

Original Paper

Development of a Core Set of Quality Criteria for Virtual Reality Applications Designed for Older Adults: Multistep Qualitative Study

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Abstract

Background: Virtual reality (VR) applications are gaining growing significance, particularly among older adults. These applications can provide valuable support to older adults by offering immersive VR content that positively influences various aspects of their daily lives, including activities of daily living. Furthermore, VR applications can contribute to the enhancement of cognitive and motor skills, ultimately leading to an improved quality of life for older individuals. Nevertheless, to ensure a positive impact, it is crucial to develop VR experiences that are tailored to the needs and preferences of the users.

Objective: This study aims to develop a core set of quality criteria and guidelines for the development of user-centered VR applications specifically designed for older adults (target group).

Methods: The multistep qualitative study design comprised several key stages, beginning with a systematic literature search. This was followed by a framework analysis aimed at identifying a core set of criteria. Subsequently, these criteria underwent validation through expert workshops. The outcomes achieved through this iterative process were organized and categorized into criteria, accompanied by explanations detailing the underlying categories or codes.

Results: The quality criteria core set for older adults-friendly VR applications has been developed through an iterative process. It is divided into 2 distinct parts, each containing criteria categorized into specific areas. The first part includes the following categories: (1) quality assurance of medical/health content, (2) data protection provisions, (3) quality requirements, (4) consumer protection, and (5) interoperability. The second part includes the following categories: (1) graphic/quality, (2) 3D character/avatar, (3) providing in-game instructions and prompts, (4) interaction, (5) navigation, and (6) promotion of user motivation and loyalty to use. The results imply a differentiated scope as well as a differentiated granularity of the criteria.

Conclusions: Considering the ongoing advancement of VR technology and the diverse needs within the older adult demographic, it is essential to assess the quality criteria core set results on an individual basis.

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KEYWORDS

virtual reality; older adults; quality criteria; user-centered

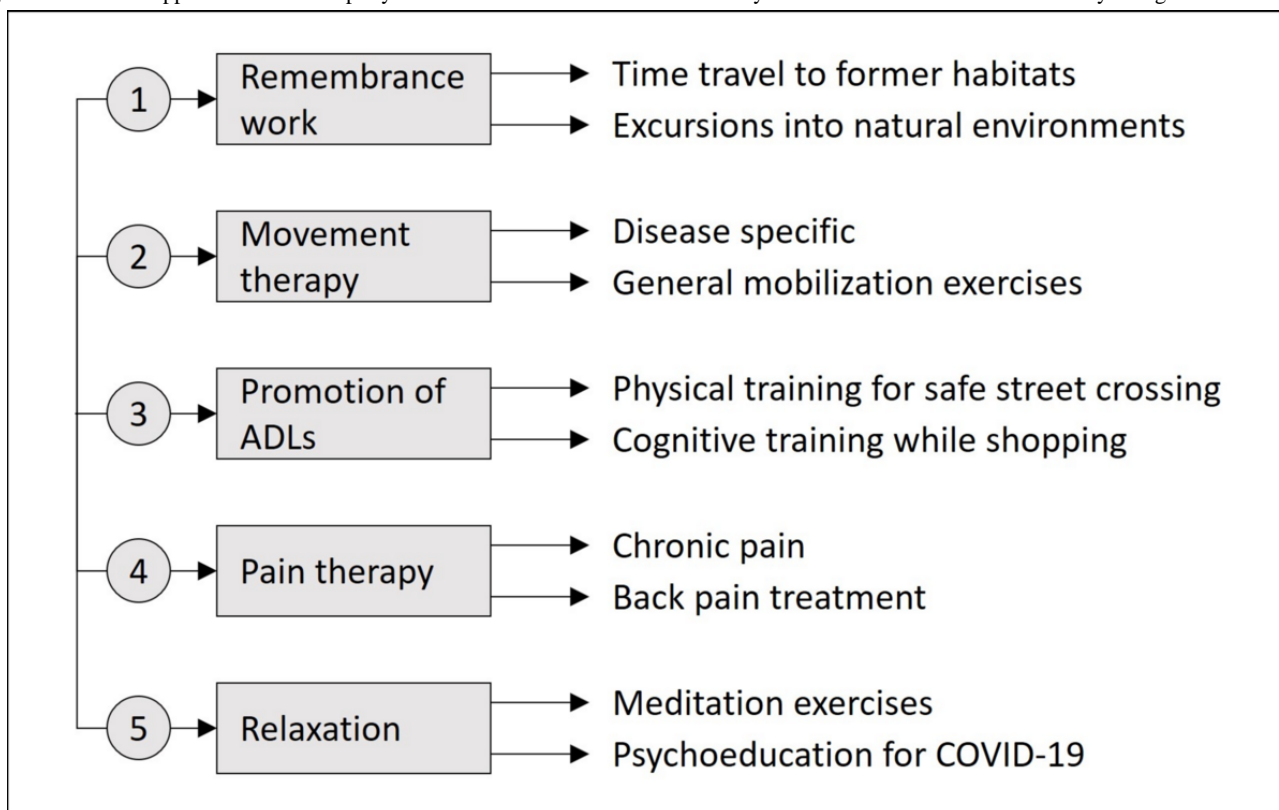
Introduction

Virtual reality (VR) goggles are a technology that has been gaining increasing popularity in recent years, and their functionality continues to expand [1]. VR goggles are a technical medium that allows immersion in VR [2]. VR stands for computer-generated environments that enable people to

experience and interact in digital worlds [3]. VR applications have found their place in various fields. While they are already a popular choice for leisure, especially among the younger generation, they are increasingly employed in health care, often in the form of “serious games,” to address specific human conditions [1,4]. VR applications offer numerous benefits, including use among older adults [2,5,6]. VR applications are

intended to specifically promote the competencies of the older adults and to help them achieve more independence in old age [7]. Figure 1 illustrates various application fields in VR for older adults, along with 2 existing exemplary scenarios.

Figure 1. Fields of application and exemplary scenarios in the context of virtual reality and seniors. ADLs: activities of daily living.



Although many interventions have been shown to improve the health status of older adults through the use of VR, there remains a need for research to determine usability and acceptance factors [8]. Furthermore, attention should be paid to target group-specific development [9]. Currently, VR applications in the health care context are typically developed through collaboration between VR developers or computer scientists on the technical side and medical staff or health scientists on the content side [10]. The challenge stems from the unfamiliarity between VR developers and medical personnel, hindering the establishment of comprehensive VR development requirements. Additionally, user-centered development is increasingly complex due to the growing heterogeneity in age-related factors among older adults [6,7,11,12].

VR development for older adults should promote healthy aging and enhance quality of life. The World Health Organization (WHO) describes healthy aging as a process of developing and maintaining the functional capacity that enables well-being in old age [13]. Under the aspect of “healthy aging,” the WHO has defined various influencing factors that can have a positive effect on the aging process. These include factors that go beyond the elimination of diseases. As a result, active health promotion throughout one’s life and targeted support measures to maintain functional capacity in old age are essential. The term health, in the context of healthy aging, is a person’s ability to perform or pursue those things that they prioritize [14]. To fulfill these goals as much as possible, the needs of older adults must be taken into account. At the same time, the feasibility of continuous development of VR must be addressed [15].

Guidelines and best practice frameworks can assist in using VR applications effectively for specific goals [16]. Guidelines developed through collaborative research with experts in VR development and older adult-focused VR applications can serve as an initial orientation guide for tailored and beneficial VR applications for older adults.

This study aimed to establish a core set of quality criteria for older adult-friendly VR applications, which could serve as guidelines for similar target-oriented VR development. It involved considering criteria relevant to older adult-oriented VR application development.

Methods

Overview

Three different approaches were combined in this study. First, a systematic literature review search (SLS) was performed on April 7, 2021, to obtain an overview of existing guidelines or development recommendations for VR applications. The results mainly considered studies on VR application development and technology development guides providing recommendations. Second, the results were clustered in a framework analysis to systematize criteria or categories. Finally, in the third step, expert workshops were conducted with VR development experts and VR application experts with reference to the target group of older adults to check or adapt the validity of the elaborated results.

Systematic Literature Search

To align with the study’s objectives, we formulated the following research question: *What universal criteria exist for development recommendations for VR applications and what are their contents?*

The following 3 main keyword groups were examined for the development of the search strategies:

1. (universal) criteria and corresponding synonyms (eg, features, characteristics, features, requirements, quality criteria);

2. development recommendations and corresponding synonyms (eg, development tips, hints, advice, suggestions, design, framework, evaluation); and
3. VR (applications) and corresponding synonyms (eg, virtual system, VR goggles, VR technology, VR head-mounted display, VR headset).

For the 3 groups of keywords, the thesaurus was also reviewed. Second, a search strategy for each database was developed. The detailed strategy for PubMed is shown in [Textbox 1](#). Specific search strategies are outlined in [Table 1](#).

Textbox 1. Search string used for the PubMed search.

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(("criteria s"[All Fields] OR "criterias"[All Fields] OR "standards"[MeSH Subheading] OR "standards"[All Fields] OR "criteria"[All Fields]) AND ("develop"[All Fields] OR "develope"[All Fields] OR "developed"[All Fields] OR "developer"[All Fields] OR "developer s"[All Fields] OR "developers"[All Fields] OR "developing"[All Fields] OR "developments"[All Fields] OR "develops"[All Fields] OR "growth and development"[MeSH Subheading] OR ("growth"[All Fields] AND "development"[All Fields]) OR "growth and development"[All Fields] OR "development"[All Fields]) AND ("recommend"[All Fields] OR "recommendable"[All Fields] OR "recommendation"[All Fields] OR "recommendation s"[All Fields] OR "recommendations"[All Fields] OR "recommended"[All Fields] OR "recommending"[All Fields] OR "recommends"[All Fields]) AND ("virtual reality"[MeSH Terms] OR ("virtual"[All Fields] AND "reality"[All Fields]) OR "virtual reality"[All Fields])) OR (("virtual"[All Fields] OR "virtuality"[All Fields] OR "virtualization"[All Fields] OR "virtualized"[All Fields] OR "virtualizing"[All Fields] OR "virtuals"[All Fields]) AND ("google"[All Fields] OR "google s"[All Fields] OR "googled"[All Fields] OR "googling"[All Fields]))
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Table 1. Database search strategies.

Database	Search strategy	Results, n
PubMed	[“criteria” OR “standard”] AND [“develop” OR “recommend”] AND [“virtual reality” AND “google”]	109
Cochrane Library	criteria OR standard (select Record Title) AND develop OR recommend (select Abstract) AND virtual reality (select Record Title)	72
Embase	criteria OR standard AND develop OR recommend AND virtual reality AND google {related terms are included}	48
CINAHL	criteria OR standard (select TI Title) AND develop OR recommend (select AB Abstract) AND virtual reality AND google (select TI Title)	59
MEDLINE	criteria OR standard AND develop OR recommend AND virtual reality AND google	98
Scopus	criteria OR standard AND develop OR recommend AND virtual reality AND google (TITLE-ABS-KEY)	81
ZB MED	Criteria (open search) AND develop (open search AND virtual reality (title)	173
ACM DL	[[Title: criteria] OR [Title: standard]] AND [[Abstract: develop] OR [Abstract: recommend]] AND [[Title: virtual reality] AND [Title: google]]	121
IEEE Computer Society Digital Library	criteria OR standard (select Document Title) AND develop OR recommend (select Abstract) AND virtual reality AND google (select Document Title)	115

Publications were included in the following scenarios (inclusion criteria): (1) involved an examination (generally valid) of criteria for development recommendations for VR applications; (2) were focused on VR; (3) were written in English or German or both; (4) full-text articles were freely available; (5) involved studies were relevant to the subject (ie, focusing on older adults), and (6) had been published after 2012.

According to Hülsbömer [17], VR has seen a surge in popularity since 2012, leading to a greater emphasis on its development and ongoing discussions and optimizations of development processes. Given the rapid technological advancements and increased demands in the digital age, it is crucial to include relevant literature to ensure the relevance and validity of the core set of quality criteria [18].

In addition, publication types with the following designs were included: articles in scientific journals, books, book chapters, study reports, guidelines, assessment instruments/assessments, legislative regulations, and reports. As the goal was to provide a comprehensive initial overview of recommendations from the VR development literature, there were no restrictions on the type of study designs reviewed.

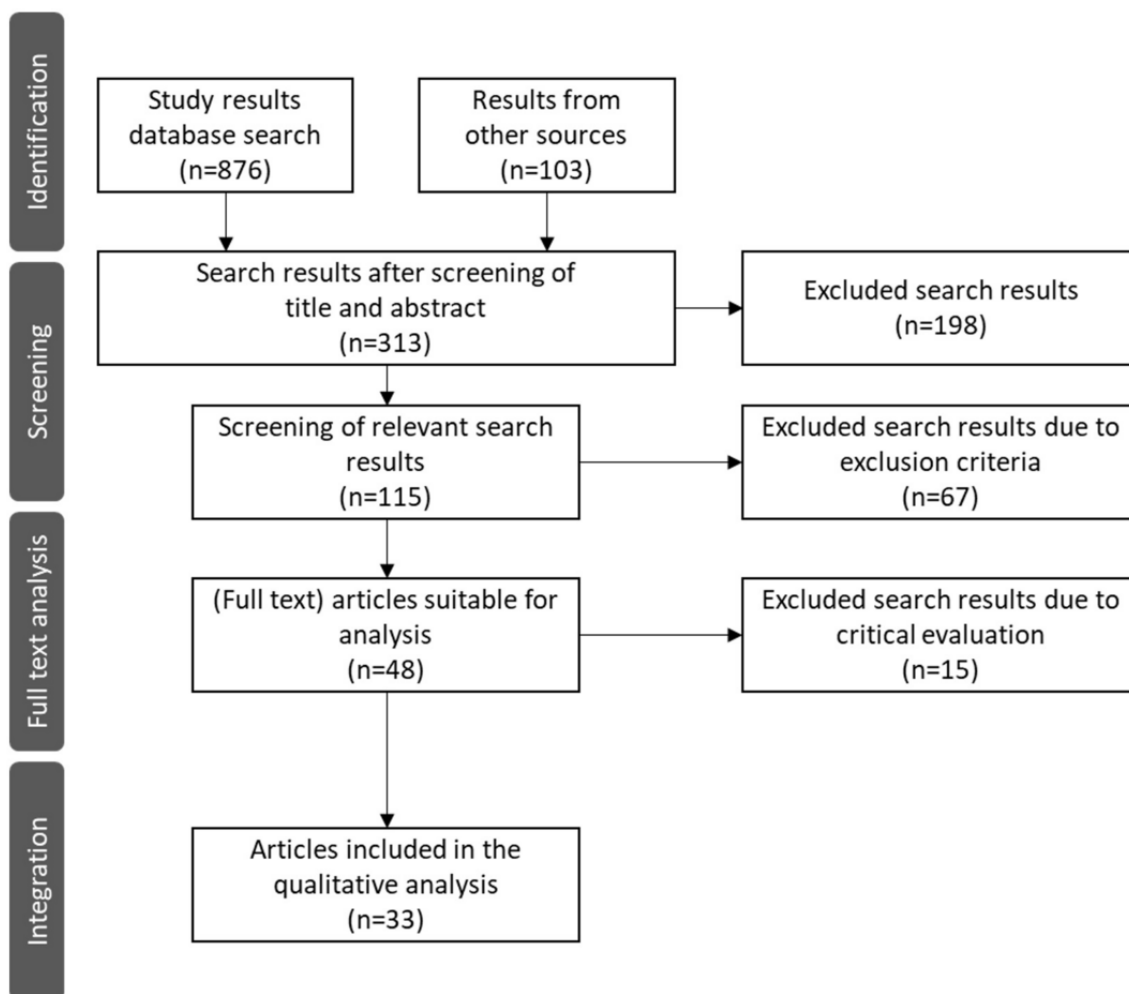
Exclusion criteria were as follows: (1) literature results not available in German or English; (2) results written before 2012; (3) study designs in the form of laboratory studies, case reports, and series; and (4) inappropriate publication types, such as book reviews, introductions, forewords, commentaries, position statements, and letters.

For searches in the databases (PubMed, Cochrane Library, Embase, CINAHL, MEDLINE, Scopus, ZB MED, IEEE Computer Society Digital Library, and ACM Digital Library), combinations of all 3 keywords were used, as exemplified in [Textbox 1](#) for the search string used on PubMed. The systematic literature search, including the analysis process, was conducted between February 2021 and April 2021. Some of the publications found in the databases meeting the inclusion and exclusion criteria were partially identified as duplicates. All relevant studies identified by the database searches were downloaded and stored in the literature management software EndNote (Clarivate Plc), which automatically eliminated duplicates. Based on the search strategy, 876 results were identified from the database search and 103 results from other sources. The selection process is illustrated using a PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart ([Figure 2](#)). The procedure is comparable to that of Moher et al [19]. After screening the titles/abstracts, 313 publications remained, of which 198 studies were excluded, which mainly dealt with informatics-based guideline development and app development (eg, health apps or digital health apps for smartphones). Among the excluded articles, the full text was not freely available in 67. Thereafter, the remaining 115 publications were screened. Prefaces or

introductory texts, statements, and general position papers were excluded at this point. Two independent reviewers assessed each title or abstract without influencing each other's decisions. The reviewers first assessed the title/abstracts for eligibility, and in the next stage assessed the full text. To perform the screening process, category formation (inclusion or exclusion) was used with EndNote. A third reviewer determined final eligibility when a discrepancy existed between the initial reviewers. Thus, 48 articles were identified for the full-text analysis. In addition, 15 results were excluded because they were thematically unsuitable, focused on only 1 topic (eg, data privacy), and were therefore not comprehensive enough. In total, 33 studies were included based on the inclusion and exclusion criteria.

The literature search yielded enough freely available literature to establish the initial structure of the core quality criteria. The identified results provided valuable initial insights for the research project. Additionally, the workshop results play a crucial role in the participatory approach, potentially informing content specifics for future older adults. Hence, we deemed the approach suitable and ruled out potential bias. [Multimedia Appendix 1](#) displays all publications included in this study for constructing the initial quality criteria core set [20-51].

Figure 2. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart of literature research procedure.



Framework Analysis

The content of the literature findings was analyzed using framework analysis, which involved iterative refinement of data-driven themes [52]. We chose framework analysis for its suitability in analyzing group-level qualitative data in research projects with specific goals, such as co-design. Framework analysis consists of 6 interrelated steps, which were conducted in this study as described in [Textbox 2](#). The analysis was conducted by 2 researchers in Microsoft Excel (Microsoft Corporation). Based on the initial notes, a set of preliminary

codes was developed for different aspects based on recurring themes from the literature. When disagreements arose regarding the codes, the 2 researchers discussed their conflicting interpretations and attempted to reach a consensus, possibly leading to the generation of new codes. The saturation of the data was determined by the 2 researchers. They jointly decided when saturation was reached for the formation of the first construct, which formed the basis for the expert workshops. The generation of additional themes and codes or categories and criteria took place in the 2 workshops.

Textbox 2. Framework analysis methodology, modified from Ritchie and Lewis [52].

1. Familiarization

This step involves a comprehensive familiarization with the data. For the development of the quality criteria core set, the individual results of the systematic literature review search (SLS) were reviewed to familiarize with the content. The initial content was developed by forming initial codes and themes. After all literature results had gone through this process, the data set was again fully analyzed.

2. Identify recurring and important themes

The theoretical framework was developed by reviewing the selected results of the SLS and synthesizing the content deemed relevant to answer the research question. Data summaries were prepared to present the data in a concise format. In addition, an initial tabulation was created with preliminary codes that were grouped in the next steps.

3. Indexing

In the indexing phase, the codes were grouped and classified into framework categories. The generated codes and themes were applied to the data summaries.

4. Charting

The multilayered data were systematized and structured according to the theoretical framework. Codes were assigned to categories based on their content match. Initially, some content was extracted from the literature, in terms of both content assignment and its execution. The summaries of the data were reorganized under the generated themes of the theoretical framework and rewritten in a more abstract manner to reflect the themes.

5. Analyzing

The generated data tables were analyzed and discussed by the 2 researchers for content and detail. The analysis included checking for content fit as well as comparability of granularity. Codes with comparable content were merged. In addition, whether contradictions existed between the codes were analyzed. Topic summaries were created to present the findings at a high level in the context of the research question.

6. Interpretation

Interpretation included discussion of content and interpretation of individual categories or codes. It can be assumed that the interpretation leaves room for the development of further criteria that were not generated in the previous steps. Content was also evaluated for complexity and completeness. Descriptions and interpretations of the themes are presented later. Explanations and insights into the themes are considered in the "Discussion" section.

Expert Workshops

The previously elaborated results of the 2 researchers were validated by conducting workshops and involving experts. Two workshops with different experts assessed the results for content fit, completeness, and level of granularity.

The first workshop, held in June 2021 due to COVID-19 pandemic restrictions, took place online and lasted for 2 hours. By involving 12 VR development experts, the previous results were revised using an interactive online collaboration platform. The experts were either self-employed or had over 10 years of experience in VR development research. The external professional reflection helped to refine and specify previous results. For the workshop, we used the MIRO platform [53] to map the previously developed results on digital boards.

The results of the framework analysis presented on the digital board were displayed on sliding digital sticky notes. The experts

modified the existing structure by adding elaborations to existing criteria and generating new criteria or content using digital sticky notes. The content was generated by answering the guiding questions. The experts could freely modify the existing content of the template. In a joint discussion round, each content point was taken up, explained, and justified by the experts. In addition, the discussion aspects were recorded and an associated protocol of the respective workshops was used for the revision. The subsequent research steps involved editing the structure of the previous quality criteria core set by incorporating the results of the workshop. This was performed by assigning individual workshop contents, which were added to the categories or explanations of the criteria. New criteria were also generated. Accordingly, the content and structure of the previous version of the core set of quality criteria were adapted.

The second workshop included 12 VR application experts who had experience in the context of VR and older adults. The experts' experience with VR and the target group of older adults

was based, for example, on project experience or use in clinical settings (eg, hospitals or nursing homes). The consultation of VR application experts in this step aimed to bridge the gap between the prior findings and empirical observations gathered while working with older adults as part of the research process. The 2-hour online workshop took place in November 2021 and followed a procedure similar to that of the first workshop. The online collaboration platform was used again, and the results developed until this point were presented on the boards of the platform. The given categories or criteria were the same as those of the first workshop. The goal was to further refine and specify the results. The guiding questions were also identical to those of the first workshop to ensure the comparability of methods. The experts engaged in an interactive process to further refine the previous version of the quality criteria core set, followed by subsequent discussions to ensure its specificity and accuracy.

After the 2 workshops, the 2 researchers systematized the results by considering the protocol results of both workshops. The systematization of the results involved assessing the execution of content to ensure comparability in terms of the criteria's level of detail and granularity. Changes were also made to the wording while preserving the original content's meaning, ensuring a consistent structure. The outcome of this process serves as the foundation for VR application development and is referred to as the provisionally valid quality criteria core set.

Ethical Considerations

The study was approved by the Ethics Committee of the German Sport University Cologne (Institute of Pedagogy and Philosophy; protocol number 095/22). As this is an observational study, no additional exemptions and approvals were necessary. Informed consent was given by all workshop participants. No secondary data analysis was performed. Participation in the workshop was voluntary. No personal data or data allowing conclusions to be drawn about the person were collected. All data were collected in an anonymized form. An ethics application was drafted and approved as part of adjacent activities of this research project. The submission of another, separate ethics application for the conduct of the workshops was waived. The Declaration of Helsinki also does not outline such a procedure for conducting a workshop in this particular format. Participants did not receive any compensation for taking part in the workshops.

Results

Systematic Literature Search

Following the completion of the SLS steps, which included identification, screening, full-text analysis, and integration, a total of 33 results were incorporated into the initial version of the quality criteria core set. The SLS uncovered the absence of

a standardized set of quality criteria for VR applications, including those designed for older adults. To formulate the core set of quality criteria in this study, guidance from digital health applications (DiGA) in Germany was incorporated. These guidelines, such as AppQ and APPKRI, were selected because they have undergone multiple evaluations and are extensively described and assessed in terms of their content. Furthermore, it is worth noting that certain VR applications also qualify as DiGA, and as such, they were taken into account. The results of various studies provided valuable insights that were deemed essential for shaping the quality criteria core set. Additionally, specific legal provisions, such as those outlined in the Digital Health Care Act [54], were selectively integrated to ensure adherence to regulatory guidelines.

Framework Analysis

The outcome of the framework analysis yielded an initial draft of the quality criteria core set, which encompassed a range of overarching categories and diverse criteria that addressed various content aspects relevant to older adult-friendly VR applications. Because of the differences in content, the development of the quality criteria core set was divided into 2 parts with the following 2 main topics: (1) "General Criteria for VR Application Design," which included the general conditions/criteria of VR applications and (2) "Content Design of VR Applications," which included criteria that are specifically attributed to the thematic content.

The results, that is, the framework analysis codes, framework analysis categories, and derived categories of the topic "General Criteria for VR Application Design," are summarized in Table 2, and those for the topic "Content Design of VR Applications" are listed in Table 3. The framework analysis codes for the general criteria within the first category were *dependability*, *validity*, *objectivity*, *reliability*, *effectivity*, *knowledge*, *utility*, *treatment*, *improvement of (health) status*, *health*, *quality of life*, *health apps*, *psyche*, and *medical device*. As a result of this analysis, the derived framework analysis categories were *quality factors* and *medicine*. These findings led to the creation of the following categories within the first part: (1) medical quality, (2) data protection, (3) information security, (4) technical quality, (5) consumer protection and fairness, (6) interoperability, and (7) usability and motivation. The categories comprising the second part were as follows: (1) graphic/quality, (2) 3D character/avatar, (3) in-game instructions and prompts, (4) interaction, and (5) navigation.

The results of the framework analysis formed the basis for the subsequent workshops, in which the developed contents were discussed with the experts. All derived categories (ie, framework analysis categories) and framework analysis codes were disclosed in the expert workshops.

Table 2. Results of the framework analysis for the first category within the first part of the quality criteria core set focused on the “General Criteria for VR^a Application Design.”

Framework analysis codes (generated from literature)	Framework analysis category	Derived category
<ul style="list-style-type: none"> • Dependability • Validity • Objectivity • Reliability • Effectivity • Knowledge • Utility 	<ul style="list-style-type: none"> • Quality factors 	<ul style="list-style-type: none"> • Medical quality
<ul style="list-style-type: none"> • Treatment • Improvement of (health) status • Health • Quality of life • Health apps • Psyche • Medical device 	<ul style="list-style-type: none"> • Medicine 	

^aVR: virtual reality.

Table 3. Results of the framework analysis for the first category within the second part of the quality criteria core set focused on the “Content Design of VR^a Applications.”

Framework analysis codes (generated from literature)	Framework analysis category	Derived category
<ul style="list-style-type: none"> • Software • Degree of accuracy • Structure • Fineness/detail • Concept • Design 	<ul style="list-style-type: none"> • Graphical representation 	<ul style="list-style-type: none"> • Graphic/quality
<ul style="list-style-type: none"> • VRISE (virtual reality–induced symptoms and effects) • VR-Technology • Texture • Value • Claim 	<ul style="list-style-type: none"> • Qualitative aspects 	

^aVR: virtual reality.

Expert Workshops

Two expert workshops were conducted, drawing upon the data obtained from the systematic literature search and the framework analysis. In this process, a total of 7 categories were mapped to the first part, which encompassed “general quality criteria.” These categories were accompanied by example criteria derived from the literature. The second part involved “specific criteria” and was structured around 5 categories, each supported by example criteria sourced from the literature. The experts actively engaged in the process by collaboratively editing or adding content. The subsequent discussion was guided by the following key questions:

1. Are the categories (1-7, part 1 or 1-5, part 2) complete?
2. Which categories are missing/not appropriate for VR?
3. Are the criteria in each category comprehensive enough? Are criteria missing/can criteria be replaced?

The results of the first workshop with VR development experts are described in the following section.

The categories presented in [Tables 2](#) and [3](#) were deemed appropriate by the experts, and there were no alterations or criticisms regarding their suitability. However, it is important to highlight that the extent and depth of input from participants varied across the 7 different categories. Notably, the categories “data protection” and “interoperability” received the fewest additional criteria. Conversely, the categories “technical quality” and “user-friendliness and motivation” saw the most substantial contributions. Nevertheless, it was necessary to scrutinize the results to identify and rectify any potential duplication, particularly in instances where the same criteria were described using different terms.

The results of the second workshop with VR application experts revealed the following: The given categories were not criticized or adapted by the application experts, and their suitability was found to be good. The input to the respective categories varied in terms of quantity and quality (ie, level of detail, execution, and description). The fewest criteria were added in the categories “information security” and “interoperability” (n=7 and n=4, respectively), whereas the highest number was added in the categories “technical quality” and “motivation” (n=19 and n=17,

respectively). The results were checked for possible duplications. During the discussion, all categories and criteria were evaluated with the workshop participants. In this process, certain criteria were either retained or excluded for further development of the quality criteria core set. Most of these decisions on the respective contents were made unanimously among the participants. In instances where there were differing opinions, the decision-making process considered the majority agreement as the determining factor.

Following the discussion in the respective expert workshops, the results were revised or adjusted. This included the formation

of subcategories as well as further criteria as a result of the reorganization of the content, which was based on the results of the workshops. The criteria were also further developed in terms of their content and categories were restructured. All changes made were based on the comments and opinions of the experts in both workshops. The current version of the quality criteria core set is briefly presented below. The first category of both parts is presented in detail in the respective subcategories (cf. Figures 3-6), whereas the remaining contents are presented in the form of categories and criteria (cf. Tables 4 and 5).

Figure 3. Excerpt of the first part of the quality criteria core set to the subcategory 1.1 Evidence.

Part 1 of the quality criteria core set: Framework conditions for the development of VR applications suitable for senior citizens.

1. Category: quality assurance of medical/health content

This category includes criteria that ensure the quality of content in a medical or health context. This includes criteria that ensure the quality of care for seniors with VR applications.

1.1 Evidence

1.1.1 Content is evidence-based
The content must be backed up by studies that are thematically identical or at least comparable. A thorough evaluation of the studies with regard to criteria such as timeliness, study design, sample, study period, methodology, as well as results and discussion must be carried out. The literature search should conform to established standards. A comparison to current study results on the topic should be considered. The assessment of the comparability of studies (results) and the transfer to the project being undertaken should be reliable. In addition, technical literature should also be included.
1.1.2 Consideration of generally accepted professional and current standards
The implementation of (medical/health) content and procedures should be based on the Lege-Artis rule. Thereby a consideration of the current gold standard takes place. Subject matter experts should be involved in VR development.
1.1.3 Quality assurance of content and procedures
The recommendations for action from guidelines on content or procedures are followed.
1.1.4 Publication of sources used for the content or its implementation
Indication/publication of a list of sources that makes the sources used easily identifiable in terms of their readability and takes into account common citation methods/standards.

The content is derived from the codes or preliminary categories derived during the framework analysis. Based on thematic focus, subcategories were formed to differentiate the categories as well as to detail the criteria. Figure 3 shows a section of subcategory

1.1 Evidence, which was assigned to the first category *Quality assurance of medical/health content* of the first part. The second subcategory of this part is *1.2 Application safety (before/during use)*, which is shown in Figure 4 with corresponding contents.

Figure 4. Excerpt of the first part of the quality criteria core set to the subcategory 1.2 Application safety (before/ during use).

<p>1.2 Application safety (before/ during use)</p>
<p>1.2.1 Health status assessment</p> <p>Before using the VR application, the health status of the person using it should be checked. Physical and mental (pre-)illnesses or limitations that could have an influence on VR use should be clarified as part of their medical history. Furthermore, factors such as medication (or its side effects) should be taken into account. In addition, contraindications to VR use should be ruled out. The use of possible aids (glasses, walking stick, hearing aid, rollator, etc.) during VR use must be considered or checked for suitability.</p> <p>Consideration should be given to having medical personnel (with appropriate qualifications, if necessary) present as caregivers during use.</p>
<p>1.2.2 Assessment of physical/mental fitness</p> <p>Physical factors, such as mobility status or mobility, should be checked by means of appropriate assessments. Assessments should also be carried out to evaluate the mental state.</p>
<p>1.2.3 Cyber/motion sickness assessment</p> <p>The user should be informed about VR in general and about the VR application to be used. A pre-test should be used to assess the cyber-/motion sickness of the user. Special assessments can be used for a further evaluation of cyber/motion sickness.</p>
<p>1.2.4 Assessment of fall/injury risk during VR application use</p> <p>The (fall) safety of the user should be ensured as far as possible. The risk of the user falling or being injured during VR use should be checked in advance. In addition to targeted information, the medical history taken, and the performance of physical and psychological assessments, a pre-test would provide initial indications under safety measures to avoid the risk of falling/injury. Moreover, depending on the application and forms of interaction, targeted assessments can be performed to evaluate the risk of falls. Furthermore, an ethics application should be considered. In addition, the insurance relationship should be clarified.</p>
<p>1.2.5 Appropriate use of technology</p> <p>For the appropriate handling of VR technology and other technologies required for its use, training should be provided by a qualified person on the use of the application for the persons involved. This would involve learning how to operate VR in terms of hardware and software, and how to handle hygiene. If the senior citizens are taught how to use the system, care should be taken to ensure that the instructions are appropriate for the target group.</p>
<p>1.2.6 Securing the hardware</p> <p>The input device should be certified.</p>
<p>1.2.7 Securing the content</p> <p>The software should be certified. The best possible guarantee for protection against misuse/malware should be fulfilled, e.g. by using security tools. Attention should be paid to fast data transfer using common procedures.</p>

Figures 5 and 6 refer to the first category graphic/quality of the second part and depict corresponding criteria in the subcategories 1.1 Object-related/environment-related and 1.2

User-related, respectively, which were thematically subordinated to the subcategories.

The complete set of quality criteria with all versions can be requested from the authors.

Figure 5. Excerpt of the second part of the quality criteria core set to the subcategory 1.1 Object related/ environment-related.

<p>Part 2 of the Quality Criteria Core Set: Specific Criteria for the Development of VR Applications for Seniors</p>
<p>1. Category: Graphic/ Quality</p> <p>This category includes criteria that map requirements related to the graphical and qualitative development of VR applications. The criteria are aimed, among other things, to keep the psychological burden on the person using the application as low as possible.</p>
<p>1.1 Object-related/ environment-related</p>
<p>1.1.1 Spatial allocation</p> <p>The spatial assignment should be clear. A strong contrast between the foreground and background should be chosen. This contributes to the immersion. Depending on the need, blurring can be supportive to the step of distinguishing between reality and virtual reality.</p>
<p>1.1.2 Color space</p> <p>If possible, warm colors should be selected in the sense of color psychology in order to achieve a more comfortable feeling among the senior citizens. The color depth and the color spectrum (e.g. 256 colors) should be chosen carefully. Color vision disorders should also be taken into account when selecting colors, or alternative representations should be offered.</p>
<p>1.1.3 Objects</p> <p>The objects should have a small number of polygons. The style should be uniform, so that there is a certain consistency in the object design in terms of level of detail and texture resolution. In addition, the object scaling should be consistent with reality, especially interactive elements should be measured virtually. To reduce unwanted effects in graphics, software solutions should be used to increase quality (e.g. methods such as anti-aliasing, texture baking). The visual level of detail should be high and at the same time clear.</p>
<p>1.1.4 Scenario</p> <p>Scenes should be designed to be ecologically valid as possible. The virtual environment should not be too dark or too futuristic or similar, so that it has a frightening effect on the person using it.</p>
<p>1.1.5 Content design</p> <p>The content should be stereoscopic to achieve high immersion. With the use of 3D, greater immersion is achieved compared to 2D. As a result, the sense of presence is stronger. The latency should be as low as possible. The frame rate should be at least 60 fps. The resolution should be as high as possible, at least 1832x1920px is recommended. Good image sharpness should be considered accordingly. The design should be as naturalistic as possible, i.e. light and shadow should be used. In addition, the realism should be increased by having a temporal illusion through a change in the environment. Computationally intensive processes should be avoided. Time periods in which the person using the application has to wait (e.g., when the application is loading) should be kept to a minimum.</p>

Figure 6. Excerpt of the second part of the quality criteria core set to the subcategory 1.2 User-related.

<p>1.2 User-related</p>
<p>1.2.1 Information gift</p> <p>The information provided in VR should be short and understandable. The use of long texts in the VR application should be avoided. Only essential content should be reproduced in short text form and in a way that is easy to read.</p> <p>The size as well as the contrast of the font should be individually adjustable. The content layout should be centered. Scrollbars should be avoided.</p> <p>An easy-to-read or large font should be chosen. The text should be left-aligned.</p> <p>Visual metaphors should be incorporated whenever possible.</p> <p>The context of use should be clearly defined.</p>
<p>1.2.2 Interaction elements</p> <p>Due to the partial sensory-motor blurring of senior citizens, the interaction elements should be large. In addition, standardized symbols should be used.</p> <p>The objects in VR should be appropriate for the target group.</p> <p>The interaction mode should be adapted to the respective generation and thus include more mechanical interaction.</p> <p>For a good body perception of the user, visual and proprioceptive information should be combined in an optimized way.</p> <p>A cursor or similar should be provided so that the selected target is clearly indicated (e.g. bright border when an object is selected).</p>
<p>1.2.3 Language</p> <p>The language should be kept simple and as presupposition-free as possible. Foreign-language terms should be avoided. Terms suitable for senior citizens should be used.</p> <p>Pictograms could be used instead of language or as a support.</p> <p>Language should be natural and accessible to the person using it. Phrases should be positive rather than negative. The form of address should be active and not passive.</p> <p>The language conversion should be done using text or dialog elements.</p>
<p>1.2.4 User interface</p> <p>The structure of the menu should be clear and include intuitive mapping. The punctuation as well as the execution of commands should be similar. The layout, navigation and terminology used should be simple, clear and consistent. Attention-grabbing elements that are not (no longer) needed should be removed.</p> <p>Complexity should be avoided as much as possible by removing things that are rarely used or not necessary.</p> <p>The elements of the user interface should be easily modifiable by the person using it (e.g. zoom in).</p> <p>The user guidance should be clear, so that choices as well as any selections made are apparent to the person using the system.</p>
<p>1.2.5 Audio</p> <p>The audio setting should be individual so that it can be selected as desired. Distractions caused by unwanted sounds should be avoided.</p> <p>The audio design should be immersive and take complex soundscapes into account (e.g. 7.1 surround sound). The audio should be senior-friendly (e.g. emphasis, speed, but also phrasing). The quality of the audio should be good and understandable through the use of clear language.</p>

Table 4. Presentation of categories, subcategories, and criteria of the first part of the quality criteria core set.

Category and subcategory	Criteria
2. Data protection provisions	
2.1 Data generation and data storage	<ul style="list-style-type: none"> • 2.1.1 Earmarking • 2.1.2 Necessity and data economy • 2.1.3 Consent • 2.1.4 Data security • 2.1.5 Ensuring the authenticity of the data • 2.1.6 Information security
2.2 Legitimacies	<ul style="list-style-type: none"> • 2.2.1 Data protection law • 2.2.2 Data participant rights • 2.2.3 Accesses and access rights
3. Quality requirements	
3.1 Technical safety	<ul style="list-style-type: none"> • 3.1.1 Robustness against disturbances • 3.1.2 Hygiene
3.2 User-related security	<ul style="list-style-type: none"> • 3.2.1 Avoiding the risk of collision • 3.2.2 Suitable spectacle ergonomics • 3.2.3 Change of operability • 3.2.4 Traceability application situation
4. Consumer protection	
4.1 Accessibility	<ul style="list-style-type: none"> • 4.1.1 User support • 4.1.2 Conditions of use
4.2 Transparency	<ul style="list-style-type: none"> • 4.2.1 Data/software update • 4.2.2 Transparent business models
5. Interoperability	
5.1 Data portability	<ul style="list-style-type: none"> • 5.1.1 Data extraction
5.2 Technology compatibility	<ul style="list-style-type: none"> • 5.2.1 Connection of external technologies • 5.2.2 Cross-generational use of technology

Table 5. Presentation of categories, subcategories, and criteria of the second part of the quality criteria core set.

Category and subcategory	Criteria
2. 3D character/avatar	
2.1 Appearance	<ul style="list-style-type: none"> 2.1.1 Character 2.1.2 Appearance/optics/optical representation
2.2 Behaviorism	<ul style="list-style-type: none"> 2.2.1 Behavior (facial expressions/gestures) 2.2.2 Tone and pitch of voice
3. Providing in-game instructions and prompts	
3.1 Didactics	<ul style="list-style-type: none"> 3.1.1 Initial learning 3.1.2 Instructions 3.1.3 Goal and task design 3.1.4 Feedback 3.1.5 Information transmission
3.2 General conditions	<ul style="list-style-type: none"> 3.2.1 Useful life 3.2.2 Local framework conditions
4. Interaction	
4.1 Functionalities	<ul style="list-style-type: none"> 4.1.1 Operation 4.1.2 Design/functionality 4.1.3 Relevance assessment
4.2 Regulation	<ul style="list-style-type: none"> 4.2.1 Evaluation/developments 4.2.2 Perception/proprioception
5. Navigation	
5.1 Operation	<ul style="list-style-type: none"> 5.1.1 Menu control 5.1.2 Control systems 5.1.3 Room design
5.2 Taxis	<ul style="list-style-type: none"> 5.2.1 Locomotion 5.2.2 Tracking
6. Promotion of user motivation and loyalty to use	
6.1 Usability	<ul style="list-style-type: none"> 6.1.1 Motivation 6.1.2 Logging 6.1.3 Configuration
6.2 Target group orientation	<ul style="list-style-type: none"> 6.2.1 Adaptability/customizability for different needs and interests 6.2.2 Practicability 6.2.3 User-friendliness

Discussion

Overview

The study's objective was to establish a foundational set of quality criteria to provide guidance for the development of VR applications catering to older adults. The findings encompassed a diverse range of quality criteria derived from various qualitative research methods. This study represents the pioneering effort to create a core set of criteria specifically tailored to the development of VR applications for older adults. It introduced a novel qualitative methodological approach that involved a systematic review search, followed by framework analysis and validation through expert workshops, to formulate these criteria.

Principal Findings

The results of the preliminary quality criteria core set provide an initial basis for older adult-friendly VR development. The individual criteria and categories are derived from the results of the SLS, the framework analysis, and the 2 expert workshops. It should be noted that the SLS research results included some of the German literature that was considered in the development process. This is attributed to the fact that the results of the quality criteria core set are primarily applicable to Germany and, as such, consider the specific regulations of the German health care system and legislation. Nevertheless, it is not precluded that these results can be extrapolated to other countries. In such instances, it is advisable to carefully examine the corresponding regulations that may diverge at the national or international level.

The validity of the criteria hinges on the research findings and the latitude for interpretation inherent in the reflective processes of the researchers involved. The expert workshops were thus crucial for the validation of the results. The results represent the criteria developed in the iterative process, which are detailed using explanation examples. Considering the thorough survey conducted across various databases and the consensus among experts during the 2 workshops, it is reasonable to consider the resulting quality criteria core set as a typical representation of a preliminary version. However, the correctness or durability of the results is uncertain. Given the rapid development of technology, particularly in the VR market, it must be assumed that the criteria within the provisional core set of quality criteria are only valid to a limited extent. Nevertheless, this version forms a first building block and serves as a guideline for basic VR development for the target group of older adults.

The categorization of criteria into their respective subcategories (as seen in [Figures 3-6](#)) is guided by thematic considerations. However, it is important to acknowledge that thematic overlaps may occur, and the precise classification of criteria into specific subcategories may need to be reevaluated based on the context of the application. For the initial draft of the quality criteria core set, which serves as the foundation, the current structuring within the subcategories and sorting is deemed appropriate.

The distribution of criteria among the respective (sub)categories is somewhat uneven, with varying numbers of criteria in each category. This suggests that certain topic areas receive more extensive coverage than others. An illustrative example of this is the category of data protection, which encompasses a broader range of content within the quality criteria core set compared with other categories. One plausible explanation for this discrepancy is that certain topic areas are subject to stringent standards and requirements, resulting in a greater abundance of detailed explanations compared with other categories.

For a general understanding, these criteria are explained in detail. However, the degree of granularity must be considered: The understanding and interpretation of the explanations vary depending on the individual's level of knowledge, experience, and assessment. Therefore, explanations provided for the individual criteria leave some room for interpretation. The fulfillment of the criteria depends on the respective framework conditions and the hardware. VR head-mounted displays and other VR hardware have different functionalities. Therefore, the requirements developed in the quality criteria form may not be fulfilled or only be insufficiently fulfilled in some cases. The functionalities of the VR hardware also determine the definition and fulfillment of the quality criteria.

The results should reflect older adult-friendly criteria. However, the heterogeneity of the target group must be considered. In old age, numerous physiological and psychological changes occur within individuals. Accordingly, the requirements for VR applications or VR systems may vary within the target group of older adults [55]. Defining older adults by age could assist in refining the criteria, while also considering the stereotypical characteristics associated with each age group. Older adults may use VR in different contexts [56]. To specify the criteria for VR applications suitable for older adults, a classification of

application areas could also be helpful. Moreover, the purpose of the VR application is significant, as are considerations about the motivations behind VR application development. The purpose of VR needs to be thoroughly justified. Additionally, older adults' level of technology familiarity and willingness to use VR technology influence these considerations [57,58]. The development of VR applications for older adults requires an analysis of the necessary functionalities relevant to the development project in the initial conceptual phase. The preliminary valid core set of quality criteria serves as a guideline to specify and define further aspects after initial considerations for application development. The validity of the individual criteria must be determined individually and possibly modified depending on the application purpose. In principle, these criteria can serve as valuable guidelines to facilitate more focused design development, beginning from the conceptual stage. By considering these criteria throughout subsequent phases, informed decisions can be made regarding their relevance and integration into the design process.

The significance of quality criteria is continually increasing, and it has become an important topic for discussion. Manser and de Bruin [59] have also called for quality criteria that are thematically related to exergames and described a different approach; however, their study also focused on the target group of older adults [59]. The authors refer to the framework proposed by Li et al [60], which represents a comparable methodological approach to this work but does not clearly map defined quality criteria.

It should be noted that for the development of a targeted VR application for older adults, a participatory approach is important. In addition to people from the creative industry (eg, VR developers, game designers, computer scientists) and people from the relevant application area, the target group should be included. The existing version of the core set of quality criteria for older adult-friendly VR applications will undergo further refinement through the inclusion of older adults in future research projects. The VR development work should thus occur through collaborative and transparent exchanges with both current users and prospective users. Feedback should also be evaluated and taken into account with regard to technical feasibility. In pretest phases and based on prototypes, new insights can be gained that can be used to further specify the core set of quality criteria.

Limitations

Individual categories or criteria, such as "data protection," must be dealt with more comprehensively to ensure the validity of the content. This example category often shows significant changes, as the topic is currently undergoing constant revision and also needs to be adapted to country-specific requirements.

The theoretical construct in the form of the preliminary valid core set of quality criteria will be tested in the next step involving practical implementation. The criteria developed so far will be incorporated into the development work so that practical testing can determine whether the individual criteria can be met. In an upcoming workshop with older adults on the current version of the quality criteria core set, the criteria will be discussed and put into their final form. When discussion and

refinement of the content is complete, the version is referred to as the “evaluated and standardized quality criteria core set.” Thereafter, the updated results will be presented in a follow-up publication, in which the target group of older adults will be directly included and verification of the theoretically constructed quality criteria will be performed using a VR application in practice.

Conclusions

User-centered development is useful if a product or measure is to reach the target audience. The quality criteria core set should

act as a kind of guideline for the implementation of the targeted development work. Attention should be paid to a possible specification of the user groups and the context of use. In addition, the heterogeneity of the target group of older adults should be considered. The quality criteria core set serves as an initial step toward user-centered VR application development, but additional research is needed to build upon the existing results and further enhance the core set.

Data Availability

The data sets are provided in the main manuscript by the authors.

Conflicts of Interest

None declared.

Multimedia Appendix 1

Included publications according to systematic literature review search (SLS). See also [20-51].

[\[DOCX File , 24 KB-Multimedia Appendix 1\]](#)

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Abbreviations

DiGA: digital health applications

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

SLS: systematic literature review search

VR: virtual reality

WHO: World Health Organization

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