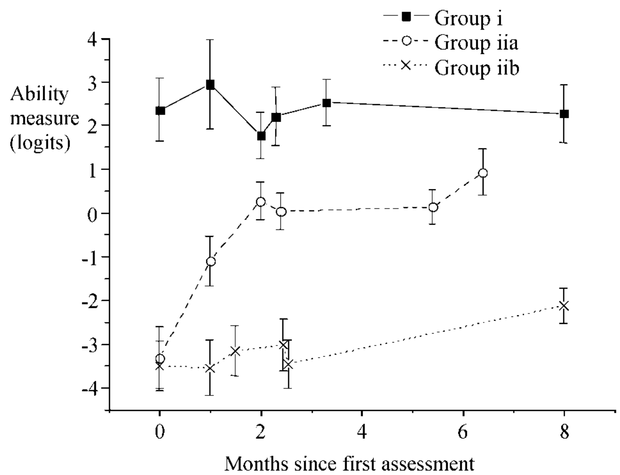

Fig. 2. Mean ability measures for experienced prosthetic users (group i), new prosthetic users with expected improvements (group iia), and new prosthetic users with additional problems (group iib) distributed over months since first assessment. Vertical bars (whiskers) indicate standard error of the measures.

Evaluation of change

Of the 75 participants, 10 (13%) underwent at least 6 assessments during this 18-month study period, 3 were in group i (experienced users) and 7 were in group ii (new users). The mean ability measures for each of the first 6 sessions for each group were plotted in Figure 2 to determine whether the intra- and inter-group changes in ability were consistent with expectations based on the clinical knowledge of the participants prosthetic experience. Overall, the results confirmed our expectations. However, in group ii, we noted 2 different patterns, 1 for persons with successful prosthetic fitting (group iia; $n = 5$) and another for those who had additional problems and, therefore, experienced difficulty learning myoelectric control (group iib; $n = 2$). As a result, their ability measures did not increase at the same rate as did those of the other participants in group ii (see Fig. 2).

DISCUSSION

In this study, aspects of validity and reliability of a newly developed instrument, the ACMC, were evaluated. The results revealed that the ACMC items met the Rasch rating scale model expectations for unidimensionality indicating that the ACMC demonstrated internal scale validity (7, 14). Similarly, persons with myoelectric prostheses met the model expectations for person response validity. Separation of items and persons into distinct strata, as well as reasonable SEs, support the reliability of the estimated item difficulty and person ability measures. The finding that the mean SEs of persons not at the upper and lower ends of the myoelectric control continuum were less than 0.54 logits further supported the reliability of the person ability estimates.

The limits of the range measurable with the ACMC is indicated by the range of item difficulty (Fig. 1). While in this study the ACMC does not demonstrate a ceiling effect (where persons with higher ability obtain maximum possible scores), persons with higher ability in another sample may achieve the maximum score. It is not possible to study improvements in these persons, or to differentiate between them, without increasing the range of the instrument. For further improvement of the ACMC, adding more difficult items will be considered. A floor effect (where persons with low ability obtain no scores) is not likely to occur in the ACMC. This is demonstrated by the results from this study, where persons with no previous experience from myoelectric control were tested and none obtained minimum possible score.

All participants who were attending the occupational therapy clinic during the study period (18 months) were consecutively enrolled in the study. Most of the subjects (64%) attended the clinic more than once, and were thus repeatedly assessed. In accordance with other studies (18), this repeated testing of the sample was used effectively to increase the sample size so as to ensure more stable estimates of item difficulties (19). Several factors converge to suggest that the use of repeated measurement did not violate the assumption of local independence. Firstly, the item calibration values remained stable between those based on the first evaluation of each participant and those based on all 210 evaluations. Secondly, most participants were tested several times, decreasing the probability that repeated testing over time in a few individuals would bias the results. Furthermore, the repeated testing of participants as they developed increasing skill ensured that most individuals were tested across a range of control ability. Earlier reports have demonstrated that when respondents repeatedly take test, the items get easier (20). Also, different items can respond differently to repeated testing, with some items becoming easier than others. However, in this study, it was the occupational therapist who rated the items. The participants knew only that they were under observation and being evaluated. This may have influenced their overall use of their prostheses, but it seems unlikely that such effects would increase with repeated testing. Future research would be needed to know for sure.

As reported earlier, items potentially observable but impossible for the participant to perform should be scored 0 rather than missing. All ACMC items except 3 can be observed in any task. More specifically, as long as the person performs a task where he or she moves about in the room, all ACMC items could be assessed (21). In this study, however, some raters have confused difficult items with missing items. Failure of some raters to leave hard items blank rather than score them as 0 could account for higher SE among those participants. Since it is not possible to differentiate retrospectively between those items that were too difficult and erroneously left blank, and those left blank because they were not observable, revision of the ACMC manual to clarify the importance of scoring all observable items and then implementing further research is warranted. Further research will also be important to further examine aspects of validity and reliability of the ability estimates. For example, the items may not be equally difficult to perform in different situations or tasks. The independence of the item difficulty relative to the type of task (e.g. feeding, cooking, doing crafts) will need to be evaluated with a larger sample. Likewise, rater severity and reliability will need to be addressed in future studies. Finally, to further validate the ACMC measures, responsiveness to treatment and prosthesis adjustment, predictive power and sensitivity to change, are also needed.

The results of this study have important implications for occupational therapists working in the field of upper limb prosthetics and for the children and adults with myoelectric hand prostheses receiving therapy. One of the main issues in clinical practice is to ensure that occupational therapy interventions are cost-effective. In the past, there was a lack of occupational therapy methodology for determining a person's current level of myoelectric control, which is vital for planning, re-evaluating, or measuring the outcomes of prosthetic control training. The ACMC has the potential to help therapists and prosthetic users to monitor individual patterns of prosthetic skill development, and evaluate intervention efficacy. The context in which these assessments are made (in the performance of purposeful and meaningful occupations) allows evaluation of spontaneous myoelectric control reflecting the most important aspects of prosthetic use. Our preliminary results indicate that by using the ACMC, it may be possible systematically to study the development of myoelectric control and search for factors that lead to an increase or decrease in myoelectric control.

The early findings by Hubbard et al. (5) indicate that the capacity to control a myoelectric prosthesis, as measured by ACMC, is fundamental to the future use of the functions of the prosthetic hand. More research is needed systematically to examine the relationship between the capacity for myoelectric control and the person's actual use of the prosthesis in everyday life, and if good myoelectric control leads to greater habitual use for performing essential daily life tasks (22).

In conclusion, the ACMC seems to yield valid interval and reliable level measures that can be used to evaluate the capacity to control a myoelectric prosthesis in both children and adults. It represents an innovative evaluation method, and may improve evaluation of the effectiveness of rehabilitation of individuals with externally powered prostheses. The results of this study also show that evaluations based on individuals' performances of natural tasks are possible and should, therefore, be encouraged.

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APPENDIX. ASSESSMENT OF CAPACITY FOR MYOELECTRIC CONTROL ITEMS

Gripping	4	Grips with weight supported
	5	Positions the hand and grips
	6	Uses the tripod pinch grip with weight supported
	7	Positions the hand and uses the tripod pinch grip
	8	Adjusts grip force to avoid crushing
	9	Grips with the arm in different positions
	10	Grips through iterative refinement, manipulates
	11	Grips object by feeding arm forwards
	12	Grips object moving towards the hand
	13	Grips with no visual feedback
	14	Adjusts grip force with no visual feedback
	16	Grips behind the back to manipulate object
Holding	17	Holds with arm supported
	18	Holds without support
	19	Holds without crushing
	20	Holds with the arm moving
	21	Holds with no visual feedback
	22	Holds with the arm moving, no visual feedback
Releasing	26	Releases with arm supported
	27	Positions the hand and releases
	28	Looses grip without dropping object
	29	Releases the grip with arm in different positions
	30	Releases through iterative refinement, manipulation
	31	Releases object with arm swinging low
	32	Releases object by feeding arm forwards at, or above, shoulder height
	33	Releases synchronized with the other hand
	34	Releases with no visual feedback
	35	Releases behind the back to manipulate object
Co-ordinating	36	Co-ordinates grip using both hands
	37	Co-ordinates release using both hands