Advancing Measurement for Shoulder Function

Expanding the FOTO Shoulder Functional Status (Shoulder FS) Item Bank:

A Brief Report

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EXECUTIVE SUMMARY

The item bank seeding process and evaluation were part of a planned item bank development and maintenance effort. This report has two parts.

PART 1: new seeded items. The *FOTO Shoulder Functional Status (FS)* is an item response theory patient-reported outcome measure which began as an item bank consisting of 37 items,[1-4] to which were added 16 new "seeded" items in two stages. Items added were those with content identified by clinicians and patients as important to include in the bank, and that were successfully calibrated on the existing Shoulder FS metric. The calibration process maintained *the same metric, enabling score compatibility between versions.* Briefly, once the original item calibrations were re-established to serve as anchor-able item parameters for subsequent item seeding efforts and analyses, items were seeded in two phases. First, 7 new items were successfully calibrated and added to the item bank. Second, using the original 37 + 7 previously seeded item calibrations as anchoring item parameters, 9 new items *were successfully calibrated and added, creating the final 53-item bank.*

PART 2: Analyses to determine value added. After including 16 new items, we assessed the specific value they added to the item bank, comparing the 53-item to the original 37-item bank. This part reviews the assessment of the improvements following the addition of new item content that clinicians and patients felt was (a) missing from the original item bank and (b) important for patient self-evaluation when reporting on shoulder functional status. The assessment focused on improved reliability, improved *computer adaptive test (CAT)* performance, and expanded score coverage.

Internal consistency reliability, as well as score-level reliability, increased with the original plus new seeded items. Score-level reliability increased mostly for higher scores, i.e., higher levels of FS.

CAT performance was also improved, needed a lower average # of items, measured with a lower average measurement error, across an extended score range. We observed *impressive new seeded item usage* with the CAT. For the 53-item CAT, 15 of the 16 new seeded items were administered. For the new seeded items, one had a usage rate ≥ 30%, one had a usage rate ≥ 20% and < 30%, six had usage rates ≥ 10% and < 20%, and seven had usage rates ≥ 1% and < 10%. Approximately one third (33.5%) of the CAT items administered were new seeded items.

Finally, the Shoulder FS *measurement continuum was extended* within and across all item parameter thresholds, which provides proof of an *improved range and density of item coverage* of the now expanded measurement continuum of the 53-item bank.

PART 1: New seeded item analyses (samples, anchoring, seeding process)

1.1 Background

As part of ongoing measure maintenance, the FOTO Shoulder FS item bank was expanded for the purpose of evolving measurement properties including the bank's clinical content and measurement coverage, reliability, and CAT administration process.

This maintenance process included several analytical steps that are described below.

All seeding analyses were conducted using a 1-parameter item response theory (IRT) model, the *Rasch rating scale model (RSM)*. IRT is a method for scoring items that considers 1 or more parameters on which items are characterized. The Rasch model considers the level of difficulty represented by each item.

1.2 Re-establish baseline item calibrations

Method

Prior to adding new seeded items to the item bank, original item parameters needed to be recreated to serve as an anchor to the new item parameters. This process ensures that the updated measure's metric remains the same as compared to the original metric, enabling score comparison between measure versions.

The original item bank included 37 items. Their item labels and descriptions are shown in the **Appendix.**

Response options (and scoring values) were:
I can't do this (1)
Much difficulty (2)
Some difficulty (3)
Little difficulty (4)
No difficulty (5)

Results

The 37 original item calibrations were re-established and thus available to serve as anchorable item parameters for all subsequent item seeding efforts and analyses.

1.3 Item seeding

Development of content for item seeding
New candidate items were developed in a collaborative effort between psychometric research scientists, practicing clinicians, and patients experiencing shoulder impairments. Sources included:

- Multiple physical therapists working with patients who were athletes or otherwise high functioning;
- A patient with a shoulder injury caused by playing racquet ball who also had outcome measure development experience;
- Input from patients seen in an orthopedic practice in San Diego, CA; and
- Concepts from reviews of existing outcome measures in the research literature.

Data collection took place during 2007-2014. A single seed item was administered to all patients with shoulder impairments for a 3-month period and then removed from the system. This process was repeated for each seed item, one at a time. Analytic work took place in 2 phases as described below.

Step 1 method: Seeding 7 new items

Phase 1 addressed a total of 83,408 Shoulder FS CAT surveys collected with 7 of the new seeded items that were administered to all patients during the data collection period.

Response data requirement for items to be seeded:

A minimum n = 10 responses for each item response category option (i.e., n ≥ 10 responses for *I can't do this* (1), for *Much difficulty* (2), for *Some difficulty* (3), for *Little difficulty* (4), and for *No difficulty* (5) response categories across candidate items was required for items to be included in seeding analyses.

Response options and scoring values remained the same as for the original items.

Step 1 results:

Using the 37 original item calibrations as anchoring item parameters, 7 new items, which met the minimum n ≥ 10 response category data requirements, underwent item response theory analyses and were successfully calibrated and added to the Shoulder FS item bank.

Step 2 method: Seeding an additional 9 new Shoulder FS items

Phase 2 addressed a total of 22,092 Shoulder FS CAT surveys that were collected with the remaining 9 new seeded items that were administered to all patients during the data collection period.

Step 2 results:

Using the original 37 plus the 7 previously seeded item calibrations from Step 2 as anchoring item parameters, 9 new items, which met the minimum $n \geq 10$ response category data requirements, underwent IRT analyses and were successfully calibrated and added to the Shoulder FS item bank. The expanded item bank went live in the FOTO Patient Outcomes system in June 2017.

Scaling

For the original 37-item bank, the measure was scaled to have a score range of approximately 0-100, with higher scores indicating better functional status. For the updated measure, including the original plus seeded items, this range was expanded. This is a unique strength of IRT approaches over older methods like classical test theory, which allows scores from the original scale be compared directly to scores from the expended item bank.

Note: the possible score range using CAT may differ slightly from the full possible range of scores when the full item bank is administered. Further, CAT administration parameters, such as stopping rules, may be adjusted from time to time while maintaining the same scoring continuum (metric).

PART 2: How this work added value to the Shoulder FS item bank: Psychometric evidence

2.1 Introduction

The following is a description of the results of analyses providing evidence of the added value of the new Shoulder FS items and the expanded Shoulder FS item bank. The Shoulder FS measure began as an item bank consisting of 37 items, to which were subsequently added a total of 16 new "seeded" items. Seeded items were those (a) with content identified by clinicians and patients as important to include in the Shoulder FS item bank, (b) whose item-level data met minimum n ≥ 10 responses per category requirements, and (c) that successfully passed IRT analytic requirements and were calibrated on the existing Shoulder FS metric and thus were available to be added to the item bank.

The item bank item seeding process and evaluation were part of a planned item bank development and maintenance effort. After including new items, we then assessed the specific value added by the 16 seeded Shoulder FS items, comparing the now 53-item Shoulder FS item bank's performance to the original 37-item Shoulder FS item bank's performance.

2.2 Added important new item content

First, we considered the original vs. original plus seeded item content of the Shoulder FS item bank. Clinicians and patients had identified specific content they felt was (a) missing from the original item bank, and (b) important for patient self-evaluation when reporting on their shoulder function status. For this unaddressed content, new "seeded" items were written, tested, and, when appropriate, calibrated and included in the expanded Shoulder FS item bank. Item content for the original and new items are described in the **Appendix**.

2.3 Improved overall reliability

Second, we considered the Shoulder FS item bank's overall reliability.

To obtain reliability estimates, we simulated N=2002 full item bank responses, assuming a normally distributed population centered on an approximate Shoulder FS score of 50. We estimated classical test theory's Cronbach's alpha and IRT's standard error-based reliability, both internal consistency-type estimates of overall measure reliability.

Internal consistency reliability, already considered excellent at approximately 0.99, increased slightly with the original plus new seeded items, as compared to the original items only (**Table 1**).

Table 1: Improved internal consistency reliability: Original vs. Original Plus Seeded Items

| Added Value	Original Only	Original Plus Seeded
Cronbach's alpha	0.989	0.992
IRT-based reliability	0.992	0.994

2.4 Enhanced score-level reliability

Third, we considered the Shoulder FS's score-level-specific reliability. We estimated score-level reliabilities across the Shoulder FS measurement continuum.

Score-level-specific reliabilities increased with the original plus seeded items bank, as compared to the original items only bank. This increase in the 53-item Shoulder FS item bank score-level-specific reliabilities is particularly noteworthy at scores ≥ 50 (**Figure 1**), that is, for patients with higher functional status such as athletes.

Figure 1: Enhanced Score-level Reliability: Original Only Items vs. Original Plus Seeded Items

Score-level Reliability Expectations: 37-item vs. 53-item Shoulder FS Banks
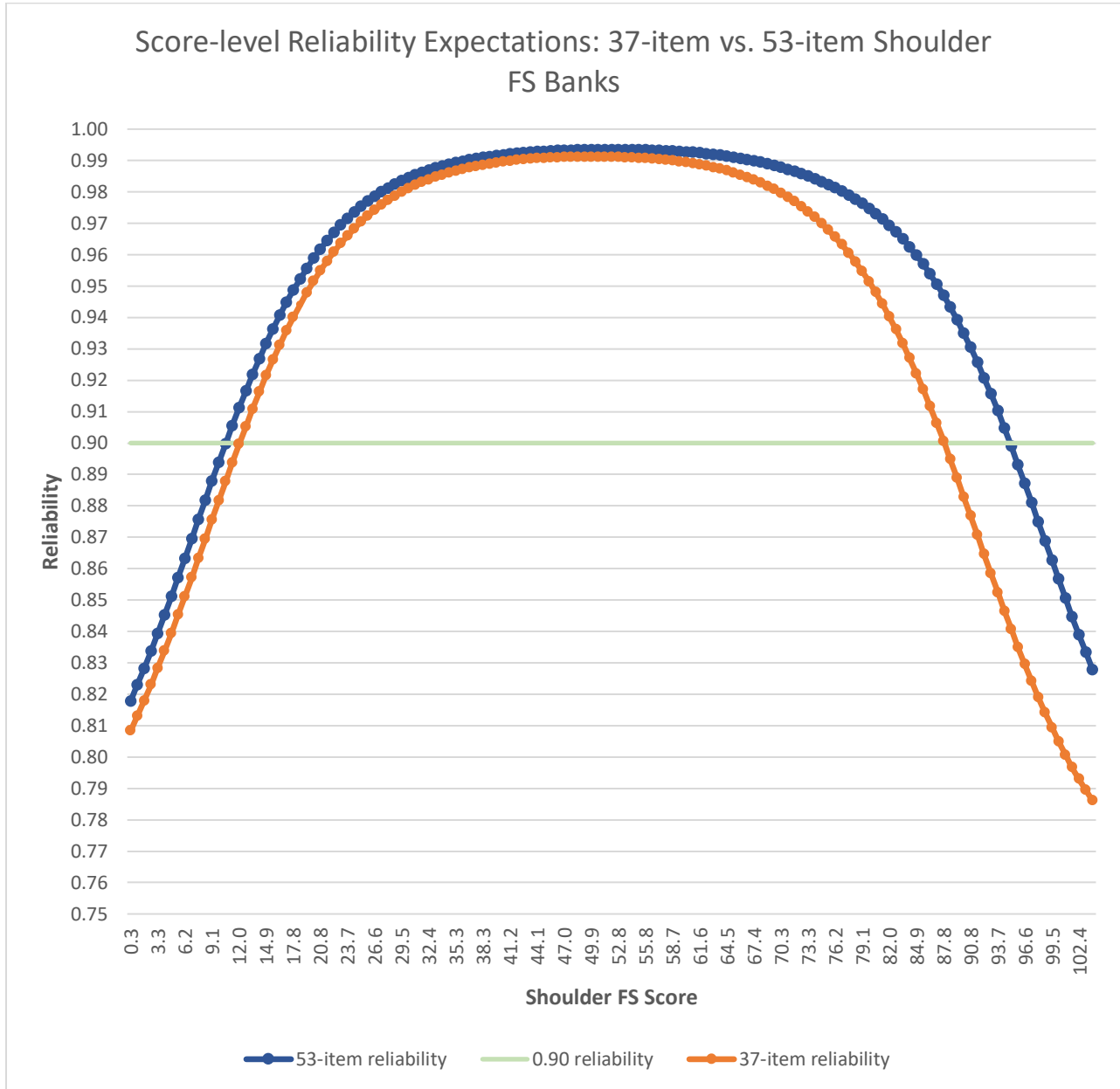
2.5 Increased reliable score range

Fourth, we evaluated the reliable score range of the 37-item vs. the 53-item Shoulder FS item banks.

For shoulder functional status, reliability-level-defined (e.g., ≥.90) score ranges increased in width with the original plus seeded items, compared to the original items only (**Table 2**).

Table 2: Increased Reliable Score Ranges: Original Only vs. Original Plus Seeded Items

Added Value	Original Only	Original Plus Seeded
Reliability standard	*Reliable score range*	*Reliable score range*
≥ 0.80	-1.9 to 101.7	-3.3 to 108.3
≥ 0.85	5.4 to 94.4	4.0 to 101.0
≥ 0.90	12.0 to 87.8	10.5 to 95.1
≥ 0.95	19.3 to 80.5	17.8 to 87.8

2.6 Improved CAT performance

Fifth, we considered the CAT performance of the 37-item vs. the 53-item Shoulder FS item bank.

A CAT is a type of dynamic assessment whereby an item selection algorithm identifies the specific items a particular person should answer (i.e., items are tailored or customized per person). That is, the item selection algorithm picks each item to administer to a person in order to locate and then refine that person's estimated score; thus, the CAT can measure most precisely that person's status in the domain of interest while simultaneously minimizing error.

CAT performance is a useful way to understand the practical value of an item bank's items by identifying with whom and how often the CAT selects specific items for administration, with the understanding that the CAT item selection algorithm identifies and administers the most informative items targeted to the level of the domain trait being measured.

We employed the following specific CAT administration parameters: (a) start with the item having the maximum information at theta=0 (i.e., item #14 – SHOULDER1 – **see Table 1**); (b) the minimum # of items to administer=4; (c) the maximum # of items to administer=12; (d) stop when the CAT standard error (SE) < 0.30; and (e) stop when the theta change across three consecutive items < 0.1372.

We employed a simulated response sample, as described above (i.e., N=2002 full item bank responses, assuming a normally-distributed population centered on an approximate Shoulder FS score of 50).

CAT administration performance improved with the original plus seeded items, compared to the original items only (**Table 3**). Improvements were small but measurable, particularly for reduced average number of items required for patient responses, and reduced measurement error. The notable increase in maximum observed score illustrates the increased score coverage for measuring higher functional status.

Table 3: Improved FOTO CAT Performance: Original Only Items vs. Original Plus Seeded Items

Added Value	Original Only	Original Plus Seeded
Average # of items	5.67	5.52
Mean SE	0.594	0.565
Correlation with Full Bank	.979	.976
Minimum observed score	6.63	6.38
Maximum observed score	93.80	98.08

2.7 New seeded item usage in the CAT administration context

Sixth, we evaluated the number of new seeded items used as well as their frequency of use in the context of a CAT administration of the Shoulder FS item bank. Frequency of use of the new items is important to evaluate because it assesses their usefulness with the intended patient population. For the 37-item Shoulder FS CAT, 35 of the 37 original items were administered; two items (POCKET, SAFESTRP) were never administered.

For the 53-item Shoulder FS CAT, 15 of the 16 new seeded items were administered, while 32 of the 37 original items were also administered. Combined with the result above related to the original 37 item-bank, this suggests that some of the new items functioned better than some of the original items. With the 53-item Shoulder FS CAT, one new seeded item was not administered (CSHOULDE8-CARRY SHOPPING BAG), while five original items (COLLAR, SAFESTRP, BALLUND, PULLBOX, JAR) were also not administered. For the new seeded items, one (FAUCETOPP) had a usage rate (i.e., the percent of N=2002 cases who were administered the item) of ≥ 30%, one (CSHOULDE5-PLACE 70-LB OVERHEAD) had a usage rate that was between 20% and less than 30%, six (CSHOULDE1-LIFT 100 LBS, CSHOULDE2-RIGOROUS SPORTS, CSHOULDE3-PLACE 25-LB OVERHEAD, CSHOULDE4-PLACE 50-LB OVERHEAD, OVRHEAD8, CSHOULDE10-DO HEAVY HOUSEHOLD) had usage rates of 10% to less than 20%, and seven (CSHOULDE6-LIFT GROC FROM FLOOR, CSHOULDE7-MAKE A BED, CSHOULDE13-PUSHOPEN HEAVY DOOR, BRIEFCASE, WHEELOPP, CSHOULDE9-CARRY HEAVY OBJECT, PUSHBOX) had usage rates between 1% and less than 10%.

Approximately one third (33.5%) of the items administered by the 53-item Shoulder FS CAT for the simulated sample were new seeded items (**Appendix**). This heavy use of the new items supports their added value.

2.8 Expanded range and more dense coverage of the Shoulder FS measurement continuum

Seventh, we examined the range and density of the item parameters of the new seeded Shoulder FS items by analyzing item threshold estimates. Thresholds are item specific and refer to the ability level at which a respondent has the same probability of selecting the lower or higher response category. Since there are 5 response categories, there are 4 thresholds for each item.

Across all threshold estimates, the minimum threshold remained at 25.53, while the maximum threshold increased from 78.13 to 83.67.

Within Threshold 1 estimates, the minimum threshold remained at 25.53, while the maximum threshold increased from 53.84 to 59.38.

Within Threshold 2 estimates, the minimum threshold remained at 32.67, while the maximum threshold increased from 60.98 to 66.52.

Within Threshold 3 estimates, the minimum threshold remained at 43.38, while the maximum threshold increased from 71.69 to 77.23.

Finally, within Threshold 4 estimates, the minimum threshold remained at 49.82, while the maximum threshold increased from 78.13 to 83.67.

The increased range across all item thresholds provides proof of the expanded measurement continuum of the 53-item Shoulder FS item bank, including improved ability to measure higher functional status. This directly addressed feedback from clinicians and patients that the original 37-item bank did not seem to adequately capture ability levels for higher functioning patients, such as athletes. These anecdotal observations were complimented by research findings of a 10% ceiling effect,[3] although ceiling effects below 15% are considered acceptable.[5-8] After adding the new items, the ceiling effect was reduced to 7.4%, illustrating the improved score coverage.

In addition, the increased range of item thresholds within each of Thresholds 1-4, as well as the increased overlap of threshold locations across thresholds, provides proof of an improved density of item coverage of the now expanded measurement continuum of the 53-item Shoulder FS item bank (**Table 4**).

Table 4: Range and density of item parameters

Threshold	Item bank version	Threshold 1	Threshold 2	Threshold 3	Threshold 4
Minimum	37-item	25.528	32.671	43.380	49.821
	53-item	25.528	32.671	43.380	49.821
Maximum	37-item	53.839	60.982	71.691	78.132
	53-item	59.377	66.520	77.229	83.670

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Appendix: Item content, CAT usage, and item location (difficulty)

Version	Item label	Item description	CAT usage: n (%) from N=2002	Location
Original	GLASSES	How much difficulty do you or would you have taking off glasses or sunglasses using your affected arm?	583 (29.1%)	37.9
Phase 2 seeded item	FAUCETOPP	How much difficulty do you or would you have using your affected arm to turn a faucet in the opposite direction as your affected arm (eg, turn left if it is your right shoulder that is affected)?	727 (36.3%)	39.5
Original	FLUSHING	How much difficulty do you or would you have flushing the toilet using your affected arm?	542 (27.1%)	40.2
Original	FAUCETSA	How much difficulty do you have using your affected arm to turn a faucet in the same direction as your affected arm (eg, turn right if it is your right shoulder that is affected)?	504 (25.2%)	40.6
Original	FACESA	How much difficulty do you or would you have using your hand on the affected arm to wash the side of your face on the same side as your affected shoulder?	278 (13.9%)	41.8
Original	EAROPP	How much difficulty do you or would you have using your affected arm to reach the earlobe on the opposite side as your affected shoulder?	183 (9.1%)	41.9
Original	SOCKSON	How much difficulty do you or would you have pulling on your socks using both hands?	107 (5.3%)	42.2
Original	UNDERPANTS	How much difficulty do you or would you have putting on underpants (eg, panties, briefs, or boxers) using both hands?	117 (5.8%)	42.3
Original	TABLE	How much difficulty do you or would you have lifting your hand on the affected side and putting it on a table in front of you while you are sitting?	129 (6.4%)	42.6
Original	WATER	How much difficulty do you or would you have using your affected arm to pick up and drink out of a full water glass?	247 (12.3%)	43.0
Original	DEODORANT	How much difficulty do you or would you have putting on deodorant under the arm opposite your affected shoulder?	153 (7.6%)	44.9
Phase 2 seeded item	BRIEFCASE	How much difficulty do you have using your affected arm to carry something of medium	105 (5.2%)	46.9

		weight (5-10 lbs) at your side (eg, briefcase or bag)?		
Original	SALT	How much difficulty do you or would you have reaching across to the middle of the table with your affected arm to get a salt shaker while sitting?	33 (1.6%)	47.8
Original	JARSTEADY	How much difficulty do you or would you have using your affected arm to steady a jar while you loosen the jar lid?	66 (3.3%)	47.9
Original	CHEST	How much difficulty do you or would you have using your affected arm to lift the lid of a chest that sits on the floor?	12 (0.6%)	48.2
Original	PUSHCHAIR	How much difficulty do you or would you have pushing yourself out of a chair using both arms?	105 (5.2%)	48.3
Original	TIE	How much difficulty do you or would you have getting a scarf or necktie over your head and around your neck, using both hands?	195 (9.7%)	48.4
Original	PULLCHAIR	How much difficulty do you or would you have pulling a chair out from a table using your affected arm?	480 (24.0%)	49.4
Original	JAR	How much difficulty do you or would you have using your affected arm to tighten a jar lid?	0 (0.0%)	50.1
Phase 2 seeded item	WHEELOPP	How much difficulty do you or would you have using your affected arm to turn a steering wheel in the opposite direction as your affected arm (eg, turn left if it is your right shoulder that is affected)?	55 (2.7%)	50.1
Original	CROOK	How much difficulty do you or would you have using your affected arm to carry something of medium weight (5-10 lb) in the crook of your arm (where your elbow bends)?	3 (0.1%)	50.2
Original	SHOULDER1	How much difficulty do you or would you have using your affected arm to place a can of soup (1 lb) on a shelf at shoulder height?	2002 (100.0%)	50.6
Original	WHEELSA	How much difficulty do you have using your affected arm to turn a steering wheel in the same direction as your affected arm (eg, turn right if it is your right shoulder that is affected)?	31 (1.5%)	50.8
Phase 1 seeded item	CSHOULDE7	How much difficulty do you have using your affected arm to make a bed?	83 (4.1%)	50.8
Phase 2 seeded item	PUSHBOX	How much difficulty do you have using your affected arm to slide a medium weight (5-10	43 (2.1%)	51.3

		lb) box across a table by pushing it away from you?		
Original	SAFESTRP	How much difficulty do you or would you have using your affected arm to reach across your body to get a car's shoulder strap (safety belt)?	0 (0.0%)	52.0
Original	PULLBOX	How much difficulty do you or would you have using your affected arm to slide a medium weight (5-10 lb) box across a table by pulling it completely to you?	0 (0.0%)	52.0
Original	SHELF	How much difficulty do you or would you have using your affected arm to reach a shelf that is at shoulder height?	23 (1.1%)	52.1
Original	POCKET	How much difficulty do you or would you have using your affected arm to pull something out of your back pocket?	5 (0.2%)	52.3
Original	COMB	How much difficulty do you or would you have combing or brushing your hair using your affected arm?	71 (3.5%)	52.5
Original	SLIDE	How much difficulty do you or would you have using your affected arm to slide hanging clothes in a closet from one end of the rod to the other?	16 (0.8%)	52.7
Original	POTATOES	How much difficulty do you or would you have using your affected arm to stir a large bowl of thick food such as mashed potatoes?	22 (1.1%)	52.9
Phase 1 seeded item	CSHOULDE6	How much difficulty do you have using your affected arm to lift a bag of groceries from the floor?	183 (9.1%)	53.0
Original	BALLUND	How much difficulty do you or would you have using your affected arm to throw a ball underhand?	0 (0.0%)	53.3
Original	COLLAR	How much difficulty do you or would you have adjusting the back of your collar with your affected hand?	0 (0.0%)	53.4
Original	STRING	How much difficulty do you or would you have using your affected arm to reach and pull the string that controls a light or fan?	29 (1.4%)	53.5
Original	SKILLET	How much difficulty do you or would you have using your affected arm to move a heavy skillet (eg, cast iron skillet) from one stove burner to another?	70 (3.5%)	54.2
Phase 2 seeded item	CSHOULDE8	How much difficulty do you have using your affected arm to carry a shopping bag or briefcase?	0 (0.0%)	54.3
Phase 2 seeded item	CSHOULDE13	How much difficulty do you have using your affected arm to push open a heavy door?	49 (2.4%)	54.5

Original	OVRHEAD1	How much difficulty do you or would you have using your affected arm to place a can of soup (1 lb) on a shelf overhead?	33 (1.6%)	54.7
Original	BED	How much difficulty do you or would you have using your affected arm to pull a medium weight object (5-10 lbs) from under a bed?	93 (4.6%)	55.2
Phase 2 seeded item	CSHOULDE9	How much difficulty do you have using your affected arm to carry a heavy object (over 10 lbs)?	100 (5.0%)	57.1
Original	MEDBOX	How much difficulty do you or would you have using your affected arm to lower a lightweight object (1-5 lb) from the top shelf of a closet?	244 (12.2%)	57.6
Original	OVRHEADSHE	How much difficulty do you or would you have using your affected arm to reach an overhead shelf?	456 (22.8%)	58.8
Phase 2 seeded item	CSHOULDE10	How much difficulty do you have using your affected arm to do heavy household chores (e.g., washing walls, washing floors)?	229 (11.4%)	59.5
Phase 2 seeded item	OVRHEAD8	How much difficulty do you have using your affected arm to place a gallon of milk (8-10 lbs) on a shelf overhead?	297 (14.8%)	62.5
Phase 1 seeded item	CSHOULDE2	How much difficulty do you have using your affected arm to participate in rigorous contact sports?	229 (11.4%)	64.7
Original	BCKSEATRE	How much difficulty do you or would you have using your affected arm to touch an object on the back seat while sitting in the front seat of a car?	257 (12.8%)	64.8
Original	BULB	How much difficulty do you or would you have using your affected arm to work overhead for more than 2 minutes?	267 (13.3%)	66.2
Phase 1 seeded item	CSHOULDE3	How much difficulty do you have using your affected arm to place a 25 lb. box on a shelf overhead?	350 (17.5%)	66.5
Phase 1 seeded item	CSHOULDE4	How much difficulty do you have using your affected arm to place a 50 lb. box on a shelf overhead?	370 (18.5%)	69.8
Phase 1 seeded item	CSHOULDE1	How much difficulty do you have using your affected arm to lift 100 lbs or more?	354 (17.7%)	70.9
Phase 1 seeded item	CSHOULDE5	How much difficulty do you have using your affected arm to place a 75 lb. box on a shelf overhead?	526 (26.3%)	71.7