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ORIGINAL ARTICLE

Dexterity, activity performance, disability, quality of life, and independence in upper limb Veteran prosthesis users: a normative study

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ABSTRACT

Purpose: To present population data on standardized measures of dexterity, activity performance, disability, health-related quality of life (HRQoL) and community integration for persons with upper limb amputation (ULA), compare outcomes to normative values, and examine differences by prosthesis type and laterality (unilateral vs. bilateral amputation).

Materials and methods: Multi-site, cross-sectional design, with in-person evaluations, functional performance, and self-report measures. Descriptive and comparative analyses were performed by amputation level and prosthesis type, data were compared for unilateral and bilateral amputation.

Results: One hundred and twenty-seven individuals participated; mean age 57 years, 59% percent body-powered prostheses users. All measures of dexterity differed ($p < 0.05$) by amputation level and by laterality. All measures of activity differed by amputation level with the best scores in transradial (TR) amputation groups. Comparisons of body-powered users with TR amputation found that dexterity was better for those with bilateral compared to unilateral amputation.

Conclusions: Dexterity is markedly impaired in persons with ULA. Individuals with more proximal ULA levels are most impacted. HRQoL and community participation are less impacted and more equivalent to unimpaired persons. Further research is needed to examine differences by terminal device type and determine how best to match persons with ULA to the optimal prosthesis type and componentry, based on individual characteristics.

➤ IMPLICATIONS FOR REHABILITATION

- This study provides population-based, comparative data on dexterity, activity performance, disability, quality of life, and independence in upper limb prosthesis users.
- The study provides preliminary analyses comparing the effectiveness of body-powered devices, myoelectric devices with single degree of freedom and multi-degree of freedom terminal devices.
- The data presented in this study can be used to benchmark outcomes in patients who are upper limb prosthesis users.
- The data will also be useful to inform comparative evaluations of existing and emerging prosthetic technology.

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Upper limb amputation; upper limb prosthesis; prosthesis use; disability evaluation; outcomes

Introduction

A National Academy of Sciences report concluded that "despite advances in prosthetic designs and research, currently available upper extremity prostheses (UEPs) are limited in their ability to mitigate impairments related to limb loss" [1]. However, the extent of limitation associated with prosthesis use and the impact of contextual factors on these limitations is not fully understood. There are a wide variety of devices and components available to persons with upper limb amputation (ULA), but little data comparing outcomes for populations of users at differing amputation levels, users with single or

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bilateral upper limb loss, or users of various device types. Such data would inform patients and clinicians and could enable benchmarking of outcomes to realistic expectations for prosthetic rehabilitation. These data can also be used to facilitate comparative effectiveness evaluations of existing prosthetic componentry and as newer technology becomes available.

The most prevalent types of UEPs are body-powered (cable harnesses operated), and externally powered (myoelectric) – most commonly operated by surface myoelectrodes. A recent systematic review that compared body-powered and myoelectric prostheses found no clear superiority by device type, and called for additional research to compare prostheses types [2].

In the past decade, new and more costly types of prostheses and components have become available, making the need for additional research even more pressing. A variety of multi-degree of freedom (DOF) prosthetic terminal devices that enable multiple grip patterns are now commercially available and – according to a national study of Veterans with major ULA – are used by nearly 11% of Veterans who use upper limb prostheses [3]. Although multiple grip terminal devices are penetrating the market, and are desired by consumers [4,5], it is unclear what benefit patients or clinicians can expect from these devices. There have been few studies comparing single- vs. multi-degree DOF terminal devices, or other terminal device types. Small studies, for instance, did not show a clear advantage of any particular type of terminal device [6–11].

Our recently completed national survey of Veterans with major upper limb loss did not identify differences by device or terminal device type in perceived difficulty with activities, likelihood of needing assistance with activities of daily living (ADL), self-reported disability or health-related quality of life (HRQoL) [12]. However, that study was limited because prosthesis and terminal device type, and function were self-reported and were therefore subject to potential misclassification of device type, and to recall bias. Further research utilizing in-person assessment of prosthesis configuration and performance measures of dexterity and function are needed to compare outcomes of users of different types of prostheses and terminal devices to confirm or refute these findings.

To help address the clinical and research gaps, an in-person, multi-site study of upper limb prosthesis users was conducted which allowed verification of prosthesis and terminal device type and the ability to quantify a wide variety of outcomes. The purposes of this manuscript are to: (1) describe the methods of this study; (2) present normative and comparative data on outcomes by amputation level and prosthesis type; and compare outcomes to prior studies; and (3) compare outcomes for unilateral and bilateral upper limb amputees, with the overarching goal of assisting policy makers, clinicians, and patients to better match individual upper limb amputees with the most appropriate devices and components.

Methods

Study design

The study used a cross-sectional, observational design with data collected at five study sites across the U.S. The study was approved by the Veterans Administration (VA) Central Institutional Review Board (IRB), Regional Health Command-Central IRB and by the Human Research Protection Office (HRPO). All participants provided voluntary informed consent.

Sample

We enrolled a convenience sample of 127 persons with major ULA (defined as having at least one amputation at or proximal to the level of wrist disarticulation), who used an active prosthesis (body-powered, myoelectric, hybrid or Life Under Kinetic Evolution (LUKE Arm) [13]. Participants with unilateral or bilateral amputations were included. Participants who could not tolerate wearing a prosthesis for at least 3 h and those with a severe health condition that might limit their ability to participate in study assessment activities were excluded. Veteran participants who participated in an earlier survey study [3] and who agreed to future study contact were invited to participate. Other participants were recruited through clinical contacts, advertisements, and word of mouth.

Data collection

Participants attended an in-person study visit at a data collection site. Physical or occupational therapists, assisted by a research coordinator, assessed participants. Study visits lasted approximately 3–4 h with rest breaks provided as needed. Study visits included collection of demographic data (age, race, ethnicity, employment), history of the participant's amputation and prosthesis use (military status, amputation etiology, history of amputation-related rehabilitation, prosthesis use), and a physical examination (weight, height, limb length, residual limb inspection). During the prosthetic evaluation, the device and its components were described by the assessor and the prosthesis and terminal device were photographed. Measures of functional performance were collected by the study assessor to quantify dexterity and activity performance. Self-reported measures, which were interviewer administered, addressed satisfaction with the prostheses, disability, HRQoL, community integration, and need for assistance with ADL. A brief description of the collected standardized measures is provided in Table 1.

Key independent variables

To allow robust comparisons, given the small sample sizes, we collapsed categories of amputation level into three categories: transradial (TR), which included persons with wrist disarticulation and TR amputation; transhumeral (TH), which included persons with elbow disarticulation and TH amputation; and shoulder (SH), which included persons with SH disarticulation and interscapulothoracic amputation. We also compared persons with unilateral and bilateral amputation.

A three-level categorical variable to classify the prostheses types used based on prosthesis and terminal device type DOF was developed. The three categories were: body-powered, myoelectric single DOF terminal device, and myoelectric multi-DOF terminal device. Assessors first characterized the prosthesis as either body-powered, myoelectric, hybrid, or LUKE Arm. LUKE Arm was categorized as myoelectric, and hybrid devices were categorized based on the function of their terminal devices (body-powered or myoelectric). The type of terminal device utilized was documented by the study assessor and verified by the study prosthetist who viewed photographs of the device. Myoelectric terminal device categories were categorized based on their DOF. Electronic terminal devices (ETDs), Greifers [14] and sensor speed hands [15] were categorized as single DOF; I-Limb [16], Michelangelo [17], Bebionic [18], and LUKE hands [13] were categorized as multi-DOF.

Table 1. Brief description of key outcome measures.

	Construct	Item content	Rating criteria	Interpretation
Functional performance				
Dexterity				
Jebsen-Taylor Hand Function (JTHF)	Dexterity	7 separate tests of fine motor activities: writing, page turning, small objects, eating, placing checkers, light cans, heavy cans	Performance speed; items per second (modified scoring)	Higher scores indicate better dexterity
Nine Hole Peg (NHP)	Dexterity	Accurately place and remove 9 plastic pegs into a pegboard	Timed measure (time limited to 6 min), score calculated as items/second (modified scoring)	Higher scores indicate faster speed, better dexterity
Box and Block	Dexterity	Number of wooden blocks transported in 60 s	Performance speed; total number of blocks transported	Higher scores indicate better performance
Southampton Hand Assessment Procedure (SHAP)	Dexterity/index of function	26 unilateral timed tasks of hand function: 12 abstract tasks and 14 activities of daily (such as zipping, pouring, buttoning)	Performance speed	Higher scores indicate better dexterity
Activity performance				
Activities Measure for Upper Limb Amputation (AM-ULA)	Activity performance	18-everyday tasks: brush/comb hair, don t-shirt, doff t-shirt, button shirt, zip jacket, don socks, tie shoes, drink from a cup, use fork, use spoon, pour 12 oz can, write, use scissors, turn doorknob, hammer nail, fold towel, use phone, reach overhead	Each item is rated on task completion: speed, movement quality, skillfulness of prosthesis use and independence. Total score is the average score ×10.	Higher scores indicate better activity performance
Brief Activities Measure for Upper Limb Amputation (BAM-ULA)	Activity performance	10 everyday tasks: tuck in shirt, lift 20 lbs, open and drink from water bottle, remove wallet from back pocket, replace wallet, lift gallon jug, open and pour jug, brush/comb hair, use a fork, open door with round knob	Ability to complete each task (yes/no). Total score is the number of activities that were completed.	Higher scores indicate better activity performance
Timed Measure of Activity Performance (T-MAP)	Activity performance	5 everyday activities: drink from a cup, wash face, food preparation, eating, dressing	Timed Measure: sum of time to complete each activity	Lower scores indicate faster speed, less difficulty
Self-report measures				
Device satisfaction				
Trinity Amputation and Prosthesis Experience Satisfaction Scale (TAPES)	Prosthetic satisfaction	10 items satisfaction with prosthesis: color, shape, noise, appearance, weight, usefulness, reliability, fit, comfort, and overall satisfaction	Satisfaction	Higher scores indicate greater prosthetic satisfaction
Quick Disability of the Arm, Shoulder, and Hand (QuickDASH)	Disability	Self-reported functional difficulty (8 items), 3 items about sleep, sensation and pain	Performance difficulty and impairment severity	Higher scores indicate greater disability
HRQoL				
Veterans RAND 12-Item Health Survey Mental Composite Score (VR-12 MCS)	Quality of life	Measure for Mental Health Component Summary	Self-rated quality of life	Higher scores indicate greater satisfaction
Veterans RAND 12-Item Health Survey Physical Composite Score (VR-12 PCS)	Quality of life	Measure for Physical Health Component Summary	Self-rated quality of life	Higher scores indicate greater satisfaction
Community Reintegration of Injured Service Members-Computer Adapted-Test (CRIS-CAT)	Extent of participation	Computer adaptive testing measuring participation in life roles	Frequency and amount of participation	Higher scores indicate better community integration
CRIS-CAT	Perceived difficulty	Computer adaptive testing measuring participation in life roles	Perceived limitations in participation	Higher scores indicate better community integration
CRIS-CAT	Satisfaction	Computer adaptive testing measuring participation in life roles	Satisfaction with participation	Higher scores indicate better community integration
Need for ADL help	Independence	Any need for help with daily activities	Yes/no	No required help indicates greater independence

Data analyses

We described participant characteristics, and prosthesis type for unilateral and bilateral amputation and by amputation level. Outcomes were compared by amputation level and laterality using the Kruskal–Wallis and Wilcoxon Mann–Whitney non-parametric tests due to small sample sizes. To establish normative values and test for differences by prosthesis type, the sample was stratified by amputation level to allow comparison of outcomes by prosthesis type for individuals with TR and TH amputations using Kruskal Wallis tests. Analyses of individuals with SH-level amputation were not included due to their small sample size ($n = 5$). Subsequent analyses were stratified by amputation level and age categories, and by prosthesis type and age categories to allow for comparison of outcomes by age group.

To contextualize the magnitude of outcome impairment, we compared our findings to data available on normative (unimpaired) samples. To facilitate comparison, we stratified our sample into three subgroups by age (18–44, 45–64, and ≥65 years) and compared to similar general population age cohorts when possible. Since our sample was predominantly male, when possible we compared them to males in the general population. Finally, when possible, we used normative values for the non-dominant side for comparison, given that upper limb prostheses are used typically as the "helper hand", not the dominant hand, in persons with unilateral amputation. For dexterity measures, we compared population values of the Jebsen Taylor Hand Function (JTHF) test [19,20], Box and Blocks test [21], Nine Hole Peg (NHP) [22,23], and Southampton Assessment Procedure (SHAP) [10,24] to values in our sample. As it was not possible to obtain exact data from prior publications due to our revised scoring method for JTHF and the NHP test, we instead transformed reported average timed scores to items completed per second, using the maximum number of items for each specific task.

Given that Activities Measure for Upper Limb Amputation (AM-ULA) [25], Brief Activities Measure for Upper Limb Amputation (BAM-ULA) [26], and Timed Measure of Activity Performance (T-MAP) [27] are amputation-specific measures, comparisons to unimpaired samples were not possible. Instead, we compared our data to values previously published on Quick Disability of the Arm, Shoulder, and Hand (QuickDASH), Veterans RAND 12-Item Health Survey Mental Composite Score (MCS), and Physical Composite Score (PCS). As there are no published population normative values available for the Community Reintegration of Injured Service Members-Computer Adapted-Test (CRIS-CAT) [28] measures for persons in their mid-50s (the mean age of our sample), we compared the scores reported for employed Veterans with no history of mental illness or substance abuse (who had a mean age of 47.7 years; range 25–60) [29]. Scores of the VR-12 MCS and PCS were compared to age-matched norms [30].

Given that dexterity measures involve single hand (or prosthesis) use, data were first combined from those with bilateral and unilateral amputation and dexterity scores were compared by amputation level and prosthesis type. Comparisons for persons with unilateral amputation only were then repeated. For activity performance measures, which involve bimanual tasks, as well as prosthesis satisfaction, self-report disability measures, HRQoL, and community integration we compared scores of persons with unilateral amputation by amputation level.

We controlled for multiple comparisons to adjust for false discovery rates in "families" or categories of tests using the Benjamini–Hochberg method to maintain a false discovery rate of 0.10 within each test category [31]. The following categories were used: dexterity (10 measures), activity performance (three measures), and self-reported function, disability, HRQoL, and community integration (six measures). Prothesis satisfaction was evaluated only by the Trinity Amputation and Prosthesis Experience Satisfaction Scale (TAPES) [32].

Wilcoxon Mann–Whitney tests were used to compare dexterity scores for persons with unilateral TR and persons with bilateral amputation who had TR amputation on their dominant side (our largest sub-group).

Results

Demographics and prosthesis characteristics are provided in Table 2. The sample was 97% male, 75% white, 85% Veterans, with a mean age of 56.9 (SD 16.5). The most common self-reported etiologies of amputation were traumatic; with 55% indicating accident and 36% combat injury (participants could indicate more than one etiology). The prosthesis that subjects wore for testing was mostly body-powered prostheses (59%) with some myoelectric single DOF (21%) and myoelectric multi-DOF (20%) devices. Prosthesis weight was 3.9 lbs (SD 2.3). One-quarter of the sample had received prosthesis training for the device used in testing. All hybrid devices in our sample were classified as myoelectric (two single DOF terminal device, five multi-DOF terminal device).

Amputation level

All measures of dexterity (JTHF tasks [33], Box and Blocks [21], NHP [22], and SHAP IOF [10]) were significantly different ($p < 0.05$) by amputation level (Table 3) and remained statistically significant after Benjamini–Hochberg adjustments. Persons with TR amputation had the best dexterity, followed persons with TH and SH amputation. Three measures of activity performance, the AM-UL, BAM-ULA, and T-MAP were significantly different by amputation level after Benjamini–Hochberg adjustment (Table 3). Those with TR amputation had the best scores for all three measures of activity.

Unilateral versus bilateral amputation

Those with bilateral amputation had better dexterity scores of all measures as compared to those with unilateral amputation, and differences remained significant after adjustment for multiple comparisons (Table 3). Those with unilateral amputation had faster ($p = 0.003$) T-MAP scores (mn 4.8) than those with bilateral amputation (8.9) even after adjustment for multiple activity measure comparisons (Table 3). Those with bilateral amputation had better CRIS-CAT scores on the extent of limitation subscale ($p = 0.048$), though this difference was no longer significant after correction for multiple comparisons. Normative values by age group are shown in Appendix.

Comparison of outcomes of persons with and without upper limb amputation

Table 4 provides comparative data to contextualize the magnitude of outcome impairment. In summary, the sub-group of persons with unilateral TR amputation ages 18–44 had JTHF scores that were 0.09–0.62 times that of unimpaired males aged 20–55. The subsample with TR unilateral amputation aged 45–64 had 0.07–0.97 times the JTHF scores of unimpaired males aged 60–69. The subsample of TRs who were 65 years or older had 0.05–0.82 times the JTHF scores of unimpaired males aged 70–89. The least amount of impairment across all age categories was in the writing

Table 2. Demographics and prosthesis characteristics of participants by amputation level ($N = 127$).

	Unilateral amputation ($N = 112$)				Bilateral amputation ($N = 15$)	All ($N = 127$)
	WD/TR ($N = 75$) Mn (SD)	ED/TH ($N = 32$) Mn (SD)	SH/FQ ($N = 5$ Mn (SD)	Total ($N = 112$) Mn (SD)	Mn (SD)	Mn (SD)
Age (years)	56.6 (17.3)	57.1 (16.3)	55.1 (23.4)	56.7 (17.1)	58.5 (10.7)	56.9 (16.5)
Years since amputation	24.2 (19.7)	18.5 (16.1)	23.3 (23.6)	22.5 (18.9)	23.1 (18.8)	22.6 (18.9)
Prosthesis weight (lbs)	3.2 (1.6)	5.2 (2.5)	6.9 (2.9)	3.9 (2.2)	4.1 (2.6)	3.9 (2.3)
	N (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)
Age category						
$18 \le$ age < 45	22 (29.3)	5 (15.6)	2 (40.0)	29 (25.9)	2 (13.3)	31 (24.4)
$46 \le$ age < 65	20 (26.7)	16 (50.0)	0 (0.0)	36 (32.1)	9 (60.0)	45 (35.4)
$66 \le$ age < 75	26 (34.7)	10 (31.3)	3 (60.0)	39 (34.8)	4 (26.7)	43 (33.9)
75+	7 (9.3)	1 (3.1)	0 (0.0)	8 (7.1)	0 (0.0)	8 (6.3)
Gender						
Male	73 (97.3)	31 (96.9)	5 (100.0)	109 (97.3)	14 (93.3)	123 (96.9)
Female	2 (2.7)	1 (3.1)	0 (0.0)	3 (2.7)	1 (6.7)	4 (3.2)
Race						
White	58 (77.3)	20 (62.5)	5 (100.0)	83 (74.1)	12 (80.0)	95 (74.8)
Black	8 (10.7)	5 (15.6)	0 (0.0)	13 (11.6)	1 (6.7)	14 (11.0)
Mixed/other	9 (12.0)	7 (21.9)	0 (0.0)	16 (14.3)	2 (13.3)	18 (14.2)
Ethnicity						
Hispanic	8 (10.7)	7 (21.9)	0 (0.0)	15 (13.4)	1 (6.7)	16 (12.6)
Not Hispanic	63 (84.0)	25 (78.1)	5 (100.0)	93 (83.0)	14 (93.3)	107 (84.3)
Unknown	4 (5.3)	0 (0.0)	0 (0.0)	4 (3.6)	0 (0.0)	4 (3.2)
Employment status[a]						
Employed full-time	15 (20.0)	6 (18.8)	0 (0.0)	21 (18.8)	1 (6.7)	22 (17.3)
Employed part-time	2 (2.7)	2 (6.3)	0 (0.0)	4 (3.6)	1 (6.7)	5 (3.9)
Student	2 (2.7)	4 (12.5)	0 (0.0)	6 (5.4)	0 (0.0)	6 (4.7)
Retired, employed after amputation	30 (40.0)	10 (31.3)	1 (20.0)	41 (36.6)	5 (33.3)	46 (36.2)
Retired, not employed after amputation	9 (12.0)	3 (9.4)	2 (40.0)	14 (12.5)	4 (26.7)	18 (14.2)
Medical leave	1 (1.3)	2 (6.3)	1 (20.0)	4 (3.6)	3 (20.0)	7 (5.5)
Unknown	16 (21.3)	5 (15.6)	1 (20.0)	22 (19.6)	1 (6.7)	23 (18.1)
Military status						
Active duty	2 (2.7)	0 (0.0)	0 (0.0)	2 (1.8)	0 (0.0)	2 (1.6)
Veteran	66 (88.0)	28 (87.5)	5 (100.0)	99 (88.4)	9 (60.0)	108 (85.0)
Civilian	7 (9.3)	4 (12.5)	0 (0.0)	11 (9.8)	6 (40.0)	17 (13.4)
Etiology of amputation[a]						
Congenital	3 (13.0)	0 (0.0)	0 (0.0)	3 (8.6)	1 (10.0)	4 (8.9)
Combat	27 (44.3)	8 (29.6)	1 (25.0)	36 (39.1)	2 (14.3)	38 (35,9)
Accident	30 (49.2)	15 (55.6)	4 (100.0)	49 (53.3)	9 (64.3)	58 (54.7)
Burn	4 (6.6)	2 (7.4)	0 (0.0)	6 (6.5)	4 (28.6)	10 (9.4)
Cancer	4 (6.6)	1 (3.7)	0 (0.0)	5 (5.4)	0 (0.0)	5 (4.7)
Diabetes	1 (1.6)	0 (0.0)	0 (0.0)	1 (1.1)	0 (0.0)	1 (0.9)
Infection	8 (13.1)	4 (14.8)	0 (0.0)	12 (13.0)	3 (21.4)	15 (14.2)
Prosthesis type						
Body powered	45 (60.0)	18 (56.3)	2 (40.0)	65 (58.0)	10 (66.7)	75 (59.1)
Myoelectric single DOF terminal device	12 (16.0)	9 (28.1)	2 (40.0)	23 (20.5)	4 (26.7)	27 (21.3)
Myoelectric multi-DOF terminal device	18 (24.0)	5 (15.6)	1 (20.0)	24 (21.4)	1 (6.7)	25 (19.7)
Terminal device type						
Body-powered hook	45 (60.0)	18 (56.3)	2 (40.0)	65 (58.0)	10 (66.7)	75 (59.1)
Externally powered prehensors	7 (9.3)	5 (15.6)	1 (20.0)	13 (11.6)	3 (20.0)	16 (12.6)
Multi-DOF Myo hand	18 (24.0)	5 (15.6)	1 (20.0)	24 (21.4)	1 (6.7)	25 (19.7)
Single-DOF Myo hand	5 (6.7)	4 (12.5)	1 (20.0)	10 (8.9)	1 (6.7)	11 (8.7)
Receipt of any training to use current prosthesis						
Yes	20 (26.7)	6 (18.8)	1 (20.0)	27 (24.1)	6 (40.0)	33 (26.0)
No	55 (73.3)	26 (81.3)	4 (80.0)	85 (75.9)	9 (60.0)	94 (74.0)

[a]Etiology of amputation: respondents could indicate multiple etiologies.

task. All three subgroups, by age, of subjects with TR amputation had 0.20–0.26 the Box and Blocks scores compared to unimpaired male groups (left or right hands, approximately same age groups). The youngest group with TR amputation had NHP scores 0.08 of age matched norms, and older sub-groups scores were 0.11–0.16 that of age matched norms. The average SHAP IOF scores of those with TR amputation was 0.43–0.44 times that of unimpaired males, with little difference in age sub-group.

Compared to normative values [34], those with TR amputation aged 18–44 have 3.94 times the QuickDASH scores as unimpaired aged 20–49 (higher scores indicate greater disability). Persons with TR amputation aged 45–64 and 65+ had 2.52 and 1.49 times higher QuickDASH scores as unimpaired males aged 50–69 and 70+, respectively, demonstrating that the magnitude of disability is greater for younger persons with TR amputation. Compared to age-matched normative samples, those with TR amputation had 1.11–1.27 greater MCS scores. PCS scores in our sample were higher than age matched norms in the persons ages 18–44 and 45–64 (1.17 and 1.40, respectively), but lower 0.91 in the group 65 and older. Our sample with TR amputation aged 18–44 and 45–65 had 0.81–0.92 times the CRIS-CAT scores than the normative comparison group, indicating worse community integration.

Outcomes by prosthesis type

Comparison of dexterity measures by amputation level (unilateral and bilateral amputation groups combined) (Table 5) revealed significant differences by prosthesis type for those with TR

Table 3. Outcomes by amputation laterality, amputation level.

	Unilateral amputation ($N = 112$)				All amputation ($N = 127$)		
	WD/TR ($N = 75$) Mn (SD)	ED/TH ($N = 32$) Mn (SD)	SH/FQ ($N = 5$) Mn (SD)	Kruskal–Wallis *p* Value	Unilateral ($N = 112$) Mn (SD)	Bilateral ($N = 15$) Mn (SD)	WMW *p* Value
Dexterity measures							
JTHFT							
Writing	0.48 (0.29)	0.26 (0.22)	0.13 (0.14	**0.0004***	0.41 (0.29)	0.86 (0.23)	**<0.0001***
Page turning	0.13 (0.09)	0.05 (0.05)	0.01 (0.02)	**<0.0001***	0.10 (0.09)	0.26 (0.16)	**<0.0001***
Small objects	0.10 (0.08)	0.04 (0.05)	0.01 (0.02)	**<0.0001***	0.08 (0.08)	0.22 (0.15)	**<0.0001***
Eating	0.17 (0.11)	0.07 (0.07)	0.00 (0.00)	**<0.0001***	0.13 (0.11)	0.22 (0.10)	**0.0021***
Checkers	0.09 (0.07)	0.05 (0.06)	0.01 (0.01)	**0.0004***	0.07 (0.07)	0.20 (0.14)	**0.0001***
Light cans	0.22 (0.13)	0.10 (0.08)	0.06 (0.01)	**<0.0001***	0.18 (0.13)	0.40 (0.25)	**0.0005***
Heavy cans	0.22 (0.16)	0.09 (0.10)	0.07 (0.04)	**<0.0001***	0.18 (0.15)	0.39 (0.23)	**0.0002***
Box and Blocks	17.2 (8.4)	8.2 (8.1)	0.8 (1.8)	**<0.0001***	13.9 (9.5)	25.7 (7.5)	**<0.0001***
9-Hole peg	0.05 (0.05)	0.02 (0.04)	0.0 (.)	**0.0205***	0.04 (0.05)	0.13 (0.07)	**<0.0001***
SHAP IOF	41.4 (18.3)	11.3 (13.9)	0.6 (1.3)	**<0.0001***	31.0 (22.4)	46.2 (21.2)	**<0.0001***
Activity measures							
AM-ULA	15.3 (6.0)	11.4 (5.2)	9.1 (6.5)	**0.0006***	13.9 (6.1)	15.4 (6.9)	0.3659
BAM-ULA	7.3 (2.1)	4.2 (2.8)	.	**0.0027***	6.8 (2.5)	8.4 (1.5)	0.1155
T-MAP (min)	4.5 (1.6)	5.5 (2.3)	.	0.0829*	4.8 (1.8)	8.9 (4.5)	**0.0027***
Prosthesis satisfaction							
TAPES	3.9 (0.7)	3.6 (0.7)	2.7 (1.5)	0.0538	3.8 0.8)	3.9 (0.7)	0.5800
Disability, HRQoL, and community integration							
QuickDASH	28.8 (18.4)	31.8 (17.7)	30.0 (19.0)	0.7263	29.7 (18.1)	30.1 (15.6)	0.7514
VR-12 MCS	52.1 (11.1)	50.9 (12.7)	53.9 (8.0)	0.8073	51.8 (11.4)	54.7 (7.2)	0.5958
VR-12 PCS	39.3 (8.7)	38.2 (11.4)	31.6 (13.5)	0.4089	38.6 (9.8)	39.7 (11.5)	0.6115
CRIS-CAT extent	49.1 (9.0)	47.9 (9.4)	46.1 (10.1)	0.6520	48.6 (9.1)	53.6 (7.7)	**0.0482**
CRIS-CAT perceived	49.0 (7.4)	47.2 (6.0)	44.0 (5.3)	0.1838	48.3 (7.0)	51.2 (9.0)	0.1873
CRIS-CAT satisfaction	50.3 (9.3)	46.6 (5.6)	46.8 (9.0)	0.1543	49.1 (8.5)	52.3 (10.8)	0.2771
	N (%)	*N* (%)	*N* (%)	Exact *p*	*N* (%)	*N* (%)	Exact *p*
Need for ADL help	12 (22.6)	6 (25.0)	2 (50.0)	1.0000	20 (24.7)	7 (58.3)	**0.0353**

*Significant after Benjamini–Hochberg adjustment with false discovery rate = 0.1. Bold values are those that are statistically significant at $p < 0.05$.

amputation in the JTHF small objects tasks ($p < 0.05$), Box and Blocks ($p < 0.05$), and the NHP test ($p < 0.001$). Differences in Box and Blocks and NHP remained after correction for multiple comparisons. For the TH group, statistically significant differences were observed before ($p < 0.05$), but not after adjustment for multiple comparison, by prosthesis type for JTHF small objects and NHP test. In all cases, body powered users had the best dexterity scores.

Comparisons of outcomes for persons with unilateral amputation only found similar patterns in differences in dexterity scores (Table 6). Significant differences in dexterity were observed in the TR group by device type for JTHF small objects and heavy cans ($p < 0.05$), and for NHP ($p < 0.001$). Only NHP differences remained after adjustment for multiple comparisons. In the TH group, significant differences were observed before and after adjustment for multiple comparisons in JTHF small objects and NHP. In all cases, those using BP devices had better dexterity scores.

Activity measures differed significantly by prothesis type before and after adjustment for multiple comparisons in the TR group for the BAM-ULA ($p < 0.01$), with body-powered users completing the fewest BAM-ULA items. No differences in activity scores by prosthesis type were observed for the TH group. TAPES satisfaction scores did not differ by prothesis type. Among the remaining measures, the CRIS-CAT perceived limitations scores in the TR group showed significant differences by prothesis type after adjustment for multiple comparisons. No differences in QuickDASH or VR-12 scores were observed. A greater proportion of TR and TH participants who used myoelectric single-DOF devices reported needing assistance with everyday activities as compared to other groups, but these differences were not statistically significant.

Comparisons of outcomes of unilateral and bilateral amputation groups by prosthesis type

Comparisons of participants with bilateral and unilateral TR amputation who used body-powered devices found significant differences in all dexterity measures except the SHAP ($p < 0.01$) (Appendix, Table A3). Dexterity was better for those with bilateral amputation as compared to unilateral amputation in all cases. When adjusted for multiple comparisons, all measures, including the SHAP IOF were statistically significantly different for groups with unilateral and bilateral amputation. Additionally, those with bilateral amputation completed significantly more BAM-ULA items than those with unilateral amputation, even after adjustment for multiple comparisons. No measures of satisfaction, disability, HRQoL, or community integration differed significantly for persons with unilateral and bilateral amputation using body powered devices.

Discussion

This study reported normative values for dexterity, activity performance, prosthesis satisfaction disability, HRQoL, and community integration in persons with ULA by amputation level and prosthesis type. This work builds on prior observational studies that reported on many of the same outcome measures by amputation level, but did not compare outcomes by device type [25–27,33,35]. Findings confirm results reported in earlier studies that dexterity, as measured by standardized tests, is significantly impaired in upper limb prosthesis users and that impairment is greater in prosthesis users with more proximal level limb loss.

We compared normative data on activity performance by amputation level but were unable to compare activity scores to

Table 4. Outcomes of unilateral TR amputation group and normative values of standardized tests.

	Unimpaired males[c]			TR unilateral amputations (prothesis side)		
	Age group	Side	Mn	Age group	Mn	Ratio of scores
JTHFT (item/s)						
Writing	20–59	NonDom	0.74[a]	18–44	0.46	0.62
Writing	60–69	NonDom	0.66[a]	45–64	0.64	0.97
Writing	70–89	NonDom	0.50[a]	65+	0.41	0.82
Page turning	20–59	NonDom	0.90[a]	18–44	0.11	0.12
Page turning	60–69	NonDom	1.14[a]	45–64	0.17	0.15
Page turning	70–89	NonDom	1.40[a]	65+	0.12	0.09
Small objects	20–59	NonDom	1.03[a]	18–44	0.10	0.10
Small objects	60–69	NonDom	1.25[a]	45–64	0.09	0.07
Small objects	70–89	NonDom	1.35[a]	65+	0.10	0.07
Eating	20–59	NonDom	1.58[a]	18–44	0.15	0.09
Eating	60–69	NonDom	1.85[a]	45–64	0.19	0.10
Eating	70–89	NonDom	2.05[a]	65+	0.16	0.08
Checkers	20–59	NonDom	0.95[a]	18–44	0.12	0.13
Checkers	60–69	NonDom	1.37[a]	45–64	0.09	0.07
Checkers	70–89	NonDom	1.47[a]	65+	0.07	0.05
Light cans	20–59	NonDom	0.64[a]	18–44	0.27	0.42
Light cans	60–69	NonDom	0.79[a]	45–64	0.24	0.30
Light cans	70–89	NonDom	0.97[a]	65+	0.18	0.19
Heavy cans	20–59	NonDom	0.62[a]	18–44	0.26	0.42
Heavy cans	60–69	NonDom	0.81[a]	45–64	0.24	0.30
Heavy cans	70–89	NonDom	0.95[a]	65+	0.18	0.19
Box and Blocks	20–44	Left	82.4	18–44	16.9[b]	0.21
Box and Blocks	45–64	Left	74.4	45–64	19.3[b]	0.26
Box and Blocks	65+	Left	64.4	65+	16.0[b]	0.25
Box and Blocks	20–44	Right	84.1	18–44	16.9[b]	0.20
Box and Blocks	45–64	Right	75.7	45–64	19.3[b]	0.25
Box and Blocks	65+	Right	66.0	65+	16.0[b]	0.24
Nine hole peg (item/s)	21–45	Left	0.50[a]	18–44	0.04[b]	0.08
Nine hole peg (item/s)	46–65	Left	0.44[a]	45–64	0.07[b]	0.16
Nine hole peg (item/s)	66+	Left	0.37[a]	65+	0.04[b]	0.11
Nine hole peg (item/s)	21–45	Right	0.52[a]	18–44	0.04[b]	0.08
Nine hole peg (item/s)	46–65	Right	0.46[a]	45–64	0.07[b]	0.15
Nine hole peg (item/s)	66+	Right	0.37[a]	65+	0.04[b]	0.11
SHAP IOF	18–45	Not specified	98.8	18–44	42.9	0.43
SHAP IOF	46–65	Not specified	98.0	45–64	43.6	0.44
SHAP IOF	66–75	Not specified	92.0	65+	39.1	0.43
QuickDASH	20–49	Not applicable	8.0	18–44	31.5	3.94
QuickDASH	50–69	Not applicable	11.5	45–64	28.9	2.52
QuickDASH	70+	Not applicable	18.0	65+	26.8	1.49
VR12 MCS	18–44	Not applicable	38.3	18–44	48.1	1.25
VR12 MCS	45–64	Not applicable	38.8	45–64	49.3	1.27
VR12 MCS	65+	Not applicable	50.9	65+	56.5	1.11
VR12 PCS	18–44	Not applicable	35.3	18–44	41.3	1.17
VR12 PCS	45–64	Not applicable	28.9	45–64	40.4	1.40
VR12 PCS	65+	Not applicable	40.7	65+	37.2	0.91
CRIS-CAT extent	25–60	Not applicable	55.8	18–44	45.4	0.81
CRIS-CAT extent	25–60	Not applicable	55.8	45–64	48.5	0.87
CRIS-CAT perceived	25–60	Not applicable	56.6	18–44	48.1	0.85
CRIS-CAT perceived	25–60	Not applicable	56.6	45–64	48.2	0.85
CRIS-CAT satisfaction	25–60	Not applicable	54.9	18–44	47.9	0.87
CRIS-CAT satisfaction	25–60	Not applicable	54.9	45–64	50.4	0.92

[a]Calculation of average items/s is not mathematically exact – instead we use the maximum items possible/average time.
[b]Prosthetic side tested.
[c]Used only male data when possible (some studies are a mostly male mix).

unimpaired persons. Although it would be inappropriate to compare scores of the AM-ULA to unimpaired persons because it is an amputation-specific measure, we can compare our findings to those previously reported. An earlier study with a smaller ($N = 46$) and younger (mean age 45.8 ± 16.5) sample reported AM-ULA scores of 19–22 for those with TR amputation and 14–16 for those with TH amputation [25]. The lower AM-ULA scores we observed in the current study (TR mn 15.8, TH mn 11.4) may be explained by differences in age as our sample was older (mn 56.7 vs. 45.8), proportion of Veterans in the samples, or by unobserved differences in health of the samples. Normative values of the T-MAP and BAM-ULA which, in theory, could be comparable because the scoring is not amputation specific, are not yet available. BAM-ULA scores in the current study (TR mn 7.3, TH 4.2) were roughly equivalent to that reported by Resnik et al. (mn 6.3) in a sample consisting of 57% TR and 37% TH amputation [26]. T-MAP values reported in the current study (TR mn 4.5, TH mn 5.5) were faster than earlier reported values (mn 6.2 min) [27]. However, the earlier study did not stratify scores by amputation level and included 27 TR and 21 TH amputees [27].

QuickDASH scores confirm that ULA results in significant disability, and disability is greater for those with more proximal amputation levels [36–38]. The ratio of QuickDASH scores compared to normative values differed by age group; those in the

Table 5. Dexterity outcomes by amputation level and device type (all subjects; bilateral amputation classified by dominant side).

	Transradial				Transhumeral			
	Body powered ($N=53$) Mn (SD)	Myo-single DOF ($N=15$) Mn (SD)	Myo multi-DOF ($N=19$) Mn (SD)	K–W p	Body powered ($N=20$) Mn (SD)	Myo-single DOF ($N=10$) Mn (SD)	Myo multi-DOF ($N=5$) Mn (SD)	K–W p
Dexterity								
JTHF								
Writing	0.56 (0.33)	0.47 (0.27)	0.53 (0.29)	0.5301	0.38 (0.35)	0.23 (0.20)	0.25 (0.17)	0.6274
Page turning	0.17 (0.13)	0.15 (0.09)	0.12 (0.07)	0.2945	0.07 (0.06)	0.04 (0.07)	0.04 (0.04)	0.2432
Small objects	0.13 (0.11)	0.12 (0.12)	0.08 (0.09)	**0.0176**	0.07 (0.06)	0.03 (0.06)	0.02 (0.02)	**0.0110**
Eating	0.19 (0.11)	0.17 (0.13)	0.13 (0.09)	0.1275	0.09 (0.09)	0.07 (0.08)	0.04 (0.04)	0.4514
Checkers	0.09 (0.08)	0.13 (0.14)	0.12 (0.08)	0.2988	0.07 (0.07)	0.05 (0.07)	0.03 (0.03)	0.7279
Light cans	0.25 (0.19)	0.23 (0.12)	0.27 (0.15)	0.6802	0.14 (0.11)	0.09 (0.10)	0.11 (0.05)	0.3597
Heavy cans	0.25 (0.22)	0.27 (0.12)	0.25 (0.13)	0.2398	0.09 (0.10)	0.09 (0.10)	0.15 (0.08)	0.2419
Box and Blocks	20.6 (9.2)	15.1 (9.1)	15.4 (6.0)	**0.0209***	11.8 (9.8)	5.2 (5.7)	7.6 (6.5)	0.2118
9 hole peg	0.07 (0.06)	0.06 (0.06)	0.01 (0.01)	**0.0001***	0.05 (0.06)	0.01 (0.03)	0.00 (0.00)	**0.0312**
SHAP IOF	44.0 (19.6)	41.0 (21.1)	39.6 (14.8)	0.5697	14.4 (15.3)	10.8 (16.6)	12.8 (12.7)	0.6742

*Significant after Benjamini–Hochberg adjustment with false discovery rate = 0.1. Bold values in this table indicate values statistically significant at $p < 0.05$.

youngest age group reported disability scores that were relatively worse than those in the older age groups. Whereas, scores of MCS and PCS, both measures of HRQoL were not impaired in our sample as compared to age-matched norms except among those aged 65 and over. In fact, it appears that participants in our sample rated their overall mental health (MCS) higher in all age groups, and their physical related HRQoL (PCS) higher than age matched norms in the groups under ages 65. The reasons for these differences should be explored in future research. Our comparison groups came from a single large study [30].

Our study failed to find statistically significant differences in dexterity or activity performance by prosthesis type. This may be because our measures lack sensitivity to subtle differences, or because other factors are confounding this relationship and need to be accounted for when making direct comparisons. It is also possible that prosthesis type is not associated with these outcomes. Future, larger studies will be needed to examine these factors. Future studies may also explore the impact of prosthesis weight on satisfaction.

An interesting finding was that dexterity was significantly better for those who had bilateral amputation as compared to those who had unilateral amputation. This suggests that increased prosthesis engagement, as would be expected in persons with bilateral amputation, results in better prosthetic function. Persons with bilateral amputation, however, did have worse scores on measures of ADL performance with a higher proportion requiring assistance with ADL.

Limitations

Our study utilized a convenience sample and consisted predominantly of Veterans. Thus, there are limits to the generalizability of findings to the entire civilian population. Although our study was one of the largest outcome studies of persons with ULA to date, the sample sizes in some subgroups (e.g., SH disarticulation and interscapulothoracic amputation; myoelectric single and multi-DOF device users, particularly at the TH level) were small, and this likely affected the precision of our estimates, and resulted in underpowered comparisons. Further research is needed to accrue larger samples and generate more precise estimates of normative values by prosthesis type and level. Our sample was limited to prosthesis users with amputation at the wrist or above. Findings are not generalizable to prosthesis users with partial hand amputation. Future research is needed to understand dexterity, activity performance, prosthesis satisfaction disability, HRQoL, and community integration of persons with partial hand amputation.

Our analyses of the impact of prosthesis type compared outcomes by amputation level but did not attempt to adjust for other factors which could potentially confound outcomes; including experience with prosthesis use and training to use the device. Although we believe that these factors should be examined in future work, the vast majority of participants in our study had been using their prostheses for many years because participants had, on average, had their amputation for more than 20 years. However, only 26% of our sample reported that they had received training to use the prosthesis that they used in testing. We did not collect data on receipt of initial prosthesis training during our in-person data collection. There are limits to the interpretability of our findings based on study design, as our subjects were not randomly assigned to their prosthesis configuration. Instead, devices had been prescribed and/or selected based on personal preferences and needs. It is possible that persons with lower levels of function are prescribed more complex devices with the expectation that they would receive the most benefit from them, or more simple devices that are easier to learn and control. Future studies which follow subjects who transition from one type of a prosthesis to another are needed.

Not all possible relationships were deemed to be in the scope of this investigation. Although we compared prosthesis type, we did not conduct more granular analyses of the impact of myoelectric terminal device type (single DOF vs. multi-DOF), due to small sample sizes. Although, we grouped all body powered terminal devices together, we acknowledge that there may be differences between types of body powered terminal devices that we were not able to discern. Our study did not have a sufficient number of participants who were using voluntary closing terminal devices, or prehensors to enable comparisons. We did not attempt to compare makes or brands of terminal devices within the categories of single and multi-DOF myoelectric devices, because of small sample sizes. Future studies, which include larger numbers of subjects would be needed to make robust comparisons. However, these studies will likely face the challenge of recruiting the needed participation, due to the relative rarity of upper limb and SH amputations. Furthermore, our study did not examine prosthesis characteristics, such as weight, or other factors associated with device satisfaction or wear time. However, prosthesis weight is included in Table 2. Such data are needed to understand drivers of satisfaction.

Table 6. Functional and self-report outcomes by amputation level and device type (unilateral amputation group only).

	Transradial				Transhumeral			
	Body powered ($N=45$)	Myo-single DOF ($N=12$)	Myo multi-DOF ($N=18$)	K–W	Body powered ($N=18$)	Myo-single DOF ($N=9$)	Myo multi-DOF ($N=5$)	K–W
	Mn (SD)	Mn (SD)	Mn (SD)	*p*	Mn (SD)	Mn (SD)	Mn (SD)	*p*
Dexterity								
JTHF								
Writing	0.49 (0.30)	0.41 (0.26)	0.52 (0.30)	0.4274	0.29 (0.26)	0.21 (0.20)	0.25 (0.17)	0.8279
Page turning	0.13 (0.09)	0.14 (0.10)	0.12 (0.07)	0.8182	0.06 (0.05)	0.02 (0.03)	0.04 (0.04)	0.1505
Small objects	0.11 (0.07)	0.11 (0.11)	0.07 (0.09)	**0.0288**	0.07 (0.06)	0.01 (0.02)	0.02 (0.02)	**0.0053***
Eating	0.18 (0.12)	0.17 (0.14)	0.14 (0.09)	0.4160	0.08 (0.09)	0.05 (0.06)	0.04 (0.04)	0.5489
Checkers	0.08 (0.06)	0.08 (0.09)	0.12 (0.08)	0.0957	0.06 (0.07)	0.03 (0.05)	0.03 (0.03)	0.5968
Light cans	0.20 (0.13)	0.22 (0.11)	0.28 (0.15)	0.2995	0.12 (0.09)	0.06 (0.07)	0.11 (0.05)	0.2330
Heavy cans	0.20 (0.17)	0.26 (0.12)	0.25 (0.14)	**0. 0481**	0.08 (0.11)	0.08 (0.09)	0.15 (0.08)	0.1519
Box and Blocks	19.00 (8.73)	14.27 (7.88)	15.28 (6.19)	0.0645	10.53 (9.34)	4.00 (4.47)	7.60 (6.50)	0.2154
9 hole peg	0.06 (0.05)	0.06 (0.06)	0.01 (0.01)	**0.0008***	0.04 (0.04)	0.00 (0.00)	0.00 (0.00)	**0.0194***
SHAP IOF	42.4 (18.4)	39.3 (23.1)	40.2 (15.0)	0.8298	13.4 (16.2)	6.6 (10.3)	12.8 (12.7)	0.5407
Activity measures								
AM-ULA	14.9 (5.3)	14.9 (7.7)	16.4 (6.5)	0.6800	12.3 (6.2)	9.4 (4.2)	11.9 (1.8)	0.2335
BAM-ULA	6.6 (2.1)	9.2 (1.0)	8.0 (1.6)	**0.0023***	4.5 (3.4)	4.0 (.)	3.5 (0.7)	0.8307
T-MAP (min)	5.0 (1.8)	3.9 (0.6)	3.9 (0.9)	0.0810	4.6 (1.7)	4.9 (1.2)	7.4 (3.0)	0.1824
Prosthesis satisfaction								
TAPES	4.0 (0.7)	3.5 (0.7)	3.8 (0.7)	0.0514	3.7 (0.9)	3.5 (0.5)	3.7 (0.5)	0.6402
Disability, HRQoL, and community integration								
QuickDASH	29.2 (19.4)	30.9 (15.8)	26.3 (18.1)	0.7196	34.0 (20.7)	28.2 (13.8)	30.5 (13.3)	0.8488
VR-12 MCS	53.5 (10.1)	46.3 (12.8)	52.4 (11.5)	0.0854	50.4 (13.1)	50.6 (14.6)	52.9 (9.4)	0.9820
VR-12 PCS	37.5 (8.9)	43.2 (6.9)	41.1 (8.2)	0.0854	34.7 (13.2)	41.9 (5.6)	44.0 (8.1)	0.1719
CRIS-CAT extent	50.1 (8.7)	44.6 (9.6)	49.5 (8.8)	0.2424	45.4 (8.3)	50.1 (10.9)	53.2 (8.6)	0.1312
CRIS-CAT perceived	49.4 (6.8)	44.3 (4.7)	51.1 (9.1)	**0.0333**	46.2 (5.0)	48.3 (7.1)	48.8 (7.9)	0.8735
CRIS-CAT satisfaction	51.2 (9.2)	46.9 (7.7)	50.2 (10.5)	0.3651	45.6 (4.9)	47.9 (5.8)	47.7 (7.9)	0.5518
	N (%)	*N* (%)	*N* (%)	exact p	*N* (%)	*N* (%)	*N* (%)	exact p
Need for ADL help	7 (21.2)	3 (37.5)	2 (16.7)	0.5738	3 (25.0)	2 (28.6)	1 (20.0)	1.0000

*Significant after Benjamini–Hochberg adjustment with false discovery rate = 0.1. Bold values in this table indicate values statistically significant at $p < 0.05$.

Responsiveness of the prostheses was not independently measured but rather subsumed in dexterity measures. Dexterity, in this context, results from the speed or responsiveness of prosthesis movement, the grip options, the shape of the prosthesis terminal device, and the need to switch between grips or other movements to orient the terminal device to perform an activity. Another worthy topic outside the scope of this study is whether any particular componentry or prosthetic model offers notable benefits or limitations compared to others in the same class.

Our comparisons of normative data for those with TR amputation to unimpaired samples was limited by the data available in current literature. Not all age groups matched perfectly. We did not find age-stratified nondominant hand data for the SHAP, thus some of the difference between those with TR amputation and the unimpaired sample may be due to use of a dominant hand. Non-dominant hand data were also not available for the Box and Block or NHP tests; however. we were able to compare to both left- and right-hand data for unimpaired groups. It was not possible to identify age-grouped data in a completely male sample for the VR-12, so some bias by gender may exist given that only 3% of our sample were women. Calculations of JTHF and NHP average items/second were not mathematically exact – instead we had to use the maximum items completed divided by the average times taken. However, given the low variance in reported times for unimpaired samples, we believe our comparisons to those with TR amputation are accurate.

Conclusions

This study estimated normative values by amputation level for standardized measures of dexterity, activity performance, disability, HRQoL, and community integration and estimated magnitude of impairment of these outcomes. We found that dexterity is markedly impaired in prosthesis users with ULA and that there is substantial upper limb related disability at all levels of ULA. Persons with more proximal amputation levels are most impacted. In contrast, HRQoL of life and community participation appear to be less impacted and more equivalent to that of unimpaired persons. Furthermore, this study estimated normative values for three prosthesis configurations (body-powered, myoelectric with single DOF terminal, and myoelectric devices with multi-DOF terminal devices) by amputation level. These data may inform clinicians and researchers and help them create benchmarks for these standardized measures by amputation level and prosthesis types.

This study did not detect differences in dexterity, activity performance, disability, HRQoL, or community integration by overall type of prosthesis used, suggesting that that more complex, expensive devices (such as myoelectric multi-DOF terminal devices) do not offer clear advantages for the average person with ULA. Further research with larger sample sizes or different designs, is needed to confirm or refute these findings, to explore whether there are differences by specific terminal device brands or functionality, and to determine how best to match prosthesis type to person based on individual characteristics.

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Appendix

Table A1. Normative values for transradial and transhumeral unilateral amputation by age category.

	Unilateral amputation WD/TR ($N=75$)			Unilateral amputation ED/TH ($N=32$)		
	18 to <45 ($N=22$) Mn (SD)	45 to <65 ($N=20$) Mn (SD)	65+ ($N=33$) Mn (SD)	18 to <45 ($N=5$) Mn (SD)	45 to <65 ($N=16$) Mn (SD)	65+ ($N=11$) Mn (SD)
Dexterity measures						
JTHFT						
Writing	0.46 (0.23)	0.64 (0.35)	0.41 (0.26)	0.11 (0.16)	0.30 (0.22)	0.29 (0.24)
Page turning	0.11 (0.07)	0.17 (0.08)	0.12 (0.10)	0.03 (0.05)	0.06 (0.05)	0.05 (0.05)
Small objects	0.10 (0.10)	0.09 (0.07)	0.10 (0.08)	0.02 (0.02)	0.04 (0.05)	0.06 (0.06)
Eating	0.15 (0.10)	0.19 (0.12)	0.16 (0.12)	0.05 (0.05)	0.05 (0.07)	0.10 (0.09)
Checkers	0.12 (0.08)	0.09 (0.07)	0.07 (0.05)	0.06 (0.10)	0.05 (0.06)	0.04 (0.03)
Light cans	0.27 (0.10)	0.25 (0.15)	0.18 (0.13)	0.05 (0.08)	0.10 (0.08)	0.12 (0.09)
Heavy cans	0.26 (0.12)	0.24 (0.16)	0.18 (0.17)	0.05 (0.04)	0.12 (0.11)	0.08 (0.09)
Box and Blocks	16.9 (6.9)	19.3 (8.2)	16.0 (9.3)	3.6 (4.4)	7.7 (7.3)	10.9 (9.8)
9-Hole peg	0.04 (0.04)	0.07 (0.05)	0.04 (0.05)	0.02 (0.04)	0.02 (0.04)	0.03 (0.03)
SHAP IOF	42.9 (15.5)	43.6 (20.1)	39.1 (19.1)	5.8 (8.8)	13.0 (12.9)	11.3 (17.2)
Activity measures						
AM-ULA	19.0 (6.5)	16.6 (6.6)	13.2 (5.2)	11.8 (5.0)	11.3 (6.1)	11.3 (4.9)
BAM-ULA	8.5 (1.6)	7.6 (2.3)	6.3 (1.7)	8.0 (.)	2.8 (1.9)	4.8 (3.0)
T-MAP (min)	4.0 (1.0)	4.3 (2.1)	5.1 (1.3)	5.5 (0.9)	5.9 (2.7)	3.2 (0.5)
Prosthesis satisfaction						
TAPES	3.8 (0.8)	3.7 (0.7)	4.0 (0.7)	3.8 (0.8)	3.7 (0.8)	3.5 (0.7)
Disability, HRQOL and community integration						
QuickDASH	31.5 (18.3)	28.9 (18.8)	26.8 (18.5)	31.6 (19.4)	31.6 (18.3)	32.3 (17.8)
VR-12 MCS	50.0 (13.7)	51.2 (13.0)	59.2 (6.0)	45.8 (13.6)	54.2 (10.8)	50.1 (16.6)
VR-12 PCS	44.2 (8.6)	43.4 (7.2)	40.9 (8.3)	44.8 (12.3)	41.9 (11.6)	39.1 (12.3)
VR-12 MCS imputed	48.1 (13.3)	49.3 (12.8)	56.5 (5.8)	48.8 (14.2)	52.2 (10.4)	49.8 (15.9)
VR-12 PCS imputed	41.3 (8.6)	40.4 (7.2)	37.2 (9.3)	41.5 (10.0)	38.5 (11.9)	36.2 (11.7)
CRIS-CAT extent	45.4 (10.7)	48.5 (9.6)	52.0 (6.1)	44.9 (13.4)	48.2 (9.1)	48.9 (8.4)
CRIS-CAT perceived	48.1 (9.3)	48.2 (7.9)	50.1 (5.4)	45.7 (5.6)	47.6 (6.8)	47.2 (5.4)
CRIS-CAT satisfaction	47.9 (10.3)	50.4 (9.5)	51.8 (8.5)	45.8 (7.2)	47.4 (5.9)	45.9 (4.8)
	N (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)
Need for ADL help	5 (35.7)	3 (20.0)	4 (16.7)	2 (50.0)	2 (15.4)	2 (28.6)

Table A2. Functional and self-report outcomes by age category and device type (unilateral, transradial amputation only).

	Body powered ($N=45$)			Myo-single DOF ($N=12$)			Myo multi-DOF ($N=18$)		
	18–<45 ($N=6$)	45–<65 ($N=11$)	66+ ($N=28$)	18–<45 ($N=7$)	45–<65 ($N=3$)	66+ ($N=2$)	18–<45 ($N=9$)	45–<65 ($N=6$)	66+ ($N=3$)
	Mn (SD)	Mn (SD)	Mn (SD)	Mn (SD)	Mn (SD)	Mn (SD)	Mn (SD)	Mn (SD)	Mn (SD)
Dexterity									
JTHF	0.43 (0.24)	0.70 (0.33)	0.42 (0.27)	0.48 (0.28)	0.38 (0.13)	0.21 (0.30)	0.46 (0.20)	0.65 (0.44)	0.43 (0.12)
Writing	0.12 (0.09)	0.18 (0.08)	0.12 (0.09)	0.12 (0.07)	0.19 (0.12)	0.15 (0.21)	0.10 (0.05)	0.14 (0.07)	0.14 (0.11)
Page turning	0.08 (0.05)	0.10 (0.07)	0.12 (0.08)	0.15 (0.11)	0.06 (0.09)	0.02 (0.01)	0.09 (0.11)	0.06 (0.08)	0.03 (0.03)
Small objects	0.11 (0.07)	0.21 (0.10)	0.18 (0.12)	0.18 (0.13)	0.20 (0.19)	0.10 (0.10)	0.16 (0.08)	0.14 (0.11)	0.07 (0.04)
Eating	0.10 (0.07)	0.09 (0.06)	0.07 (0.06)	0.10 (0.09)	0.08 (0.12)	0.02 (0.02)	0.15 (0.09)	0.10 (0.08)	0.09 (0.04)
Checkers	0.19 (0.10)	0.23 (0.14)	0.20 (0.13)	0.27 (0.07)	0.20 (0.18)	0.09 (0.04)	0.32 (0.11)	0.30 (0.19)	0.11 (0.03)
Light cans	0.16 (0.10)	0.24 (0.19)	0.19 (0.18)	0.29 (0.06)	0.25 (0.22)	0.15 (0.01)	0.32 (0.13)	0.24 (0.10)	0.10 (0.10)
Heavy cans	18.0 (7.9)	23.1 (7.3)	17.6 (9.1)	15.7 (7.2)	12.7 (11.7)	4.5 (4.9)	17.1 (6.7)	15.7 (4.7)	9.0 (4.0)
Box and Blocks	0.04 (0.03)	0.09 (0.04)	0.05 (0.05)	0.07 (0.06)	0.07 (0.07)	0.00 (0.00)	0.01 (0.02)	0.00 (0.00)	0.00 (0.00)
9 hole peg	39.7 (21.2)	46.0 (17.5)	41.6 (18.6)	43.3 (18.1)	37.7 (34.6)	27.5 (33.2)	44.7 (9.7)	42.0 (20.0)	23.3 (2.1)
SHAP IOF									
Activity measures									
AM-ULA	16.1 (1.4)	17.5 (6.3)	13.7 (5.1)	18.3 (5.8)	11.5 (10.3)	7.8 (3.1)	18.9 (6.7)	15.1 (6.5)	11.3 (2.8)
BAM-ULA	7.5 (0.7)	7.1 (2.8)	6.1 (1.8)	9.2 (1.1)	9.0 (.)	. (.)	8.3 (2.2)	8.0 (1.4)	7.5 (0.7)
T-MAP (min)	4.4 (1.4)	4.7 (2.6)	5.3 (1.4)	3.8 (0.5)	3.5 (0.3)	4.3 (0.8)	3.8 (0.9)	3.8 (1.2)	4.3 (0.2)
Prosthesis satisfaction									
TAPES	4.2 (0.6)	3.8 (0.8)	4.1 (0.7)	3.4 (0.9)	3.6 (0.3)	3.9 (0.2)	4.0 (0.7)	3.6 (0.7)	3.7 (0.8)
Disability, HRQOL, and community integration									
QuickDASH	27.7 (14.6)	34.1 (21.4)	27.6 (19.7)	39.0 (9.7)	22.0 (22.8)	15.9 (3.2)	28.3 (24.5)	23.0 (9.6)	27.3 (10.4)
VR-12 MCS	52.5 (9.3)	49.6 (15.4)	59.4 (6.5)	44.4 (15.4)	50.2 (6.6)	55.8 (1.0)	52.7 (14.8)	54.5 (11.2)	59.7 (1.8)
VR-12 PCS	45.6 (8.0)	41.8 (7.8)	39.3 (8.1)	**45.9 (6.9)**	44.9 (8.9)	49.4 (8.6)	41.8 (10.4)	45.8 (5.8)	47.5 (4.8)
VR-12 MCS imputed	50.4 (8.8)	47.5 (15.4)	56.6 (6.3)	42.7 (15.7)	49.6 (6.5)	5.4 (0.0)	50.7 (13.9)	52.4 (10.8)	57.5 (2.6)
VR-12 PCS imputed	42.8 (8.2)	38.7 (7.7)	35.8 (9.2)	43.1 (6.6)	41.5 (8.9)	46.1 (8.3)	39.0 (10.4)	43.0 (5.6)	43.7 (5.4)
CRIS-CAT extent	46.1 (12.7)	47.6 (10.8)	52.0 (6.3)	40.2 (8.9)	49.9 (8.5)	52.2 (7.3)	49.1 (10.0)	49.4 (9.2)	51.3 (5.6)
CRIS-CAT perceived	48.6 (7.4)	47.7 (9.0)	50.3 (5.7)	43.1 (5.4)	45.2 (4.2)	47.0 (3.2)	51.6 (11.7)	50.8 (7.5)	50.6 (4.0)
CRIS-CAT satisfaction	47.7 (7.9)	49.1 (10.9)	52.8 (8.7)	44.2 (7.8)	53.4 (7.1)	46.5 (2.5)	50.9 (13.1)	51.3 (8.5)	45.8 (5.4)
	N (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)
Need for ADL help	2 (33.3)	2 (28.6)	3 (15.0)	2 (66.7)	1 (33.3)	0 (0.0)	1 (20..0)	0 (0.0)	1 (50.0)

Table A3. Comparison of function participants with unilateral and bilateral amputation: TR body-powered users only.

	Unilateral WD/TR ($N=45$) Mn (SD)	Bilateral WD/TR ($N=8$) Mn (SD)	WMW *p* Value
Dexterity measures			
JTHFT			
Writing	0.49 (0.30)	0.93 (0.2)	**0.0008***
Page turning	0.13 (0.09)	0.36 (0.15)	**0.0012***
Eating	0.11 (0.07)	0.27 (0.18)	**0.0094***
Small objects	0.18 (0.12)	0.27 (0.08)	**0.0287***
Checkers	0.08 (0.06)	0.19 (0.13)	**0.0083***
Light cans	0.20 (0.13)	0.51 (0.28)	**0.0059***
Heavy cans	0.20 (0.17)	0.53 (0.22)	**0.0010***
Box and Blocks	19.0 (8.7)	29.8 (6.2)	**0.0035***
9-Hole peg	0.06 (0.05)	0.15 (0.08)	**0.0036***
SHAP IOF	42.4 (18.4)	52.9 (25.1)	0.0878*
Activity measures			
AM-ULA	14.9 (5.3)	16.8 (5.9)	0.2334
BAM-ULA	6.6 (2.1)	9.0 (0.8)	**0.0124***
T-MAP	5.0 (1.8)	7.6 (3.7)	0.0826
Prosthesis satisfaction measures			
TAPES	4.0 (0.7)	4.2 (0.4)	0.8044
Disability, HRQoL, and community integration			
QuickDASH	29.2 (19.4)	22.7 (13.2)	0.5339
VR-12 MCS	55.8 (10.7)	56.6 (8.9)	0.9569
VR-12 PCS	40.9 (8.1)	46.8 (9.5)	0.0787
VR-12 MCS imputed	53.5 (10.1)	55.2 (8.2)	0.8424
VR-12 PCS imputed	37.5 (8.9)	43.6 (9.1)	0.0865
CRIS-CAT extent	50.2 (8.7)	55.4 (5.9)	0.1265
CRIS-CAT perceived	49.4 (6.8)	53.6 (11.0)	0.2634
CRIS-CAT satisfaction	51.2 (9.2)	52.8 (7.1)	0.4446
	N (%)	*N* (%)	Exact *p*
Need for ADL help	7 (21.2)	3 (60.0)	0.1026

*Significant after Benjamini–Hochberg adjustment with false discovery rate = 0.1. Bold values in this table indicate values statistically significant at $p < 0.05$.