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TITLE:

Computerized Adaptive Testing System of Functional Assessment of Stroke

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KEYWORDS:

Stroke, patient outcome assessment, motor skills, postural balance, activities of daily living, computerized adaptive testing, item response theory

SUMMARY:

Here, we present a protocol to develop the computerized adaptive testing system of the functional assessment of stroke (CAT-FAS). The CAT-FAS can simultaneously assess four functions (two motor functions [upper and lower extremities], postural control, and basic activities of daily living) with sufficient reliability and administrative efficiency.

ABSTRACT:

The computerized adaptive testing system of the functional assessment of stroke (CAT-FAS) can simultaneously assess four functions (motor functions of the upper and lower extremities, postural control, and basic activities of daily living) with sufficient reliability and administrative efficiency. CAT, a modern measurement method, aims to provide a reliable estimate of the examinee's level of function rapidly. CAT administers only a few items whose item difficulties match an examinee's level of function and, thus, the administered items of CAT can provide sufficient information to reliably estimate the examinee's level of function in a short time. The

CAT-FAS was developed through four steps: (1) determining the item bank, (2) determining the stopping rules, (3) validating the CAT-FAS, and (4) establishing a platform of online administration. The results of this study indicate that the CAT-FAS has sufficient administrative efficiency (average number of items = 8.5) and reliability (group-level Rasch reliability: 0.88 - 0.93; individual-level Rasch reliability: ≥70% of patients had Rasch reliability score ≥0.90) to simultaneously assess four functions in patients with stroke. In addition, because the CAT-FAS is a computer-based test, the CAT-FAS has three additional advantages: the automatic calculation of scores, the immediate storage of data, and the easy exporting of data. These advantages of the CAT-FAS will be beneficial to data management for clinicians and researchers.

INTRODUCTION:

Dysfunctions of the upper and lower extremities (UE and LE), postural control, and basic activities of daily living (BADL) are major sequelae of stroke[1-3]. The assessment of these four functions in patients with stroke is fundamental for clinicians to evaluate patients' levels of dysfunctions, set treatment goals and plans, and monitor the longitudinal trajectories of these functions.

The Fugl-Meyer Assessment (FM),[4] the Postural Assessment Scale for Stroke patients (PASS),[5] and the Barthel Index (BI)[6] have good psychometric properties to assess the UE/LE motor functions, postural control, and BADL, respectively, in patients with stroke[7-9]. However, the total of 72 items from these three measures impedes the feasibility of assessing all three measures within a time-limited therapeutic session. A more efficient testing method is warranted. Computerized adaptive testing (CAT) is a modern measurement method. Compared with conventional measurement methods, CAT provides a more reliable estimate of the examinee's level of function in much less time[10-12]. In conventional measurement methods, each examinee receives the same test form (or item sets), in which many items are too difficult or too easy for the examinee. These items provide limited information for estimating the examinee's level of function and are time-intensive for examinees. In contrast, in CAT, each examinee gets a tailored item set, in which the difficulty level of the selected items meets the function level of the examinee. Because these items are tailored for that particular examinee, CAT can provide a more reliable estimate of the examinee's level of function with fewer items and, thus, in much less time. The steps of CAT development are shown in **Supplementary File 1: Appendix 1**.

Because CAT promises reliable and efficient assessments, the CAT-FAS was developed to improve the administrative efficiency of the three measures previously used (FM, PASS, and BI)[13]. This paper describes the development and administration of the CAT-FAS. This protocol provides information for researchers to develop their CATs and for prospective users of the CAT-FAS to administer it. We also address the strengths and weaknesses of the CAT-FAS.

PROTOCOL:

This study protocol was approved by a local institutional review board, and all patients gave informed consent.

1. Development of the CAT-FAS

1.1. Retrieve the secondary and encrypted data from the FAS study[14] to conduct simulations (**Supplementary File 1: Appendix 2**).

NOTE: In the study, a total of 301 patients were recruited from a rehabilitation ward of a medical center and assessed at 14 d after stroke onset. Among the 301 patients, 262 patients were repeatedly assessed at 30 d after stroke onset. The study recruited patients who had (1) a diagnosis of stroke, (2) first onset of stroke, (3) onset of stroke within 14 d before hospitalization, (4) the ability to follow commands, and (5) the ability to give informed consent personally or by proxy. Patients who had other major diseases were excluded. In each assessment session, patients were assessed with the FM, PASS, and BI by a well-trained occupational therapist (**Supplementary File 1: Appendices 3-5**).

1.1.1. Establish the **item bank** of the CAT-FAS by adopting the item bank of the FAS (**Supplementary File 1: Appendix 2A**).

NOTE: The item bank has sufficient items fit the Rasch partial credit model[15,16] and covers a wide range of item difficulties. The item bank contains 58 items (**Supplementary File 1: Appendix 3**) selected from the FM-UE (26 items), FM-LE (11 items), PASS (12 items), and BI (nine items).

1.1.2. Retrieve the item difficulties of all items in the item bank from the FAS study (**Supplementary File 1: Appendix 2A** - Item difficulty).

NOTE: Each item in the item bank has a set of parameters to depict the difficulty of the item (*i.e.*, item difficulties), which are estimated by the Rasch partial credit model. The CAT-FAS uses the item difficulties to (1) select items with difficulties tailored to the examinee's level of function (step 1.3.3) and (2) estimate the examinee's level of function (step 1.3.5).

1.1.3. Retrieve each patient's responses (*e.g.*, 0, 1, or 2 points) to the items of the item bank of the FAS (**Supplementary File 1: Appendix 2B**).

NOTE: In previous studies[14], all items of the item bank of the FAS were administered to the patients. In this simulation study, these responses of the patients were retrieved and used as the simulated responses (patients were not administered by the CAT-FAS) to the items of the CAT-FAS (step 1.3.4).

1.1.4. Retrieve the ability distribution (*i.e.,* the standard deviation [SD] of the scores) of the patients in the four functions (BADL, postural control, and UE/LE motor functions; **Supplementary File 1: Appendix 2C**).

NOTE: The abilities of the patients in the four functions are the final scores of the assessment of the item bank (**Supplementary File 1: Appendix 2C**). The scores (and SD of the scores) of the four functions are estimated in a previous study[14] by the Rasch partial credit model, based on the patients' responses to each item (step 1.1.3). In this study, the SD of the scores is retrieved and used as prior information to calculate the reliability of the CAT-FAS (step 1.3.6).

1.2. Determine the operational algorithms of the CAT-FAS (**Supplementary File 1: Appendix 7**).

1.2.1. Adopt the maximum *a posteriori* (MAP) method for estimating each patient's scores of the four functions with Newton-Raphson iteration[17].

1.2.2. Use the criterion of D-optimality for the item selection[18]. An item with the maximum determinant of the Fisher information matrix is selected from the item bank for administration.

1.2.3. Adopt 10 candidate sets of stopping rules for exploring the properties of the CAT-FAS *via* simulation (**Supplementary File 1: Appendix 8**).

NOTE: The first five candidate sets are "reaching limited reliability increase (LRI) criterion" (*i.e.*, an LRI < 0.001, < 0.005, < 0.010, < 0.015, or < 0.020). The other five candidate sets are "reaching either LRI criterion or threshold of reliability" (*i.e.*, a Rasch reliability ≥ 0.90, paired with the aforementioned five LRI criteria). The LRI and threshold of reliability are frequently adopted stopping rules in CATs[13,17].

1.3. Explore the measurement reliability and efficiency (number of items needed for administration) of the CAT-FAS *via* steps 1.3.1 to 1.3.11 of simulation (**Figure 1**).

NOTE: **Supplementary File 1: Appendix 9** shows the screenshot of the software.

1.3.1. Use a specified set of stopping rules (*i.e.*, from the first to the last candidate sets of stopping rules which are in step 1.2.3, successively) to explore the properties of the CAT-FAS (**Figure 1A**).

1.3.2. Set the initial CAT-FAS scores of the four functions (BADL, postural control, UE motor function, and LE motor function) to 0 for specified patients (*i.e.*, from the first to the last patient in the data, successively; **Figure 1B,C**).

1.3.3. Adaptively select an item with the maximum determinant of the Fisher information matrix (*i.e.*, the criterion of D-optimality) from the item bank for administration (**Figure 1D**).

NOTE: The information matrix of each item is calculated based on a patient's scores of the four functions and the item's difficulty (from step 1.1.2). To ensure that the CAT-FAS administers at least one item in each function/domain, the first four items of the CAT-FAS are selected from the four functions.

1.3.4. Obtain the patient's response to the selected item from step 1.1.3 (**Figure 1E**).

1.3.5. Simultaneously estimate the CAT-FAS scores (and standard errors [SEs] of the scores) of the four functions using the MAP method with an iterative Newton-Raphson process (**Figure 1F**).[19] During the iterative Newton-Raphson process, renew the scores and SEs of the four functions in each iteration until the criterion of convergence is met. Convergence occurs when the differences in scores between two consecutive iterations are <0.001.

1.3.6. Count the number of items which are administered, save the latest renewed CAT-FAS scores (and SEs), and calculate the individual-level Rasch reliability of each function using the following formula:

1 - ([SE^2 of step 1.3.5] / [SD^2 of the scores of step 1.1.4]).

1.3.7. Calculate the LRI using the last renewed individual-level Rasch reliability (step 1.3.6) minus that of the previous estimation (**Figure 1G**).

1.3.8. Check whether the specified set (*e.g.*, the first candidate set) of stopping rules is met (**Figure 1H**). If not, repeat steps 1.3.3 - 1.3.8 until the specified set of stopping rules is met. If so, save the latest renewed CAT-FAS scores (and SEs) as the final CAT-FAS scores (and SEs).

1.3.9. Repeat steps 1.3.2 to 1.3.8 until all patients' administrations are completed (**Figure 1I**).

1.3.10. Finish the simulation of the CAT-FAS with the specific set of stopping rules and save the results of the simulation (**Figure 1J**).

NOTE: The results should include (1) the final CAT-FAS scores (and SEs) of the four functions, (2) the number of items needed to complete the CAT-FAS, (3) the Rasch reliability of each patient (*i.e.*, individual-level Rasch reliability), and (4) the average Rasch reliability of all patients.

1.3.11. Repeat steps 1.3.1 to 1.3.11 to explore the properties of the CAT-FAS with other candidate sets of stopping rules until all candidate sets of stopping rules are explored (**Figure 1K**).

1.4. Select the final set of stopping rules for the CAT-FAS according to the average Rasch reliability of ≥0.90 in at least three functions and the average items of administration of ≤10.0.

1.5. Develop an online administration platform for the CAT-FAS by writing a computer program to establish a website (**Supplementary File 1: Appendix 10**).

2. Administration of the CAT-FAS

2.1. Connect the examiner's electronic device (*e.g.*, personal computer, tablet, or smartphone) to the online administration platform of the CAT-FAS using an internet browser.

2.2. Log in to the administration system (**Supplementary File 1: Appendix 11**).

2.3. Click **Data management** to access data from previous examinees (**Supplementary File 1: Appendix 12**).

2.4. Click **New examinee** to create an account for a new examinee by entering the examinee's name and ID number.

2.5. Select an examinee and click **Start** (**Supplementary File 1: Appendix 13**).

2.6. Click **New assessment** to create a new assessment or click **Results** to review the results of the examinee's previous assessments.

2.7. Administer the items shown on the screen to the examinee (**Supplementary File 1: Appendix 14**).

2.8. Rate the examinee's performance or responses by clicking the rating scale shown at the bottom of the screen (**Supplementary File 1: Appendix 14**).

2.9. Explain the results of the CAT-FAS to the examinee, including the T-scores with a 95% interval, the percentile ranks of the T-scores, and the reliabilities of the four functions of the CAT-FAS. These results are calculated and shown automatically by the CAT-FAS (**Supplementary File 1: Appendix 15**).

2.10. Click **OK** and return to the **Data management** page.

REPRESENTATIVE RESULTS:

The results of the simulation showed that the 10 candidate sets of stopping rules had sufficient average Rasch reliability (0.86 - 0.95) and varied administrative efficiency (the average number of items = 6.4 - 17.5). Considering the trade-off between reliability and administrative efficiency, the set of **LRI < 0.010** was selected as the optimal set of stopping rules for the CAT-FAS because of its sufficient average Rasch reliability (0.88 - 0.93, see **Table 1**), individual-level Rasch reliability (≥70% of the patients had a Rasch reliability of ≥0.90), and administrative efficiency (the average number of items = 8.5, see **Table 2**).

FIGURE AND TABLE LEGENDS:

Figure 1: Process of exploring the performance of the CAT-FAS *via* simulation analysis. This figure shows the process of exploring the measurement reliability and efficiency (number of items needed for administration) of the CAT-FAS with 10 candidate sets of stopping rules.

Table 1: Rasch reliability of the CAT-FAS. For the CAT-FAS, the average Rasch reliability of the four functions ranged from 0.88 to 0.93, and the individual-level Rasch reliability shows ≥70% of the participants with a Rasch reliability of ≥0.90.

Table 2: Efficiency (number of items) of the CAT-FAS. The average number of items needed for administration is 8.5. Most participants (66.4%) were assessed using 5 - 10 items.

DISCUSSION:

The results presented here showed that the CAT-FAS administered about 10% of the items in the original tests (the average number of items used in the CAT-FAS: 8.5 items *vs.* the original tests: 72 items). These findings indicate that the CAT-FAS has good administrative efficiency. The results were in line with previous studies, which reported that a CAT administered only about 10 items or less to assess social function, balance, or activities of daily living in patients with stroke[10,11,20]. The CAT-FAS, having good administrative efficiency, has great potential to reduce the time and burden for both patients and clinicians.

The average Rasch reliability of the CAT-FAS was 0.88 - 0.93, and more than 70% of the patients had a Rasch reliability of ≥0.90. These results reveal a good Rasch reliability of the CAT-FAS in patients with stroke. The good Rasch reliability of the CAT-FAS can be ascribed to two factors: a sound item bank and the feature of multidimensionality. First, the item bank of the CAT-FAS contains 58 items that cover a wide range of functional level for each domain[14]. The sufficient item coverage of the item bank can provide sufficient information to reliably estimate the examinee's level of function. Second, the CAT-FAS is a multidimensional CAT (*i.e.*, four domains of the CAT-FAS), in which a patient's item response on any domain can be used to simultaneously estimate the patient's abilities (scores) of all four domains by considering the correlations among all domains. This feature of a multidimensional CAT has been proven to improve the Rasch reliability in previous studies on developing multidimensional CATs[21,22]. The CAT-FAS with good Rasch reliability can be used to precisely calibrate the patients' levels of the four functions (UE/LE motor function, postural control, and BADL) with limited random measurement error.

In addition, because the CAT-FAS is a computer-based test, the CAT-FAS has three additional advantages: an automatic calculation of scores, an immediate storage of data, and the easy exporting of data. The automatic calculation of scores saves examiners' time and reduces mistakes in scoring. The immediate storage of data improves the efficiency of monitoring an examinee's longitudinal changes in the four functions. The easy exporting of data enhances the efficiency of processing electronic medical records, sharing administration results between/within clinicians and patients, and analyzing data for research. These advantages of the CAT-FAS improve the overall efficiency of data management for clinicians and researchers.

The results presented here revealed that the CAT-FAS, with different sets of stopping rules, showed different performances on administrative efficiency and reliability. In general, a trade-off relationship was found between administrative efficiency and reliability. For example, the set of **LRI < 0.001** had a higher reliability and lower administrative efficiency compared to the set of **Rasch reliability ≥ 0.90** or **LRI < 0.020**. The set of **LRI < 0.010** had both sufficient administrative efficiency and sufficient reliability, so it was selected as the final set of stopping rules for the CAT-FAS. If prospective users need the CAT-FAS to have a higher administrative efficiency or reliability, they can select another set of stopping rules for administering the CAT-FAS.

The first four items of the CAT-FAS were selected within each of the four domains. This design can prevent an unexpected situation that may occur in a multidimensional CAT. The unexpected situation is that a domain's score of a multidimensional CAT might be estimated without administering any items from that domain. The unexpected situation occurs because a multidimensional CAT can use (1) the scores of the other domains and (2) the correlations among domains to estimate the scores of the domain without any items being administered[15]. In contrast, the CAT-FAS's item selection rule of the first four items promises that at least one item from each domain is administered. Thus, the CAT-FAS can provide more representative information to estimate patients' four functions.

Three limitations of the CAT-FAS are noticed. First, the training time for administration may be long because prospective users have to become familiar with the 58 items in the item bank, as well as with the instructions and rating criteria. Second, the four domains of the CAT-FAS cannot be administered separately. Third, the results presented here were from a simulated study instead of actual administrations of the CAT-FAS in patients with stroke. Therefore, the results may be somewhat different from those of an actual administration. Field tests of the CAT-FAS are warranted in the future.

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DISCLOSURES:
The authors have nothing to disclose.

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Figure 1

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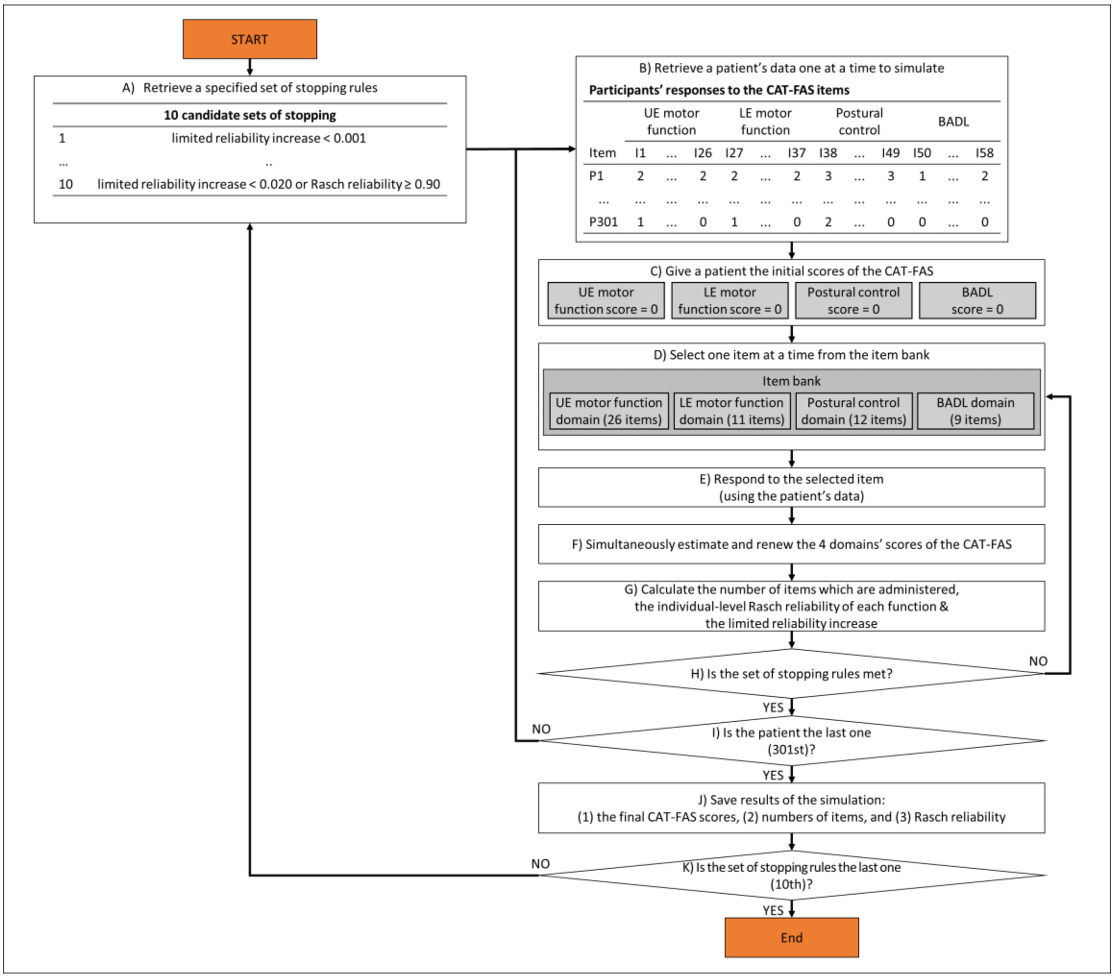

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	Average	% of the patients with reliability ≥ 0.90
CAT-FAS		
UE motor function	0.88	69.8
LE motor function	0.9	76.2
Postural control	0.93	88.6
BADL	0.9	78.9
Item bank (58 items)		
UE motor function	0.9	69.4
LE motor function	0.92	77.4
Postural control	0.96	96
BADL	0.94	93.4

UE: upper extremity; LE: lower extremity; BADL: basic activities of daily living

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	Average	Range	% of the patients using 5–10 items	% of the patients using > 10 items
CAT-FAS	8.5	~4-13	66.4	19.5

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Name of Material/ Equipment	Company
Computer	Any
MATLAB software	The MathWorks Inc
Java Development Kit	Oracle

Catalog Number	Comments/Description
	Compatible with software listed belo
http://www.mathworks.com/products/matlab/	Numerical computing software, whicl
https://www.oracle.com/java/	Programming language, which is used

N

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Article Title: The Computerized Adaptive Testing System of the Functional Assessment of Stroke

Signature:

Date: 2018/3/12

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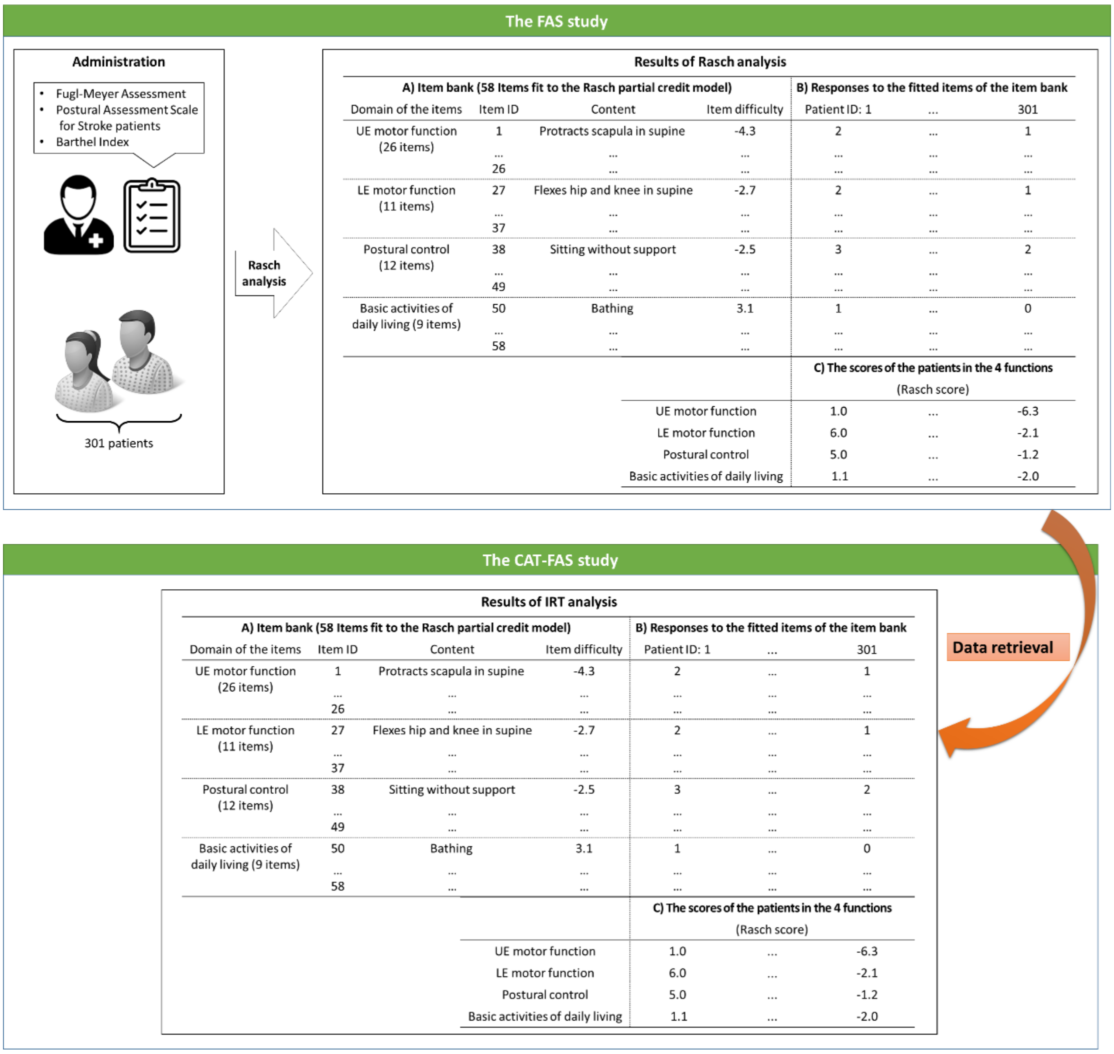
• **Protocol:**

1) We target 1 page of filmable content in the protocol. This article lacks filmable content as we cannot film section 1. Can steps to perform FAS be shown to demonstrate how the item bank is built? This can be added as a subsection under section 1.

Response: We have added the illustration of the steps of the FAS study to the Supplementary File 1: Appendix 2 as follows: "

Appendix 2. Data retrieval of the CAT-FAS study



". (Supplementary File 1: Appendix 2)

2) Several specific comments have been made on your protocol steps in the attached word doc.

Response: We have revised the manuscript according to the specific comments in the word doc. Please find the tracked changes and our responses to the specific comments in the revised manuscript.

• **Protocol Highlight:** Please highlight ~1-2.5 pages text (which includes headings and spaces) in yellow, to identify which steps should be visualized to tell the most cohesive story of your protocol steps.

1) I have highlighted steps that can be filmed. We ideally need >1-1.5 pages of filmable content in the protocol. Please see the first comment on section 1.

Response: We have highlighted the steps of the Protocol section 1 that can be filmed as follows: "

1 Development of the CAT-FAS

1.1 Retrieve the secondary and encrypted data from the FAS study[14] to conduct simulations (Supplementary File 1: Appendix 2).

1.1.1 Establish the item bank of the CAT-FAS by adopting the item bank of the FAS (Supplementary File 1: Appendix 2.A).

1.1.2 Retrieve the item difficulties of all items in the item bank from the FAS study (Supplementary File 1: Appendix 2.A. Item difficulty).

1.1.3 Retrieve each patient's responses (e.g., 0, 1, or 2 points) to the items of the item bank of the FAS (Supplementary File 1: Appendix 2.B).

1.1.4 Retrieve the ability distribution (*i.e.,* SD of the scores) of the patients in the 4 functions (BADL, postural control, UE/LE motor functions; Supplementary File 1: Appendix 2.C).

1.2 Determine the operational algorithms of the CAT-FAS (Supplementary File 1: Appendix 4).

1.2.1 Adopt the maximum *a posteriori* (MAP) method for estimating each patient's scores of the 4 functions with Newton-Raphson iteration.[17]

1.2.2 Use the criterion of D-optimality for item selection.[18] An item with the maximum determinant of the Fisher information matrix is selected from the item bank for administration.

1.2.3 Adopt 10 candidate sets of stopping rules for exploring properties of the CAT-FAS *via* simulation (Supplementary File 1: Appendix 5).

1.3 Explore the measurement reliability and efficiency (number of items needed for administration) of the CAT-FAS *via* steps 1.3.1 to 1.3.11 of simulation (Figure 1).

1.3.1 Use a specified set of stopping rules (*i.e.,* from the first to the last candidate sets of stopping rules which are in step 1.2.3, successively) to explore the properties of the CAT-FAS (Figure 1.A).

1.3.2 Set initial CAT-FAS scores of the 4 functions (BADL, postural control, UE motor function, and LE motor function) to 0 for specified patients (*i.e.,* from the first to the last patient in the data, successively; Figure 1.B and C).

1.3.3 Adaptively select an item with the maximum determinant of the Fisher information matrix (*i.e.,* the criterion of D-optimality) from the item bank for administration (Figure 1.D). The information matrix of each item is calculated based on a patient's scores of the 4 functions and the item difficulty (from step 1.1.2. To ensure that the CAT-FAS administers at least one item in each function/domain, the first 4 items of the CAT-FAS are selected from the 4 functions.

1.3.4 Obtain the patient's response to the selected item from step 1.1.3 (Figure 1.E).

1.3.5 Simultaneously estimate the CAT-FAS scores [and standard errors (SEs) of the scores] of the 4 functions using the MAP method with an iterative Newton-Raphson process (Figure 1.F).[19] During the iterative Newton-Raphson process, renew the scores and SEs of the 4 functions in each iteration until the criterion of convergence is met. Convergence occurs when the differences of scores between two consecutive iterations < 0.001.

1.3.6 Count the number of items which are administered, save the latest renewed CAT-FAS scores (and SEs), and calculate the individual-level Rasch reliability of each function using the following formula: 1 - ([SE^2 of step 1.3.5] / [SD^2 of the scores of step 1.1.4]) (Figure 1.G).

1.3.7 Calculate LRI using the last renewed individual-level Rasch reliability (1.3.6) minus that of the previous estimation (Figure 1.G).

1.3.8 Check whether the specified set (*e.g.*, the first candidate set) of stopping rules is met (Figure 1.H). If not, repeat steps 1.3.3 to 1.3.8 until the specified set of stopping rules is met. If so, save the latest renewed CAT-FAS scores (and SEs) as the final CAT-FAS scores (and SEs).

1.3.9 Repeat steps 1.3.2 to 1.3.8 until all patients' administrations are completed (Figure 1.I).

1.3.10 Finish the simulation of the CAT-FAS with the specific set of stopping rules and save the results of the simulation (Figure 1.J).

1.3.11 Repeat steps 1.3.1 to 1.3.11 to explore the properties of the CAT-FAS with other candidate sets of stopping rules until all candidate sets of stopping rules are explored (Figure 1.K).

1.4 Select the final set of stopping rules for the CAT-FAS according to the average Rasch reliability ≥ 0.90 in at least 3 functions and the average items of administration ≤ 10.0.

1.5 Develop an online administration platform of the CAT-FAS by writing a computer program to establish a website (Supplementary File 1: Appendix 7).

” (Lines 90–209, Pages 3–5, Protocol section 1)

2) The highlighted steps should form a cohesive narrative, that is, there must be a logical flow from one highlighted step to the next.

Response: Thank you for your reminder. We have highlighted the steps to form a cohesive narrative.

3) Notes cannot be filmed and should be excluded from highlighting.

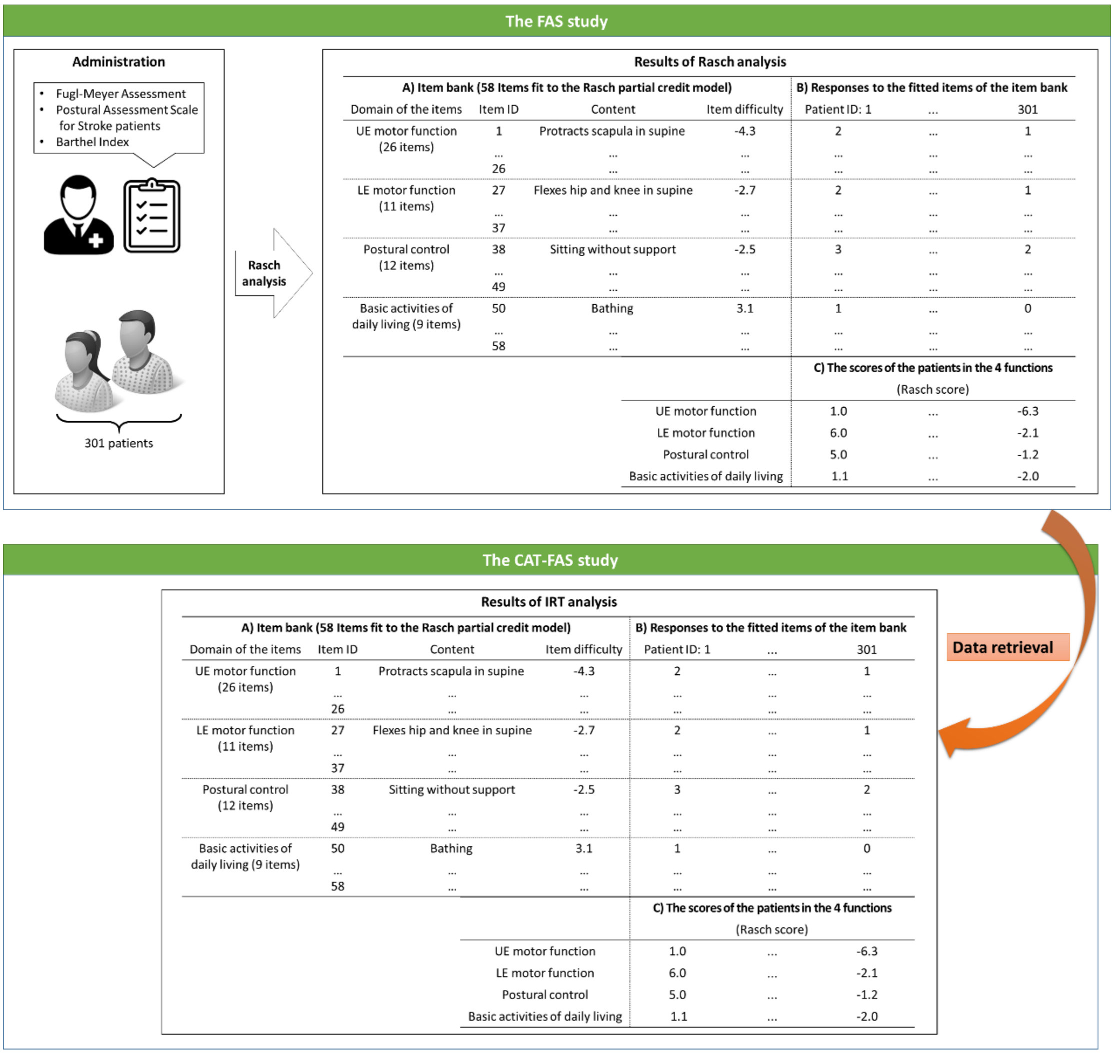
Response: We did not highlight the text in the notes.

4) Please bear in mind that software steps without a graphical user interface/calculations/ command line scripting (e.g. section 1) cannot be filmed.

Response: We have added 4 figures to the Supplementary File 1 to illustrate each step of the section 1 of the Protocol as follows: “

1.1 Retrieve the secondary and encrypted data from the FAS study[14] to conduct simulations (Supplementary File 1: Appendix 2).

Appendix 2. Data retrieval of the CAT-FAS study



1.1.1 Establish the item bank of the CAT-FAS by adopting the item bank of the FAS (Supplementary File 1: Appendix 2.A).

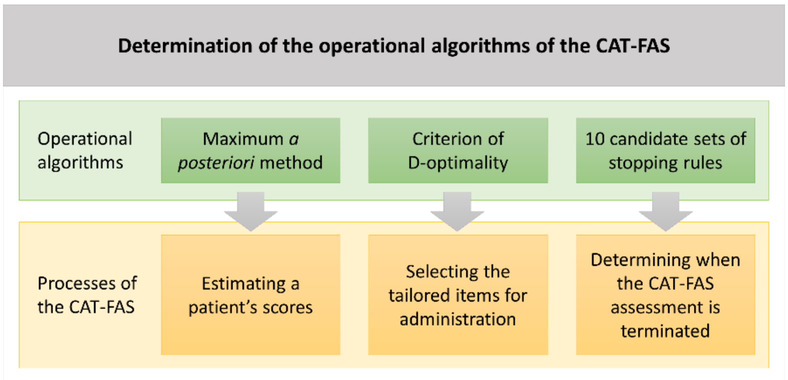
1.1.2 Retrieve the item difficulties of all items in the item bank from the FAS study (Supplementary File 1: Appendix 2.A. Item difficulty).

1.1.3 Retrieve each patient’s responses (e.g., 0, 1, or 2 points) to the items of the item bank of the FAS (Supplementary File 1: Appendix 2.B).

1.1.4 Retrieve the ability distribution (i.e., SD of the scores) of the patients in the 4 functions (BADL, postural control, UE/LE motor functions; Supplementary File 1: Appendix 2.C).

1.2 Determine the operational algorithms of the CAT-FAS (Supplementary File 1: Appendix 4).

Appendix 4. Determination of the operational algorithms of the CAT-FAS



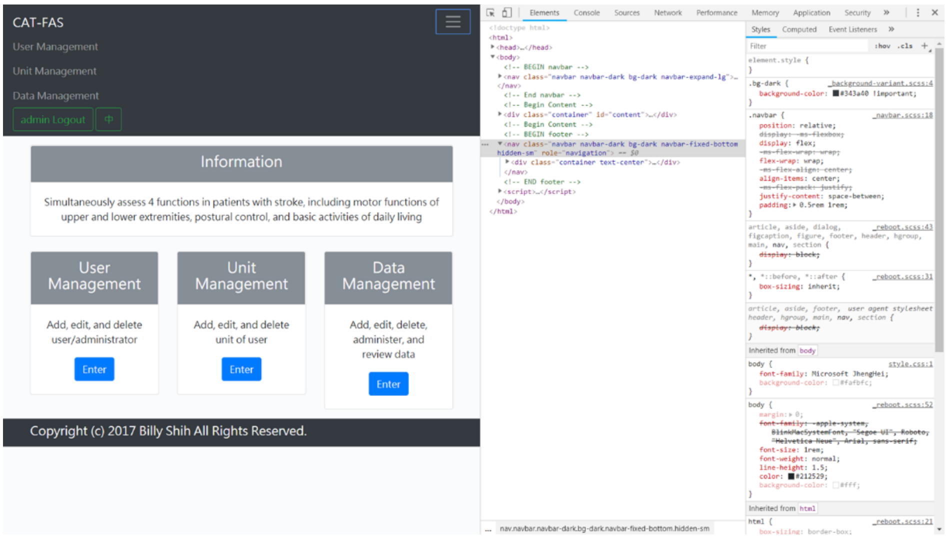
1.2.3 Adopt 10 candidate sets of stopping rules for exploring properties of the CAT-FAS *via* simulation (Supplementary File 1: Appendix 5).

Appendix 5. 10 candidate sets of stopping rules.

10 candidate sets of stopping rules	
Reaching limited reliability increase (LRI) criterion	
1	LRI < 0.001
2	LRI < 0.005
3	LRI < 0.010
4	LRI < 0.015
5	LRI < 0.020
Reaching either LRI criterion or threshold of reliability	
6	LRI < 0.001 or Rasch reliability ≥ 0.90
7	LRI < 0.005 or Rasch reliability ≥ 0.90
8	LRI < 0.010 or Rasch reliability ≥ 0.90
9	LRI < 0.015 or Rasch reliability ≥ 0.90
10	LRI < 0.020 or Rasch reliability ≥ 0.90

1.5 Develop an online administration platform of the CAT-FAS by writing a computer program to establish a website (Supplementary File 1: Appendix 7).

Appendix 7. Screenshot of the development of the online administration platform of the CAT-FAS



" (Lines 92–209, Pages 3–5, Protocol section 1)

• **Figures:** Fig 1 needs to be referenced somewhere in your manuscript text.
Response: We have added the reference to Figure 1 in Step 1.3 as follows: "1.3 Explore the measurement reliability and efficiency (number of items needed for administration) of the CAT-FAS *via* steps 1.3.1 to 1.3.11 of simulation (Figure 1)." (Lines 154–155, Page 4, Protocol section 1)

• **Figure/Table Legends:** Please expand the legends to adequately describe the figures/tables. Each figure or table must have an accompanying legend including a short title, followed by a short description of each panel and/or a general description.
Response: We have added the general description of each figure and table as follows: "Figure 1: Process of exploring performance of the CAT-FAS *via* simulation analysis. The process of exploring the measurement reliability and efficiency (number of items needed for administration) of the CAT-FAS with 10 candidate sets of stopping rules." (Lines 258–260, Page 6, Figure and table legends),
"Table 1: Rasch reliability of the CAT-FAS. For the CAT-FAS, the average Rasch reliability of the 4 functions ranges from 0.88 to 0.93, and individual-level Rasch reliability shows ≥ 70% of participants with Rasch reliability ≥ 0.90." (Lines 262–264, Page 7, Figure and table legends), and

"Table 2: Efficiency (number of items) of the CAT-FAS. The average number of items needed for administration is 8.5. Most participants (66.4%) were assessed using 5–10 items." (Lines 266–267, Page 7, Figure and table legends)

• **Table of Materials:** Please revise the table of the essential supplies, reagents, and equipment. The table should include the name, company, and catalog number of all relevant materials/software in separate columns in an xls/xlsx file. Please include items such as software used.

Response: We have added the information on the software that was used in this study to the table of the essential supplies as follows: "

Name of Material/ Equipment	**Company**	**Catalog Number**	**Comments/Description**
Computer	Any		Compatible with software listed below
MATLAB software	The MathWorks Inc.	http://www.mathworks.com/products/matlab/	Numerical computing software, which is used in the Protocol Section 1 (Step 1.3)
Java Development Kit	Oracle	https://www.oracle.com/java/	Programming language, which is used in the Protocol Section 1 (Step 1.5)

" (Table of the essential supplies)

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Table 1: Rasch reliability of the CAT-FAS

	Average	% of the patients with reliability ≥ 0.90
CAT-FAS		
UE motor function	0.88	69.8
LE motor function	0.90	76.2
Postural control	0.93	88.6
BADL	0.90	78.9
Item bank (58 items)		
UE motor function	0.90	69.4
LE motor function	0.92	77.4
Postural control	0.96	96.0
BADL	0.94	93.4

UE: upper extremity; LE: lower extremity; BADL: basic activities of daily living.

Table 2: Efficiency (number of items) of the CAT-FAS

	Average	Range	% of the patients using 5–10 items	% of the patients using > 10 items
CAT-FAS	8.5	4~13	66.4	19.5

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Appendix 1. Steps of development of computerized adaptive testing

In general, a computerized adaptive testing (CAT) is developed through 5 stages: (1) Development of an item pool, (2) Field testing of the item pool, (3) Establishment of a calibrated item bank, (4) Simulation study to determine a set of stopping rules, and (5) Development of an administration platform of the CAT.

(1) Development of an item pool.

CAT developers have to establish a pool of items by designing new items or selecting items from existing tests/scales. The item pool should include items with varied difficulty for examinees.

(2) Field testing of the item pool.

CAT developers administer the item pool to target subjects with sufficient sample size, and the subjects' level of function (or ability) should range from low to high.

(3) Establishment of a calibrated item bank.

CAT developers analyze the data of field testing using IRT software to obtain the fitness and calibrated item parameters of each item in the item pool. Thereafter, CAT developers remove the items with poor fitness from the item pool and retain or select partial items with varied item parameters to establish the calibrated item bank of the CAT.

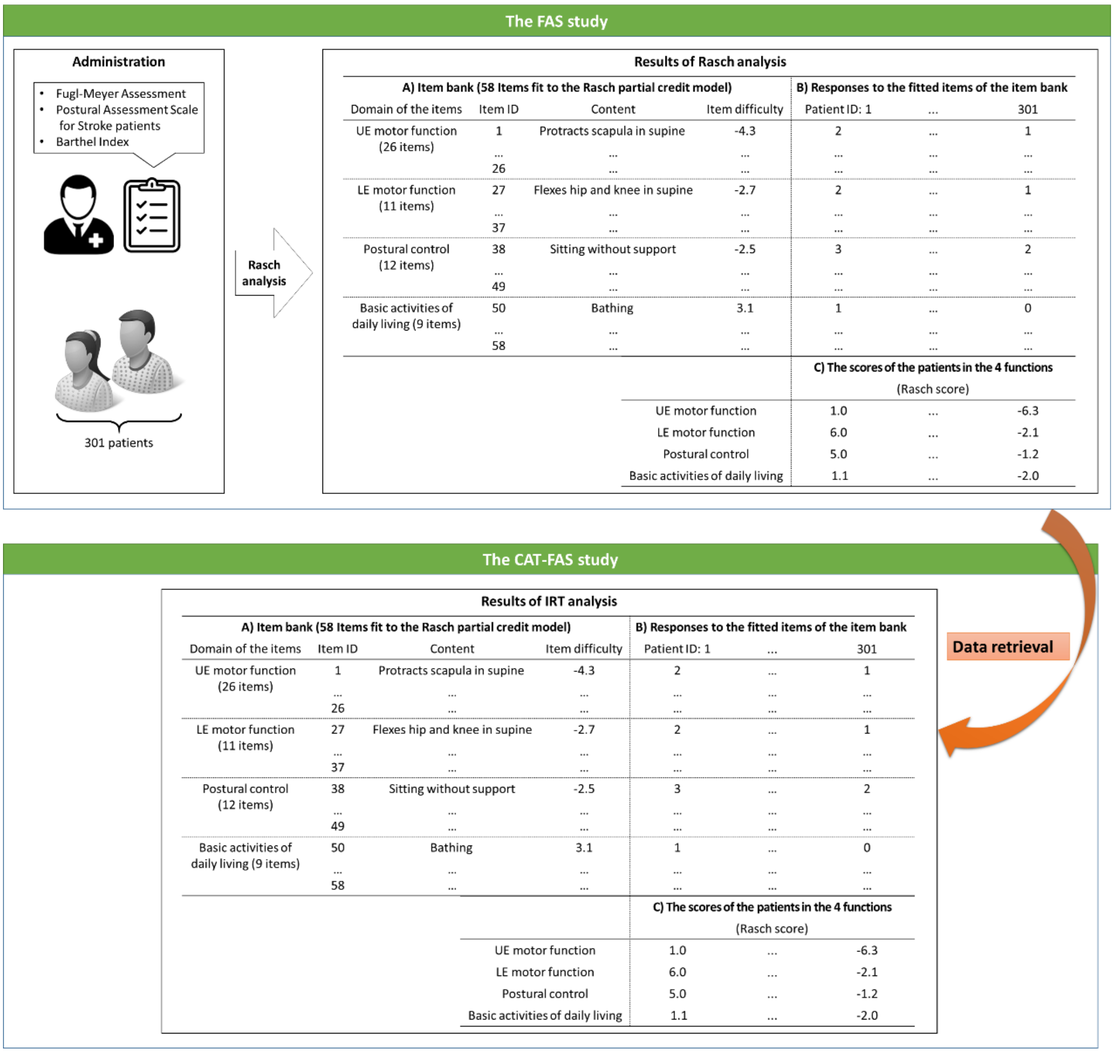
(4) Simulation study to determine a set of stopping rules

CAT developers conduct a simulation study to explore the CAT's performance (reliability and number of items administered) when the CAT adopts different sets of stopping rules. In general, the larger the number of items administered in a CAT, the higher the reliability. Therefore, CAT developers should determine a set of stopping rules with optimal balance between the reliability and the number of items administered.

(5) Development of an administration platform of CAT

CAT developers should develop a website/software/APP for administering the CAT to improve the accessibility for users.

Appendix 2. Data retrieval of the CAT-FAS study



Appendix 3. Fugl-Meyer Assessment

Fugl-Meyer Motor Assessment_U/E & L/E

◎**Upper Extremity**

A. SHOULDER/ELBOW/FOREARM

1. Reflex-activity	a	Flexors	0 2
	b	Extensors	0 2
2. a. flexor synergy			
Shoulder		Retraction	0 1 2
		Elevation	0 1 2
		Abduction	0 1 2
		Outwards rotation	0 1 2
Elbow		Flexion	0 1 2
Forearm		Supination	0 1 2
b. extensor synergy			
Shoulder		Add-/Inw. rotation	0 1 2
Elbow		Extension	0 1 2
Forearm		Pronation	0 1 2
3. Hand to lumbar spine			0 1 2
Shoulder		Flexion 0-90	0 1 2
Elbow 90		Pro-/Supination	0 1 2
4. Shoulder		Abduction 0-90	0 1 2
		Flexion 90-180	0 1 2
Elbow 0		Pro-/Supination	0 1 2
5. Normal reflex-activity	a	Flexors/ Extensors	0 1 2

B. WRIST

1. Elbow 90		Wrist-stability	0 1 2
		Wrist-flexion/extension	0 1 2
2. Elbow 0		Wrist-stability	0 1 2
		Wrist-flexion/extension	0 1 2
Circumduction			0 1 2

C. HAND

1. Finger		Mass flexion	0 1 2
		Mass extension	0 1 2
2. Grasp	a	MP joints extended, PIPs & DIPs flexed; grasp is tested against resistance	0 1 2
	b	Patient is instructed to adduct thumb, all other joints at 0	0 1 2

	c	Opposes thumb pad of index finger; a pencil is interposed	0 1 2
	d	Patient grasps a cylinder-shaped object (small can), with the volar surfaces of the first and second fingers against each other	0 1 2
	e	A spherical grasp; patient grasps a tennis ball	0 1 2

D. COORDINATION/SPEED

Finger to nose (5 repetitions)		Tremor	0 1 2
		Dysmetria	0 1 2
		Time	0 1 2

◎**LOWER EXTREMITY**

E. HIP/KNEE/ANKLE

1. Reflex-activity		Flexors	0 2
		Extensors	0 2
2. a. flexor synergy			
Hip		Flexion	0 1 2
Knee		Flexion	0 1 2
Ankle		Dorsi-flexion	0 1 2
b. extensor synergy			
Hip		Extension	0 1 2
		Adduction	0 1 2
Knee		Extension	0 1 2
Ankle		Plantar flexion	0 1 2
3. Knee (sitting)		Flexion	0 1 2
Ankle		Dorsi-flexion	0 1 2
4. Knee (standing)		Flexion	0 1 2
Ankle		Dorsi-flexion	0 1 2
5. Normal reflex-activity		Flexors/ Extensors	0 1 2

F. COORDINATION/SPEED

Heel to opposite knee (5 repetitions)		Tremor	0 1 2
		Dysmetria	0 1 2
		Time	0 1 2

Fugl-Meyer, A. R., Jaasko, L., Leyman, I., Olsson, S. & Steglind, S. The post-stroke hemiplegic patient 1: A method for evaluation of physical performance. *Scandinavian Journal of Rehabilitation Medicine.* **7** (1), 13-31, (1975).

Appendix 4. Postural Assessment Scale for Stroke patients

Postural Assessment Scale for Stroke patients

Maintaining a Posture				
1. Sitting without support (sitting on the edge of an 50-cm-high examination table [a Bobath plane, for instance] with the feet touching the floor)	0 cannot sit	1 can sit with slight support, for example, by one hand	2 can sit for more than 10 seconds without support	3 can sit for 5 minutes without support
2. Standing with support (feet position free, no other constrains)	0 cannot stand, even with support	1 can stand with strong support of 2 people	2 can stand with moderate support of 1 people	3 can stand with support of only 1 hand
3. Standing without support (feet position free, no other constraints)	0 cannot stand without support	1 can stand without support for 10 seconds or leans heavily on I leg	2 can stand without support for I minute or stands slightly asymmetrically	3 can stand without support for more than I minute and at the same time perform arm movements above the shoulder level
4. Standing on nonparetic leg (no other constraints)	0 cannot stand on nonparetic leg	1 can stand on nonparetic leg for a few seconds	2 can stand on nonparetic leg for more than 5 seconds	3 can stand on nonparetic leg for more than 10 seconds
5. Standing on paretic leg (no other constraints)	0 cannot stand on paretic leg	1 can stand on paretic leg for a few seconds	2 can stand on paretic leg for more than 5 seconds	3 can stand on paretic leg for more than 10 seconds
B. Changing Posture Scoring of items 6 to 12 is as follows (items 6 to 11 are to be performed with a 50-cm-high examination table, like a Bobath plane; items 10 to 12 are to be performed without any support; no other constraints):				
	cannot perform the activity	can perform the activity with much help	can perform the activity with little help	can perform the activity without help
6. Supine to affected side lateral	0	1	2	3
7. Supine to nonaffected side lateral	0	1	2	3
8. Supine to sitting up on the edge of the table	0	1	2	3
9. Sitting on the edge of the table to supine	0	1	2	3
10. Sitting to standing up	0	1	2	3
11. Standing up to sitting down	0	1	2	3
12. Standing, picking up a pencil from the floor	0	1	2	3

Benaim, C., Perennou, D. A., Villy, J., Rousseaux, M. & Pelissier, J. Y. Validation of a standardized assessment of postural control in stroke patients: The Postural Assessment Scale for Stroke Patients (PASS). *Stroke*. **30** (9), 1862-1868, (1999).

Appendix 5. Barthel Index

Barthel Index

Instructions: Choose the scoring point for the statement that most closely corresponds to the patient's current level of ability for each of the following 10 items. Record actual, not potential, functioning. Information can be obtained from the patient's self-report, from a separate party who is familiar with the patient's abilities (such as a relative), or from observation. Refer to the Guidelines section on the following page for detailed information on scoring and interpretation.

Bowels
0 = incontinent (or needs to be given enemata)
1 = occasional accident (once/week)
2 = continent
Patient's Score: ____________

Bladder
0 = incontinent, or catheterized and unable to manage
1 = occasional accident (max. once per 24 hours)
2 = continent (for over 7 days)
Patient's Score: ____________

Grooming
0 = needs help with personal care
1 = independent face/hair/teeth/shaving (implements provided)
Patient's Score: ____________

Toilet use
0 = dependent
1 = needs some help, but can do something alone
2 = independent (on and off, dressing, wiping)
Patient's Score: ____________

Feeding
0 = unable
1 = needs help cutting, spreading butter, etc.
2 = independent (food provided within reach)
Patient's Score: ____________

Transfer
0 = unable – no sitting balance
1 = major help (one or two people, physical), can sit
2 = minor help (verbal or physical)
3 = independent
Patient's Score: ____________

Mobility
0 = immobile
1 = wheelchair independent, including corners, etc.
2 = walks with help of one person (verbal or physical)
3 = independent (but may use any aid, e.g., stick)
Patient's Score: ____________

Dressing
0 = dependent
1 = needs help, but can do about half unaided
2 = independent (including buttons, zips, laces, etc.)
Patient's Score: ____________

Stairs
0 = unable
1 = needs help (verbal, physical, carrying aid)
2 = independent up and down
Patient's Score: ____________

Bathing
0 = dependent
1 = independent (or in shower)
Patient's Score: ____________

Total Score: ______________

(Collin et al., 1988)

Scoring:
Sum the patient's scores for each item. Total possible scores range from 0 – 20, with lower scores indicating increased disability. If used to measure improvement after rehabilitation, changes of more than two points in the total score reflect a probable genuine change, and change on one item from fully dependent to independent is also likely to be reliable.

Sources:

- Collin C, Wade DT, Davies S, Horne V. The Barthel ADL Index: a reliability study. *Int Disabil Stud*. 1988;10(2):61-63.
- Mahoney FI, Barthel DW. Functional evaluation: the Barthel Index. *Md State Med J*. 1965;14:61-65.
- Wade DT, Collin C. The Barthel ADL Index: a standard measure of physical disability? *Int Disabil Stud*. 1988;10(2):64-67.

Appendix 6. The 58 items of the CAT-FAS

Item of the CAT-FAS
FM-UE subset
1. Shoulder retraction
2. Shoulder elevation
3. Shoulder abduction
4. Shoulder external rotation
5. Elbow flexion
6. Forearm supination
7. Shoulder adduction/internal rotation
8. Elbow extension
9. Forearm pronation
10. Hand to lumbar spine
11. Shoulder flexion 0° to 90°
12. Elbow 90° pronation/supination
13. Shoulder abduction 0° to 90°
14. Shoulder flexion 90° to 180°
15. Elbow 0° pronation/supination
16. Elbow 90° wrist stability
17. Elbow 90° wrist flexion/extension
18. Elbow 0° wrist stability
19. Elbow 0° wrist flexion/extension
20. Circumduction
21. Hand, mass extension
22. Hook grasp
23. Lateral prehension
24. Palmar prehension
25. Cylinder grip
26. Spherical grip
FM-LE subset
27. Hip flexion, supine
28. Knee flexion, supine
29. Hip extension, supine
30. Hip adduction, supine
31. Knee extension, supine
32. Ankle plantar flexion, supine
33. Knee flexion, sitting
34. Ankle dorsiflexion, sitting

35. Knee flexion to 90°, standing
36. Ankle dorsiflexion, standing
37. Heel to opposite knee, time

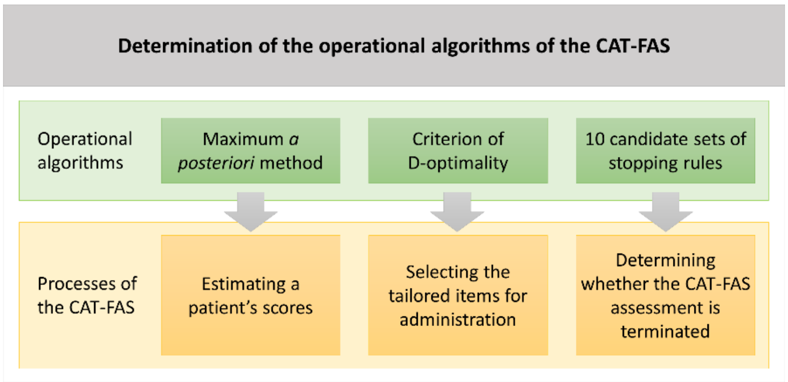
PASS subset

38. Sitting without support
39. Standing with support
40. Standing without support
41. Standing on unaffected leg
42. Standing on paretic leg
43. Supine to affected side lateral
44. Supine to unaffected side lateral
45. Supine to sitting up on the edge of the table
46. Sitting on the edge of the table to supine
47. Sitting to standing up
48. Standing up to sitting down
49. Standing, picking up a pencil from floor

BI subset

50. Bathing
51. Grooming
52. Dressing
53. Bowels
54. Bladder
55. Toilet use
56. Transfers
57. Mobility
58. Stairs

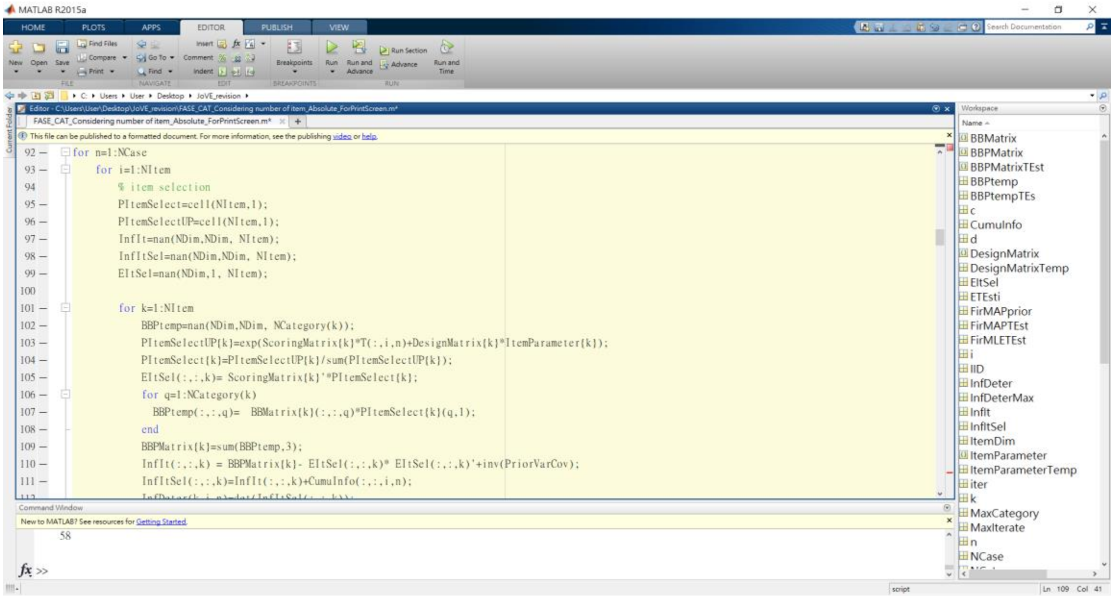
Appendix 7. Determination of the operational algorithms of the CAT-FAS



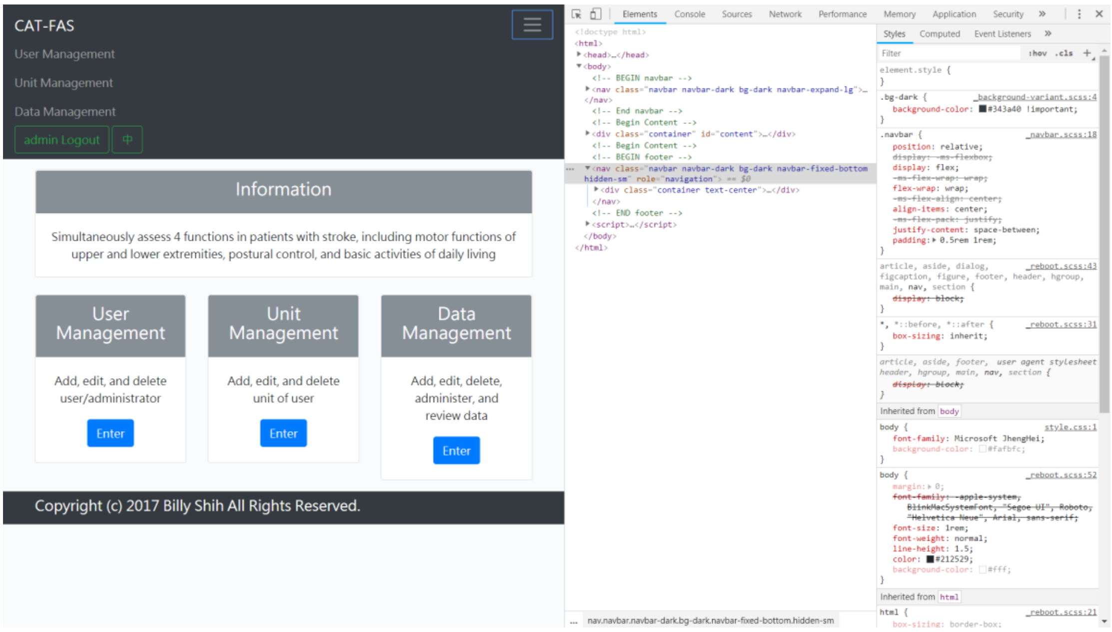
Appendix 8. 10 candidate sets of stopping rules

10 candidate sets of stopping rules	
Reaching limited reliability increase (LRI) criterion	
1	LRI < 0.001
2	LRI < 0.005
3	LRI < 0.010
4	LRI < 0.015
5	LRI < 0.020
Reaching either LRI criterion or threshold of reliability	
6	LRI < 0.001 or Rasch reliability ≥ 0.90
7	LRI < 0.005 or Rasch reliability ≥ 0.90
8	LRI < 0.010 or Rasch reliability ≥ 0.90
9	LRI < 0.015 or Rasch reliability ≥ 0.90
10	LRI < 0.020 or Rasch reliability ≥ 0.90

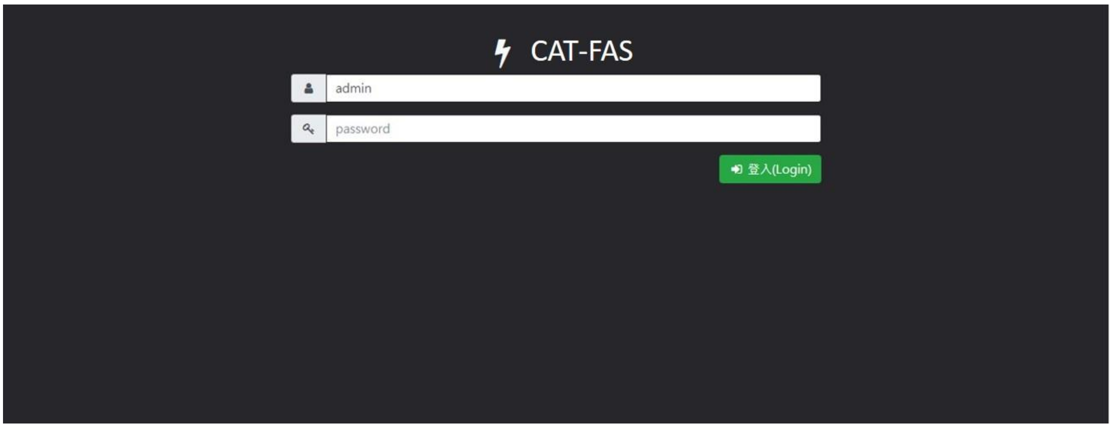
Appendix 9. Screenshot of the software conducting simulation of the CAT-FAS



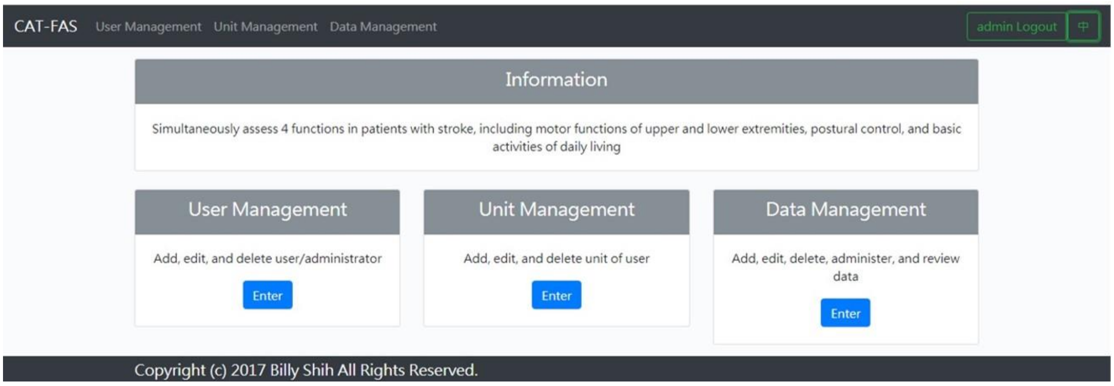
Appendix 10. Screenshot of the development of the online administration platform of the CAT-FAS



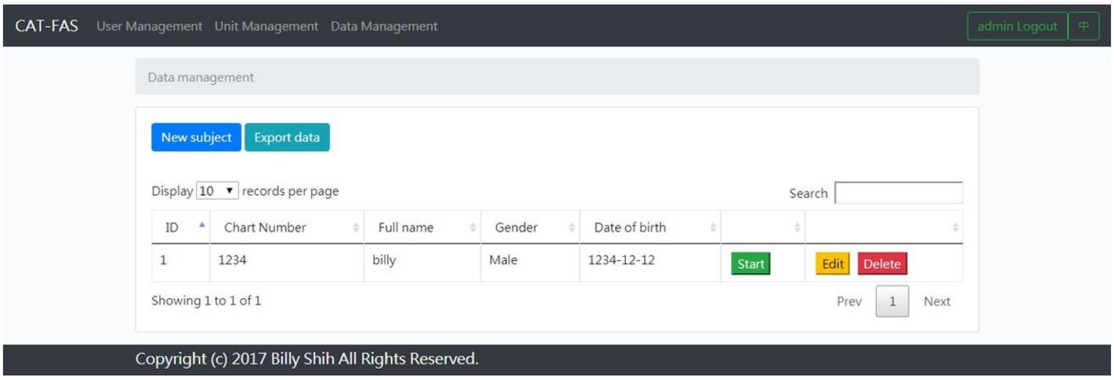
Appendix 11. Login page of the CAT-FAS



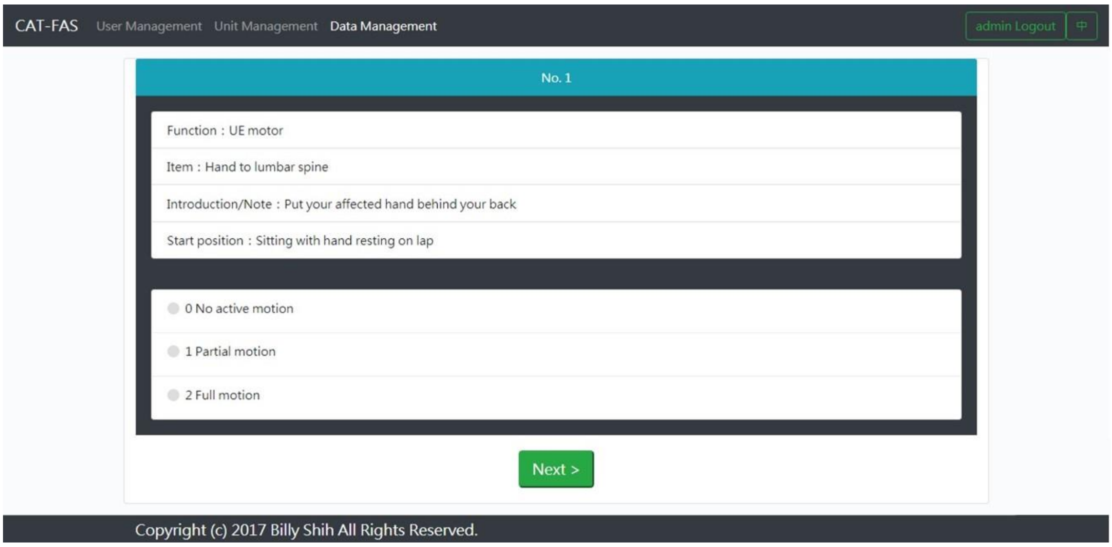
Appendix 12. Home page of the CAT-FAS



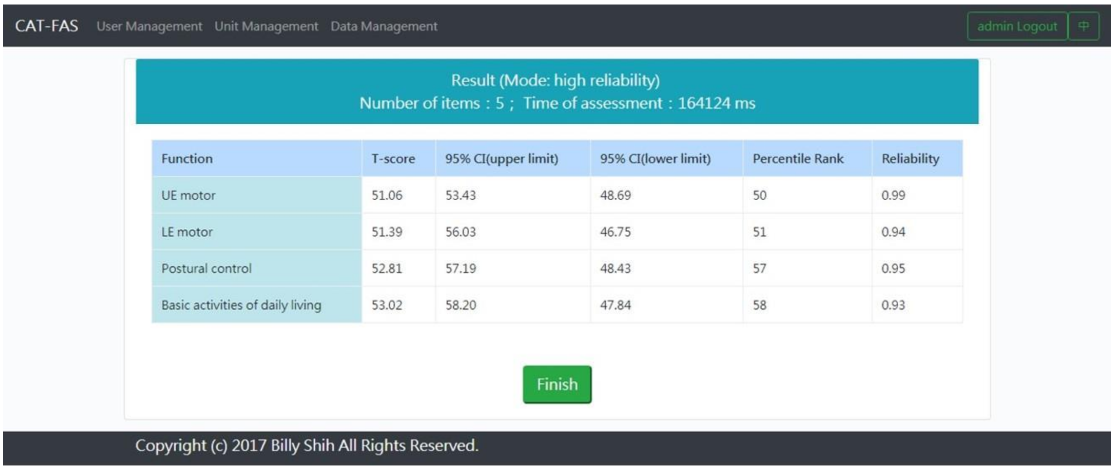
Appendix 13. Data management page of the CAT-FAS



Appendix 14. Example of an item of the CAT-FAS



Appendix 15. Results of the CAT-FAS administration



Function	T-score	95% CI(upper limit)	95% CI(lower limit)	Percentile Rank	Reliability
UE motor	51.06	53.43	48.69	50	0.99
LE motor	51.39	56.03	46.75	51	0.94
Postural control	52.81	57.19	48.43	57	0.95
Basic activities of daily living	53.02	58.20	47.84	58	0.93