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ORIGINAL ARTICLE

PM&R

Creating adjusted scores targeting mobility empowerment (CASTLE 2): Using response probabilities to expand interpretation of prosthetic limb users survey of mobility (PLUS-M) scores for individuals with lower limb amputation

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Abstract

Background: Prosthetists and other rehabilitation specialists often need to identify which aspects of mobility should be prioritized in order to make meaningful changes in a patient's health outcomes. By comparing a patient's responses on the Prosthetic Limb Users Survey of Mobility (PLUS-M) to predicted responses, clinicians can identify areas for improvement and provide more targeted rehabilitation.

Objective: To generate PLUS-M T-score maps based on patient presentation (ie, etiology and amputation level) to provide guidance on the next steps in a patient's rehabilitation care.

Design: A frequency response method was used to generate PLUS-M T-score maps. The maps predicted the most probable response to each item on the PLUS-M based on the T-score. The maps were then tested using a separate test dataset. Accuracy was evaluated by comparing differences and Spearman correlation coefficients between predicted and actual scores.

Setting: Clinical orthotics and prosthetics care.

Participants: Maps were generated based on a training dataset from a large sample ($N = 28{,}719$) of patients with lower limb amputation. A separate test dataset ($N = 26{,}535$) was used to test the model. Individuals were included in the training and test datasets if they were adults with unilateral above-knee or below-knee amputation.

Interventions: Not applicable.

Main Outcome Measure(s): PLUS-M 12-item short form (v1.2).

Results: PLUS-M T-score maps were generated for two amputation levels (above and below knee) and two etiologies (dysvascular and nondysvascular), in addition to one for all patients. PLUS-M T-score maps predicted patient scores with high accuracy (difference scores >91.5% and Spearman correlation coefficients >0.801).

Conclusions: Clinicians can use the developed PLUS-M T-score maps to better understand patients' mobility. This insight can help clinicians improve care by identifying key rehabilitation goals for their patients.

INTRODUCTION

Among individuals with lower limb amputation, mobility is linked to various aspects of well-being including quality of life and satisfaction.[1,2] Measuring mobility during the course of rehabilitation helps clinicians work with their patients to set realistic goals based on their current ability.[3] Mobility can be measured using different types of outcome measures, including performance-based and patient-reported outcome (PRO) measures. PROs are particularly well suited to clinical practice as they are effective in estimating a patient's function, which offers valuable insights for clinicians when providing care to their patients.[4,5] Nevertheless, there remain opportunities to advance the implementation and utility of PRO measures[4] in rehabilitation following amputation by making them easier to interpret.

The Prosthetic Limb Users Survey of Mobility (PLUS-M) is a PRO measure designed specifically for individuals with lower limb amputation.[6] It has strong evidence of reliability and validity[6–8] and is available in multiple languages.[9–13] The PLUS-M provides clinicians with a T-score that denotes a patient's mobility. A T-score of 50 represents average mobility for the entire population of lower limb prosthesis users based on a development sample of more than 1000 prosthesis users.[6] Recent research on a national sample of nearly 30,000 patients with lower limb amputation has improved interpretation of PLUS-M T-scores by deriving normative values based on age, amputation level, and etiology, factors that are all known to affect mobility.[14,15] Clinicians can use these normative T-scores to evaluate a patient's mobility relative to that of their peers.

Although PLUS-M T-scores provide a quantitative assessment of prosthetic mobility in a broad context (ie, mobility relative to the general population of prosthesis users), they are not intended to provide the specificity needed to drive treatment plans for an individual patient. This limitation is common to PRO measures that score an individual's ability based on a comprehensive set of items rather than offer prescriptive guidance. However, there is opportunity to use PLUS-M to identify potential underlying aspects of mobility where a patient excels (ie, those areas where less rehabilitation and training may be needed) or could improve (ie, those areas where more targeted rehabilitation or training could be beneficial). Investigators recently created T-score maps, figures that estimate the probability of each response for Patient-Reported Outcome Measurement Information system (PROMIS) short forms based on a respondent's T-score.[16] These maps enable clinicians to forecast the expected response to each item in the questionnaire based on T-score alone. Projected responses can be compared to patients' true responses to identify opportunities for intervention. Clinicians and patients can also use T-score maps to contextualize changes in T-scores over time or those that result from provision of an intervention. However, there are currently no such maps available for outcome measures specific to individuals with amputation.

Therefore, the purpose of this study was to create T-score maps forecasting the most probable response for each item in the PLUS-M 12-item short form (v1.2).[6] The goal was to generate PLUS-M T-score maps that are specific to different amputation levels (ie, below knee [BK] and above knee [AK]) and common etiologies (ie, trauma or diabetes/dysvascular disease) to investigate how response probabilities vary based on these factors. It was hypothesized that, in a large sample of patients seen in clinic, there would be strong correlations between responses predicted by the PLUS-M T-score maps and patients' actual responses.

METHODS

Sample

To generate and test the T-score maps, a large dataset of outcomes collected from patients with lower limb amputation were split into two sets—a training sample and test sample. Data were collected in private prosthetic clinics located across the United States. The training sample was collected between April 2016 and December 2021 and the test sample was collected between January 2022 and December 2022. The outcomes data were collected as a part of routine care at these clinics. This database review was approved by the Western Copernicus Group Institutional Review Board (protocol #20170059) and designated to qualify for exempt status. Study results are presented according to the Strengthening the Reporting of Observational Studies in Epidemiology guidelines (see Supplementary Checklist).

Individuals were included if they were adults (≥ 18 years old), answered all 12 questions on the PLUS-M 12-item short form, had their amputation due to trauma or diabetes/dysvascular disease, and had either a unilateral AK amputation or BK amputation. Patients with an ankle disarticulation were grouped with patients with transtibial amputation (ie, BK) based on recent evidence noting no differences in functional outcomes for these surgical levels.[17–19] Similarly, patients with knee disarticulation and transfemoral amputation were combined in the AK group.

Generation of T-score maps

The PLUS-M is scored yielding a T-score that ranges from 0 to 100 and is centered around 50. Each item in the PLUS-M short form consists of a question focused on mobility (eg, "Are you able to walk a short distance in your home?") and five response options (eg, 5 = "without any difficulty," 4 = "with a little difficulty," 3 = "with some difficulty," 2 = "with much difficulty," 1 = "unable to do"). The 12-item short form (v1.2) administered in clinic has scoring limits of 21.8–71.4 based on the items selected for the short form.

A frequency response method was used to create the PLUS-M T-score maps. A training dataset was first used to determine the percentage of patients with a given T-score that selected each of the five response options (1 = "unable to do", 5 = "without any difficulty") for each item in the PLUS-M short form. The response with the highest percentage was selected as the most probable response. For example, if a sample of individuals with a resultant T-score of 50.0 had the following response frequencies to one of the 12 items: "unable to do" 51.2% of the time, "with much difficulty" 29.1% of the time, "with some difficulty" 15.2% of the time, "with a little difficulty" 3.9% of the time, and "without any difficulty" 0.5% of the time, the response of "unable to do" would be selected to be the most probable response. This process was repeated for each item of the PLUS-M and each T-score. The 12 items were then stacked vertically with T-scores across the horizontal axis to create a T-score map. The map is read by drawing a vertical line at the chosen T-score with each color representing the most probable response for each of the 12 items in the PLUS-M short form.

To further identify how different subsets of patients with lower limb amputation respond to the items in the PLUS-M, T-score maps were generated for four subgroups: patients with below-knee amputation due to trauma (BK_T), patients with below-knee amputation due to diabetes/dysvascular disease (BK_DV), patients with above-knee amputation due to trauma (AK_T), and patients with above-knee amputation due to diabetes/dysvascular disease (AK_DV). Lastly, a T-score map was generated for all patients (ALL) combined.

Comparison of predicted to actual item responses—Accuracy

Data from a sample of patients withheld from building the T-score maps (ie, the test sample) was then used to assess the accuracy of the item-level responses predicted by the T-score maps. For each individual, a PLUS-M T-score was first calculated according to the developers' instructions.[20] Responses to all 12 items were then predicted for each individual using the PLUS-M T-score maps. These predictions were then compared to patients' actual responses using methods similar to those used to evaluate the accuracy of PROMIS T-score maps.[16] First, a difference score was calculated as the difference between predicted and actual responses. For example, if the map predicted a response of "unable to do" but the actual response was "with some difficulty," the difference score would be −2. Directionality of the difference score was maintained such that actual responses denoting higher functionality than predicted responses were negatively scored and vice versa. The percentage of scores with ±1 response was calculated for each item and averaged across all 12 items. Second, Spearman correlation coefficients were calculated to represent how similar the rank was between the predicted and actual responses. A correlation coefficient of 1.0 would represent a perfect monotonic relationship. A Spearman correlation coefficient was calculated for each item as well as an average across all 12 items.

RESULTS

Sample Characteristics

Both the training sample and test sample were similar with respect to age, height, weight, gender, amputation level, and etiology (Table 1). The training dataset consisted of 28,719 PLUS-M questionnaires from 28,719 patients and the test dataset consisted of 26,535 questionnaires from 17,260 patients.

When analyzing T-scores from each group (BK_T, BK_DV, AK_T, AK_DV), the mean T-score was found to be highest for the BK_T group and lowest for the AK_DV group (Table 1). In the BK_T group, 9.6% of the responses had the highest possible T-score, 71.4, and in the AK_DV group, 8.8% of responses had the lowest possible T-score, 21.8 (Figure 1).

T-score maps

To use the T-score maps, the clinician draws a vertical line up from the individual's T-score located on the horizontal axis (Figure 2). The vertical line intersects the most probable response to each item in the PLUS-M 12-item short form. Specific answers are coded according to the colors noted in the figure legend. Clinicians can then compare the participant's actual response to the predicted response from the map. When a patient's actual response is below the predicted response, these items may be recommended for discussion during the clinical encounter. The patient and clinician can then discuss next steps in care together.

Comparison of predicted to actual item responses

On average, accuracy of the T-score map predictions was high exceeding 91.5%, meaning that a vast majority of the predicted responses were within ±1 response option of the test dataset patients' true responses

TABLE 1 Sample demographics and characteristics of the test and training samples used to generate and test the PLUS-M T-score maps, respectively.

		Training sample (***N*** = 28,719)	Testing sample (***N*** = 26,535)
Characteristic		Median (IQR)	Median (IQR)
Age (y)		61 (52–69)	61 (52–69)
Height (m)		1.75 (1.68–1.88)	1.75 (1.68–1.83)
Weight (kg)		88.5 (74.8–104.3)	88.9 (74.8–106.1)
		N (%)	N (%)
Gender	Male	21,808 (76)	20,206 (76)
	Female	6902 (24)	6306 (24)
	Not specified	9 (<1)	23 (<1)
Amputation level	Above knee	6269 (22)	5453 (21)
	Below knee	22,450 (78)	21,082 (79)
Amputation Etiology	Trauma	9467 (33)	9497 (36)
	Diabetes/dysvascular disease	19,252 (67)	17,038 (64)
		Mean (SD)	**Mean (SD)**
PLUS-M T-score	BK_T	54.1 (10.4)	52.3 (10.0)
	BK_DV	46.8 (10.7)	46.0 (10.2)
	AK_T	49.7 (10.2)	48.3 (9.9)
	AK_DV	39.9 (10.2)	39.4 (9.9)
	ALL	48.0 (11.3)	47.2 (10.7)

Abbreviations: AK_DV, above-knee amputation, dysvascular etiology; AK_T, above-knee amputation, traumatic etiology; BK_DV, below-knee amputation, dysvascular etiology; BK_T, below-knee amputation, traumatic etiology; IQR, interquartile range; PLUS-M, Prosthetic Limb Users Survey of Mobility.

(Table 2). In addition, there was a strong correlation between the predicted and actual responses with Spearman correlation coefficients >0.801 across all of the groups (Table 3).

DISCUSSION

In total, five PLUS-M T-score maps were generated based on a large sample of existing patient data. The developed maps show the most probable responses to individual PLUS-M items across patients with different amputation levels and etiologies. All maps exhibited high accuracy in predicting specific item responses based on the patient's T-score.

There was a consistent diagonal pattern of responses across the maps, indicating that the PLUS-M items on the 12-item short form are arranged with increasing difficulty (as reflected by higher rates of "unable to do" responses in items near the bottom of the questionnaire). On the aggregate, these results confirmed performance of the PLUS-M as intended by the developers.[6]

Comparing the four level/etiology groups, there were slight differences in the distribution of responses. For example, the AK_DV and BK_DV groups report few "with much difficulty" responses and more "unable to do" responses (Figures 3, 4) when compared to the AK_T and BK_T groups (Figures 5, 6). Patients with amputation due to diabetes/dysvascular disease tend to have lower PLUS-M T-scores compared to their peers with amputation due to trauma (Figure 1)[14,15]; therefore, it should be expected to observe more responses on the lower end of the scale as was observed. Particularly of note, patients with an AK amputation with diabetes/dysvascular disease had an average T-score of 39.9—around 1 SD below their peers with an amputation due to trauma. Because of the differences across level of amputation and etiology, the specific maps are recommended for individual patient care. The ALL T-score map would be more appropriate for group comparisons.

It is also noted that some responses change contrary to the diagonal pattern for adjacent T-scores (eg, the response for "Are you able to walk on an unlit street or sidewalk" is forecasted to be "with much difficulty" for T-score of 38.4 but changes to "unable to do" for T-score of 39.0 in the ALL T-score map). This is a limitation of the frequency response method where the response option with the highest percentage of respondents in the training dataset is selected for the map, but in some cases, two adjacent responses may have nearly equal numbers of respondents (ie, the probability of selecting the two adjacent response options is very similar).

There was possible evidence of ceiling and floor effects[21] with the PLUS-M™ 12-item short form in the BK_T and AK_DV groups, respectively. Although

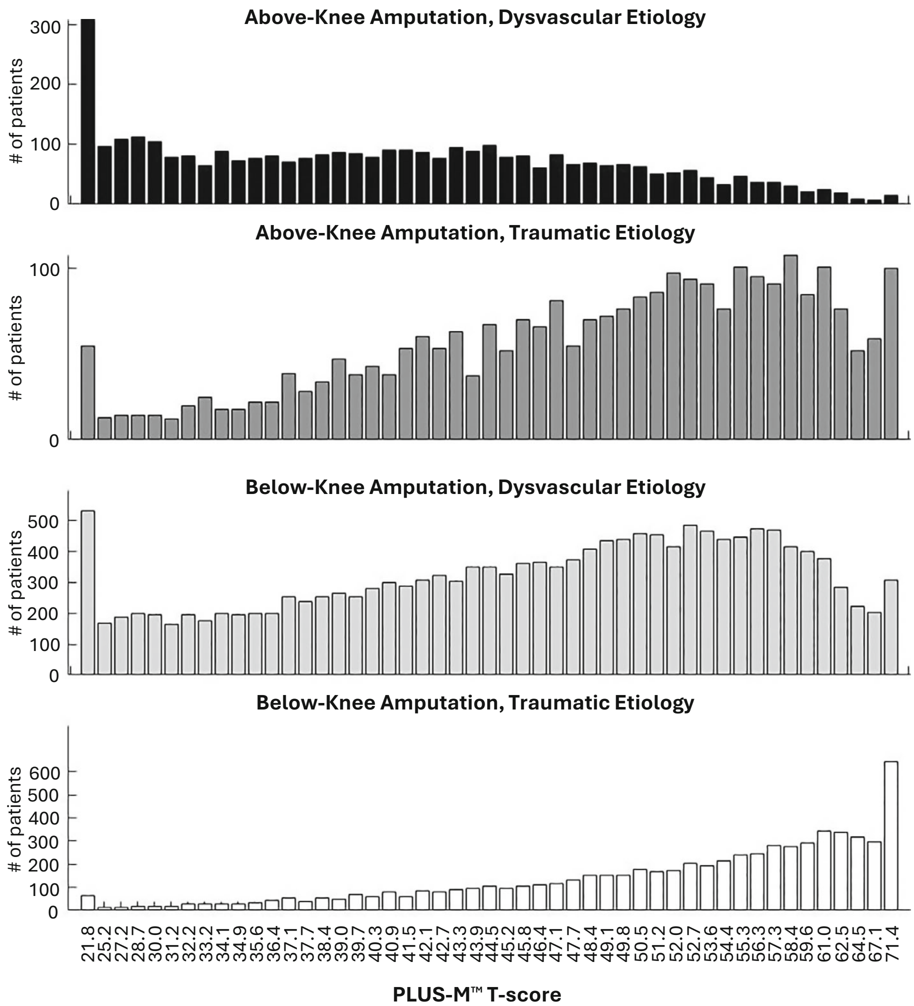

FIGURE 1 Frequency of each T-score across AK_DV, AK_T, BK_DV, and BK_T. Number of patients at each T-score is presented for each group in the training sample. Note *y*-axis is scaled differently for each group. AK_DV, above-knee amputation, dysvascular etiology; AK_T, above-knee amputation, traumatic etiology; BK_DV, below-knee amputation, dysvascular etiology; BK_T, below-knee amputation, traumatic etiology.

the BK_T group had a higher mean T-score (54.1 in the training sample and 52.3 in the test sample, Table 1), there was a higher percentage of patients who scored at the maximum T-score (9.6% of patients in this group). This observation was also noted by the PLUS-M instrument developers. This potential ceiling effect among patients with high levels of mobility has prompted additional focus groups to identify content that could be used to expand the PLUS-M item bank.[22] Similarly, the AK_DV group expectedly had a lower mean T-score (39.9 in the training sample and 39.4 in the test sample, Table 1). However, a higher proportion of patients in this group scored at the minimum T-score (8.8% of patients in this group). These results suggest use of the PLUS-M computerized adaptive test (CAT) or development of targeted short forms may be necessary for individuals that score on the low end or high end of the 12-item short form.[23] The CAT is an online administration of the PLUS-M where each item is asked one at a time and the subsequent item is selected based on the previous response to more efficiently calculate the T-score in fewer items. The CAT uses items from the entire item bank and therefore allows for additional items at the lower and higher ends of mobility to be included for more precise scoring. Using these alternative forms of PLUS-M may enable clinicians to better monitor progress in patients with very high or low mobility as they can offer more precise scores and be more sensitive to changes when measuring mobility near the extremes.

The PLUS-M T-score maps from the present study can also serve as a tool for identifying specific elements of mobility that clinicians could target to improve a patient's overall mobility. As an example, consider a 58-year-old patient with an AK amputation due to trauma who has a PLUS-M T-score of 39.7. The patient responded, "with much difficulty" to the first item, "Are you able to walk a short distance in your home?"; however, it is predicted that a patient with this T-score, amputation level, and etiology would respond "with some difficulty" to this item. Therefore, discussing and addressing the patient's mobility around their home would be an area of opportunity for targeted rehabilitation.

Further, it is possible to use the T-score maps to set secondary goals based on a patient's peers. From the previously mentioned patient's age, amputation level, and etiology, it can be determined that their peer-

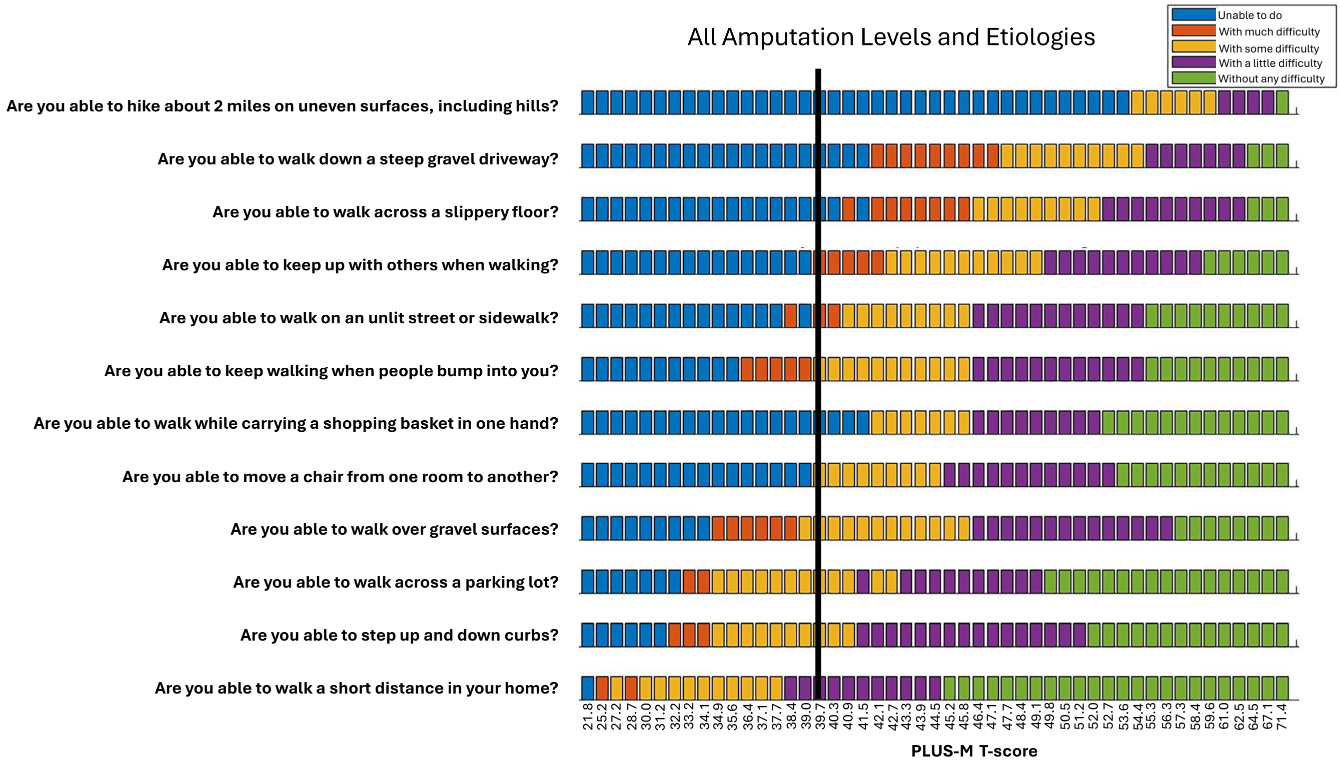

FIGURE 2 PLUS-M map all amputation levels and etiologies (ALL). Maps can be read by drawing a vertical line at the T-score of interest. The colors the line crosses represent the predicted response to each item of the PLUS-M 12-item short form. PLUS-M, Prosthetic Limb Users Survey of Mobility.

TABLE 2 Accuracy – difference scores.

	ALL (%)	AK_DV (%)	AK_T (%)	BK_DV (%)	BK_T (%)
Item #1	93.8	89.8	93.6	94.7	96.1
Item #2	95.2	92.7	95.8	95.6	98.4
Item #3	95.1	92.8	97.4	95.6	98.2
Item #4	96.1	94.2	97.9	96.0	98.7
Item #5	89.6	83.4	93.1	89.6	96.4
Item #6	88.1	86.3	94.6	89.9	96.1
Item #7	95.9	93.7	95.8	95.7	97.8
Item #8	91.5	90.2	95.5	91.3	96.3
Item #9	95.2	92.9	94.3	94.0	97.0
Item #10	93.8	92.8	96.2	93.2	95.6
Item #11	94.9	95.2	97.4	95.5	97.4
Item #12	86.3	94.3	92.9	88.4	88.2
Average	93.0	91.5	95.4	93.3	96.4

Note: The percentage of the test sample with predicted scores within one category of the patient's actual answer is shown. The average percentage across all 12 items is noted in the bottom row.
Abbreviations: AK_DV, above-knee amputation, dysvascular etiology; AK_T, above-knee amputation, traumatic etiology; BK_DV, below-knee amputation, dysvascular etiology; BK_T, below-knee amputation, traumatic etiology.

TABLE 3 Accuracy – Spearman correlation coefficients.

	ALL	AK_DV	AK_T	BK_DV	BK_T
Item #1	0.746	0.726	0.766	0.734	0.785
Item #2	0.779	0.810	0.774	0.771	0.805
Item #3	0.822	0.844	0.824	0.817	0.835
Item #4	0.840	0.840	0.828	0.832	0.837
Item #5	0.828	0.743	0.819	0.814	0.831
Item #6	0.846	0.791	0.854	0.845	0.843
Item #7	0.849	0.841	0.833	0.840	0.826
Item #8	0.829	0.823	0.835	0.820	0.827
Item #9	0.843	0.797	0.831	0.825	0.832
Item #10	0.828	0.777	0.822	0.815	0.824
Item #11	0.836	0.801	0.825	0.824	0.849
Item #12	0.743	0.817	0.788	0.742	0.794
Average	0.816	0.801	0.817	0.807	0.824

Note: The Spearman correlation coefficient was calculated between the predicted and actual responses in the test dataset for each item. The average correlation coefficient across all 12 items is noted in the bottom row.
Abbreviations: AK_DV, above-knee amputation, dysvascular etiology; AK_T, above-knee amputation, traumatic etiology; BK_DV, below-knee amputation, dysvascular etiology; BK_T, below-knee amputation, traumatic etiology.

average PLUS-M™ T-score, calculated from Equation 1 in Fylstra et al.,[9] is 49.4. Subsequently, this patient is about 10 points lower than their peers (ie, 1 SD below average). Using the AK_T map and the peer-average T-score of 49.4, it can be predicted that a patient would answer "without any difficulty" to the first PLUS-M question, "with a little difficulty" to the second

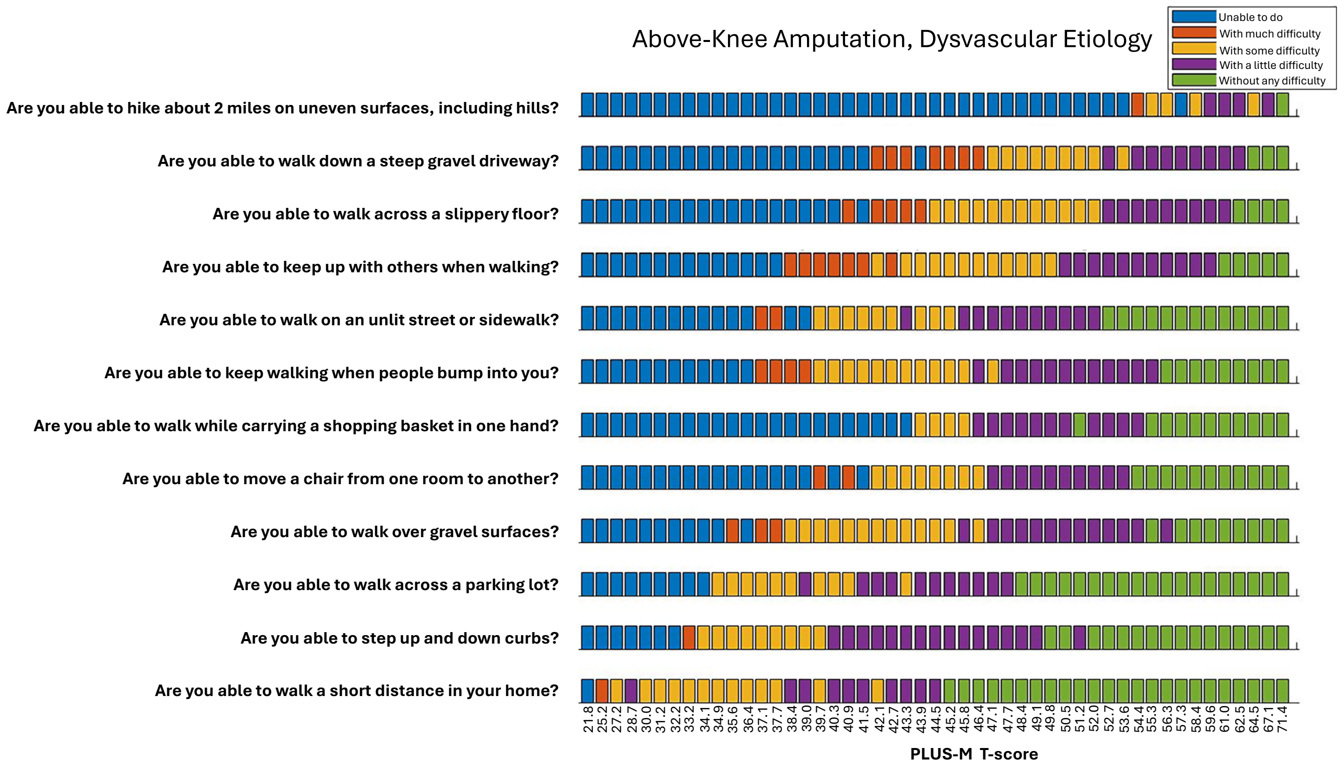

FIGURE 3 PLUS-M map for individuals with above-knee amputation due to diabetes/dysvascular disease. PLUS-M, Prosthetic Limb Users Survey of Mobility.

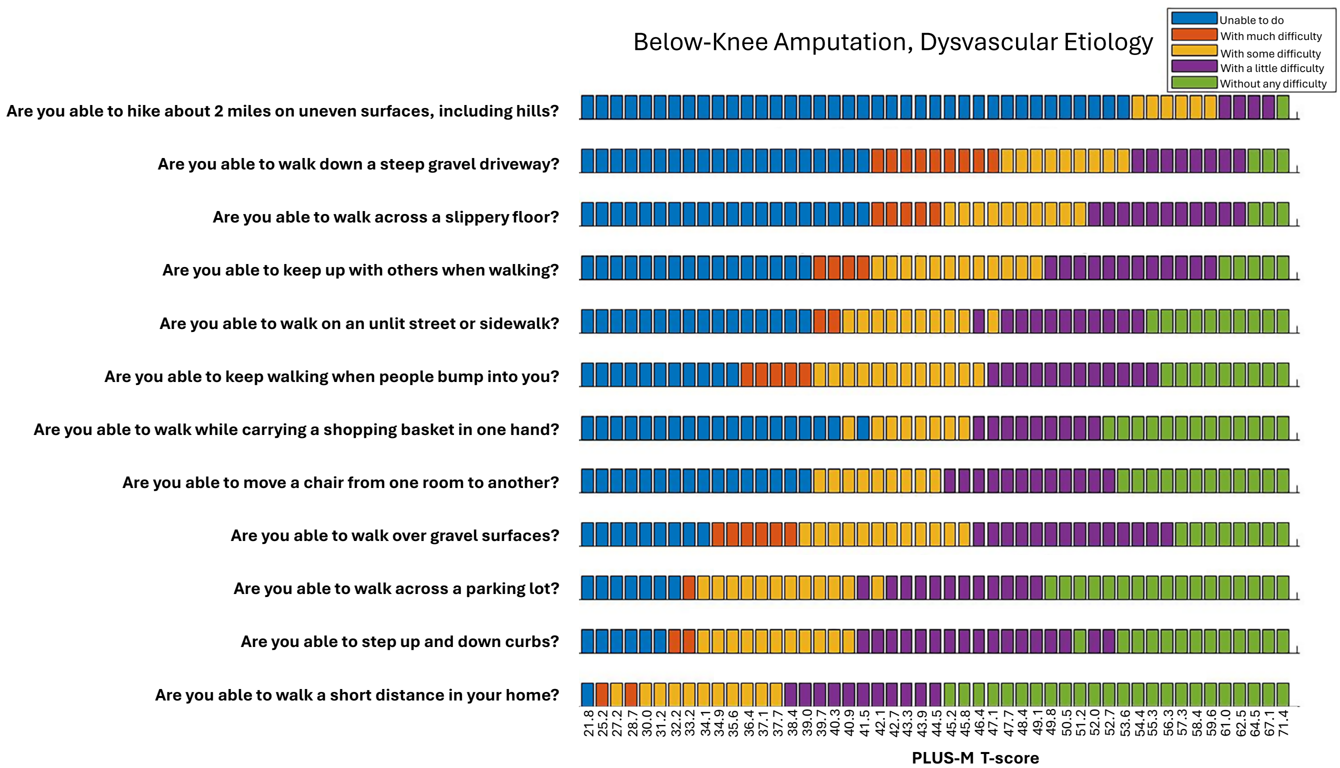

FIGURE 4 PLUS-M map for individuals with below-knee amputation due to diabetes/dysvascular disease. PLUS-M, Prosthetic Limb Users Survey of Mobility.

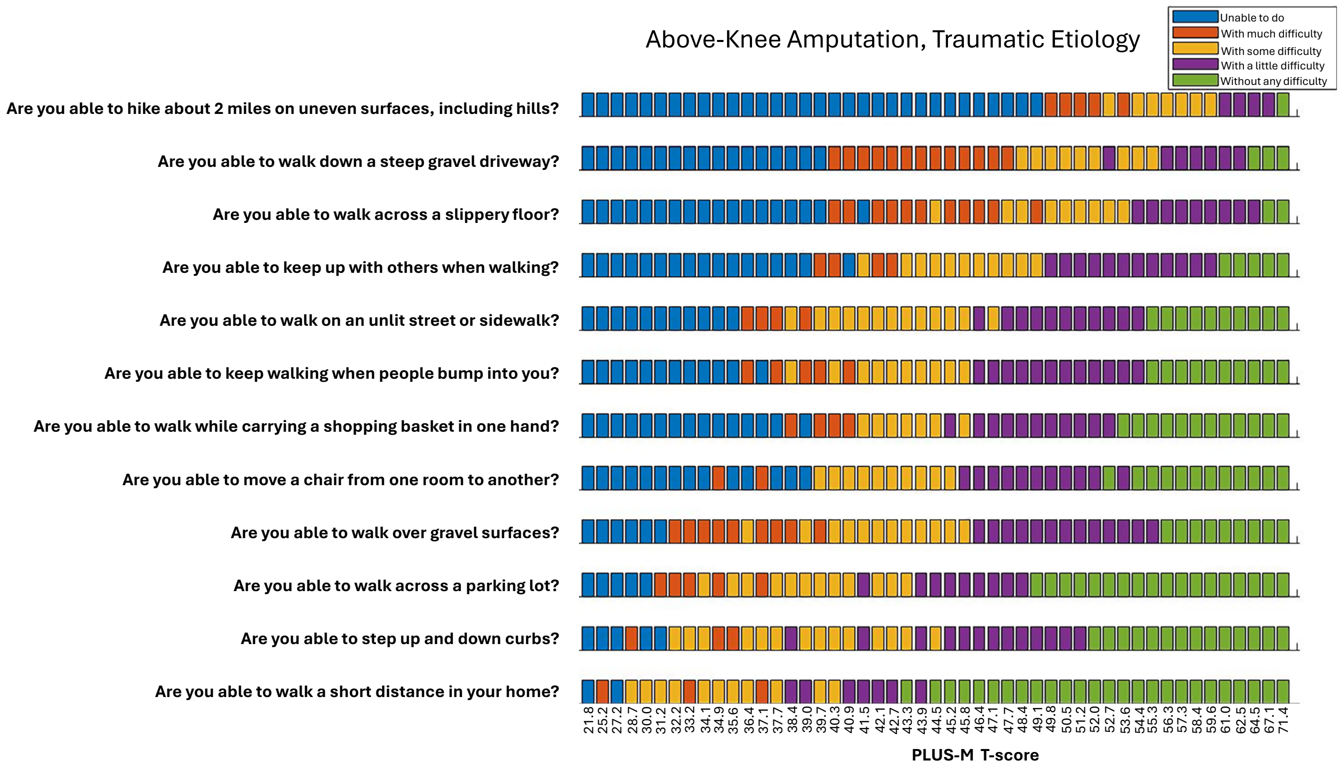

FIGURE 5 PLUS-M map for individuals with above-knee amputation due to trauma. PLUS-M, Prosthetic Limb Users Survey of Mobility.

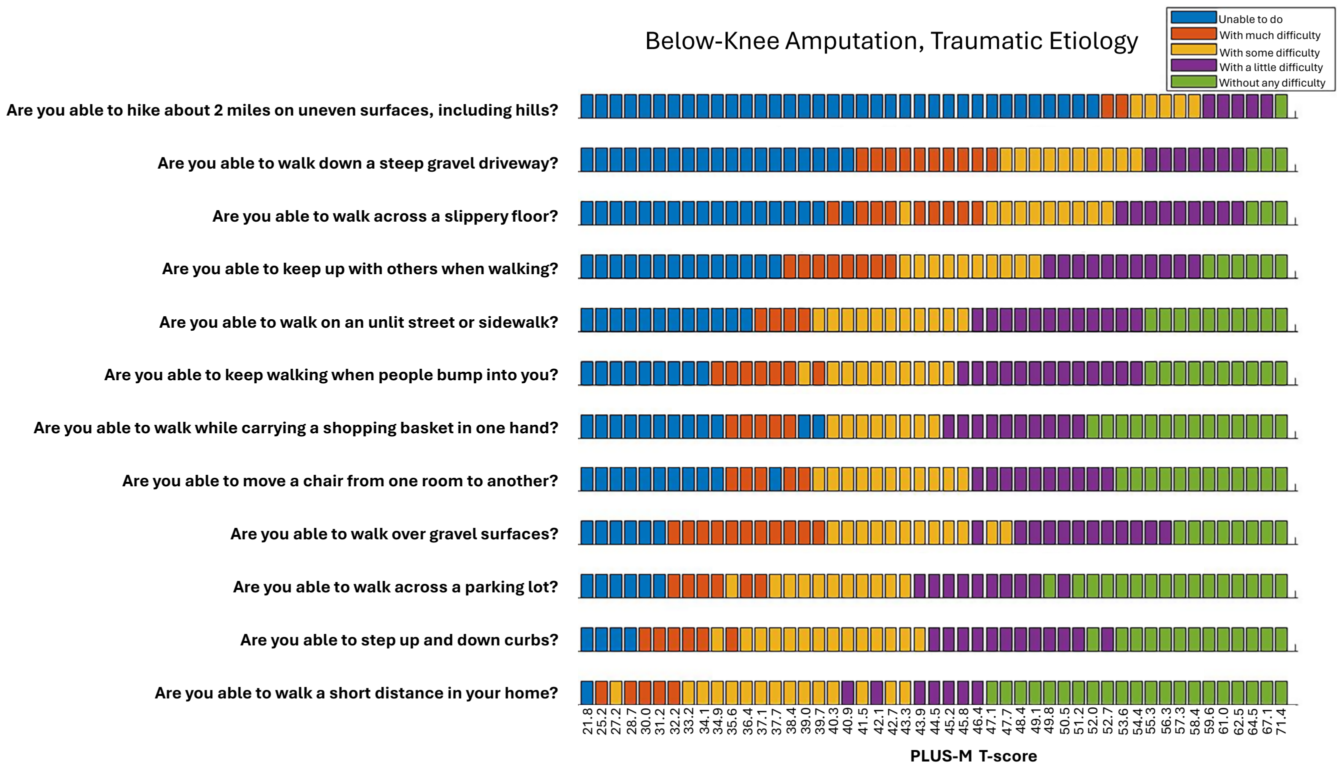

FIGURE 6 PLUS-M map for individuals with below-knee amputation due to trauma. PLUS-M, Prosthetic Limb Users Survey of Mobility.

question, and so on. However, the specific responses from this patient, with a T-score of 39.7, were "with much difficulty" for the first question (−3 from peer-average), "without any difficulty" for the second question (+1 from peer-average), and so on. Using this information, the clinician could identify areas where the patient differs most from their peers. For example, if they answered, "unable to do" for the item, "Are you able to keep walking when people bump into you?" (−3 from peer-average), the clinician may be able to make adjustments to the prosthesis to increase their stability. Alternatively, the clinician may refer the patient to physical therapy to improve their dynamic balance and confidence. As illustrated, the PLUS-M T-score maps developed in this study can be used by the patient's *entire* care team to guide targeted, patient-specific care.

In addition to guiding care decisions targeting improvements in mobility, the PLUS-M™ T-score maps can also provide meaningful context to changes in a patient's T-score. For example, a change in T-score from 34.9 to 45.2 can be viewed as generally changing from walking around the home "with some difficulty" to "without any difficulty." This knowledge can be a powerful motivator for patients to understand the *significance* of a change in their T-score, rather than just focusing on achieving a higher number (ie, T-score) at the next visit.

Limitations

There are a few limitations to this work. First, the focus of the analysis was on the most common amputation levels and causes of amputation, specifically AK or BK and trauma or diabetes/dysvascular disease. Future work, with increased data availability, may be able to extend this analysis to include other levels and etiologies of amputation. In addition, this work focused on mobility using the PLUS-M instrument. There is current ongoing work to expand the item bank of the PLUS-M to address potential ceiling effects. Additionally, as new instruments are developed to measure other aspects of patients' health and well-being, an approach similar to the current one may provide the means to make rehabilitation more effective for patients.

CONCLUSION

The goal of this study was to expand interpretation of PLUS-M T-scores by developing maps of the most probable response to each item of the PLUS-M 12-item short form. Results from this study demonstrated the utility of this method and provided multiple population-specific T-score maps based on patient characteristics such as amputation level and etiology. The resulting T-score maps have high accuracy and demonstrate promise as a new clinical tool. Clinicians can use these T-score maps to contextualize PLUS-M T-scores, understand changes in PLUS-M T-scores, and guide selection of interventions designed to improve patient outcomes.

ACKNOWLEDGMENTS

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DATA AVAILABILITY STATEMENT

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

ETHICS APPROVAL

This database review was approved by the Western Copernicus Group Institutional Review Board (protocol #20170059) and designated to qualify for exempt status.

DISCLOSURES

Dr. Hafner reports consulting fees for projects unrelated to this work from Liberating technologies and Apple. Hanger Clinic; honoraria for presenting at an online symposium unrelated to this work. The other authors have nothing to disclose.

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