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SYSTEMATIC REVIEW

Evaluation Tools for Assistive Technologies: A Scoping Review

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Abstract

Objective: Assistive technologies (ATs) support independence and well-being in people with cognitive, perceptual, and physical limitations. Given the increasing availability and diversity of ATs, evaluating the usefulness of current and emerging ATs is crucial for informed comparison. We aimed to chart the landscape and development of AT evaluation tools (ETs; ATETs) across disparate fields in order to improve the process of AT evaluation and development.

Data Sources: We performed a scoping review of ATETs through database searching of MEDLINE, Embase, CINAHL, HaPI, PsycINFO, Cochrane Reviews, and Compendex as well as citation mining.

Study Selection: Articles explicitly referencing ATETs were retained for screening. We included ETs if they were designed to specifically evaluate ATs.

Data Extraction: We extracted 5 attributes of ATETs: AT category, construct evaluated, conceptual frameworks, type of end user input used for ATET development, and presence of validity testing.

Data Synthesis: From screening 23,434 records, we included 159 ATETs. Specificity of tools ranged from single to general ATs across 40 AT categories. Satisfaction, functional performance, and usage were the most common constructs of 103 identified. We identified 34 conceptual frameworks across 53 ETs. Finally, 36% incorporated end user input and 80% showed validation testing.

Conclusions: We characterized a wide range of AT categories with diverse approaches to their evaluation based on varied conceptual frameworks. Combining these frameworks in future ATETs may provide more holistic views of AT usefulness. ATET selection may be improved with guidelines for conceptually reconciling results of disparate ATETs. Future ATET development may benefit from more integrated approaches to end user engagement.

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Assistive technologies (ATs) are products for assisting with managing a broad range of health conditions and for improving quality of life of end users (fig 1), for example, older adults and persons with disabilities. ATs have the potential to facilitate self-care,[1,2] reduce health care costs,[3] and empower end users.[4] As such, ATs have diverse purposes and functions, ranging from devices that compensate for body function impairments, to those that help with participation in social activities. Some examples include sensory aids for sensory impairments,[5] prostheses[6] and wheelchairs for mobility restrictions,[7] telerehabilitation systems for barriers to care access,[8] and social robots for psychological well-being.[9]

Despite the rise in AT options, it remains challenging to ensure end users gain awareness of available options, can make informed choices about AT, and are able to navigate the services that provide ATs. Even when AT is successfully obtained by end users, AT abandonment remains a prevalent problem,[10,11] leading to reduced

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benefits from AT provision. AT abandonment often occurs due to low satisfaction with AT design or inability of the AT to meet end users' specific needs or chosen activities.[10,12] Therefore, evaluating the overall usefulness of AT from an end user perspective is fundamental to ensuring that end users benefit from their ATs and avoid abandonment. This imperative formed the principal motivation for this study.

Nielsen describes usefulness as the combination of utility, the degree to which a product meets one's needs, and usability, the easiness and pleasantness of using the product.[13] For the purposes of this review, we used the term AT usefulness to represent an overarching construct by which end users ascribe value to ATs. Therefore, uptake and ongoing use of ATs is contingent not only on their efficacy, but also on the myriad ways they may or may not be considered useful to end users,[14] for example, in terms of satisfaction,[15] quality,[16] or associated stigma.[17]

Such considerations are important for matching AT to individuals, service delivery, and also throughout the development process of ATs. Moreover, these design considerations are particularly important when developing ATs for people with multiple disabilities or comorbidities, as their needs may be complex and multidimensional. To address these needs, greater emphasis has been placed on ensuring end user input is meaningfully incorporated into the design of ATs with the belief that better AT evaluation during development leads to greater benefits, for example, improved AT mechanics or user experience.[18-20] This trend is consistent with broader calls for the integration of end user perspectives in AT development through methodologies such as user-centered design and participatory research.[21-23]

In both prototyping research and with final products, researchers often use structured interviews, focus grouping, and ad hoc questionnaires to evaluate end user perspectives on AT usefulness.[15,24,25] Whereas these methods offer important insights, their lack of standardization limits comparisons across technologies. Moreover, these assessments can be time-consuming, resource intensive, and often only occur at one time point in AT development; consequently, such approaches do not necessarily lead to successful integration of end user perspectives when AT development requires multiple iterations.

Addressing these challenges, standardized evaluation tools (ETs) are a common approach to assessing aspects of AT usefulness. These tools have the advantage of being readily administered and allowing quantitative comparison across time points. However, ETs of ATs (or ATETs) across AT fields can be heterogeneous; they may evaluate varied or overlapping constructs and may draw on theories, models, and frameworks from different research fields. Moreover, there is limited guidance on selecting the most appropriate application of ETs for AT development, especially for emerging ATs. Whereas fit and comfort may be of particular interest in prosthetics,[26] accessibility may be of greater concern in e-health[27] where usability relates to all AT. Furthermore, ETs generally require validation to clarify their suitability; some ETs may be thoroughly validated while others are not.

List of abbreviations:

AT	**assistive technology**
ATET	**assistive technology evaluation tool**
ET	**evaluation tool**
ICF	**International Classification of Functioning, Disability and Health**
MeSH	**Medical Subject Headings**

If ETs are to be used for the development of ATs, they too should be grounded in end user priorities to ensure ATs are developed in alignment with their needs and values. Such alignment may also support better service delivery postdevelopment. However, it is unclear the extent to which end users' input has been incorporated into existing ETs. Moreover, it is unclear which of these needs and values may be transferable across AT fields. These considerations are particularly salient to older adults, as they represent a large population of AT users who may use multiple and diverse combinations of ATs. There remains ambiguity in distinguishing concepts and considerations worth evaluating in ATs generally from those particular to specific ATs.

These gaps represent barriers to assessing the overall usefulness of ATs. As such, they hinder the advancement of knowledge necessary for reducing AT abandonment, addressing of end users' unmet needs, and enhancing of benefits gained by AT end users. To date, the AT literature lacks a comprehensive overview of ATETs across the disparate AT fields that may raise, define, and ameliorate these gaps.

The objective of this scoping review was to expand the understanding of how ATs are evaluated across AT fields by characterizing the landscape of existing tools used to evaluate ATs in peer-reviewed literature. In doing so, we aimed to describe how the overarching construct of AT usefulness is constituted in AT evaluation. We also aimed to examine the ways in which end user perspectives are integrated into these ETs. Fulfilling these objectives would help us to better understand and operationalize the assessment of AT usefulness throughout the AT development process in a way that considers the layered needs and contexts of end users. To address these objectives, we asked the specific research questions: (1) what tools have been specifically developed for the evaluation of ATs; (2) what constructs are evaluated by these tools and what conceptual frameworks do they rely on to do so; and (3) to what extent do these tools include end user input and demonstrate validation testing.

Methods

Study design

To examine ATETs, we undertook a scoping review of the literature applying the framework of Arksey and O'Malley[28] and guidelines from the Joanna Briggs Institute.[29] Considering the broad nature of ATs and the diverse ways and contexts in which they can be evaluated, a scoping review provided the flexibility to iteratively develop our search strategy. We based our search strategy on the International Organization for Standardization 9999 definition of AT[30] (see fig 1) and the following definition of ET: *Evaluation Tool*: A quantitative instrument that directly assesses one or several: (1) qualities of the AT, e.g. usability, ergonomics, aesthetics, or (2) perceptions of users with respect to AT, e.g. satisfaction, confidence, or (3) AT-specific skills, e.g. wheelchair skills, or (4) impacts of AT on users, e.g. Quality of Life, abilities, limitations.

While evaluation of ATs regularly involves using instruments that measure users' functional capacity, mental state, symptoms, and quality of life, we consider only those instruments explicitly developed for the context of using ATs.

Search strategy

We developed a search strategy using Ovid MEDLINE (supplemental appendix S1, available online only at http://www.

ISO 9999:2016

2.3

assistive product

any product (including devices, equipment, instruments and software), especially produced or generally available, used by or for **persons with disability** (2.12)

- for **participation** (2.13),
- to protect, support, train, measure or substitute for **body functions** (2.4)/structures and activities, or
- to prevent **impairments** (2.11), **activity limitations** (2.2) or **participation restrictions** (2.14)

Fig 1 International Organization for Standardization definition for assistive products (technology).

archives-pmr.org/). Our search logic targeted the intersection of the concepts: ATs, ETs, rehabilitation, and older adults or people with disabilities. To construct the search strategy, we mapped keywords related to these concepts to Medical Subject Headings (MeSH) terms in MEDLINE. Associated keywords were added based on "scope notes." We iterated the search strategy through MeSH tree exploration and as we encountered new terms that fit our concepts. This process continued until no new MeSH terms were added. We then translated the MEDLINE search strategy into Embase (Ovid), CINAHL (EBSCOhost), PsycINFO (EBSCOhost), HaPI (Ovid), Cochrane Reviews (Ovid), and Compendex (Engineering Village). Search strategies across databases were iteratively adjusted as new terms arose. There were no restrictions on the search time frame. However, search results were limited to English records.

Screening

Records from all databases were downloaded into references software EndNote[a] for deduplication and screening. We removed duplicates matched on title, year, author, or volume. With verification, we removed remaining duplicates based on title or year match.

For screening of title and abstract, 3 researchers screened one-third of the database. A screening guide was created by the first author based on initial screening of 400 records. The screening guide was reviewed and discussed with the entire research team. Initial screening by the second and third researchers was conducted together with the first screener until >95% agreement was achieved. As screening continued, any ambiguities were resolved by the research team through discussion.

For each record, we screened abstracts only if the title referenced at least 1 type of AT. Records were retained for full-text screening if the abstract named or indicated use of a formal tool to evaluate AT. We used this criterion to exclude the majority of studies using ad hoc questionnaires or interview methods to evaluate AT.

In the full text of retained records, we identified formally developed tools used to evaluate AT. For these tools, we used citation mining and targeted searches to access the tool itself, records that detail the development of the tool, and records demonstrating validation testing (validity or reliability) of the tool. Using these "source" documents, 2 researchers independently screened each tool for inclusion in the scoping review according to the following inclusion criteria: (1) met our definition of evaluation tool; (2) specifically developed to evaluate AT or in context of AT; and (3) readily administered. We excluded tools if they (1) were ad hoc questionnaires; (2) focused on evaluating user characteristics instead of the AT; and (3) were surveys. We also included checklists and guidelines if they could be readily used as a list of criteria either met or unmet (ie, could be easily scored). For tools where screeners disagreed, inclusion was determined in discussion with the entire team.

Table 1 Attributes extracted from ETs

Data	Description
AT category	The specific type or scope of AT that the tool was developed to evaluate.
Construct evaluated	The primary construct(s) that the tool measures. Constructs measured by subscales were also recorded.
Conceptual framework	The defined framework, model, or theory according to which the conceptual content of the tool was developed.
End user input	The type of user input used for tool development.
Validation testing	Reliability or validity studies conducted (Yes/No).

Data extraction and coding

To address the research questions of this scoping review, we extracted and coded data from the source documents of included ETs according to 5 a priori attributes: (1) AT category; (2) construct evaluated; (3) conceptual framework; (4) end user input; and (5) validation testing (table 1). Extraction and coding (supplemental appendix S2A, available online only at http://www.archives-pmr.org/) were performed according to an extraction guide by the first author and a second researcher for 30% of ETs; codes were progressively compared, with initial differences and ambiguity discussed and resolved as they arose. Remaining ETs were extracted and coded by the first author and reviewed by the second researcher. The senior author also reviewed the coding scheme. Where possible, we used the ET's own terms as codes for each attribute. For articles using multiple words interchangeably to describe the constructs evaluated, we gave preference to the predominant term in the article. As the extraction process progressed, we relied more heavily on existing codes where terms were theoretically or practically identical, for example, "upper extremity prosthesis" and "prosthetic arm" were both coded as "upper limb prostheses" while "limb prosthesis" remained separate.

For AT categories, we also reviewed tools at the item level to determine whether ETs were applicable to broader AT categories or specific to narrower categories. For example, "I like how my prosthesis looks" applies to prostheses generally, but "I can easily put my shoe on my prosthesis" applies only to lower-limb prostheses.

We extracted conceptual frameworks as an umbrella term to capture the models, formal frameworks, and theories used to develop ETs. These conceptual frameworks were included if they

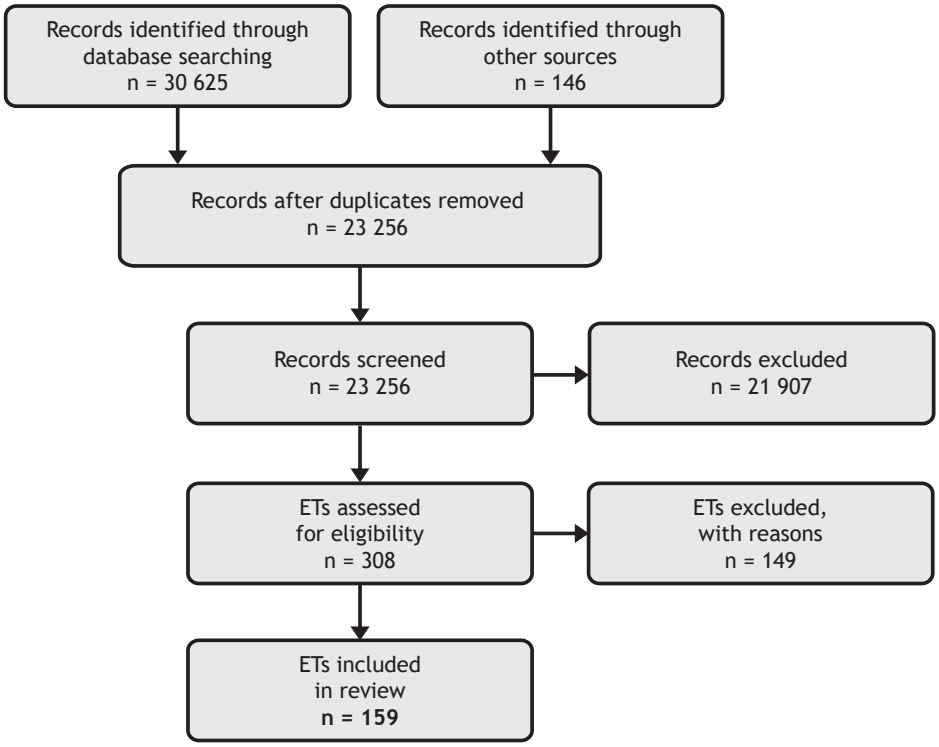


Fig 2 Flow diagram detailing article counts from initial search to inclusion.

were explicitly used to inform the conceptual content generation for the ET. Conversely, frameworks used primarily for guiding the structural organization of ET items (as opposed to content generation) were not included, for example, Rasch analysis or classical test theory.

End user input was identified as any instance where end users were provided with the opportunity to contribute to or provide opinions about the conceptual content, that is, items of the ET. Instances where data were collected from participants but did not allow for participant feedback were not considered as input.

Data summary

Data were descriptively summarized and conceptually mapped to illustrate the landscape of ETs. We statistically summarized each attribute according to the frequency of ETs using Excel.[b] We conceptually mapped end user input vs validation testing by cross-tabulation. The remaining attributes were also cross-tabulated; notable trends were identified via visual inspection of a chord diagram.

We categorized identified AT categories, conceptual frameworks, and constructs evaluated into larger thematic domains (supplemental appendix S2B, available online only at http://www.archives-pmr.org/) in order to chart broad groupings of ATETs. For AT categories, we acknowledge formal classification systems for AT do exist.[30,31] However, these taxonomies have not seen widespread adoption in the development of ATETs. Our thematic categorization aimed to chart broad groupings as they exist in the literature, without adhering to a specific taxonomy. Therefore, with AT categories and conceptual frameworks, we made groupings to approximate fields of study. For constructs evaluated, we made groupings according to broadly related constructs.

Results

In total, our final database search identified 30,625 articles (fig 2) on September 15, 2018. Figure 2 details the screening results. In total, we identified 308 unique ETs as candidates for inclusion. The first author evaluated the primary source(s) of each ET for inclusion. A second researcher independently reviewed each ET for inclusion, resulting in 93 (30%) ambiguous ETs being reviewed by 4 researchers on the team. Of the original evaluation, 18 (5.8%) inclusion decisions were changed. A total of 159 ATETs (supplemental appendix S3, available online only at http://www.archives-pmr.org/) were included in this scoping review.[32-186]

Throughout the screening process, we encountered articles studying translations, adaptations, and modifications for some tools. For these, we considered them as part of the same ET. However, we considered tools based on existing tools, but given a different name, as independent tools.

For complete lists and counts of extracted data and thematic domain organization (supplemental appendix S4-S6, available online only at http://www.archives-pmr.org/).

AT categories

Across all ATETs, we identified 40 categories of AT (fig 3). These ranged from narrowly specific categories, for example, manual wheelchairs,[140] to broader categories, for example, mobility aids,[161] to ATs in general.[74]

The most common categories of AT evaluated were hearing aid (20 ETs), general AT (19 ETs), and lower-limb prosthesis (17 ETs). Of the least common, 14, 9, and 5 ATs were evaluated by 1, 2, and 3 ETs, respectively. The AT categories evaluated by

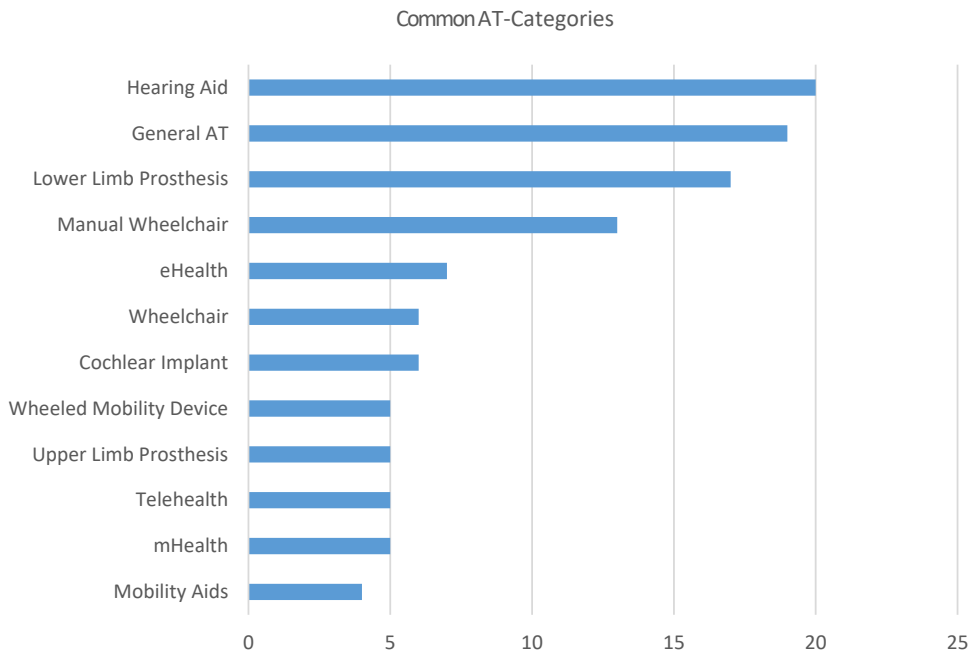


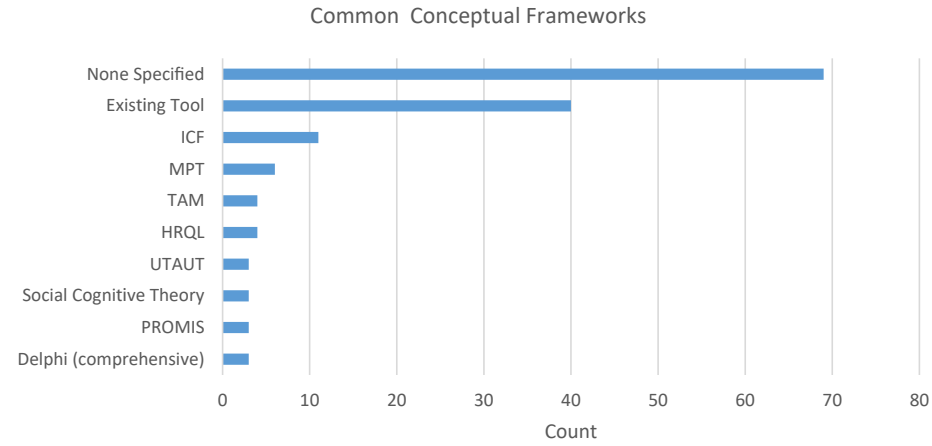
Fig 3 The most common AT categories evaluated. Counts represent number of ETs for each AT category. AT categories evaluated by ≥4 ETs were included. In this review, digital health technology appeared differentiated as eHealth (web-based health services), mHealth (health applications focused on mobile technology platforms), and Telehealth (technology focused on providing remote client-clinician interaction) according to our code list (see supplemental appendix S2).

1 ET also ranged from narrow to general, for example, electronic mobile shower commode[61] or medical devices.[154]

Conceptual frameworks

In total, we identified 34 conceptual frameworks (fig 4), with 51 ETs (32%) explicitly pointing to 1 or more conceptual frameworks as the primary basis for the development of the tool. With 11 ETs, the most common framework used was the International Classification of Functioning (ICF) developed by the World Health Organization.[187] Conversely, 18 frameworks each appeared in the development of a single ET and 8 frameworks appeared twice.

We identified 12 ETs that cited particular outcomes, for example, health-related quality of life, as the conceptual basis. Concept definitions from the International Organization for Standardization were also used in the development of 3 ETs. Additionally, we identified 6 ETs developed using methodologies



MPT – Matching Person and Technology
TAM – Technology Acceptance Model
HRQL – Health-related Quality of Life
UTAUT – Unified Theory of Acceptance and Usage of Technology
PROMIS – Patient-Reported Outcomes Measurement Information System

Fig 4 The most common conceptual frameworks explicitly used for ET development. Counts represent number of ETs related to each conceptual framework. Frameworks used by ≥3 ETs were included.

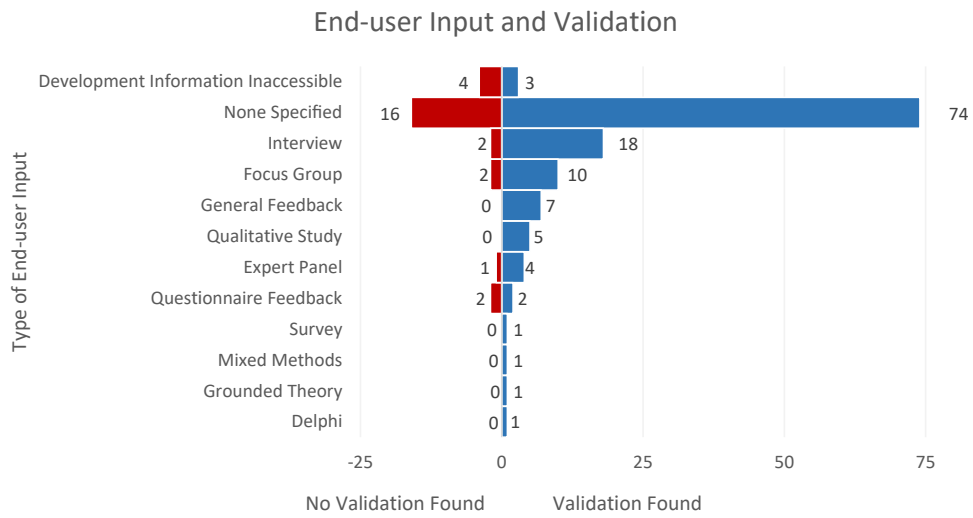


Fig 5 Number of ETs where validation evidence was not found (left) and was found (right). The vertical axis categorizes the types of end user input that was explicitly used in ET development.

that inform the conceptual makeup of the tool, that is, grounded theory, Delphi process, and participatory action research. The development of 1 ET also referenced a past study as the conceptual framework.[77]

A total of 69 (43%) ETs did not explicitly specify a particular conceptual framework as the basis for tool development. These tools often used a generalized literature review,[185] clinical experience,[88] or expert panels.[123] Moreover, we coded 40 ETs as being based on existing ETs to develop the conceptual content of the ET. For example, some ETs selected items from multiple existing ETs[42,56,114] whereas others adapted more general tools to suit AT evaluation.[78,188] Of these ETs, 7 were also explicitly aligned with at least 1 specific conceptual framework. We also identified 2 ETs provided by the AT industry, that is, ETs developed by companies involved in AT production and development.

For 4 ETs, we were unable to determine whether a specific framework was defined in their development. The best sources we could access for these tools only described their content or validation.

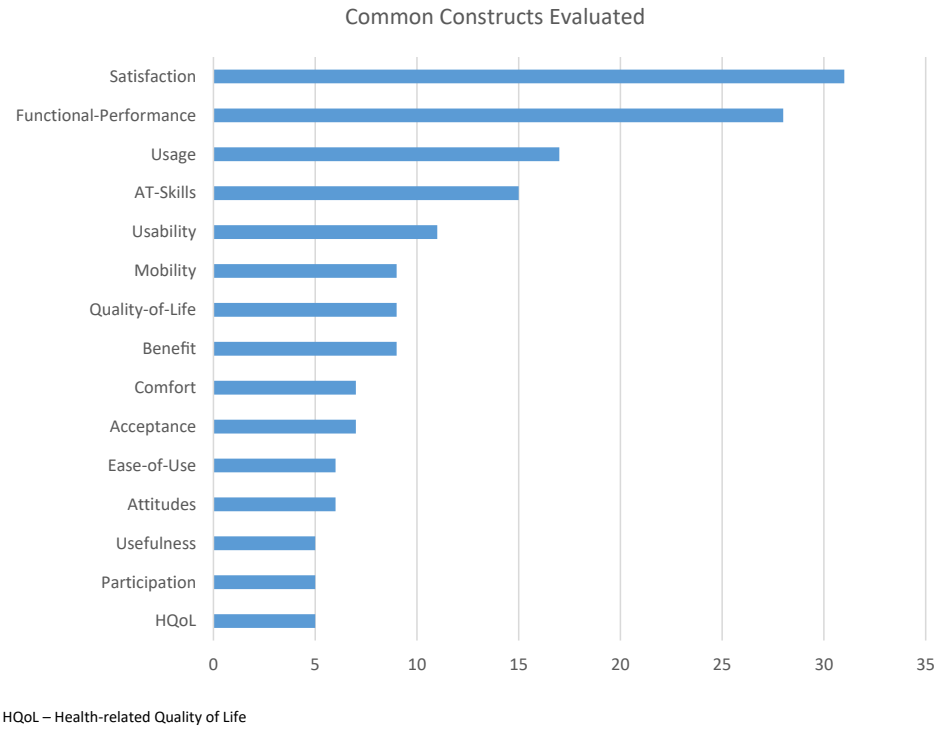


Fig 6 The most common constructs evaluated. Counts represent number of ETs evaluating each construct. Constructs evaluated by ≥5 ETs were included. Several ETs evaluated multiple constructs; these ETs were counted once for each construct they evaluated.

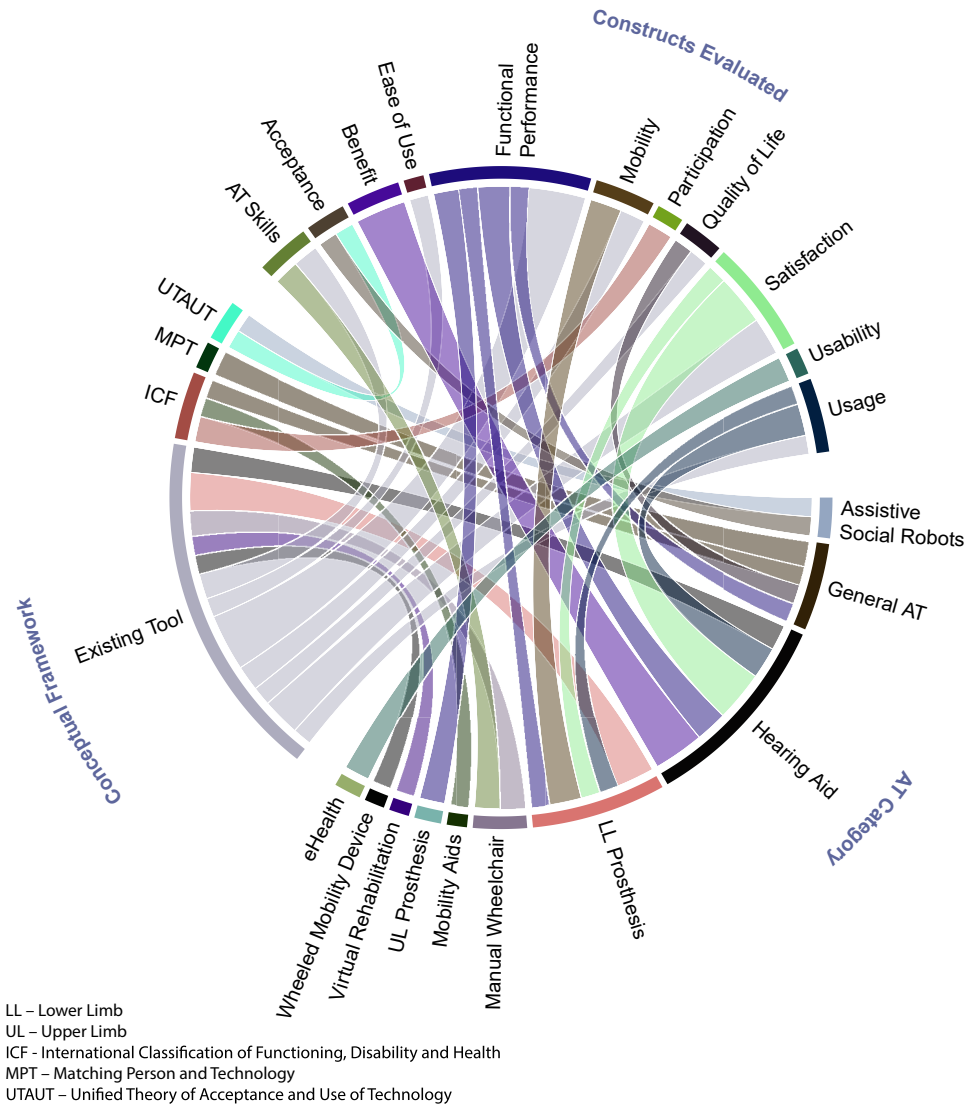


Fig 7 Chord diagram indicating paired linkages between attributes; pairings with ≥3 linkages were included. Thicker bands indicate a greater number of linkages. Bands flow from AT category to conceptual framework to constructs evaluated to conceptual framework. These bands may be interpreted as a combination of both quantity and consistency of ETs, representing their overall footprint in the ATET literature. For example, the strong linkages appear with the heavily represented hearing aid AT category with satisfaction, benefit, and usage. Aside from existing tool, the ICF was the most heavily represented conceptual framework, with consistent linkages to general AT, mobility aids, and participation. Moreover, assistive social robots, Unified Theory of Acceptance and Use of Technology, and acceptance were consistently interlinked. Unsurprisingly, functional performance was assessed in ETs for a variety of AT categories.

End user input and validation

Across all tools included in our scoping review, 57 (36%) involved some form of end user input during ET development while the remaining ETs did not specify any such input (fig 5). We identified 10 categories of end user input, with the most common input involving interviews (18 ETs) and focus groups (10 ETs). Four types of end user input appeared only once.

For 127 (80%) ETs, our targeted searches found quantitative evidence of validation (see fig 5). While we did not fully assess the degree or type of validation, the most common evidence supporting validity was in the form of Cronbach alpha and test-retest reliability. While identifying evidence for validation, we observed that some tools were only tested via Cronbach alpha in a single context; other tools were thoroughly validated using multiple measures and across multiple populations and languages.

For 5 ETs, measurement validation was not applicable; these ETs were in the form of checklists or guidelines that could be used as checklists.

Constructs

In total, we identified 103 constructs evaluated by ETs (fig 6). For 66 (42%) ETs, 2-9 constructs were coded. The most common constructs evaluated were satisfaction (31 ETs), functional performance (28 ETs), and usage (17 ETs); these constructs appeared independently in some ETs and together in others. For functional performance, we collapsed all instances where the performance of AT related tasks, for example, wheelchair transfer, were evaluated.

Table 2 Categorization of AT categories, conceptual frameworks, and evaluated constructs into thematic domains

AT Category	No. ET	Conceptual Framework	No. ET	Construct Evaluated	No. ET
Mobility aids	36	Health frameworks	18	Functioning & activities	71
Hearing amplification devices	32	AT frameworks	12	Attitudes	63
Orthotics & limb prosthetics	31	Outcomes	9	User experience	56
Assistive digital media and communication	26	Technology design	6	AT design factors	40
General AT	22	Methodologies	6	Effects	34
Oral health	6	Psychosocial Frameworks	6	Status/well-being	25
Assistive robots	4	Standardized definitions	4	Personal factors	6
Other AT	2	Other frameworks	4	Participation	8
				Needs	6

NOTE. ET counts are sum totals of constituent attributes; for example, an ET evaluating 2 different "attitudes" constructs is counted twice or an ET evaluating both a "user experience" construct and an "effects" construct is counted twice.

Of the least common, 58 constructs were evaluated once; 13 were evaluated twice; 10 were evaluated 3 times; and 6 constructs were evaluated 4 times. Of the singletons, some were novel constructs specific to particular AT categories, for example, sense of presence for the AT category virtual rehabilitation. Other constructs were similar to more frequently coded constructs but remained conceptually distinct. For example, discontinuance is closely related to usage, yet it is the conceptual inverse.

Conceptual mapping

To explore the interrelationships between AT categories, frameworks, and constructs evaluated, we charted the data in a chord diagram (Figure 7). This representation provides a visual means of identifying particularly frequent linkages between concepts. For visual clarity, we used a cutoff count of 3 or more pairings. The ICF, Unified Theory of Acceptance and Use of Technology, and Matching Person and Technology assessment process were the only conceptual frameworks meeting this cutoff. Of 31 ETs evaluating satisfaction, 17 pointed to no specific framework. Of 28 tools evaluating functional performance, 11 pointed to no specific framework and 9 were based on existing tools. Complete cross-tabulation and chord diagram results are displayed in supplemental appendix S7-S10 (available online only at http://www.archives-pmr.org/).

Hearing aid appeared to have the most frequently consistent linkages. Common constructs evaluated included AT skills, benefit, functional performance, satisfaction, and usage. Of the 20 hearing aid ETs 13 pointed to no specific framework. Furthermore, all ETs evaluating the construct benefit were associated with hearing aid ETs, save for one ET evaluating cochlear implant.

Thematic categorization

To summarize each ET attribute, we categorized data into thematic domains (table 2). AT categories were grouped into 8 domains, with the majority of ETs evaluating "mobility aids." Conceptual frameworks were grouped into 8 domains. Of the ETs that explicitly incorporated a framework, the most common were "health frameworks." Moreover, "mobility aids" were most commonly developed using "health frameworks" (10 ETs). Frameworks related to "technology design" were exclusively associated with "assistive robots" (5 ETs) and "assistive media" (4 ETs) while "AT frameworks" primarily informed "general AT" (7 ETs) and "mobility aids" (4 ETs). Constructs were grouped into 9 domains. The most commonly evaluated constructs related to "functioning & activities."

Discussion

AT evaluation is the process of determining the degree to which ATs successfully promote participation, remedy impairments, and mitigate health-related limitations, that is, determining overall AT usefulness. In this process, ATETs provide quantitative evidence that supports the innovation of novel AT products, identifies limitations and potential improvements for existing ATs, and aids the matching to and procurement of ATs by end users. As such, readily and appropriately administered ATETs benefit all AT stakeholders, including AT developers, researchers, clinicians, and end users.

Our scoping review characterized ETs specifically developed for AT contexts according to 5 attributes: construct(s) evaluated, applicable AT category, explicit conceptual framework, end user input, and validation testing. Our results demonstrate ATETs occupy a diverse landscape of AT categories, evaluate a wide range of constructs, and draw on disparate conceptual frameworks. Moreover, our scoping review includes ETs from the earlier periods of AT evaluation. While this particular perspective lends greater representation to AT fields with longer histories, it allows us to highlight the overall conceptual footprint of ATETs across time.

Conceptual frameworks

Conceptual frameworks underpin particular approaches to AT evaluation. They highlight the constructs to be evaluated as well as the relationships between constructs, they determine how these constructs and ET results are interpreted, and they influence how end user input is incorporated into ET development. Awareness of these conceptual frameworks helps inform our understanding of how overall AT usefulness is characterized in the AT literature. We identified conceptual frameworks representing a variety of perspectives on AT evaluation, from psychology and social science theories[142] to end user oriented methodologies[109] to frameworks specific to AT.[14] However, these frameworks were sporadically employed. Two frameworks stood out as approaches for

holistically evaluating and selecting appropriate AT for end users: the Human Activity Assistive Technology model,[8,189] and the Matching Person and Technology assessment process.[190] These frameworks (models, more specifically) have proven useful in conceptually guiding research and practice[189,191] and appear broadly applicable across AT categories. Yet, only 8 ETs were based on these frameworks. Similarly, the ICF, which aims to provide a comprehensive framework for health and disability, was the most common conceptual framework, but formed the basis of only 11 ETs spanning 2 AT domains: "general AT" and "mobility aids". Half of the identified frameworks were employed only once. These results indicate a potential gap between theoretical conceptions of AT and applied methods for assessing overall AT usefulness.

Conversely, the diverse domains of conceptual frameworks we identified highlight opportunities for applying new and improved approaches to AT evaluation. For example, "technology design" frameworks such as the Technology Acceptance Model[192] and Unified Theory of Acceptance and Use of Technology,[193] used to develop ETs for "assistive robots" and "assistive media," may be useful for informing future ETs of limb prostheses as they become more technologically sophisticated. Such opportunities may be leveraged to better support holistic research and development of ATs as multi or transdisciplinary endeavors aimed at meeting end users' unmet needs. Moreover, these opportunities for conceptual cross-application may apply across multiple AT domains we identified.

AT categories

For ATs, we identified 7 distinct thematic domains (and an "other AT" domain). However, within these domains, 4 specific AT categories represented over 40% of the 159 ATETs identified: hearing aid (domain of "hearing aid amplification devices"), general AT, lower-limb prosthesis (domain of "orthotics & limb prosthetics"), and manual wheelchair (domain of "mobility aids"). As such, these AT categories appear to be nodal points of reference in AT evaluation. They indicate particularly influential subfields of AT literature that shape how AT usefulness is broadly examined. ETs for more recently emergent ATs, that is, domain of "assistive digital media and communication", appeared more widely distributed. This may simply reflect the broad applications of digital media as AT. Moreover, the definitions and boundaries of these AT categories continue to evolve as digital technology rapidly advances.[194,195] Ensuring that tools used for assessing AT usefulness can keep pace with such a dynamic domain may then be an important avenue of future research.

Of the 7 thematic domains for AT categories, "hearing amplification devices" emerged as particularly distinct. ETs in this domain represented a fifth of ATETs identified, yet also appear relatively homogenous. This may be explained by a long and prodigious history, with the oldest included ET from 1984.[91] These ETs consistently evaluate AT in similar ways, that is, most commonly in terms of satisfaction, usage, functional performance, and benefit. While these ETs were usually based on existing tools[99] and literature review,[85] they were rarely situated in an explicit conceptual framework. This combination of long history and consistency is highlighted by the strong representation and linkages related to hearing aid in figure 3. Moreover, these characteristics underscore the historical contingencies of AT evaluation, where historically distinct fields may conceptualize comparable constructs according to their own traditions. For example, benefit as a construct capturing the holistic effect of AT appears primarily in the domain of "hearing amplification devices" and originates from early ET development in the 1980s to the 1990s,[89,91,104] whereas ETs in other domains consider the combination of "quality of life" and "functional performance."[122,170] While this well-established approach to assessing overall AT usefulness of "hearing amplification devices" may be sufficient, the field may benefit from other evaluation approaches that integrate better with the broader ecosystem of ATs. For example, user experience[159] may be a more relevant aspect of AT usefulness now that hearing aids have smartphone integration.

Constructs

The most frequently evaluated construct, satisfaction, was also evaluated in a wide range of AT categories, from wheelchairs[148] to telehealth,[185] and scopes, from orthopedic shoes[167] to general AT.[76] However, the vast majority of ATETs evaluating satisfaction appeared unassociated with any formal conceptual frameworks. This disconnect suggests the construct of satisfaction may not be equivalent across AT domains. User satisfaction has been widely studied across multiple fields and is conceptually integrated into frameworks such as Nielson's usability heuristics.[13] Considering this hierarchy of satisfaction as a component of usability, it was interesting to see satisfaction (31 ETs) represented far more than usability (11 ETs) as the primary construct evaluated, or even compared to the closely related constructs of usability, user experience, and ease of use, together (21 ETs total). This disconnect further highlights a gap between usability research and AT evaluation. Future ATETs aimed at user-centered design may benefit from directly incorporating usability frameworks.

Usage, functional performance, and AT skills were also common constructs, with the latter 2 constructs being consolidations of various AT-specific tasks and skills. The construct of usefulness itself was only evaluated in 5 ETs. Less common constructs (1-10 ETs) were also widely distributed across identified (thematic) domains. Some of these were distinct, for example, stigma in the domain "attitudes" or learnability in the domain "user experience." Other constructs were closely related, for example, discontinuance and usage or utility, practicality, and convenience. The latter examples highlight ambiguity in the extent to which ETs evaluating similar constructs may or may not be interchangeable.

Considering the diverse conceptual frameworks that inform many of the evaluated constructs, there is little guidance on the structural relationships between constructs evaluated across different ETs and how we may amalgamate such evidence. For example, how might we compare the overall AT usefulness of 2 lower-limb prostheses when the evidence describes, in one instance, functional mobility and use-related factors according to the Predisposing, Reinforcing, and Enabling Constructs in Educational Diagnosis and Evaluation (PRECEDE) framework[127] and, in another instance, functional performance and utility according to a health-related quality of life framework?[124] Such ambiguity in the interchangeability and relationships among constructs evaluated can make ET selection challenging. This challenge is compounded by the heterogeneity with which constructs are evaluated across ETs even within a single domain: some ETs measure a single construct (eg, satisfaction)[129] and others measure multiple subconstructs as part of a broader construct (eg, satisfaction, activity restriction, and psychosocial adjustment).[130] Similarly, selecting and interpreting ETs of different scopes, that is, "general AT" vs more specific domains,

face similar challenges. The former may be more appropriate for broader contexts where multiple types of AT are considered while the latter can provide more AT-specific detail. However, combining both may require clear situating of overlapping constructs, for example, quality of life.[124,190] Whereas addressing such considerations will be contingent on the conventions of a given AT domain, for example, "assistive media" vs "oral health," greater consolidation and standardization of constructs may support easier selection ETs and interpretation of their results. The taxonomy of AT outcomes by Jutai et al aims to provide clarity in these respects.[14] However, it has not seen widespread adoption.

End user input and validation

Across the 159 ETs included, the vast majority demonstrated some degree of validation testing. While we made no systematic assessment of these tests, standard measures of internal consistency and reliability were commonly used.[196] Conversely, only a little over a third of ETs involved end user input in their development. This low proportion may be partly explained by a quarter of ETs being based on existing tools. Furthermore, not all AT evaluation contexts require end user input (eg, measuring ambulation).

However, for assessment of end user perspectives on ATs (existing or during development), it may be desirable to use ATETs developed in explicit alignment with end user priorities. Of the end user input we observed, interviews and focus groups were the most popular. Other forms of input ranged from less involved general feedback to more integrated delphi[129] and mixed methods[148] studies. End user input for ET development exists on a broader spectrum of end user engagement in the process of AT development, from tokenistic participation[197] on one end to participatory research[198] and co-creation[199] on the other. The latter approaches not only support the moral imperative of democratizing research[200] but also allow for novel opportunities to address end users' unmet assistive needs and preempt potential issues leading to AT abandonment. This is echoed in the growing body of guidelines for such user-centered approaches.[201-203] For example, recent work outlines a framework for the development of ethical AT for dementia.[204] AT stakeholders should consider the strengths and limitations of these approaches to incorporating end user perspectives when considering ATETs. From our results, the landscape of ATETs has considerable room for engaging end users using more integrated approaches for ATET development.

Study limitations

Our screening strategy required abstracts to explicitly reference ATETs, meaning some ETs may have been overlooked. However, more popular ETs were likely captured in other records. Caution should be used in interpreting the representativeness of AT-specific ETs for AT evaluation generally. Some domains may tend to use non−AT-specific ETs for AT evaluation. For example, the System Usability Scale is commonly used to evaluate assistive robots.[205] Moreover, the search strategy was aimed at identifying ATETs over a large timeframe. As such, the proportional representation of ETs and their attributes should also be interpreted with caution, for example, hearing aid ETs discussed earlier. Some ETs may have fallen out of use due to newer ETs or changing AT contexts such as evolving technology. Our results do not describe the extent of use or preference of ETs in current research or clinical practice. Furthermore, our data do not distinguish between the propensity of an AT field to generate ETs from the size of the field in terms of overall research activity. Rather, our scoping review creates a transdisciplinary landscape within which guidance regarding the above considerations may be addressed in future work.

While we made efforts to precisely define and operationalize the attributes we extracted from ETs, their coding can be open to interpretation. For closely related constructs, the choice to retain separate codes or to collapse into a single code is subjective. Therefore, the construct coding of this scoping review should be interpreted as indicative of trends in AT evaluation.

As this scoping review focused on peer-reviewed literature, it did not necessarily capture ETs used by AT professionals from other sources such as books and manuals, for example, for augmentative and alternative communication.[206,207] Future work may address this gap by better integrating such tools into peer-reviewed literature.

Conclusions

By characterizing key attributes of ATETs across the landscape of various AT fields, this scoping review creates a conceptual nexus for understanding how ATs are evaluated in the literature. Results provide a consolidated database of ATETs that represents a wide range of AT categories and the multitudinous aspects by which overall AT usefulness may be constituted. These approaches delineate a rich landscape of inquiry and the many potential ways ATs can benefit people with disabilities. However, navigating the evidence for such benefits across AT categories can be a daunting task, making it difficult to compare and judge AT usefulness. Moreover, the selection of appropriate ATETs remains a challenge. These challenges must also be considered when developing ATs and setting AT policy.

We identified opportunities to address these challenges through providing guidance on and advancing approaches to AT evaluation. Given the sporadic and heterogeneous application of conceptual frameworks in ET development, the conceptual positioning of constructs evaluated can be ambiguous. Future research should provide guidance on how to better situate such disparate ETs in contemporary contexts; this would ease the selection process and interpretation of existing ETs. Such guidance may also help streamline AT selection and service delivery for both AT professionals and clients. Considering the low rate of ETs that include end user input, bridging this gap through more integrated approaches of end user engagement will help better align ATETs with end user values. Moreover, consolidating multiple conceptual frameworks in developing such ETs may lead to a more holistic perspective of AT usefulness. Future ET development in this vein may better highlight end user needs and perspectives that prevail across AT populations and categories. Likewise, ensuring linkage of AT evaluation with service delivery evaluation would further support more holistic AT interventions. Such a new generation of ATETs would help simplify the process of comparing, servicing, and developing ATs, thereby reducing AT abandonment and improving benefit derived from ATs. The results of this scoping review provide a comprehensive starting point to pursue these endeavors.

Suppliers

a. EndNote software; Clarivate Analytics.
b. Excel; Microsoft.

Keywords

Health care quality; access, and evaluation; Outcome assessment, health care; Rehabilitation; Self-help devices

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