A Scoping Review of the Inquiry Instruments Being Used to Evaluate the Usability of Ambient Assisted Living Solutions

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Abstract: This paper reports a scoping review of the literature to identify the inquiry instruments being used to evaluate the usability of AAL solutions, which resulted in the inclusion of 35 studies. The results show that a significant number of the included studies reported the use of non-valid inquiry instruments, such as ad-hoc questionnaires. Among the studies using valid and reliable inquiry instruments, System Usability Scale (SUS) emerged as the most used one. In general, valid and reliable inquiry instruments are being used together with additional data gathering methods, to perform comprehensive usability evaluations. Moreover, in terms of the quality of the design of the included studies, it should be pointed the adequacy of the participants' characteristics and the tasks they performed. In turn, these studies did not present evidence of the preparation and independence of the evaluators.

1 INTRODUCTION

Ambient Assisted Living (AAL) is one of the resources available to support the increasing older adults' population, not only to optimize healthcare services but also to mitigate the individuals' disabilities. It refers to intelligent technologies, products and services embedded in the physical environment to support the care of older adults and to promote their autonomy, independence, safety, social participation, and well-being (Queirós et al., 2015).

A distinctive characteristic of AAL is the interaction with all kinds of elements through user interfaces that comprise multimodal interactions, including modalities such as, for instance voice, haptic, gesture or body movement interaction. User satisfaction and performance are key aspects of these interfaces based on novel concepts and control schemes together with context awareness. High complexity in terms of implementation of user interaction mechanisms must be translated in simple and usable interfaces.

Therefore, usability evaluation is essential to surpass design problems and to guarantee that ALL solutions might be accepted and used by their target users (i.e., older adults).

Over real systems or prototypes, the best alternatives are either evaluations conducted by experts, which are also known as inspection (da Costa et al., 2019; Dix et al., 2004), or evaluations involving users that might use testing and inquiry methods (Bernsen & Dybkjær, 2010). These methods can be combined to perform comprehensive usability evaluations (Martins, Queirós, et al., 2015).

Usability testing (e.g., observation or performance evaluation) usually involves observing users and measuring their performance while they perform predefined tasks. The respective methods focus on the users and their tasks, and seek empirical evidence, mostly quantitative, about how to improve the user interaction (Martin & Hanington, 2012).

In turn, inquiry methods (e.g., interviews, focus groups, or questionnaires) involve collecting the perceptions of the users. Although the data collected are subjective, inquiry methods provide valuable information on what the users want and help to identify usability strengths and weaknesses (Martins, Queirós, et al., 2015).

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Established instruments such as the System Usability Scale (SUS) (Brooke, 1996; Martins et al., 2015), Post-Study System Usability Questionnaire (PSSUQ) (Lewis, 1992) or International Classification of Functioning, Disability and Health Usability Scale (ICF-US) (Martins, Rosa, et al., 2015), are inquiry instrument being used for the evaluation of usability of a wide range of products and user interfaces.

This scoping review aimed to identify the inquiry instruments being used to evaluate the usability of AAL solutions. The study intends to contribute to the quality of user-centred usability evaluation of AAL solutions by reviewing the main research recently published and determining and discussing the methods and inquiry instruments being used.

The rest of the paper is organized as follows: the next section presents the research questions and methods of the present scoping review; the results are presented in Section 3; Section 4 provides the discussion of the results and a conclusion.

2 RESEARCH QUESTIONS AND METHODS

Considering the aforementioned objective, the scoping literature review was informed by the following research questions:

- RQ1. What are the inquiry instruments being used to evaluate the usability of ALL solutions?
- RQ2. Are the reported inquiry instruments valid and reliable?
- RQ3. What is the quality of the experimental design of the studies using valid and reliable inquiry instruments?

The authors defined a protocol to perform this scoping literature with explicit descriptions of the methods to be used and the steps to be taken, which is described in this section.

The resources chosen for the review were three electronic databases (i.e., Scopus, Web of Science, and IEEE Xplorer). Boolean queries were prepared to include all the articles that have their titles, abstract or keywords conformed with the conjunction (i.e., AND Boolean operator) of the following Boolean expressions:

- 'AAL' OR 'Ambient assisted living' OR 'ambient assisted technology' OR 'ambient assistive technology' OR 'ambient intelligence'.
- 'UX' OR 'user experience' OR 'usability'.
- 'Evaluation' OR 'assessment'.

The electronic literature search was performed in January 2021 and included all the references published before December 31, 2020.

The inclusion and exclusion criteria were the following:

- References were included if they reported usability evaluation of AAL solutions based on inquiry methods.
- References were excluded if they: i) did not have abstracts; ii) were not written in English; iii) reported on reviews, surveys, or market studies; iv) were books, reported workshops, or were special issues announcements; and v) reported on studies that are not relevant for the objective of this scoping review.

The analysis and selection of the references were performed in three steps:

- First step - the authors removed the duplicates, the references without abstract and that were not written in English.
- Second step - the authors assessed all titles and abstracts for relevance and those clearly not meeting the inclusion and exclusion criteria were removed.
- Third step - the authors then assessed the full text of the remaining references against the outlined inclusion and exclusion criteria and the final list of the studies to be included for the review was created.

Throughout this entire process, all the references were analysed by three authors and any disagreement between the authors was discussed and resolved by consensus.

The analysis of the included studies considered the following dimensions: i) demographic characteristics; ii) purposes; iii) interaction modalities; iv) usability evaluation methods; v) usability inquiry instruments; and vi) quality of the experimental design.

Based on the demographic data, a synthesis of studies' characteristics was prepared, which included: i) the number of studies published in conference proceedings and in scientific journals; and ii) the distribution of the studies by year.

Additionally, tabular presentations were prepared with the purposes of the AAL solutions being reported and the respective interaction modalities (i.e., visual interaction together with voice, auditory, gesture or other interaction modalities, such as immersive virtual reality or robots).

Moreover, the included studies were analysed and classified according to the type of the inquiry instruments being used.

Finally, concerning the subset of studies that used valid and reliable inquiry instruments, an analysis of the quality of their experimental design was performed, considering the following aspects (Silva et al., 2019): i) additional data gathering to allow the triangulation of the usability evaluation results; ii) adequacy of the number and characteristics of the individuals participating in the usability studies; and iii) usability evaluators.

3 RESULTS

3.1 Study Selection

A total of 5635 studies were retrieved from the search of the selected databases.

The first step of the selection process yielded 2996 studies since 2639 studies were removed because they were duplicated, did not have abstracts, or were not written in English.

During the second step, 2919 studies were removed, because they reported on reviews, surveys, or market studies and workshops, were special issues announcements, or were not relevant for the objective of this scoping review.

Finally, after the full text analysis (i.e., the third step) 42 studies were removed since they did not meet the inclusion and exclusion criteria.

Therefore, 35 studies were included in this scoping review (Table 1).

3.2 Demographic Characteristics

Looking to the types of publications, six articles (Bleser et al., 2013; Cavallo, Aquilano, et al., 2014; Chartomatsidis & Goumopoulos, 2019; Dias et al., 2015; Werner et al., 2012; Zhunio et al., 2020) were published in conference proceedings and the remainder 29 articles were published in scientific journals.

In turn, almost 75% of the studies were published in the last five years and 40% of the articles were published in the last two years.

3.3 Purposes of the Studies and Interaction Modalities

As can be seen in Table 2, 11 different purposes emerged from the analysis of the included articles: i) daily living activities; ii) falls prevention; iii) home monitoring; iv) remote care; v) telerehabilitation; vi) medication management; vii) physical activity; viii) cognitive activity; ix) physical and cognitive activity; x) social inclusion; and xi) participation in leisure activities.

All the studies reported the use of traditional interfaces based in visual interaction. Moreover, as represented in Table 3, 85% of the studies (i.e., 29 studies) reported additional interaction modalities, namely voice, auditory, gesture and immersive virtual reality interactions, or interaction with robots.

3.4 Inquiry Instruments

Table 4 presents the different types of inquiry instruments reported by the included studies. In 12 studies, the usability evaluation was based on ad-hoc questionnaires prepared by the researchers. In general, the data gathered with these ad-hoc questionnaires were complemented with other evaluation techniques, namely interviews (Bleser et al., 2013; Palestra et al., 2019), think aloud (Werner et al., 2012), observation (Blasco et al., 2014), and performance evaluation (Brauner & Ziefle, 2020; Orso et al., 2017). Moreover, four studies considered questionnaires based on acceptance models (i.e., Technology Acceptance Model - TAM and Unified Theory of Acceptance and Use of Technology - UTAUT), which in some cases were complemented by interviews and performance evaluation (Goumopoulos et al., 2017), or observation (Morán et al., 2015).

Moreover, 18 studies (i.e., almost 60% of the included studies) used valid and reliable inquiry instruments: i) SUS (14 studies); ii) SUS and PSSUQ (one study); iii) SUS and Computer System Usability Questionnaire (CSUQ) (one study); and iv) ICF-US (two studies).

3.5 Quality Assessment

Except four studies (Cortellessa et al., 2018; Konstantinidis et al., 2016; Macis et al., 2019; Wohlfahrt-Laymann et al., 2019), the remainder studies using valid and reliable inquiry instruments complement the results of these instruments with additional data gathering methods, such as interviews, observation, performance evaluation, think aloud, and additional questionnaires, to consolidate the usability evaluation by applying triangulation techniques (Table 5).

Table 6 presents the results of the analysis of the adequacy of the evaluator's preparation and the characteristics of the participants and the tasks they performed. Only three studies referred the characteristics of the evaluators, namely if they were

adequately trained or if they were external to the development of the AAL solution. Moreover, in 11 studies, the number and characteristics of the participants were adequate. Finally, in all included studies, the tasks that the participants needed to perform were coherent with the functions of the AAL solution being developed.

Table 1: Included studies.

References
(Adcock et al., 2020; Adcock et al., 2019; Blasco et al., 2014; Bleser et al., 2013; Brauner & Ziefle, 2020; Cavallo, Aquilano, et al., 2014; Cavallo et al., 2018; Cavallo, Limosani, et al., 2014; Chartomatsidis & Goumopoulos, 2019; Cortellessa et al., 2018; Costa et al., 2017; Costa et al., 2015; Delmastro et al., 2019; Di Nuovo et al., 2018; Dias et al., 2015; Fiorini et al., 2017; Goumopoulos et al., 2017; Gullà et al., 2019; Konstantinidis et al., 2016; Macis et al., 2019; Money et al., 2019; Morán et al., 2015; Orso et al., 2017; Palestra et al., 2019; Pedroli et al., 2018; Pripfl et al., 2016; Rebsamen et al., 2019; Sánchez-Morillo et al., 2015; Teixeira et al., 2017; Vaziri et al., 2016; Werner et al., 2012; Wohlfahrt-Laymann et al., 2019; Yilmaz, 2019; Zhunio et al., 2020; Zlatintsi et al., 2020)

Table 2: Purposes of the included studies.

Purposes	References
Daily living activities	(Blasco et al., 2014; Cavallo, Aquilano, et al., 2014; Cavallo et al., 2018; Cavallo, Limosani, et al., 2014; Di Nuovo et al., 2018; Dias et al., 2015; Gullà et al., 2019; Werner et al., 2012; Yilmaz, 2019; Zlatintsi et al., 2020)
Falls prevention	(Money et al., 2019; Pripfl et al., 2016; Vaziri et al., 2016)
Home monitoring	(Costa et al., 2015; Delmastro et al., 2019; Macis et al., 2019; Sánchez-Morillo et al., 2015; Wohlfahrt-Laymann et al., 2019)
Remote care	(Cortellessa et al., 2018; Costa et al., 2017; Fiorini et al., 2017)
Telerehabilitation	(Morán et al., 2015; Palestra et al., 2019; Pedroli et al., 2018)
Medication management	(Teixeira et al., 2017)
Physical activity	(Bleser et al., 2013; Brauner & Ziefle, 2020; Chartomatsidis & Goumopoulos, 2019; Konstantinidis et al., 2016; Rebsamen et al., 2019)
Cognitive activity	(Zhunio et al., 2020)
Physical and cognitive activity	(Adcock et al., 2020; Adcock et al., 2019)
Social inclusion	(Goumopoulos et al., 2017)
Participation in leisure activities	(Orso et al., 2017)

Table 3: Interaction modalities.

Interaction	References
Auditory and voice interaction	(Blasco et al., 2014; Bleser et al., 2013; Costa et al., 2017; Dias et al., 2015; Goumopoulos et al., 2017; Macis et al., 2019; Orso et al., 2017; Sánchez-Morillo et al., 2015; Teixeira et al., 2017; Wohlfahrt-Laymann et al., 2019)
Gesture recognition	(Adcock et al., 2020; Adcock et al., 2019; Brauner & Ziefle, 2020; Chartomatsidis & Goumopoulos, 2019; Morán et al., 2015; Palestra et al., 2019; Rebsamen et al., 2019; Vaziri et al., 2016)
Immersive virtual reality	(Gullà et al., 2019; Pedroli et al., 2018)
Robotics interaction	(Cavallo, Aquilano, et al., 2014; Cavallo et al., 2018; Cavallo, Limosani, et al., 2014; Cortellessa et al., 2018; Di Nuovo et al., 2018; Fiorini et al., 2017; Pripfl et al., 2016; Werner et al., 2012; Zlatintsi et al., 2020)

Table 4: Inquiry instruments.

Instruments	References
Ad-hoc questionnaires	(Blasco et al., 2014; Bleser et al., 2013; Brauner & Ziefle, 2020; Cavallo, Aquilano, et al., 2014; Cavallo, Limosani, et al., 2014; Costa et al., 2017; Costa et al., 2015; Fiorini et al., 2017; Orso et al., 2017; Palestra et al., 2019; Werner et al., 2012; Yilmaz, 2019)
Questionnaires based on acceptance models	
TAM	(Goumopoulos et al., 2017; Morán et al., 2015; Zhunio et al., 2020)
UTAUT	(Cavallo et al., 2018)
Usability scales and questionnaires	
ICF-US	(Dias et al., 2015; Teixeira et al., 2017)
SUS	(Adcock et al., 2020; Adcock et al., 2019; Chartomatsidis & Goumopoulos, 2019; Delmastro et al., 2019; Di Nuovo et al., 2018; Gullà et al., 2019; Konstantinidis et al., 2016; Money et al., 2019; Pedroli et al., 2018; Rebsamen et al., 2019; Sánchez-Morillo et al., 2015; Vaziri et al., 2016; Wohlfahrt-Laymann et al., 2019; Zlatintsi et al., 2020)
SUS and PSSUQ	(Macis et al., 2019)
SUS and CSUQ	(Cortellessa et al., 2018)

Table 5: Additional data gathering in the studies using valid and reliable usability evaluation instruments.

Additional data gathering methods	References
Interviews	(Pedroli et al., 2018)
Interviews and observation	(Vaziri et al., 2016)
Interviews and performance evaluation	(Chartomatsidis & Goumopoulos, 2019)
Interviews, performance evaluation and think aloud	(Money et al., 2019; Sánchez-Morillo et al., 2015)
Interviews and Mobile App Rating Scale (MARS)	(Gullà et al., 2019)
Observation	(Zlatintsi et al., 2020)
Observation and think aloud	(Teixeira et al., 2017)
Observation and think aloud and Game Experience Questionnaire (GEQ)	(Adcock et al., 2020)
Performance evaluation	(Delmastro et al., 2019; Dias et al., 2015)
Performance and observation	(Adcock et al., 2019)
Think aloud and TAM	(Rebsamen et al., 2019)
UTAUT	(Di Nuovo et al., 2018)

Table 6: Adequacy of the evaluator's preparation, participants characteristics and tasks.

Evaluator's preparation, participants characteristics and tasks performed	References
Evaluators' preparation	(Adcock et al., 2019; Sánchez-Morillo et al., 2015)
Participants' characteristics	(Adcock et al., 2019; Di Nuovo et al., 2018; Gullà et al., 2019; Macis et al., 2019; Money et al., 2019; Pedroli et al., 2018; Rebsamen et al., 2019; Sánchez-Morillo et al., 2015; Vaziri et al., 2016; Wohlfahrt-Laymann et al., 2019; Zlatintsi et al., 2020)
Tasks	(Adcock et al., 2020; Adcock et al., 2019; Chartomatsidis & Goumopoulos, 2019; Delmastro et al., 2019; Di Nuovo et al., 2018; Gullà et al., 2019; Konstantinidis et al., 2016; Macis et al., 2019; Money et al., 2019; Pedroli et al., 2018; Rebsamen et al., 2019; Sánchez-Morillo et al., 2015; Vaziri et al., 2016; Wohlfahrt-Laymann et al., 2019; Zlatintsi et al., 2020)

4 DISCUSSION AND CONCLUSION

Considering the selected databases, the search queries, and the inclusion and exclusion criteria, this scoping review identified 35 studies. In terms of the purposes of the included studies, they are in line with the current concerns related to the adoption of technological solutions to support the increasing older adults' population, both in terms of care provision and promotion of active ageing paradigms (Jaschinski & Ben Allouch, 2019): i) healthcare provision (i.e., home monitoring, remote care, telerehabilitation and medication management); ii) secure and supportive environment (i.e., daily living activities and falls prevention); iii) healthy lifestyles (i.e., physical activity and cognitive activity); and iv) social involvement and active participation (i.e., social inclusion and participation in leisure activities).

The importance of usability evaluation increased over the years and seems that the researchers are looking beyond the technological perspective and are interesting to gather the users' opinions about new AAL solutions. This is slightly different from the results of (Queirós et al., 2015), which evidenced focus on the development of technological solutions rather than the development of services that could satisfy the real needs of older adults.

The results also evidenced the involvement of users in all the developmental phases, which is an essential requirement when developing AAL solutions (Queirós et al., 2017).

In terms of the first research question (i.e., what are the inquiry instruments being used to evaluate the usability of ALL solutions?), the results point to the use of a diversity of instruments: i) ad-hoc questionnaires - 12 studies; ii) questionnaires based on acceptance models - four studies; iii) studies using usability evaluation scales or questionnaires - 18 studies.

Concerning the validity of the reported inquiry instruments (i.e., the second research question), ad-hoc questionnaires might provide useful information to assess design options, but they are not valid nor reliable instruments to measure usability. This means that their results are not reproducible neither comparable. Moreover, acceptance models, such as TAM or UTAUT, might be used to have a comprehensive perspective of intentions of use, but they are not adequate to discriminate usability features.

In turn, established inquiry instruments were designed to provide reliable and repeatable results, as well as a depth understating of the usability features being evaluated. Instruments such as SUS, PSSUQ, ICF-US or CSUQ are valid and reliable inquiry instruments to measure usability and to allow comparability between different studies. These instruments were applied in 18 of the includes studies. Furthermore, SUS was the most relevant instrument since it was used in 16 studies.

Considering the third research question (i.e., what is the quality of the experimental design of the studies using valid and reliable inquiry instruments?), it should be noted that there is a concern in using triangulation techniques, as it is recommended by the literature (Silva et al., 2019). Fourteen of the 18 studies that report the use of valid and reliable inquiry instruments also reported the use of additional data gathering methods, such as interviews, observation, performance evaluation or think aloud.

Moreover, in most studies the tasks performed by the participants were representative of the functions of the solutions being evaluated, as well as the number and characteristics of the participants of the experimental set-up were adequate.

In terms of negatives aspects, it should be pointed that the included studies did not present evidence to show that the usability evaluators were adequately trained nor that they were external to the development process. This aspect should be improved in future studies.

The limitations of this scoping review are related to the dependency on its keywords and the databases selected. Despite these limitations, the authors believe that the systematically collected evidence contributes to the understanding of the current trends of the development of AAL solutions. Therefore, it is possible to conclude that future research related to usability evaluation of AAL solutions should consider using valid and reliable inquiry instruments such as SUS, instead of ad-hoc questionnaires. Moreover, special attention should be considered to the preparation and independence of the evaluators and the possibility of conducting field trials for long periods in the real context or close to the real context where the AAL solutions are going to be used.

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