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Authors

Palimaru, Alina Ionela
Cunningham, William E
Dillistone, Marcus
et al.

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Alina Ionela Palimaru, MPP, William E. Cunningham, MD, MPH, Marcus Dillistone, BA, Arturo Vargas-Bustamante, PhD, MPP, Honghu Liu, PhD, Ron D. Hays, PhD

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Running head: Fatigability in Adults with Spinal Cord Injury

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Authors: Alina Ionela Palimaru[1], MPP, William E. Cunningham[1, 2], MD, MPH, Marcus Dillistone[3], BA, Arturo Vargas-Bustamante[1], PhD, MPP, Honghu Liu[2,4,5], PhD, Ron D. Hays[1, 2], PhD

[1] UCLA, Department of Health Policy and Management, Fielding School of Public Health, 650 Charles E. Young Dr. S., Los Angeles, CA 90095, USA

[2] UCLA, Division of General Internal Medicine & Health Services Research, Department of Medicine, UCLA, Geffen School of Medicine, Los Angeles, CA 90095, USA

[3] Royal Society of Medicine, Senior Associate, 1 Wimpole Street, Marylebone, London W1G 0AE, UK

[4] UCLA, Division of Public Health & Community Dentistry, School of Dentistry, Los Angeles, CA 90095, USA

[5] UCLA, Department of Biostatistics, Fielding School of Public Health, 650 Charles E. Young Dr. S., Los Angeles, CA 90095, USA

Corresponding author:

Alina Ionela Palimaru

UCLA Fielding School of Public Health

Department of Health Policy and Management

650 Charles E. Young Dr S

Los Angeles, CA 90095

Tel: 310-994-3620

Fax: 310-825-3317

Email: alinapalimaru@ucla.edu

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Compliance with ethical standards

Conflicts of interest

We certify that no party having a direct interest in the results of the research supporting this article has or will confer a benefit on us or on any organization with which we are associated AND, if applicable, we certify that all financial and material support for this research (eg, NIH or NHS grants) and work are clearly identified in the title page of the manuscript.

The manuscript submitted does not contain information about medical device(s).

Human and animal rights

All procedures performed in this study involving human participants were in accordance with the ethical standards of the UCLA institutional review board and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained from all individual participants included in the study.

Authors' contribution

AIP was involved in conception and design, collection of data, analysis and interpretation of data; drafted the article; revised the article critically for important intellectual content; involved in final approval.

WEC was involved in conception and design, interpretation of data; revised the article critically for important intellectual content; involved in final approval.

HL was involved in conception and design, interpretation of data; revised the article critically for important intellectual content; involved in final approval.

MD was involved in survey design; design and implementation of fatigability vector; revised the article critically for important intellectual content; involved in final approval.

RDH was involved in conception and design, interpretation of data; revised the article critically for important intellectual content; involved in final approval.

Development and Psychometric Evaluation of a Fatigability Index for Full-Time Wheelchair Users with Spinal Cord Injury

Abstract

Purpose: To develop and evaluate psychometrically a self-reported instrument assessing physical fatigability (PF) and mental fatigability (MF) in adults with spinal cord injury (SCI).

Design: Cross-sectional.

Setting: Peer-support groups at rehabilitation centers, on-line support groups.

Participants: Adults with SCI (N=464) in the US.

Interventions: Not applicable.

Main Outcome Measures: The dimensional structure was assessed by confirmatory factor analysis. The relationship between item responses and fatigability was measured with item response theory (graded response model). Reliability was measured with test information functions. Differential item functioning was evaluated with Wald chi-square tests and the weighted area between the curves (wABC). Construct validity was assessed using the known groups method.

Results: An 82-item pool was developed from prior qualitative research and consultations with rehabilitation experts. A non-probability sample (N=464) was used to evaluate the psychometric properties of the PF and MF scales. The item pool was reduced to 75 based on factor loadings and R^2. Both scales are primarily unidimensional, despite moderate multidimensionality. There is good discrimination overall: 18 PF items and 26 MF items have high or very high discrimination power (slopes > 1.35). The measurement precision in the theta range -2.0 to 2.5 is the equivalent of 0.94 reliability for PF and 0.91 for MF. For

both measures, F-statistics p-values were significant at $p < .01$, and means were higher for those with paraplegia vs quadriplegia, and for those with incomplete paraplegia.

Conclusions: The Fatigability Index is the first instrument designed to assess physical and mental fatigability in adults with SCI. It highlights causes of fatigue and areas requiring immediate intervention. Development of short-forms and further research on representative samples are necessary.

Keywords: fatigability, physical fatigue, mental fatigue, spinal cord injury, health-related quality of life.

List of Abbreviations: SCI (spinal cord injury); PF (physical fatigability); MF (mental fatigability); CFA (confirmatory factor analysis); IRT (item response theory); DIF (differential item functioning); wABC (weighted area between the curves); CCC (category characteristic curves); RMSEA (Root Mean Square Error of Approximation); CFI (Comparative Fit Index); TLI (Tucker-Lewis Index); PUC (percent uncontaminated correlations); ECV_{GEN} (explained common variance on the general dimension); I-ECV (individual explained common variance).

Introduction

Spinal cord injury (SCI) affects approximately 300,000 individuals in the US.[1] A prevalent symptom associated with SCI is fatigue: "a subjective lack of physical and/or mental energy that is perceived by the individual or caregiver to interfere with usual or desired activities."[2] About 25% of individuals with SCI report fatigue that is severe enough to impact upon daily functioning and well-being.[3,4] Adults with SCI may experience fatigue associated with their age, their full-time use of a wheelchair, daily activities, co-morbidities, and other consequences of SCI (e.g., poor posture, pressure management).[4-11] Just like non-

SCI adults, persons with SCI may try to avoid fatigue and exhaustion by decreasing or completely eliminating certain activities (cooking) or wheelchair maneuvers (wheelchair-to-car transfers).

Fatigability is "a characteristic describing an individual's susceptibility to experiencing fatigue for a given quantifiable demand."[2] There are two forms of fatigability. The first is performance-related fatigability, which is observed and could be measured by a clinician, and refers to erosion in force, power, speed or stamina related to performance of a given activity.[2] The second type of fatigability is perceived (self-reported) fatigability, which is the focus of this study: it refers to feelings of tiredness and wear related to duration and intensity of an activity.[2] Self-reported fatigability has been measured in contexts other than SCI, with instruments such as the Physical Energy Scale from the Motivation and Energy Inventory, the Dutch Exertion Fatigue Scale, the Situational Fatigue Scale, and the Pittsburgh Fatigability Scale.[12-17] To date, no self-reported fatigability instrument specifically for SCI individuals has been developed and assessed psychometrically.

Development of such targeted instruments aligns with patient-centered care goals of being "respectful of and responsive to individual patient preferences, needs, and values, and ensuring that patient values guide all clinical decisions."[18] In this study we aimed to develop and evaluate a SCI fatigability measure that could complement clinical processes like rehabilitation, seating, pressure/posture management, or other interventions to ameliorate the symptoms.

Methods

We developed the measures following the International Society for Quality of Life Research (ISOQOL) minimum standards and recommendations for patient-reported outcome measures (Figure 1).[19]

Initial Fatigability 82-Item Pool

First, we conducted a literature review to identify areas of interest relating to fatigue, that is, causes of fatigue in adults with SCI, and the relationship between fatigue and health-related quality of life in this subgroup of the population.[3-17] We also identified existing fatigue instruments that were evaluated psychometrically among persons with SCI.[3-17] We conducted 20 in-depth interviews with adults with SCI who are full-time wheelchair users, exploring quality of life in the context of SCI, and preferences for different health outcome measures, with findings reported elsewhere.[20] The need for two separate scales emerged from these in-depth interviews. Physical fatigue was defined as reduced physical function due to wear or disease (tiredness and weakness are symptoms of fatigue). Physical fatigue was also described as progressive, increasing in severity over time. Interviewees defined mental fatigue as reduced mental function due to perceived high level of stress, worries about the future, perceived need for extensive logistical planning, and perceived bureaucratic burden (such as filling out forms for health or welfare benefits). Participants discussed that for many activities, physical and mental fatigue can compete and conspire to frustrate and reduce what a disabled person can do in their life. With input from experts in wheelchair and seating assessment, rehabilitation, wheelchair sports coaching, survey development and psychometric evaluation, we drafted a large pool of Physical Fatigability (PF) and Mental Fatigability (MF) items (Table 1). The items represent four areas of fatigability: health problems, problems in the home environment, activities in

the home, and activities away from home (which may be more demanding, with varying degrees of logistical challenges and physical exertion). For example, going to a doctor's appointment differs from taking an overnight trip away from home.

We asked, separately, about the level of physical and mental fatigue associated with 41 activities using the following response scale: 0 (no fatigue), 1 (Mild fatigue), 2 (Moderate fatigue) and 3 (Extreme fatigue), and Did not have this/Did not do this. In addition, we assessed the importance of each item to the respondent. For health, they were asked *"How important is it that each of the following is treated?"*; regarding activities they were asked *"How important is it that you can perform each of these activities?"* The importance questions were not used in the analyses reported here.

Field Test Data Collection and Sampling

Eligibility included being 18 years or older, U.S. residents, with a self-reported diagnosis of SCI, at least 1-year post hospital discharge, full-time wheelchair users, and could read and write in English. Excluded were individuals unable to provide informed consent (including cognitive impairments such as dementia or Alzheimer's disease), and those who were part-time wheelchair users.

This was a non-probability (convenience) sample recruited nationally through (1) print advertisements distributed through peer support groups in the United States (US), and veterans' support groups (local chapters of Paralyzed Veterans of America); (2) online advertisements distributed through organizations such as The Dana and Christopher Reeve Foundation (Members' Board: http://www.spinalcordinjury-paralysis.org/) and the United Spinal Association (http://www.spinalcord.org/resource-center/askus/index.php). In addition, 4 separate paid ad campaigns were conducted via Facebook Ads at 2-week

intervals, with target specifications including US as a location, "SCI" and "wheelchairs" as user interests, and a population target of 12,000 for each campaign. Upon expressing interest in being interviewed, participants were sent an email with information about the study, and were given the option to take the survey online or via the phone. All respondents in this study, including several with high neck injuries who were on ventilators, chose to take the survey online between January and May 2017. No remuneration was provided for survey participation. A total of 491 individuals expressed interest in the study; 478 completed the survey. Fourteen respondents were eliminated because they resided in Australia, New Zealand, Canada, England and Scotland. The final sample was 464. This study was approved (Certified Exempt) by the Institutional Review Board of the University of California Los Angeles (IRB#16-000231).

Missing Data

Inappropriately missing data was 6% and was similar across all diagnosis levels. This degree of missing data is considered small in magnitude, and acceptable by traditional standards.[21] In contrast, appropriately missing data due to items not being applicable was 21%. The number of *"did not have"* or *"did not do this"* responses per item varied from 2% to 85%.

The high proportion of the not-applicable answers resulted in some response options rarely being chosen – that is, a data sparsity problem. We further investigated the position of the not applicable responses in relation to the other response options. Average PF and MF scores were used as dependent variables in one-way ANOVAs with response options for each item as the independent variables. Duncan multiple range tests were used to compare mean scores by each response option.[22] Means for both PF and MF for those

picking the not applicable response to items were closer to the Mild Fatigue score than any other answer option. Therefore, we collapsed the not applicable response with the "Mild fatigue" responses so that no cell had less than 5% of data (23 participants). We retained items with the high levels of not applicable responses because the majority of them were considered by at least half of the respondents to be "Vital" or "Important" for them to be able to do. For example, the high not applicable rate for an item such as *"Taking a vacation away from home"* may reflect inadequate transport and leisure infrastructure for people in wheelchairs, but it is possible that such services will improve in future.

Categorical Confirmatory Factor Analysis (CFA)

We investigated the factor structure of the 41 PF items and the 41 MF items using Mplus v. 7.4.[23] The hypothesized structure was based on theories proposed by previous studies.[20,24] For the PF scale, we hypothesized five multi-item domains: "Health challenges," "Daily living challenges," "Mental tasks," "Access challenges," and "Seating challenges." The hypothesized structure for the MF scale included four multi-item domains: "Daily living challenges," "Access challenges," "Concentration challenges," and "Health challenges."

A five-factor categorical confirmatory analysis model, a modified four-factor model, and a bifactor model were fit for the PF items. For the MF scale, a four-factor categorical confirmatory analysis model, a modified four-factor model, and a bifactor model were fit. All models used weighted least squares means and variances adjusted (WLSMV) estimation.[25] The multi-factor models specified correlations among the domains (factors), but not among item error variances. We also estimated item means, standard deviations, item-total correlation (corrected for overlap), and coefficient alpha for each multi-item scale using Stata 15.[26]

The following commonly used model fit indices and thresholds were used: Root Mean Square Error of Approximation (RMSEA) < 0.08; Comparative Fit Index (CFI) > 0.95; and the Tucker-Lewis Index (TLI) > 0.95.[27-31] Factor loadings (i.e. the relation of an item to the hypothesized scale) were also inspected, looking for standardized loadings lower than 0.30, and R^2 lower than 10% as indicators of potential problematic items. For the bi-factor model, an instrument is considered primarily unidimensional if the percent uncontaminated correlations (PUC) < 0.80 (this is the percentage of covariance that reflects only variance from the general dimension), the explained common variance on the general dimension (ECV_{GEN}) > 60%, and omega hierarchical, the variance in raw total scores that can be attributed to individual differences on the general factor (Omega H) > 0.70.[32,33]

Item Response Theory (IRT) - Graded Response Model Analysis

Unidimenional IRT has several underlying assumptions. Unidimensionality was evaluated using CFA. Local independence means that after accounting for the underlying factor, items are uncorrelated.[34] To assess this we evaluated the residual correlation matrix for any values higher than 0.20. Monotonicity was evaluated by graphing item characteristic curves depicting the relationships between IRT estimated fatigability scores and responses to each item.[19,35] Reliability (analogous to IRT information) of at least 0.70 was considered adequate for group comparisons.[36]

Differential Item Functioning (DIF) analyses evaluated whether the items were free of measurement bias—that is, conditional on estimated fatigability, the probability of selecting each response option was not associated with other factors such as age, time since injury, level of injury (paraplegia or quadriplegia) or gender.[34,37,38] For this study we used the Wald chi-square procedure which evaluates the equality of parameter estimates

184 across groups. The approach obviates the need to identify DIF-free anchor items, and
185 estimates the mean difference between the groups based on all the items in the scale.[37] To
186 avoid false positives due to multiple hypotheses testing we applied the Benjamini-
187 Hochberg adjustment ($P < 0.01$).[31,35,37-39] The magnitude of DIF was assessed using the
188 weighted area between the curves (wABC) method, which measures the DIF effect size
189 whilst accounting for the underlying distribution: for measurement items with four
190 response categories, a wABC of 0.24 is considered non-negligible.[35,37]

191 *Construct Validity*

192 We assessed construct validity for the PF/MF scales, with F statistics evaluating the
193 significance of difference between means among the four diagnosis groups.[40] We
194 hypothesized that means would be higher for those with paraplegia and for those with
195 incomplete paraplegia than for those with complete paraplegia. Finally, we examined the
196 magnitude of correlations between responses to the PF and MF measures. We expected
197 these two measures to be highly correlated, but we also expected to have higher
198 correlations between the PF and MF Access Challenges scales, PF and MF Health Challenges
199 scales, and PF and MF Daily Living Challenges scales. The rationale for these hypotheses is
200 that individuals with comparatively higher mobility might exert themselves more in order
201 to perform otherwise "normal" daily activities, and would thus be more susceptible to
202 feeling exhausted. A wider range of activities also requires more cognitive and logistical
203 planning and worry, for example anticipating access to parking (or lack thereof) and ramps
204 in public spaces, resulting in higher physical and mental fatigability.

205 **Results**

206 *Sample Characteristics*

The 82-item fatigability survey was administered to a sample of individuals with SCI in 27 states in the US (Table 2). Supplemental Table 1 and Supplemental Figure 1 show readability scores for the item pool.

CFA Analyses

The hypothesized PF five-factor model was a poor fit to the data (RMSEA=0.095; CFI=0.812; and TLI=0.830). After removing two items with loadings below 0.30, and R^2 below 10% (*PFAway8 – Receiving a session of physiotherapy,* and *PFAway11 – Going out to a restaurant*), we moved the "Mental tasks" items under the "Daily living challenges" items. This four-factor model had a better, but still less than optimal fit: RMSEA = 0.081; CFI=0.922; and TLI = 0.940 (Supplemental Table 2).

For the MF scale, the initial and modified four-factor models were a poor fit to the data: (RMSEA=0.098, CFI=0.846, TFI=0.851; and RMSEA = 0.088, CFI=0.888, TLI = 0.901) (Supplemental Table 3). Supplemental Tables 4 and 5 show PF and MF item means, item-total correlations, and coefficient alphas.

Correlations among the PF factors and among the MF factors ranged from 0.575 to 0.772 and 0.565 to 0.856, respectively, suggesting the potential for a single general factor that may underlie the items in each scale.[25,41] In addition, an exploratory factor analysis showed that the first factor explained 30% of the PF variability, and 35% of the MF variability (at least 20% is desirable), and the eigenvalue ratio (first to second) was 4.11 for the PF scale and 4.33 for the MF scale (ratios in excess of 4 provide support for unidimensionality).[19]

The bifactor models yielded RMSEA=0.076, CFI=0.931, TLI=0.956 for PF, and RMSEA=0.073, CFI=0.923, TLI=0.911 for MF.[32,41] Tables 3 and 4 show PF and MF bifactor

loadings and the I-ECV values (each item's explained common variance). On both scales certain items suggested some multidimensionality. However, 32 PF items and 28 MF items had stronger loadings on the general factor than on the specific factors, suggesting unidimensionality of the PF and MF scales respectively. The loadings on the general factor of each scale were close to those of the 1-factor model, although slightly lower. Across both PF and MF items, ECV_{GEN} was 0.70, PUC was 0.71, while Omega H was 0.882 (PF) and 0.869 (MF). So, both scales were primarily unidimensional.

We assessed local dependence by fitting a one factor CFA model for each scale separately, and evaluating residual correlations. On both scales we found several problematic correlations: 0.201 and 0.203 (PF) and 0.207, 0.211, -0.216, -0.223 (MF). We further examined the effect of including the few locally dependent (LD) items on the IRT item discrimination parameters. For both scales, we first ran a base graded response model with the 39 (PF) and 36 (MF) items respectively. Then we ran alternative models excluding one LD item at a time and compared the item slopes across all models. We found that the effect of the LD items was minimal, so we decided to keep the base model for both scales.

IRT Parameters

Parameter estimates from the base IRT graded response model, fit in STATA15, are given in Tables 5 and 6. The measurement precision in the theta range between -2.0 and 2.5 is the equivalent of 0.94 reliability for PF and 0.91 for MF (Figure 2). Sixty-eight of the total 75 items showed well-differentiated category characteristic curves (CCC), indicating that each answer choice is the most likely answer at some point along the fatigability trait. In seven of the items the CCCs showed minor problems: in some the "extreme fatigue" option was

252 subsumed under “moderate fatigue,” in others the “mild fatigue” choice was subsumed
253 under “moderate fatigue.”

254 *Differential Item Functioning*

255 After Benjamini-Hochberg adjustment, there was no significant DIF by age or time since
256 injury. Tables 7 and 8 show chi-square and wABC values with significant DIF by gender and
257 diagnoses for the two measures. Only two items exceeded the 0.24 threshold for non-
258 ignorable DIF in the diagnosis comparison: *“Taking an overnight trip away from home”* (PF
259 scale) (wABC = 0.28), and *“Posture problems”* (MF scale) (wABC = 0.31). Given the same
260 level of fatigability, uniformly across the continuum respondents with paraplegia (n=288)
261 were more likely than those with quadriplegia (n=176) to report physical fatigue when
262 taking an overnight trip away from home. For mental fatigue relating to posture problems,
263 at the lower end of the theta range those with paraplegia were less likely than those with
264 quadriplegia to report mental fatigue, but more likely to report it as fatigability increased.
265 Figure 3 shows graphical representations of the effect size for both items. The impact of
266 DIF on the overall mean scores for the two diagnosis groups was small. When DIF was
267 accounted for by estimating item parameters separately for paraplegia and quadriplegia,
268 the mean score difference between the groups was 0.49 SD (PF), and 0.74 SD (MF). When
269 DIF was ignored by constraining all items to have equal parameters across diagnosis
270 groups, the mean differences were 0.42 SD and 0.64 SD for the PF and MF scores,
271 respectively. So adjusting for DIF makes only 0.07 SD (PF) and 0.10 SD (MF) change in the
272 difference between diagnosis groups.

273 *Construct Validity*

For both scales, F-statistics p-values for paraplegia and incomplete paraplegia groups were significant at $p < .01$, and means were higher for those who reported having a paraplegia vs quadriplegia, and for those with an incomplete paraplegia vs complete paraplegia, incomplete and complete quadriplegia (Supplemental Tables 6 and 7). The correlation between the two scales was 0.92. The largest significant correlations were found between the PF and MF Access scales (0.86), PF and MF Health scales (0.75), and PF and MF Daily living scales (0.81).

Visualizing Fatigue

To ensure ease of application in clinical settings, patient answers need to be presented in a simple and meaningful way, that delivers an instant picture of a person's physical and/or mental fatigability footprint, and in doing so, immediately highlights areas for possible intervention.

To visualize a patient's vulnerability to fatigue, we propose a Fatigability Vector that includes all items retained after the psychometric assessment (Figure 4). To our knowledge, this visualization approach has not been proposed before. In this vector, each survey item has its own spoke with the four answer options. Taken together, they capture the full response plot for both physical and mental fatigue, showing the respondent's physical and mental fatigability footprint. A clinician can thus identify areas that require immediate intervention, to address extreme fatigability, as well as preemptive intervention in the case of mild and moderate fatigue. The chart can also help compare physical and mental fatigability, and a patient's footprint over time, showing the result of the intervention over time.

Discussion

297 We developed and evaluated the psychometric properties of two measures: physical and
298 mental fatigability. The need for two separate scales emerged from our in-depth
299 interviews. During the cognitive interviews conducted prior to the field test (see Figure 1)
300 we found that participants had no trouble differentiating between the two scales, which
301 aligned with our findings from the in-depth interviews. A specific index of susceptibility to
302 fatigue in SCI—that is, fatigability-- can help clinicians establish the level of vulnerability of
303 an individual. It can also highlight issues that might cause fatigue and require further
304 probing, such as correct techniques to self-propel in manual wheelchairs, moving up and
305 down ramps, or doing wheelchair transfers. Adding this index to other SCI-specific
306 instruments, such as the self-reported Spinal Cord Independence Measure III, can increase
307 the focus on patient-centered care in SCI. More broadly, the index could be incorporated
308 into wheelchair assessment and prescription protocols by mobility vendors.

309 The test information curves for the fatigability measures reported here show that
310 the questions work best for individuals with mild and moderate fatigability, where
311 interventions could ameliorate symptoms. But they are also informative for those with
312 limited fatigability and extreme fatigability, where the need for interventions is more
313 immediate.

314 This study also found that 18 PF items and 26 MF items had high or very high
315 discrimination power (slopes > 1.35). In addition, the item category characteristics are
316 generally well-differentiated for 68 of the 75 items. For the few items where that is not the
317 case, it might be helpful to collapse one or more of the answer categories into an adjacent
318 response option and offer fewer response options in the future.

319 **Limitations**

Socially desirable response bias is a concern with this type of self-reported data, even though the survey was not administered in person or via telephone.[42,43] Another limitation is selection bias. Certain types of individuals may be more likely to respond because they are computer-literate, or have access to a peer-group based at a rehabilitation center, while other types of individuals may be more inclined to offer their time to complete the surveys for no remuneration. Non-representative sampling makes the generalizability of findings problematic especially because we did not formally explore the extent to which the measurement process is similar across different measurement situations, for example community vs clinical settings, and modes of administration. A larger and more-representative sample would allow more definitive evaluation of DIF.[31] Finally, because the denominator is unknown for this convenience sample, the response rate is unknown.

Conclusions

These findings should be confirmed with larger, representative datasets, which would improve the precision of the estimates. Future research needs to be done to evaluate whether the not applicable response category should be treated differently. Future research should focus on the development of short forms for the two measures, and exploring computer-adaptive test administration of the existing item banks.

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Figure 1. Overview of survey development and testing approach. (No legend)

Figure 2. Physical and Mental Fatigability Test Information and Standard Error

The lower axis shows the range of fatigability. The blue curve (test information) shows that the measurement precision, or reliability, in the theta range -2.0 to 2.5 is 0.94 for physical fatigability, and 0.91 for mental fatigability. Both scales display fairly high precision in discriminating among individuals with a relatively wide range of fatigability.

Figure 3. Graphical Representation of Differential Item Functioning Effect Size (No legend)

Figure 4. Combined Physical and Mental Fatigability Vector

The vector displays concentric circles, beginning with no fatigue in the center, then radiating out for increasing levels of fatigue (mild, moderate, and extreme). Around the perimeter of the vector, we have added the range of survey items, such as posture management, attending a sporting event, wheelchair use over an uneven surface, home adaptation issues, and pressure management.

Each survey item, such as home adaptation, has its own spoke in the wheel of the proposed a Fatigability Vector, so when, for example, someone answers the question on home adaptation, they have the four answer choices. The vector captures a hypothetical full response plot where physical and mental fatigability are overlaid, which can be linked and filled with color to show the overall fatigability footprint.

Table 1 Physical and Mental Fatigue (PF/MF) Item Pool

ItemID		Item Stem and Item Content
Health		During the past 4 weeks did you experience each of the following? If so, how much physical & mental fatigue did each cause you?
PF&MF	Hlth1	Sleep problems
PF&MF	Hlth2	Pain
PF&MF	Hlth3	Indigestion problems
PF&MF	Hlth4	Dehydration problems
PF&MF	Hlth5	Poor posture
PF&MF	Hlth6	Spasticity
PF&MF	Hlth7	Stress
PF&MF	Hlth8	Medication side-effects
Home environment		During the past 4 weeks did you experience each of the following? If so, how much physical & mental fatigue did each cause you?
PF&MF	Envr1	Lack of peace and quiet
PF&MF	Envr2	Inadequately adapted home
PF&MF	Envr3	Inadequate medical care when at home
PF&MF	Envr4	Inadequate non-medical care when at home
Activities at home		During the past 4 weeks did you experience each of the following? If so, how much physical & mental fatigue did each cause you?
PF&MF	Home1	Wheelchair transfer to and from bed
PF&MF	Home2	Sitting in a wheelchair for an hour or more
PF&MF	Home3	Concentrating for an hour or more (such as reading, writing, or holding a conversation)
PF&MF	Home4	Using a computer for an hour or more
PF&MF	Home5	Wheelchair use around the home
PF&MF	Home6	Spending all day in your wheelchair
PF&MF	Home7	Pressure management (preventing pressure sores)
PF&MF	Home8	Posture management
PF&MF	Home9	Household chores, such as cleaning and tidying
PF&MF	Home10	Preparing and clearing away a meal
PF&MF	Home11	Eating a meal
PF&MF	Home12	Letter-writing, form filling or paying bills
Activities away from home		During the past 4 weeks did you experience each of the following? If so, how much physical & mental fatigue did each cause you?
PF&MF	Away1	Wheelchair use over a smooth surface
PF&MF	Away2	Wheelchair use over an uneven surface
PF&MF	Away3	Wheelchair transfer to and from car

PF&MF	Away4	Traveling in your vehicle for an hour or more
PF&MF	Away5	Using an adapted taxi
PF&MF	Away6	Using a bus
PF&MF	Away7	Using a train
PF&MF	Away8	Receiving a session of physiotherapy
PF&MF	Away9	Going to a doctor's appointment
PF&MF	Away10	Shopping, such as having access and reaching merchandise
PF&MF	Away11	Going out to a restaurant
PF&MF	Away12	Attending an event, such as cinema, theater, or a show
PF&MF	Away13	Visiting friends
PF&MF	Away14	Attending a sporting event
PF&MF	Away15	Taking a day trip away from home
PF&MF	Away16	Taking an overnight trip away from home
PF&MF	Away17	Taking a vacation away from home

Abbreviations: Physical Fatigue (PF); Mental Fatigue (MF). These 41 items were presented separately for the physical fatigue and the mental fatigue scales, hence 82 total item count. The answer range was: No Fatigue (0), Mild Fatigue (1); Moderate Fatigue (2), Extreme Fatigue (3); Did not have or Did not do this (99). However, due to sparse distributions, the "Did not have or Did not do this" category was collapsed into "Mild fatigue" (based on Duncan Multiple Range Test results) in order to have no cell with <5% of the data (23 participants). For all these items, higher scores mean higher vulnerability to physical and mental fatigue respectively.

Table 2. Sample participant characteristics (N=464)

Age (Mean years, SD)		45	(12)
Time Since Injury (Mean, SD)		13	(12)
Sex (%)			
	Male	222	(48)
	Female	242	(52)
Ethnicity (%)			
	Hispanic	16	(3)
	Non-Hispanic	446	(96)
Race (%)			
	White	424	(91)
	Black or African American	14	(3)
	Asian	6	(1)
	Native Hawaiian or Other Pacific Islander	-	-
	American Indian or Alaska Native	5	(1)
	Other	14	(3)
Living Arrangements (%)			
	Alone with no caregiver support	70	(15)
	Alone but with visiting caregiver support	62	(13)
	With a live-in caregiver who is a family member	213	(46)
	With a live-in caregiver who is not a family member	7	(2)
	With someone who is not your caregiver	111	(24)
	In a nursing home	-	-
	In some other living arrangement	1	(0.2)
Education (%)			
	8th grade or less	44	(9)
	Some high school, but did not graduate	10	(2)
	High school graduate or GED	60	(13)
	Some college or 2-year degree	162	(35)
	4-year college graduate	104	(22)
	More than 4-year college degree	84	(18)
Employment Status (%)			
	Full-time paid work (30 or more hours a week)	61	(13)
	Full-time voluntary work (less than 30 hours a week)	-	-
	Part-time paid work (30 or more hours a week)	48	(10)
	Part-time voluntary work (less than 30 hours a week)	51	(11)
	Not working, but seeking work	14	(3)
	Not working due to disability	210	(45)
	Student	33	(7)
	Retired	46	(10)
Worries about financial situation (%)			
	All the time	187	(40)
	Occasionally	162	(35)
	Rarely	90	(20)
	Never	23	(5)
Spinal Cord Diagnosis (%)			
	Complete paraplegia	139	(30)

Incomplete paraplegia	149	(32)
Complete quadriplegia	70	(15)
Incomplete quadriplegia	106	(23)
Type of Wheelchair Used (%)		
Manual (I self-propel)	321	(69)
Manual (I am pushed)	39	(8)
Power chair	160	(34)

Note: The numbers for "Type of Wheelchair Used" do not add up to 100 because participants could select a combination of wheelchair options.

Table 3. Physical Fatigability Bifactor Loadings and I-ECV Values

Item Content	General Factor	Health Challenges	Daily Living Challenges	Seating Challenges	Access Challenges	I-ECV
Sleep problems	0.377	0.725				0.213
Pain	0.730	0.218				0.918
Indigestion problems	0.385	0.906				0.153
Dehydration problems	0.560	0.092				0.974
Spasticity	0.419	0.284				0.685
Stress	0.323	0.458				0.332
Medication side-effects	0.420	0.126				0.917
Wheelchair transfer to and from bed	0.477		0.320			0.690
Wheelchair use around the home	0.700		0.496			0.666
Household chores, such as cleaning and tidying	0.551		0.830			0.306
Preparing and clearing away a meal	0.478		0.206			0.843
Eating a meal	0.555		0.278			0.799
Lack of peace and quiet	0.476		0.276			0.748
Inadequately adapted home	0.583		0.143			0.943
Inadequate medical care when at home	0.374		0.083			0.953
Inadequate non-medical care when at home	0.380		0.107			0.927
Concentrating for an hour or more (such as reading, writing, or holding a conversation)	0.604		0.108			0.969
Using a computer for an hour or more	0.566		0.024			0.998
Letter-writing, form filling or paying bills	0.678		0.038			0.997
Sitting in a wheelchair for an hour or more	0.512			0.672		0.367
Poor posture	0.615			0.244		0.864
Spending all day in your wheelchair	0.935			0.263		0.927
Pressure management (preventing pressure sores)	0.496			0.335		0.687
Posture management	0.745			0.078		0.989
Wheelchair use over a smooth surface	0.773				0.251	0.905
Wheelchair use over an uneven surface	0.811				0.126	0.976
Wheelchair transfer to and from car	0.608				0.063	0.989
Traveling in your vehicle for an hour or more	0.510				0.679	0.361
Using an adapted taxi	0.543				0.597	0.453
Using a bus	0.653				0.172	0.935
Using a train	0.621				0.199	0.907
Going to a doctor's appointment	0.968				0.210	0.955

Shopping, such as having access and reaching merchandise	0.962	0.167	0.970
Attending an event, such as cinema, theater, or a show	0.518	0.435	0.586
Visiting friends	0.582	0.555	0.524
Attending a sporting event	0.702	0.530	0.637
Taking a day trip away from home	0.643	0.570	0.560
Taking an overnight trip away from home	0.648	0.465	0.660
Taking a vacation away from home	0.495	0.462	0.534

Abbreviations: Physical Fatigue (PF); Item explained common variance (I-ECV);

Items stem was: During the past 4 weeks did you experience each of the following? If so, how much physical fatigue did each cause you?

Answer options: No fatigue (0); Mild fatigue (1); Moderate fatigue (2); Extreme fatigue (4).

Table 4. Mental Fatigability Bifactor Loadings and I-ECV Values

Item Content	General Factor	Health Challenges	Daily Living Challenges	Concentration Challenges	Access Challenges	I-ECV
Sleep problems	0.434	0.467				0.463
Pain	0.573	0.341				0.738
Poor posture	0.493	0.721				0.319
Stress	0.476	0.197				0.854
Medication side-effects	0.482	0.298				0.723
Wheelchair transfer to and from bed	0.759		0.041			0.997
Sitting in a wheelchair for an hour or more	0.704		0.316			0.832
Wheelchair use around the home	0.778		0.360			0.824
Spending all day in your wheelchair	0.832		0.319			0.872
Pressure management (preventing pressure sores)	0.787		0.348			0.836
Posture management	0.836		0.248			0.919
Household chores, such as cleaning and tidying	0.723		0.365			0.797
Preparing and clearing away a meal	0.683		0.364			0.779
Eating a meal	0.735		0.378			0.791
Lack of peace and quiet	0.505		0.320			0.714
Inadequately adapted home	0.526		0.574			0.456
Inadequate medical care when at home	0.470		0.476			0.494
Concentrating for an hour or more (such as reading, writing, or holding a conversation)	0.590			0.195		0.902
Using a computer for an hour or more	0.737			0.530		0.659
Letter-writing, form filling or paying bills	0.794			0.225		0.926
Wheelchair use over a smooth surface	0.567				0.589	0.481
Wheelchair use over an uneven surface	0.468				0.782	0.264
Wheelchair transfer to and from car	0.303				0.785	0.130
Traveling in your vehicle for an hour or more	0.774				0.065	0.993
Using an adapted taxi	0.723				0.254	0.890
Using a bus	0.736				0.075	0.990
Using a train	0.761				0.272	0.887
Going to a doctor's appointment	0.741				0.501	0.625
Shopping, such as having access and reaching merchandise	0.871				0.142	0.974
Going out to a restaurant	0.513				0.273	0.779
Attending an event, such as cinema, theater, or a show	0.648				0.419	0.705
Visiting friends	0.761				0.448	0.743

Attending a sporting event	0.806	0.413	0.792
Taking a day trip away from home	0.697	0.563	0.605
Taking an overnight trip away from home	0.702	0.424	0.733
Taking a vacation away from home	0.502	0.615	0.400

Abbreviations: Mental Fatigue (MF); Item explained common variance (I-ECV);

Items stem was: During the past 4 weeks did you experience each of the following? If so, how much mental fatigue did each cause you?

Answer options: No fatigue (0); Mild fatigue (1); Moderate fatigue (2); Extreme fatigue (4).

Table 5. Physical Fatigue Item Response Theory Parameters

Scale	Item Content	Slope	Threshold 1	Threshold 2	Threshold 3
Health Challenges					
PF Hlth1	Sleep problems	1.07	-2.83	-0.31	1.43
PF Hlth2	Pain	1.27	-2.47	-0.46	0.8
PF Hlth3	Indigestion problems	0.89	-1.98	1.56	2.94
PF Hlth4	Dehydration problems	0.54	-2.01	1.94	2.56
PF Hlth6	Spasticity	0.99	-1.60	0.48	2.34
PF Hlth7	Stress	1.13	-2.01	0.27	1.71
PF Hlth8	Medication side-effects	0.82	-2.77	0.85	2.84
Daily Living Challenges					
PF Home1	Wheelchair transfer to and from bed	1.02	-1.27	1.13	3.02
PF Home5	Wheelchair use around the home	1.68	-0.32	1.17	2.44
PF Home9	Household chores, such as cleaning and tidying	1.70	-1.94	0.38	1.53
PF Home10	Preparing and clearing away a meal	2.13	-1.14	0.73	2.01
PF Home11	Eating a meal	1.50	0.62	2.03	3.98
PF Envr1	Lack of peace and quiet	0.77	-1.94	2.29	3.88
PF Envr2	Inadequately adapted home	1.00	-2.04	1.15	2.43
PF Envr3	Inadequate medical care when at home	1.04	-1.46	2.15	3.61
PF Envr4	Inadequate non-medical care when at home	0.95	-2.08	2.03	2.89
PF Home3	Concentrating for an hour or more (such as reading, writing, or holding a conversation)	1.51	-0.64	0.68	2.28
PF Home4	Using a computer for an hour or more	1.15	-1.02	0.63	3.06
PF Home12	Letter-writing, form filling or paying bills	1.13	-0.53	2.36	3.41
Seating Challenges					
PF Home2	Sitting in a wheelchair for an hour or more	1.68	-0.81	0.69	2.21
PF_Hlth5	Poor posture	0.55	-2.25	1.73	3.09
PF Home6	Spending all day in your wheelchair	1.24	-2.27	-0.47	1.07
PF Home7	Pressure management (preventing pressure sores)	0.91	-0.53	2.22	3.44
PF Home8	Posture management	1.10	-1.03	1.50	3.16
Access Challenges					
PF Away1	Wheelchair use over a smooth surface	1.35	-0.08	1.66	3.18
PF Away2	Wheelchair use over an uneven surface	1.36	-1.57	0.04	1.28
PF Away3	Wheelchair transfer to and from car	1.56	-1.11	0.92	1.97
PF Away4	Traveling in your vehicle for an hour or more	1.42	-1.35	0.38	1.85
PF Away5	Using an adapted taxi	2.26	-2.94	1.83	2.45

PF Away6	Using a bus	1.96	-2.69	2.23	2.69
PF Away7	Using a train	2.39	-2.71	2.03	2.47
PF Away9	Going to a doctor's appointment	1.15	-1.61	1.28	3.06
PF Away10	Shopping, such as having access and reaching merchandise	1.69	-1.01	0.56	1.77
PF Away12	Attending an event, such as cinema, theater, or a show	2.05	-1.12	0.99	2.28
PF Away13	Visiting friends	2.03	-1.16	1.09	1.82
PF Away14	Attending a sporting event	1.71	-1.81	1.40	2.25
PF Away15	Taking a day trip away from home	2.11	-1.75	0.48	1.45
PF Away16	Taking an overnight trip away from home	1.86	-2.48	0.17	1.15
PF Away17	Taking a vacation away from home	1.17	-3.13	0.88	2.85

Abbreviations: Physical Fatigue (PF).

Items stem was: During the past 4 weeks did you experience each of the following? If so, how much physical fatigue did each cause you?

Table 6. Mental Fatigue Item Response Theory Parameters

ItemID	Item Content	Slope	Threshold 1	Threshold 2	Threshold 3
Health Challenges					
MF Hlth1	Sleep problems	0.86	-3.24	-0.11	1.57
MF Hlth2	Pain	0.89	-3.34	-0.22	1.34
MF Hlth5	Poor posture	0.38	-3.75	2.12	3.47
MF Hlth7	Stress	1.01	-2.34	-0.28	1.52
MF Hlth8	Medication side-effects	0.48	-3.35	1.71	3.81
Daily Living Challenges					
MF Home1	Wheelchair transfer to and from bed	1.52	-0.32	1.29	2.45
MF Home2	Sitting in a wheelchair for an hour or more	1.65	-0.25	1.31	1.93
MF Home5	Wheelchair use around the home	2.07	-0.01	1.08	1.94
MF Home6	Spending all day in your wheelchair	1.35	-1.19	0.61	1.57
MF Home7	Pressure management (preventing pressure sores)	1.32	-0.41	1.92	3.32
MF Home8	Posture management	1.53	-0.19	1.56	2.81
MF Home9	Household chores, such as cleaning and tidying	2.22	-0.78	0.72	1.67
MF Home10	Preparing and clearing away a meal	2.25	-0.41	0.94	1.99
MF Home11	Eating a meal	2.53	0.52	1.77	2.71
MF Envr1	Lack of peace and quiet	0.42	-2.72	2.56	3.74
MF Envr2	Inadequately adapted home	0.85	-2.06	1.42	2.63
MF Envr3	Inadequate medical care when at home	0.62	-1.95	2.48	3.81
Concentration Challenges					
MF Home3	Concentrating for an hour or more (such as reading, writing, or holding a conversation)	1.85	-0.70	0.57	1.93
MF Home4	Using a computer for an hour or more	1.62	-0.46	0.66	2.66
MF Home12	Letter-writing, form filling or paying bills	1.24	-0.44	1.51	2.81
Access Challenges					
MF Away1	Wheelchair use over a smooth surface	1.70	0.72	1.95	3.92
MF Away2	Wheelchair use over an uneven surface	2.02	-0.44	0.86	1.95
MF Away3	Wheelchair transfer to and from car	1.78	-0.66	1.32	1.96
MF Away4	Traveling in your vehicle for an hour or more	2.44	-0.56	0.68	1.53
MF Away5	Using an adapted taxi	1.49	-2.47	2.60	3.01
MF Away6	Using a bus	2.11	-2.46	2.40	2.61
MF Away7	Using a train	2.66	-2.85	2.17	2.40
MF Away9	Going to a doctor's appointment	1.87	-1.01	1.16	2.07
MF Away10	Shopping, such as having access and reaching merchandise	3.10	-0.54	0.60	1.41

MFAway11	Going out to a restaurant	3.36	-0.12	1.16	1.61
MF Away12	Attending an event, such as cinema, theater, or a show	2.51	-0.69	1.14	1.59
MF Away13	Visiting friends	2.59	-0.64	1.21	2.13
MF Away14	Attending a sporting event	1.80	-1.57	1.52	2.31
MF Away15	Taking a day trip away from home	3.08	-1.03	0.69	1.35
MF Away16	Taking an overnight trip away from home	2.59	-1.44	0.72	1.18
MF Away17	Taking a vacation away from home	1.48	-2.64	1.37	2.02

Abbreviations: Mental Fatigue (MF). Items stem was: During the past 4 weeks did you experience each of the following? If so, how much mental fatigue did each cause you?

Table 7 **Chi-square and wABC values for physical fatigability items with significant DIF by sex and diagnosis**

Comparison	Item	wABC	Chi-square	p-value
Sex	PFHome1	0.10	24.2	0.0001
Sex	PFHome9	0.14	22.1	0.0002
Sex	PFHome10	0.08	17.5	0.0015
Sex	PFHome3	0.05	14	0.0012
Sex	PFHome6	0.10	17.8	0.0013
Sex	PFaway1	0.22	25.7	0.0001
Sex	PFAway3	0.13	15.2	0.0043
Sex	PFAway10	0.08	13.3	0.0100
Sex	PFAway15	0.08	21.8	0.0002
Diagnosis	PFHlth6	0.16	24.1	0.0001
Diagnosis	PFEnvr2	0.19	29.3	0.0001
Diagnosis	PFHome2	0.13	16.9	0.0021
Diagnosis	PFHome3	0.21	32.7	0.0001
Diagnosis	PFHome8	0.15	27	0.0019
Diagnosis	PFAway3	0.10	16.3	0.0027
Diagnosis	PFAway4	0.09	23	0.0001
Diagnosis	PFAway6	0.17	18.6	0.0009
Diagnosis	PFAway13	0.07	18.9	0.0033
Diagnosis	PFAway16	**0.28**	20.5	0.0004

Abbreviations: Weighted area between the curves (wABC).

Table 8. Chi-square and wABC values for mental fatigability items with significant DIF by sex and diagnosis

Comparison	Item	wABC	Chi-square	p-value
Sex	MFHlth1	0.09	15.1	0.0062
Sex	MFHome8	0.06	14.4	0.0011
Sex	MFEnvr2	0.07	18.3	0.0092
Sex	MFAway14	0.07	15	0.0047
Sex	MFAway15	0.06	15.1	0.0045
Diagnosis	MFHlth1	0.12	16.1	0.0029
Diagnosis	MFHlth5	**0.31**	39.1	0.0001
Diagnosis	MFHlth7	0.10	13.8	0.0079
Diagnosis	MFHome8	0.14	21.6	0.0002
Diagnosis	MFEnvr3	0.10	17	0.0001
Diagnosis	MFAway16	0.10	24.4	0.0001

Abbreviations: Weighted area between the curves (wABC).

Figure 1. Overview of survey development and testing approach.

1. Conducted Literature Review

We identified areas of interest to fatigue in the context of SCI (e.g., causes, risk factors, impact on quality of life).

2. Identified Existing Fatigue and Fatigability Measures

We ascertained their strengths, weaknesses, and relevance to spinal cord injury (SCI).

3. Conducted In-depth Interviews

We identified activities (of different duration and intensity) and risk factors that make adults with SCI vulnerable to fatigue. We also consulted rehabilitation and seating experts, and a wheelchair tennis coach.

4. Drafted Instrument Items

We drafted items to assess Physical Fatigability and Mental Fatigability.

5. Conducted Cognitive Interviews

We conducted 8 cognitive interviews between December 2016 and January 2017 by phone. Interviewees represented all 4 injury types (complete and incomplete, paraplegia and quadriplegia). After 3 interviews and expert review the order and phrasing of several items were changed, 2 new items were written and added (one to the health symptom list and one to the demographic survey). After 2 more interviews and expert review we added a *"Did not have this"* or *"Did not do this"* response option for all questions. The last 3 interviews resulted in no changes.

6. Evaluated Readability

None of the items fell in the "fairly difficult", "difficult", or "very difficult" categories of the Flesch-Kincaid scale. Supplemental Table 1 shows mean, median, standard deviation, and range of item readability scores. Supplemental Figure 1 shows the F-K scores by item.

7. Conducted Field Test and Completed Psychometric Analyses

The final sample size was 464, recruited from across the United States.

Figure 2. Physical and Mental Fatigability Test Information and Standard Error

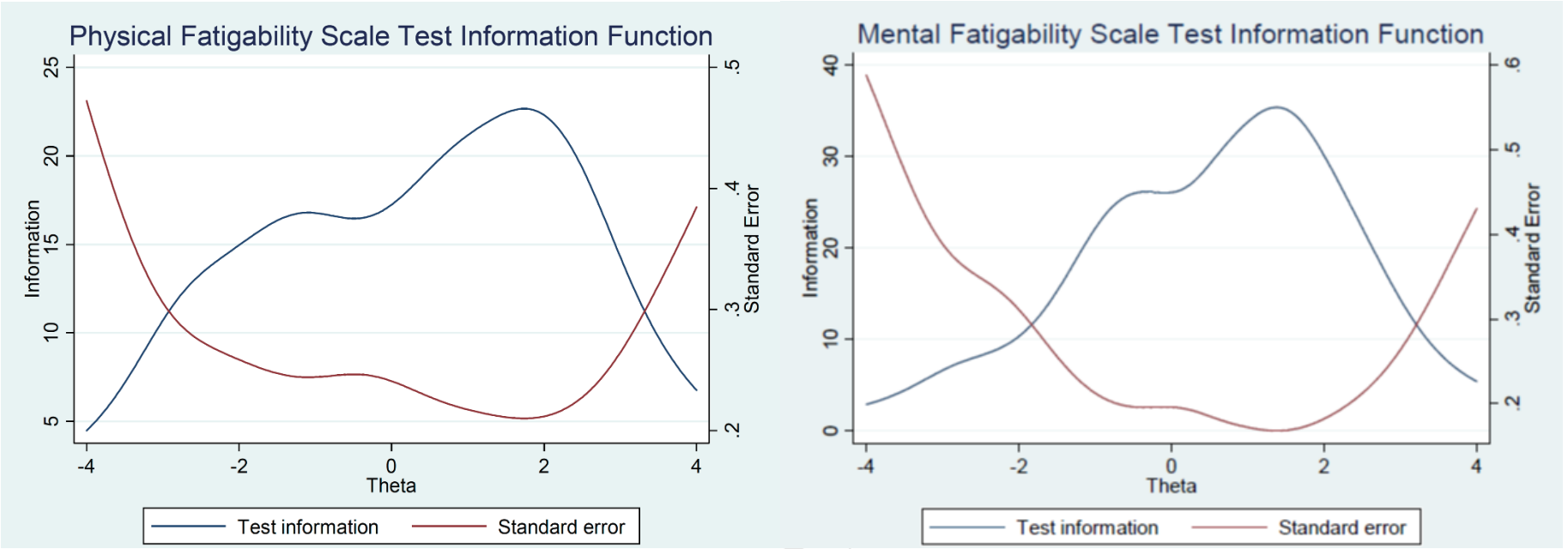


Figure 3. Graphical Representation of Differential Item Functioning Effect Size

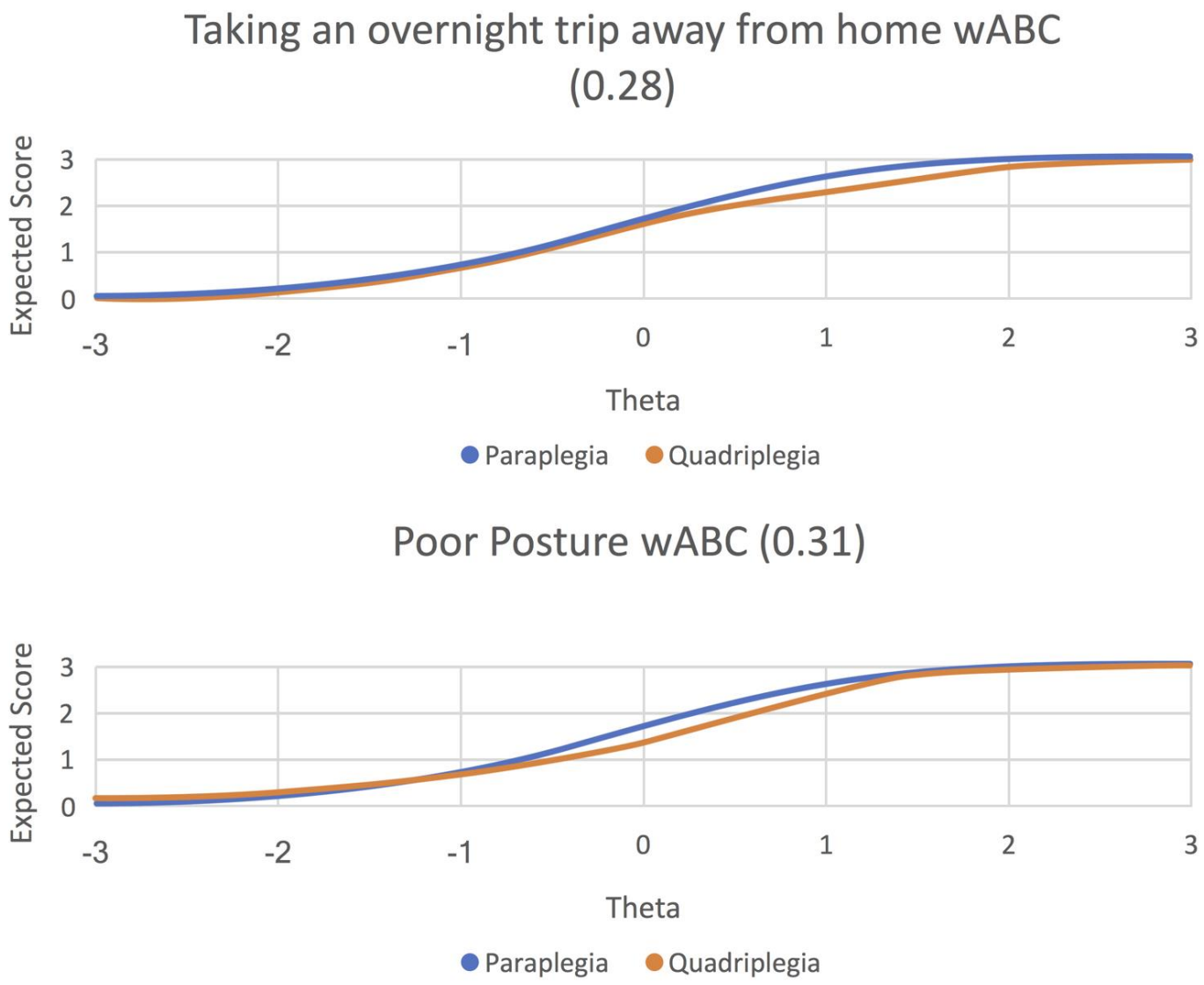
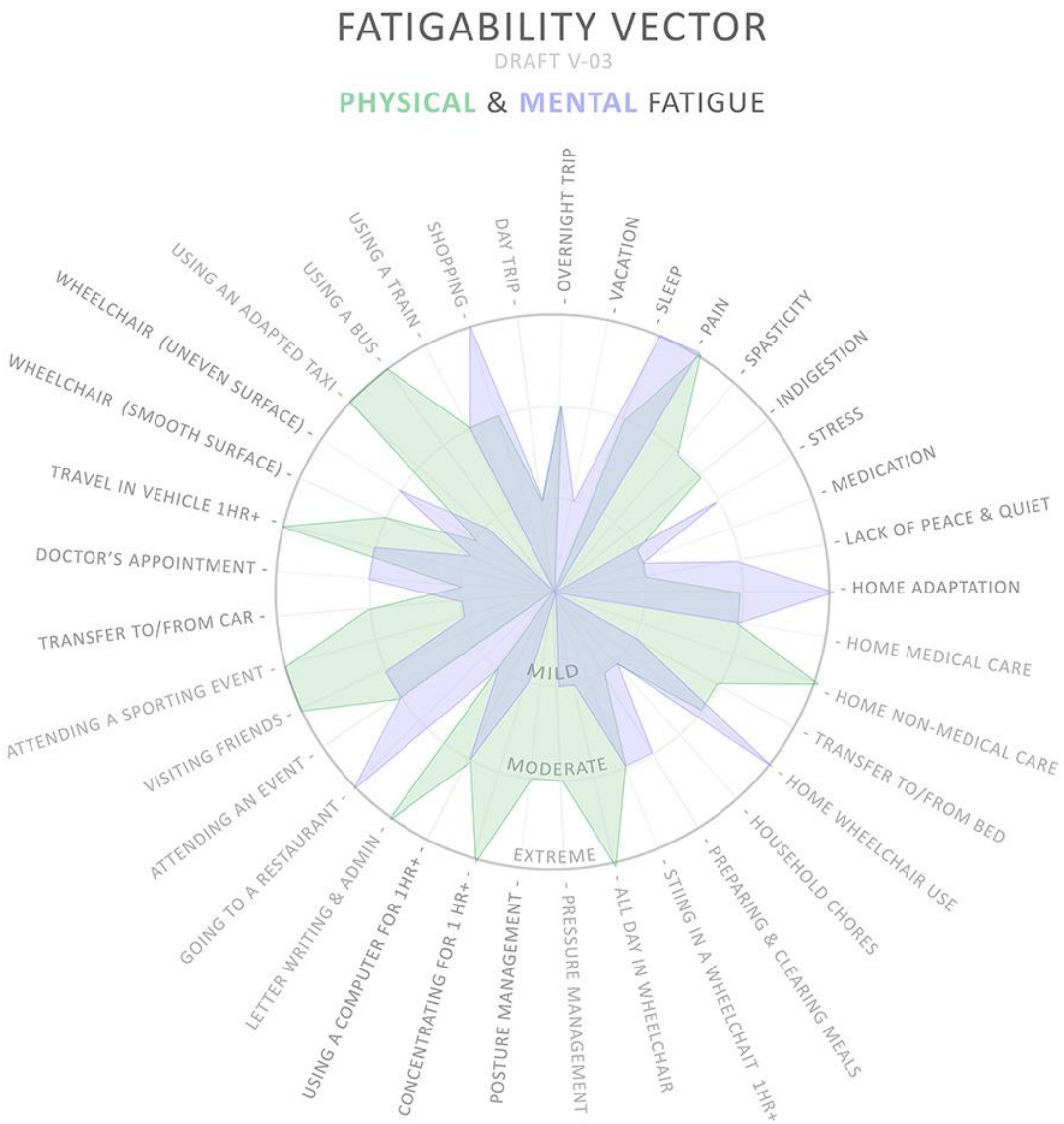
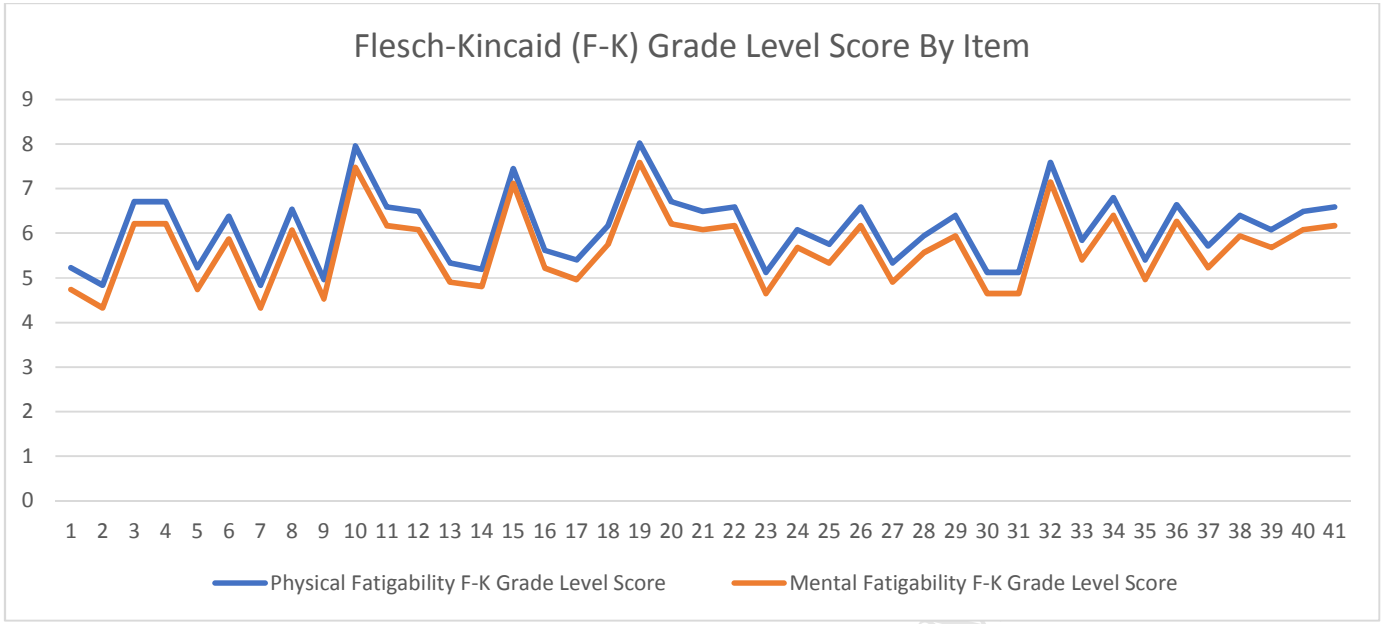


Figure 4. Combined Physical and Mental Fatigability Vector



Supplemental Figure 1. Flesch-Kincaid (F-K) Grade Level Score By Item, Physical and Mental Fatigability Scales.



Supplemental Table 1.
Mean, median, standard deviation, and range of item readability scores

Scale	Score	Mean	(95% CI)	SD	Median	Range
Physical Fatigability						
	F-K without answers	6.11	(5.9-6.4)	0.83	6.17	4.84-8.02
	FRE without answers	67.38	(65.6-69.1)	5.71	67.44	52.86-76.27
Mental Fatigability						
	F-K without answers	5.67	(5.4-5.9)	0.84	5.75	4.33-7.59
	FRE without answers	70.5	(68.8-72.3)	5.72	70.46	56.25-79

Abbreviations: F-K (Flesch-Kincaid grade level score); FRE (Flesch Reading Ease score); CI (Confidence interval); SD (standard deviation). Reading difficulty: Very easy (FRE 90-100; F-K 5th grade); Easy (FRE 80-90; F-K 6th grade); Fairly easy (FRE 70-80; F-K 7th grade); Standard (FRE 60-70; F-K 8th-9th grade); Fairly difficult (FRE 50-60; F-K 10th-12th grade); Difficult (FRE 30-50; F-K 13th-16th grade); Very difficult (FRE 0-30; F-K > College graduate).

Supplemental Table 2. Physical Fatigability Four Factor Categorical Analysis Standardized Factor Loadings

Scale	Item Content	Standardized factor loadings* (SE)		R^2
Health Challenges				
PF Hlth1	Sleep problems	0.635	(0.046)	0.404
PF Hlth2	Pain	0.392	(0.033)	0.213
PF Hlth3	Indigestion problems	0.638	(0.047)	0.406
PF Hlth4	Dehydration problems	0.701	(0.044)	0.491
PF Hlth6	Spasticity	0.569	(0.046)	0.323
PF Hlth7	Stress	0.422	(0.053)	0.178
PF Hlth8	Medication side-effects	0.504	(0.046)	0.254
Daily Living Challenges				
PF Home1	Wheelchair transfer to and from bed	0.493	(0.036)	0.243
PF Home5	Wheelchair use around the home	0.819	(0.021)	0.671
PF Home9	Household chores, such as cleaning and tidying	0.693	(0.026)	0.480
PF Home10	Preparing and clearing away a meal	0.530	(0.038)	0.281
PF Home11	Eating a meal	0.598	(0.032)	0.358
PF Envr1	Lack of peace and quiet	0.453	(0.039)	0.205
PF Envr2	Inadequately adapted home	0.603	(0.035)	0.363
PF Envr3	Inadequate medical care when at home	0.385	(0.039)	0.148
PF Envr4	Inadequate non-medical care when at home	0.378	(0.043)	0.143
PF Home3	Concentrating for an hour or more (such as reading, writing, or holding a conversation)	0.608	(0.032)	0.369
PF Home4	Using a computer for an hour or more	0.585	(0.032)	0.342
PF Home12	Letter-writing, form filling or paying bills	0.706	(0.031)	0.498
Seating Challenges				
PF Home2	Sitting in a wheelchair for an hour or more	0.570	(0.042)	0.325
PF_Hlth5	Poor posture	0.709	(0.039)	0.503
PF Home6	Spending all day in your wheelchair	0.948	(0.015)	0.898
PF Home7	Pressure management (preventing pressure sores)	0.881	(0.017)	0.776
PF Home8	Posture management	0.887	(0.033)	0.787
Access Challenges				
PF Away1	Wheelchair use over a smooth surface	0.818	(0.018)	0.669
PF Away2	Wheelchair use over an uneven surface	0.827	(0.027)	0.684
PF Away3	Wheelchair transfer to and from car	0.642	(0.031)	0.412
PF Away4	Traveling in your vehicle for an hour or more	0.723	(0.025)	0.523
PF Away5	Using an adapted taxi	0.726	(0.024)	0.527

PF Away6	Using a bus	0.671	(0.025)	0.451
PF Away7	Using a train	0.676	(0.027)	0.457
PF Away9	Going to a doctor's appointment	0.959	(0.017)	0.920
PF Away10	Shopping, such as having access and reaching merchandise	0.958	(0.015)	0.918
PF Away12	Attending an event, such as cinema, theater, or a show	0.640	(0.027)	0.410
PF Away13	Visiting friends	0.767	(0.021)	0.588
PF Away14	Attending a sporting event	0.866	(0.020)	0.749
PF Away15	Taking a day trip away from home	0.821	(0.017)	0.674
PF Away16	Taking an overnight trip away from home	0.794	(0.022)	0.631
PF Away17	Taking a vacation away from home	0.653	(0.034)	0.427

RMSEA = 0.081

RMSEA CI = [0.079 - 0.090]

CFI = 0.922

TFI = 0.940

* Statistically significant P < 0.0001

Abbreviations: Physical Fatigue (PF); Standard Error (SE); Root Mean Square Error of Approximation (RMSEA); Confidence Interval (CI); Comparative Fit Index (CFI); Tucker-Lewis Index (TLI). Note: For adequate model fit, RMSEA < 0.08; CFI > 0.95; TLI > 0.95.

Items stem was: During the past 4 weeks did you experience each of the following? If so, how much physical fatigue did each cause you?

Answer options: No fatigue (0); Mild fatigue (1); Moderate fatigue (2); Extreme fatigue (4).

Supplemental Table 3. Mental Fatigability Four Factor Categorical Analysis Standardized Factor Loadings

Scale	Item Content	Standardized factor loadings* (SE)		R^2
Health Challenges				
MF Hlth1	Sleep problems	0.627	0.041	0.393
MF Hlth2	Pain	0.787	0.036	0.619
MF Hlth5	Poor posture	0.744	0.036	0.554
MF Hlth7	Stress	0.347	0.066	0.135
MF Hlth8	Medication side-effects	0.383	0.049	0.147
Daily Living Challenges				
MF Home1	Wheelchair transfer to and from bed	0.786	0.020	0.617
MF Home2	Sitting in a wheelchair for an hour or more	0.771	0.031	0.594
MF Home5	Wheelchair use around the home	0.841	0.018	0.707
MF Home6	Spending all day in your wheelchair	0.832	0.019	0.693
MF Home7	Pressure management (preventing pressure sores)	0.794	0.020	0.631
MF Home8	Posture management	0.886	0.015	0.784
MF Home9	Household chores, such as cleaning and tidying	0.789	0.021	0.623
MF Home10	Preparing and clearing away a meal	0.753	0.021	0.567
MF Home11	Eating a meal	0.806	0.020	0.649
MF Envr1	Lack of peace and quiet	0.549	0.037	0.302
MF Envr2	Inadequately adapted home	0.644	0.032	0.415
MF Envr3	Inadequate medical care when at home	0.568	0.034	0.322
Concentration Challenges				
MF Home3	Concentrating for an hour or more (such as reading, writing, or holding a conversation)	0.573	0.036	0.328
MF Home4	Using a computer for an hour or more	0.719	0.026	0.517
MF Home12	Letter-writing, form filling or paying bills	0.775	0.024	0.600
Access Challenges				
MF Away1	Wheelchair use over a smooth surface	0.769	0.021	0.591
MF Away2	Wheelchair use over an uneven surface	0.794	0.020	0.630
MF Away3	Wheelchair transfer to and from car	0.680	0.021	0.462
MF Away4	Traveling in your vehicle for an hour or more	0.803	0.027	0.645
MF Away5	Using an adapted taxi	0.787	0.02	0.619
MF Away6	Using a bus	0.739	0.025	0.546
MF Away7	Using a train	0.823	0.02	0.677
MF Away9	Going to a doctor's appointment	0.819	0.037	0.671
MF Away10	Shopping, such as having access and reaching merchandise	0.941	0.043	0.886

MFAway11	Going out to a restaurant	0.581	0.042	0.337
MF Away12	Attending an event, such as cinema, theater, or a show	0.767	0.020	0.588
MF Away13	Visiting friends	0.888	0.013	0.788
MF Away14	Attending a sporting event	0.920	0.016	0.847
MF Away15	Taking a day trip away from home	0.861	0.013	0.741
MF Away16	Taking an overnight trip away from home	0.816	0.018	0.665
MF Away17	Taking a vacation away from home	0.724	0.024	0.524

RMSEA = 0.088

RMSEA CI = [0.085 - 0.091]

CFI = 0.888

TFI = 0.901

* Statistically significant P < 0.0001

Abbreviations: Mental Fatigue (MF); Standard Error (SE); Root Mean Square Error of Approximation (RMSEA); Confidence Interval (CI); Comparative Fit Index (CFI); Tucker-Lewis Index (TLI). Note: For good model fit, RMSEA < 0.08; CFI > 0.95; TLI > 0.95.

Items stem was: During the past 4 weeks did you experience each of the following? If so, how much mental fatigue did each cause you?

Answer options: No fatigue (0); Mild fatigue (1); Moderate fatigue (2); Extreme fatigue (4).

Supplemental Table 4. Physical Fatigue Item means (SD), item-total correlations, and coefficient alphas, by scale

Scale	Item Content	Mean	(SD)	Item-total correlation	Coefficient alpha
Health Challenges					
PF Hlth1	Sleep problems	1.72	(0.885)	0.385	0.743
PF Hlth2	Pain	1.85	(0.905)	0.652	
PF Hlth3	Indigestion problems	1.14	(0.815)	0.392	
PF Hlth4	Dehydration problems	0.87	(0.474)	0.377	
PF Hlth6	Spasticity	1.32	(0.937)	0.528	
PF Hlth7	Stress	1.46	(0.926)	0.500	
PF Hlth8	Medication side-effects	1.34	(0.825)	0.462	
Daily Living Challenges					
PF Home1	Wheelchair transfer to and from bed	1.11	(0.852)	0.536	0.846
PF Home5	Wheelchair use around the home	0.84	(0.851)	0.635	
PF Home9	Household chores, such as cleaning and tidying	1.45	(0.835)	0.474	
PF Home10	Preparing and clearing away a meal	1.15	(0.796)	0.628	
PF Home11	Eating a meal	0.43	(0.669)	0.572	
PF Envr1	Lack of peace and quiet	0.99	(0.686)	0.381	
PF Envr2	Inadequately adapted home	1.24	(0.841)	0.502	
PF Envr3	Inadequate medical care when at home	0.94	(0.679)	0.546	
PF Envr4	Inadequate non-medical care when at home	1.08	(0.742)	0.479	
PF Home3	Concentrating for an hour or more (such as reading, writing, or holding a conversation)	1.03	(0.916)	0.539	
PF Home4	Using a computer for an hour or more	1.12	(0.869)	0.493	
PF Home12	Letter-writing, form filling or paying bills	0.75	(0.720)	0.466	
Seating Challenges					
PF Home2	Sitting in a wheelchair for an hour or more	1.1	(0.896)	0.634	0.758
PF_Hlth5	Poor posture	1.08	(0.798)	0.398	
PF Home6	Spending all day in your wheelchair	1.77	(0.936)	0.615	
PF Home7	Pressure management (preventing pressure sores)	0.75	(0.703)	0.441	
PF Home8	Posture management	0.98	(0.799)	0.548	
Access Challenges					
PF Away1	Wheelchair use over a smooth surface	0.69	(0.804)	0.658	0.907
PF Away2	Wheelchair use over an uneven surface	1.52	(1.003)	0.678	
PF Away3	Wheelchair transfer to and from car	1.12	(0.867)	0.569	
PF Away4	Traveling in your vehicle for an hour or more	1.34	(0.910)	0.542	
PF Away5	Using an adapted taxi	1.09	(0.400)	0.457	

PF Away6	Using a bus	1.05	(0.385)	0.445
PF Away7	Using a train	1.06	(0.375)	0.457
PF Away9	Going to a doctor's appointment	1.09	(0.745)	0.534
PF Away10	Shopping, such as having access and reaching merchandise	1.21	(0.945)	0.669
PF Away12	Attending an event, such as cinema, theater, or a show	1.07	(0.745)	0.713
PF Away13	Visiting friends	1.11	(0.807)	0.672
PF Away14	Attending a sporting event	1.12	(0.650)	0.569
PF Away15	Taking a day trip away from home	1.39	(0.819)	0.709
PF Away16	Taking an overnight trip away from home	1.57	(0.823)	0.661
PF Away17	Taking a vacation away from home	1.38	(0.769)	0.437

Abbreviations: Physical Fatigue (PF); Standard Error (SE). Note: Item-total correlations were corrected for item overlap. Item names indicate the initial four categories in which they were grouped when the survey was administered (Hlth, for health issues; Home, for activities at home; Envr, environmental issues, and Away, for activities away from home). Items stem was: During the past 4 weeks did you experience each of the following? If so, how much physical fatigue did each cause you? Answer options: No fatigue (0); Mild fatigue (1); Moderate fatigue (2); Extreme fatigue (4).

Supplemental Table 5. Mental Fatigue Item means (SD), item-total correlations, and coefficient alphas, by scale

Scale	Item Content	Mean	(SD)	Item-total correlation	Coefficient alpha
Health Challenges					
MF Hlth1	Sleep problems	1.68	(0.916)	0.438	0.788
MF Hlth2	Pain	1.75	(0.921)	0.698	
MF Hlth5	Poor posture	0.98	(0.632)	0.363	
MF Hlth7	Stress	1.65	(0.946)	0.580	
MF Hlth8	Medication side-effects	1.27	(0.920)	0.409	
Daily Living Challenges					
MF Home1	Wheelchair transfer to and from bed	0.82	(0.861)	0.621	0.895
MF Home2	Sitting in a wheelchair for an hour or more	0.85	(0.949)	0.736	
MF Home5	Wheelchair use around the home	0.74	(0.914)	0.797	
MF Home6	Spending all day in your wheelchair	1.28	(0.995)	0.644	
MF Home7	Pressure management (preventing pressure sores)	0.73	(0.735)	0.613	
MF Home8	Posture management	0.72	(0.794)	0.740	
MF Home9	Household chores, such as cleaning and tidying	1.10	(0.898)	0.631	
MF Home10	Preparing and clearing away a meal	0.89	(0.877)	0.667	
MF Home11	Eating a meal	0.41	(0.668)	0.685	
MF Envr1	Lack of peace and quiet	1.00	(0.790)	0.389	
MF Envr2	Inadequately adapted home	1.20	(0.876)	0.498	
MF Envr3	Inadequate medical care when at home	0.98	(0.772)	0.494	
Concentration Challenges					
MF Home3	Concentrating for an hour or more (such as reading, writing, or holding a conversation)	1.14	(0.938)	0.785	0.814
MF Home4	Using a computer for an hour or more	0.99	(0.902)	0.685	
MF Home12	Letter-writing, form filling or paying bills	0.84	(0.836)	0.542	
Access Challenges					
MF Away1	Wheelchair use over a smooth surface	0.38	(0.640)	0.544	0.931
MF Away2	Wheelchair use over an uneven surface	0.96	(0.915)	0.712	
MF Away3	Wheelchair transfer to and from car	0.92	(0.852)	0.627	
MF Away4	Traveling in your vehicle for an hour or more	1.07	(0.961)	0.729	
MF Away5	Using an adapted taxi	1.02	(0.440)	0.500	
MF Away6	Using a bus	1.03	(0.387)	0.501	
MF Away7	Using a train	1.06	(0.358)	0.506	
MF Away9	Going to a doctor's appointment	1.02	(0.792)	0.698	
MF Away10	Shopping, such as having access and reaching merchandise	1.08	(0.967)	0.808	

MFAway11	Going out to a restaurant	0.75	(0.879)	0.778
MF Away12	Attending an event, such as cinema, theater, or a show	0.97	(0.860)	0.788
MF Away13	Visiting friends	0.90	(0.760)	0.711
MF Away14	Attending a sporting event	1.05	(0.625)	0.558
MF Away15	Taking a day trip away from home	1.21	(0.878)	0.784
MF Away16	Taking an overnight trip away from home	1.30	(0.862)	0.766
MF Away17	Taking a vacation away from home	1.22	(0.660)	0.439

Abbreviations: Mental Fatigue (MF); Standard Error (SE). Note: Item-total correlations were corrected for item overlap. Item names indicate the initial four categories in which they were grouped when the survey was administered (Hlth, for health issues; Home, for activities at home; Envr, environmental issues, and Away, for activities away from home). Items stem was: During the past 4 weeks did you experience each of the following? If so, how much mental fatigue did each cause you? Answer options: No fatigue (0); Mild fatigue (1); Moderate fatigue (2); Extreme fatigue (4).

Supplemental Table 6. Physical Fatigability scale means (SD) by validity variables: F statistic (p value)

Scale		Complete Paraplegia	Incomplete Paraplegia	Complete Quadriplegia	Incomplete Quadriplegia	Paraplegia	Quadriplegia
Health challenges	Means (SD)	9.37 (4.13)	11.18 (3.34)	7.91 (3.40)	9.22 (3.01)	10.31 (3.85)	8.70 (3.23)
	F (p)	1.56 (0.212)	38.03 (0.0001)	19.96 (0.0001)	2.27 (0.1325)	21.45 (0.0001)	
Seating challenges	Means (SD)	5.85 (2.76)	6.35 (3.60)	5.25 (1.55)	4.83 (2.77)	6.10 (3.19)	5.01 (2.37)
	F (p)	0.76 (0.3850)	10.52 (0.0013)	1.73 (0.1892)	11.48 (0.0008)	15.43 (0.0001)	
Daily living challenges	Means (SD)	12.10 (5.92)	14.57 (5.78)	10.04 (4.16)	10.06 (5.26)	13.38 (5.97)	10.05 (4.84)
	F (p)	0.17 (0.673)	43.01 (0.0001)	10.82 (0.0011)	17.90 (0.0001)	38.90 (0.0001)	
Access challenges	Means (SD)	16.90 (7.89)	21.37 (7.76)	16.07 (4.24)	15.14 (5.49)	19.21 (8.12)	15.51 (5.04)
	F (p)	3.04 (0.0817)	58.24 (0.0001)	4.68 (0.0309)	18.94 (0.0001)	29.66 (0.0001)	

Note: We hypothesized that means were higher for those who reported having paraplegia vs quadriplegia, and for those with incomplete paraplegia.

Supplemental Table 7. Mental Fatigability scale means (SD) by validity variables: F statistic (p value)

Scale		Complete Paraplegia	Incomplete Paraplegia	Complete Quadriplegia	Incomplete Quadriplegia	Paraplegia	Quadriplegia
Health challenges	Means (SD)	7.51 (3.07)	8.67 (3.08)	5.7 (2.38)	6.30 (2.49)	8.11 (3.12)	6.06 (2.46)
	F (p)	0.66 (0.4162)	46.02 (0.0001)	24.74 (0.0001)	16.16 (0.0001)	54.69 (0.0001)	
Concentration challenges	Means (SD)	2.73 (2.21)	3.69 (2.48)	2.92 (1.83)	2.26 (2.09)	3.22 (2.40)	2.52 (2.01)
	F (p)	2.00 (0.1577)	23.30 (0.0001)	0.02 (0.8903)	13.18 (0.0003)	10.46 (0.0013)	
Daily living challenges	Means (SD)	11.02 (7.55)	12.80 (7.79)	9.15 (3.44)	8.46 (5.51)	11.94 (7.71)	8.73 (4.80)
	F (p)	0.35 (0.5519)	20.54 (0.0001)	4.27 (0.0394)	15.13 (0.0001)	24.56 (0.0001)	
Access challenges	Means (SD)	13.78 (7.79)	21.30 (9.70)	14.27 (5.77)	12.39 (5.35)	17.67 (9.58)	13.14 (5.58)
	F (p)	13.03 (0.0003)	64.27 (0.0001)	3.19 (0.0748)	24.85 (0.0001)	32.55 (0.0001)	

Note: We hypothesized that means were higher for those who reported having paraplegia vs quadriplegia, and for those with incomplete paraplegia.