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Special Communication

Developing the FARSEEING Taxonomy of Technologies: Classification and description of technology use (including ICT) in falls prevention studies

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ABSTRACT

Background: Recent Cochrane reviews on falls and fall prevention have shown that it is possible to prevent falls in older adults living in the community and in care facilities. Technologies aimed at fall detection, assessment, prediction and prevention are emerging, yet there has been no consistency in describing or reporting on interventions using technologies. With the growth of eHealth and data driven interventions, a common language and classification is required.
Objective: The FARSEEING Taxonomy of Technologies was developed as a tool for those in the field of biomedical informatics to classify and characterise components of studies and interventions.
Methods: The Taxonomy Development Group (TDG) comprised experts from across Europe. Through face-to-face meetings and contributions via email, five domains were developed, modified and agreed: Approach; Base; Components of outcome measures; Descriptors of technologies; and Evaluation. Each domain included sub-domains and categories with accompanying definitions. The classification system was tested against published papers and further amendments undertaken, including development of an online tool. Six papers were classified by the TDG with levels of consensus recorded.
Results: Testing the taxonomy with papers highlighted difficulties in definitions across international healthcare systems, together with differences of TDG members' backgrounds. Definitions were clarified and amended accordingly, but some difficulties remained. The taxonomy and manual were large documents leading to a lengthy classification process. The development of the online application enabled a much simpler classification process, as categories and definitions appeared only when relevant. Overall consensus for the classified papers was 70.66%. Consensus scores increased as modifications were made to the taxonomy.
Conclusion: The FARSEEING Taxonomy of Technologies presents a common language, which should now be adopted in the field of biomedical informatics. In developing the taxonomy as an online tool, it has become possible to continue to develop and modify the classification system to incorporate new technologies and interventions.

1. Introduction

Healthy independent living is a key aim for ageing populations. Improving or maintaining levels of physical activity, function and independence, as well as the prevention of falls and fall related injuries, are two key factors to promote this aim. Falls are a leading cause of injury, immobility and premature residential and nursing

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home admission, and an important public health issue. Falls occur in 30–60% of older adults each year and rates rise steadily with age [1,2]. High incidence is seen among those in long-term care institutions [3]. Some 10–20% of these result in serious injury, hospitalisation or death [4]. In about 1% of the patients who fall, a femur fracture occurs [5] which is the most common serious injury related to falls and is associated with substantial mortality, morbidity, and economic costs [6].

Falls in older adults have multiple causes. Intrinsic risk factors include a history of falls, advanced age, impaired mobility and gait, medical diseases, medication, sedentary behaviour, fear of falling, visual impairments, foot problems, nutritional deficiencies and impaired cognition. Extrinsic risk factors include environmental hazards (like poor lighting, slippery floors and uneven surfaces), footwear and clothing, and inappropriate walking aids or assistive devices [7]. Meta-regression analysis of the predisposing risk factors has shown that gait difficulties, muscular weakness and an impaired standing balance are the most prevalent risk factors for fall [8].

Cochrane reviews on falls and fall prevention have shown that it is possible to prevent falls significantly in older people both living in the community [9] as well as in care facilities and hospitals [3]. However, a comprehensive approach mixing strategies according to the 'integrated care concept' [10], targeting those at high risk of falling and population-based policies has been identified as both lacking and essential to tackle this population-wide problem [11,12].

Over recent years a number of technologies, including Information and Communication Technologies (ICTs), have emerged aimed at fall detection (including personal alarms for use in case of fall), fall assessment, fall prediction and fall prevention. The fields of falls prevention and biomedical informatics have become closely aligned. The use of body worn inertial sensors has been found to be a promising approach to fall risk assessment [13], in particular when combined with further fall risk factors (e.g. visual impairment, peripheral neuropathy) [14] or the walking environment where physical activities are performed. There is a range of ICT based approaches with wearable or ambient devices that have been applied to automatic fall monitoring and alarm systems [15,16], as well as being used to assess fall characteristics (e.g. velocity and force characteristics) and to build predictive models of fall risk [17–19]. ICTs are also used in exercise interventions (e.g. exercise games or "exergames"), such as those that provide strength and balance training to older adults. Such exergames are seen as a promising potential way to provide a fun and motivating interactive training environment for older adults in the future, helping to increase their adherence while training both cognitive and motor skills [20–22]. Furthermore, wearable motion sensor data are used for valid information about physical performance [23], a better understanding of falls [17] and real-world physical activities [24] in the context of activity promotion and fall-prevention [25]. Interconnected (mobile) devices such as smartphones and tablets may make these applications easily accessible for end-users: including people at risk, carers and researchers.

All these examples underline the relevance and potential of technologies in this field. Terms such as eHealth, digital health, mobile health and mHealth are becoming common parlance. As technology use in the health field increases, data from devices will play an important role in fall prevention strategies; our strategies will be data driven. However, the fast growing literature in this emerging research area lacks appropriate documentation with consistent descriptions to enable the identification of goals, research designs, settings, and influential components including the used technologies or ICTs. The Cochrane review on smart home technologies [26] recommends a need for "International consistency in describing and reporting on technology-enabled interventions ... this could enhance the design, delivery, implementation and dissemination of research projects and ... quality and accessibility of the evidence base". Previous classification approaches have not included ICTs [27], or were very specific in terms of focussing on single technologies [28].

The "FAll Repository for the design of Smart and sElf-adaptive Environments prolonging INdependent livinG (FARSEEING)" project (www.farseeingresearch.eu) was an EC FP7 funded research project on health promotion, fall prevention and technical development. One element of this project was the development of a taxonomy as a classification system to characterise the major influential components of studies with ICTs in the field of fall prevention, which would be useful for researchers, clinicians and technologists. In common with the previous work on a taxonomy for fall-prevention interventions [27] we wished to encourage investigators to report all studies on the development, the use, and the uptake of technologies in the field of fall-prevention and mobility promotion in a standardised and comprehensive manner, and to produce a taxonomy that could be used to classify existing and future interventions across international boundaries.

Here, we report the process of development, involving repeated testing and refinement, from the initial stages of design through to the final version of the taxonomy (online FARSEEING Taxonomy V1.0). In the methods section, we present the development of the taxonomy in two stages. In the results section, we report the outcomes from testing the final version of the taxonomy through the evaluation of five selected studies on use of technology for falls prevention.

2. Methods

2.1. Stage 1: Developing the initial taxonomy

A Taxonomy Development Group (TDG) was established, made up of 11 representatives from eight different institutions across seven European countries. The Group members were from different disciplines, including Human Movement Science, Psychology, Nursing, Bioengineering, Health Services Research, Clinical Physiology, Geriatric Rehabilitation, Physiotherapy, Public Health, Electronic and Computer Engineering, bringing different perspectives and knowledge on the issue of technology use in falls prevention. This group also included representatives from different European projects and programmes dedicated to falls prevention such as the European Innovation Partnership on Active and Healthy Ageing. Three Group members (CT, KP and RP) had been involved in the development of the ProFaNE taxonomy for fall-prevention interventions [27]. Given that there was a degree of overlap both in scope and in personnel, we adopted the ProFaNE taxonomy as a starting point in terms of both framework and methodology. As it was our intention to develop a scheme of classification, a set of terms and definitions to be used in a practical context, we developed a taxonomy. There was a need to provide a common language and define terms to overcome the practical issue of lack of uniformity in descriptions of interventions and their components; to provide practical assistance, in as simple a way as possible, to those describing interventions. Much like the process reported by Lamb et al. [27], our process was iterative, beginning with a development stage followed by subsequent stages of testing and refinement.

Two meetings were held in Manchester, in November 2012 and January 2013, where the domains, sub-domains and categories of the taxonomy were developed. All TDG members attended both meetings. Five separate domains were agreed: Approach (Domain A); Base (Domain B); Components (Domain C); Descriptors (Domain D) and Evaluation (Domain E). Within these domains, sub-domains and categories were created. An example of the hierarchical classification, taken from the 'Descriptors' and 'Evaluation' domains is presented in Table 1.

Table 1
Examples from two of the domains with sub-domains and categories.

Domain	Sub-domain 1	Sub-domain 2	Categories
D: Descriptors	D1: Technology location		D1.1: Body worn or body fixed D1.2: Located in the environment D1.3: Portable
	D2: Technology type		D2.1: SY (System) D2.2: DE (Device) D2.3: SE (Sensor) D2.4: AC (Actuator)
E: Evaluation	E6: Participant perceptions	E6.1 Device	E6.1.1 Physical Dimension E6.1.2 Usability E6.1.3 Privacy E6.1.4 Function E6.1.5 Human interaction E6.1.6 Self-concept E6.1.7 Routine E6.1.8 Sustainability
		E6.2 Service Satisfaction	E6.2.1 Service Satisfaction

The taxonomy was initially developed as a spreadsheet and accompanying handbook, which contained definitions for all the above domains, with sub-domains and categories. The definitions were drawn from a number of sources. Where possible, we used existing definitions from the ProFaNE group's work [29,27]. Definitions of study designs were based upon the Centre for Reviews and Dissemination [CRD] guidance, an internationally recognised source of good practice [30]. We utilised Medical Subject Headings [MeSH] from the US National Library of Medicine for the definitions of chronic diseases, symptoms and impairments. Definitions of health providers were taken from the International Classification of Health Accounts (ICHA). For definitions of descriptors of technologies we consulted the International Organization for Standardization (ISO) and, in a small number of cases, the Oxford English Dictionary (OED). Where definitions were not drawn from these sources, we used the expertise from within the TDG (including two experts in the field of technology development, AB and SM) to reach consensus on definitions that would be useful in practice. Definitions of user service satisfaction were drawn from the service dimensions of the Quebec User Evaluation of Satisfaction with Assistive Technology [31]. Stakeholder technology perceptions were drawn from a conceptual framework for defining obtrusiveness in home telehealth technologies [32]. The TDG worked through each domain, discussing and seeking consensus on each sub-domain and category. Following each of these meetings, the first, then second drafts of the taxonomy were created, and discussed by the group by email, before being reviewed and refined in a final development meeting. The process of developing the taxonomy is presented in Fig. 1.

2.2. Stage 2: Refining and agreeing the taxonomy and manual

A third and final development meeting was held in Manchester in July 2013. Prior to this meeting the second draft of the taxonomy was circulated for review and comment. Nine members of the TDG were in attendance (AB, AH, BV, CT, EB, HHH, KP, NG, SM). Members who were unable to attend (AC, RP) were given the opportunity to comment by email. At this meeting, a number of important amendments were made to the structure of the taxonomy. Clarification was sought on some sub-domains and categories, which resulted in the separation of Domain B into B1 (Site of recruitment) and B2 (Main site of delivery); the clarification of 'primary aim' as the primary or dominant aim of the study and not of the technology being used; and the need to be clear about the assessments being classified in Domain C.

During the meeting, the individual TDG members read and worked through the taxonomy with a paper included in the FARSEEING systematic review of older adults' perceptions of technologies [33]. This paper, reporting on the use of an iPad App to encourage physical activity [34], was provided in order to test the taxonomy. Once each member had worked through the taxonomy, classifications were shared and discussed. This process led to further refinements of the categories and definitions through consensus decision making.

Following this final face-to-face meeting, contact between all of the TDG members continued via email, with researchers from the University of Manchester managing further testing of the taxonomy with five more papers included in the FARSEEING systematic review [35–39]. In addition, members of the Manchester team met to discuss and develop the taxonomy both together and with subsets of the TDG on a number of occasions during the development period. Through this process, feedback from TDG members regarding difficulties in applying the taxonomy led to further refinements and simplifications. The structure of the taxonomy, and the definitions in the handbook, changed and developed as a result of this further testing. This version of the taxonomy (FARSEEING Taxonomy V1.0) was produced and distributed among FARSEEING partners in October 2013, and was accepted as a deliverable by the European Commission in May 2015.

2.3. Stage 3: Developing the online app

During the process of developing of the taxonomy (stages one and two), it became clear that the number of different subdomains and categories provided could present an obstacle for wide adoption of the taxonomy. For example, a study could include multiple systems, together with a number of devices and sensors. Therefore, a (possibly huge) matrix would be required to allow the recording of all technological aspects. Users might perceive such a matrix as complicated and cumbersome, thus limiting the adoption of the taxonomy.

To overcome this issue, it was decided to develop an online application, consisting of an electronic version of the taxonomy manual and an online, web-based tool that would help them in properly classifying their own studies with respect to the taxonomy. The tool, available at the URL http://taxonomy.farseeingresearch.eu/ has been developed around the well-known metaphor of the 'buying a flight ticket' process: users are guided through a number of steps, each step consisting of a simple form to be filled in with information about the study. The steps correspond to the five domains identified in the taxonomy. Users provide

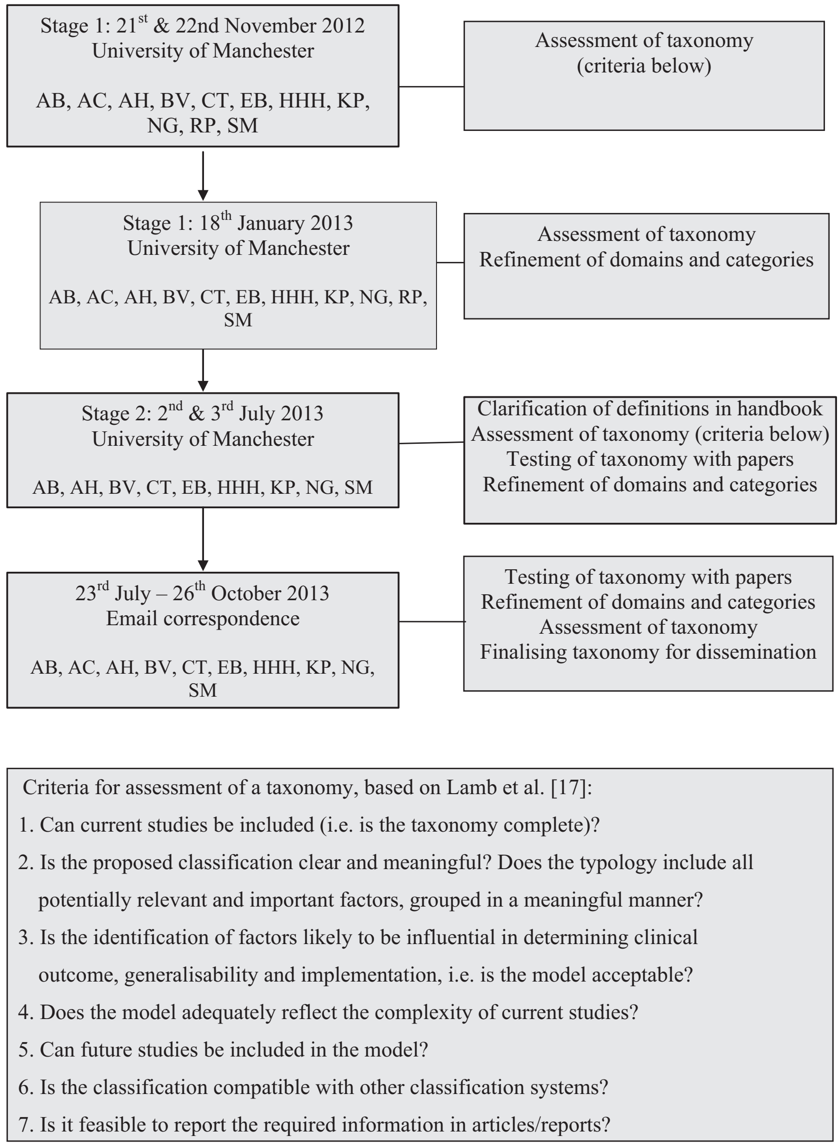

Fig. 1. Taxonomy development process.

information with respect to these domains by ticking one or more domain-related options. For each possible option, users can view the option's definition by clicking on specific information icons. In this way, users do not need to access the printed version of the taxonomy handbook. Moreover, users are guaranteed to access the latest version of the taxonomy if it is updated, since it can be regularly updated in the online tool. At the end of the process, users are presented with a summary of the selected features characterising their study, with the possibility of saving such information for including it in the study or for further reference.

Following the usability principle for human–machine interfaces of not overwhelming users with unnecessary information, each step requires the user to provide a minimal set of information, and detailed options are presented only when meaningful. For example, when initially accessing a specific domain, only the related subdomains are presented to the users. When a user selects a specific sub-domain, then the category terms related to that specific sub-domain are shown. The same holds for categories and subcategories: the latter are shown only when the user selects a category. In this way, users are free to provide the desired level of information about their studies (see Fig. 2). By providing detailed information they can better classify a study, but they are not obliged to dig into the taxonomy, if they are not seeking a detailed classification.

The online, web-based application has been built using industrial standards for distributed web applications, and in particular by exploiting the technical framework Spring (https://spring.io/). All the relevant data are stored in a robust database accessible by researchers. Future extensions will allow users to query for studies that have been tagged with respect to the taxonomy. The online application allows authorised users to upload new versions of the taxonomy, allowing for future extensions, updates, and clarifications. The system keeps track of all the versions of the taxonomy to guarantee consistency and to allow researchers to inspect the changes. The process of updating the taxonomy simply consists on uploading the taxonomy itself in the spreadsheet form: the application automatically parses the spreadsheet file and, if no errors are found, the uploaded taxonomy is used from that moment onward.

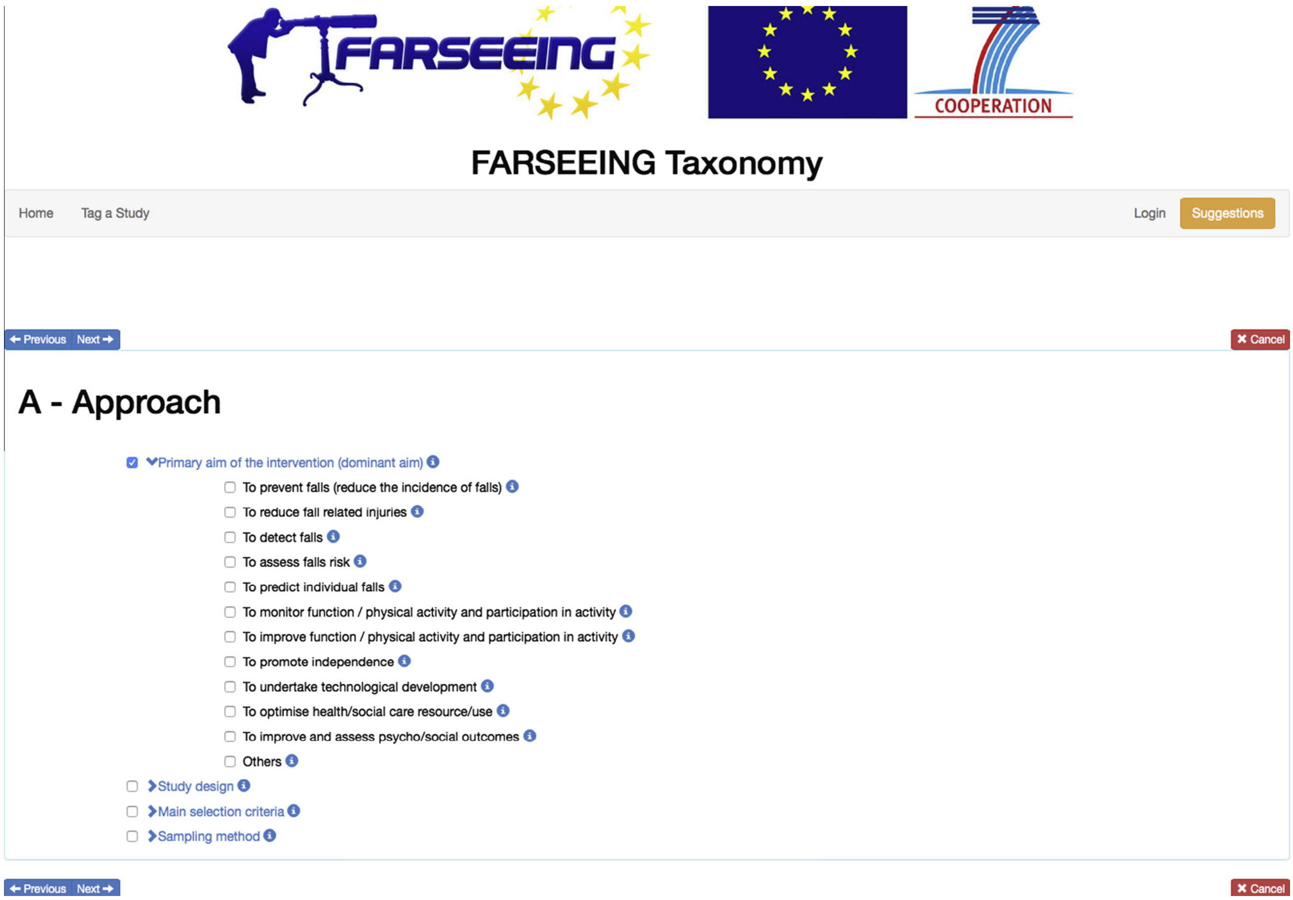

Fig. 2. Example screen from online application.

3. Results

The full version of the taxonomy and the accompanying handbook are available as PDFs on the FARSEEING project website (farseeingresearch.eu). The taxonomy is intended for use primarily as a web-based tool and the online application can be viewed at http://taxonomy.farseeingresearch.eu. The taxonomy is divided into five domains. Each of these domains contains further sub-domains, which in turn contain a range of categories. Each sub-domain also contains a category marked 'other' allowing free-text entry for studies that do not fit easily into the categories currently available. An overview of the entire taxonomy at domain and sub-domain levels is presented in Table 2.

In working through the first paper as a group, face-to-face, we were able to achieve high levels of consensus in applying the taxonomy; we had been able to discuss our selections and reach agreement in the majority of domains and sub-domains. Once we had returned to our own workplaces, and were using the taxonomy in isolation, consensus was much harder to achieve. Feedback from the second paper tested [39] highlighted that members of the TDG were unclear about how many categories to select. If a study had multiple selection criteria, was it possible to select more than one if the 'primary selection criteria' was being requested? As a result, the sub-domain was altered to 'main selection criteria', in order to encapsulate all of the criteria. At this stage, sub-domain A2 (study design) was also refined to eliminate repetition, reducing the number of categories to seven. Testing with the third paper [37] revealed that members of the TDG from different European countries were having difficulty in achieving consensus on sub-domain B1 (recruitment site). It was thought that this was, in part, due to the different health and social care systems in operation in the relevant countries. Not all of the categories were familiar to all of the members and, in some cases, none of the definitions

Table 2
Domains and sub-domains of the FARSEEING Taxonomy.

Domain	Sub-domain
A: Approach	A1: Primary aim of the intervention reported in the study
	A2: Study design
	A3: Main selection criteria
	A4: Sampling method
B: Base	B1: Recruitment site
	B2: Main site of delivery
C: Components of outcome measures	C1: Outcome measures carried out by
	C2: Medium of outcome measurement
	C3: Outcome measurement method
	C4: Outcome measurement implementation
D: Descriptors (description of technologies)	D1: Technology location
	D2: Technology type
	D3: Functionality
	D4: Method
	D5: Initial training/instruction
	D6: Supervision/follow up
	D7: Intervention utilisation
	D8: Control Groups
E: Evaluation	E1: Costs
	E2: Funding
	E3: Sustainability
	E4: Ethics
	E5: Stakeholder technology perceptions
	E6: Participant perceptions
	E7: Participant adherence

adequately described a particular recruitment site. For example, a "day care centre" in the UK was variously categorised as an 'ambulatory care centre', 'all other ambulatory centres' and 'community based'. Initially, Domain C (components) had been about assessment methods and implementation, based on the fall-prevention interventions taxonomy by Lamb et al. [27]. Feedback from the TDG members demonstrated that this was not always relevant for the application of the FARSEEING taxonomy and in fact 'outcome measures' was a more useful component to describe. Participants in the studies were not often having their own functional changes assessed, but were providing their feedback on technologies through various outcome measurements.

In the categorisation of the fourth paper used to test the taxonomy [38] there were limited selections within Domain E (evaluation). Participant perceptions (sub-domain E6) were well described and all members of the TDG made selections in these categories. However, only two members of the TDG categorised costs (E1) and funding (E2), indicating either that these were not reported prominently, or that categorising the paper using a paper based tool and handbook was too long and unwieldy.

In the final two papers used to test the taxonomy [36,39] greater consensus was achieved. This indicates that the refinements applied to the taxonomy and the definitions had removed some of the confusion and difficulties experienced previously. Selections made in Domain B (recruitment site) were less varied, although perfect consensus was still not achieved. In the main, consensus was achieved in Domain D (descriptions of technology), indicating that our categories and definitions were appropriate. However, selection of categories was dependent upon clear descriptions within the study papers. The delivery of a group tele-exercise Tai Chi programme reported by Wu and Keyes [39] was agreed to be using a system (D2.1) but beyond this was variously described as two-way communication (D2.1.15), closed circuit television (D2.1.16), using video recording and playing (D2.2.11), television (D2.2.13) and an image processor (D2.3.11). Clear description of the type of system and components within any system is necessary in order to fully understand the study and the use of technology.

The levels of consensus achieved on the sub-domains and categories for each of the papers, excluding the first paper where consensus was achieved through face-to-face discussion [34], are presented in Table 3. Due to the large number of categories within each domain, the number of coders and the limited number of papers, it was not feasible to calculate Kappa statistics. However, percentage agreement was calculated and is presented, with overall agreement across the five papers at 70.66%.

4. Discussion

The reporting of studies using technologies in the identification and prevention of falls, and the promotion of independence amongst older adults, is a rapidly growing field. The lack of consistency in reporting and defining elements of these studies has created difficulties in synthesising results and understanding what works [26]. We have developed a classification system which includes the key elements that should be described and reported in order to provide enhancements to the design, delivery, implementation and dissemination of research studies and to improve the evidence base, stated as necessary in the 2008 Cochrane review on smart home technologies [26]. Our taxonomy provides a common language that builds upon the work done to develop the STARE-HI criteria [40,41]. Both pieces of work were borne out of the need to clearly describe interventions using ICT, or health informatics, in order to provide robust evidence. The FARSEEING taxonomy presents categories and definitions that can be used within the STARE-HI framework for reporting study context (including the description of technologies) and methods.

As it is essential to involve experts in the field in the development of taxonomies [42], TDG members were brought together from a variety of different fields. Many were members of the FARSEEING consortium and all were actively involved in research in the field of using biomedical technologies in fall detection, assessment, prediction and prevention.

The initial development of the domains, sub-domains and categories involved a series of face-to-face meetings and discussions until consensus was achieved. The subsequent refinements to the taxonomy were carried out at-a-distance using email and teleconferencing, where consensus was more difficult to achieve. Each member of the TDG provided comments on their selections and engaged in debate over the classifications via email, which enabled further development and refinement. There were occasions where the specialists in computer engineering (AB and SM) selected different categories to the other members of the group, who had more clinical and public health expertise. This highlights the need for clear categorisation and description within the taxonomy, and within reported studies, in order for the study and the intervention to be understood correctly. We have attempted to remove this ambiguity by amending the pop-up information within the online version of the taxonomy (see below).

The papers selected to test the taxonomy were drawn from the FARSEEING systematic review of users' perceptions of technologies to detect, monitor and prevent falls [33]. All studies included older adults; two including participants with a previous fall history [35,37]. One feasibility study [34] and two RCTs [35,39] were included, with the remaining studies being classified as observational studies and/or evaluations [36–38]. In terms of the technologies, whilst all of the papers described systems, the location, application, functionality and method varied. There was one iPad application study (portable computer; persuasive; visual) [34], two personal emergency alarm studies (body-worn, or body-fixed; located in the environment; alert; sound) [35,36], two home monitoring and positioning studies (located in the environment; monitoring; sound) [37,38] and one service delivery study (communication; delivery; sound; visual) [39]. These studies were selected to provide the TDG with a range of different types of technologies and study designs with which to test the taxonomy.

Within the individual Domains, discussions led to the clarification and definition of terms, which were then used in subsequent test versions and have been incorporated into the online application. Regarding the aims of the study (Domain A: Approach), we clarified that we wished to ascertain the aims of the study, as opposed to the aims of the individual technologies. The aim of the technology may be to monitor activity levels, but the study may aim to prevent falls. Where average or low consensus is reported in Table 3, this indicates several differences between our classifications. In some cases this could be explained by our differences in research methodology experience, as the computer scientists and engineers were in agreement with each other, but not with the rest of the group. As already reported, there was much discussion regarding Domain B: Base (B1 Site of Recruitment and B2 Main Site of Delivery) and these discussions and clarifications led to several adjustments in the taxonomy. The levels of consensus reported in Table 3 demonstrate that the average consensus score was achieved for two papers in relation to the main site of recruitment and the main site of delivery [37,38]. Whilst we were able to obtain very high levels of consensus toward the end of the process, TDG members are convinced of the need to conduct further work on Domain B, to overcome the challenges presented by the differing names of services within local health and social care communities.

Table 3
Levels of consensus for each paper used for testing the taxonomy.[a]

Domains/sub-domains	Brownsell & Hawley	Londei	Steele	Heinbuchner	Wu
A: APPROACH					
A1: Primary aim	Very high	Average	Low	High	High
A2: Study design	High	High	Average	Average	High
A3: Main selection criteria	High	Very high	High	Very high	Very high
A4: Sampling method	High	Average	Low	High	Very high
B: BASE					
Recruitment site	High	Average	Average	High	Very high
Main site of delivery	Very high	Very high	Average	Very high	Very high
C: COMPONENTS OF OUTCOME MEASURES					
C1: Carried out by	High	Average	Average	High	High
C2: Medium	High	Average	Not described	High	Average
C3: Method	High	Average	Not described	High	High
C4: Implementation (tool)	High	Average	Average	High	High
D: DESCRIPTORS					
D1: Location	Very high	Very high	Average	Very high	High
D2: Type	Very high	Very high	Very high	Very high	Very high
D3: Functionality	Very high	Average	Low	Very high	Average
D4: Method	High	High	Low	Very high	Very high
D5: Training	High	Not described	Not described	Not described	Very high
D6: Supervision / follow up	Average	Not described	Not described	Not described	Very high
D7: Utilisation	Average	Not described	Not described	Not described	Not described
D8: Control Group	Average	Very high	High	Very high	Average
E: EVALUATION					
E1: Costs	Not described	Very high	Very high	Not described	High
E2: Funding	Average	Very high	Very high	Not described	Average
E3: Sustainability	Average	Average	Not described	Not described	High
E4: Ethics	Low	Very high	Very high	Not described	Not described
E5: Stakeholder perceptions	Not described	Very high	Not described	Not described	Not described
E6: User perceptions	High	Very high	High	Very high	Low
E7: Adherence	Low	Very high	Average	High	Very high
% Agreement	70.5	71.2	59.8	74.6	77.2

Agreement levels: Very high = 8–9 members of TDG in agreement; High = 6–7 members in agreement; Average = 4–5 in agreement; Low = 1–3 in agreement.
[a] The table represents the process of refinement and development, with the order of testing going from left to right so that the first column shows the first paper assessed [35] and the last column shows the results from the final paper assessed [39].

Initially, within Domain C: Components, we were collecting information about the tools used to assess participants, in line with the ProFaNE taxonomy [27]. However, through further application of the taxonomy, it became clear that this was not always appropriate or applicable, as participants were often assessing the usability or accuracy of the technologies, as opposed to the technology being used to assess participants' function. After testing the taxonomy with the fourth paper [38] it was agreed to alter Domain C to include the outcome measures that were included in the studies. This alteration appears to have improved agreement in the final two papers (Table 3), but more data are required.

Domain D: Descriptors of Technologies was where we were able to achieve the best consensus (Table 3). This is perhaps not surprising, as our task was to develop a taxonomy of technologies and the greater part of our face-to-face discussions concerned the categories within this domain. It seems we achieved a level of understanding and clarity for the categories within this domain within the group that was not matched in the other domains. The two records of low consensus are due to limited completion of the functionality (D3) and method (D4) categories for the third paper [38]. This could be due to the fact that the study was concerned with older adults' attitudes towards Wireless Sensor Networks in general as opposed to consideration of a particular installation, although an example mote (sensor node) was used for illustrative purposes.

Domain E: Evaluation continued to present difficulties in terms of achieving consensus throughout the process, not least because the papers themselves often did not provide detail in this area. As we were using the paper-based tool, the process was lengthy and fewer categories were selected towards the end than at the beginning of classification, which may point to fatigue with the process. There are three instances within Table 3 where consensus is recorded as low. This is due to only a small number of TDG members completing the sections. Where consensus is reported as very high, this is due into very clear reporting of the user perceptions and adherence to the interventions, or to near consensus on the fact that the papers did not report on the other aspects of evaluation at all [37,38]. As the papers were drawn from the FARSEEING systematic review, it is to be expected that user perceptions would be clearly reported. However, the majority of studies included in the taxonomy development process did not report costs, funding, sustainability, ethics or stakeholder perceptions in great detail.

4.1. Limitations

There are some limitations to our work. Despite having a panel of experts as members of the TDG who were experienced in reviewing academic papers, we still had difficulties in reaching consensus. The variability in how services and sites, and health and social care systems, are described in different countries presented difficulties in achieving consensus in describing studies. It may be necessary for the TDG to reduce the number of categories within Domain B (B1 Recruitment Site and B2 Main Site of Delivery) in order to simplify the classification and reach agreement on terms and categories that can work across international boundaries. However, caution is needed so that useful information is not lost. Additionally, the lack of detail provided in some papers made it difficult to classify and categorise these studies. Our recommendations regarding this issue follow in the next section. Finally, there is a limitation in the number of papers that we used to test the taxonomy. Due to time constraints, the members of the TDG were unable to carry out the lengthy process of using the paper-based tool to classify further studies. Now that the online tool is fully operational, the taxonomy would benefit greatly from testing with a broader range of studies. The online tool also enables a larger group of researchers to use the taxonomy, providing feedback to aid further development and refinement.

4.2. Recommendations

As a group, we recommend that researchers and journals adopt the taxonomy in order to standardise the approach to reporting studies in the fields of biomedical informatics and fall prevention. We propose that the Domains and Sub-Domains are used as minimum requirements for reporting studies related to ICT-based interventions, including Ambient Assisted Living, as this will ensure accurate, complete and useful reporting of studies that have used ICT in falls detection and prevention. The online tool developed out of our realisation that a paper-based tool and handbook would be cumbersome to use and difficult to implement. We recommend that researchers use the online tool to classify their studies and provide the TDG with feedback on the usability and categorisation within the taxonomy. We will use the feedback from users of the online tool to further refine the taxonomy. This feedback will help us, in particular, to review Domain E to see whether information regarding the evaluation of studies is being clearly reported. We anticipate that using the online tool will make the process of classification quicker and may result in more complete responses within Domain E. Equally, it may illustrate that researchers and technologists need to devote more time to reporting the financial, ethical and sustainable elements of their studies. We recommend that authors present more detail in presenting their studies not least in the areas of costs, funding, sustainability, ethics and stakeholder perceptions.

The online taxonomy provides the opportunity in the future for collecting data based on research communities' classifications of studies, enabling us to explore how studies are classified by peers and permitting us to adapt the taxonomy to consider new and emerging biomedical technologies.

With the increasing connectedness of people, devices, the use of data in healthcare and the rise of the internet of things, technology or digitalisation holds promise to make integrated care possible. Efficient evidence-based practice is dependant on information driven services. The quality of healthcare provision is, at least in part, dependant on evidence from rigorously performed and reported research. The complexity of integrated approaches requires a framework where technology, services, context, intervention and outcomes can be considered together. Our taxonomy provides the common language for such a framework, enabling descriptions of how health and technology operate to achieve effective integrated services for falls prevention. We recommend that the taxonomy is adopted by the ISO, which is working on a comprehensive standardisation framework for integrated care, with the involvement of one of our authors (NG).

5. Conclusions

This paper reports on the process of developing the FARSEEING Taxonomy and the difficulties encountered by the expert panel TDG. The improvements made to the taxonomy throughout the process led to the development of the online tool, which is active and available to researchers, clinicians and technologists. As more people access and apply the taxonomy to their studies, we will receive feedback that will enable us to develop and improve the taxonomy through an iterative process. The TDG will reconvene in 2016 to review and update the FARSEEING Taxonomy.

6. Summary table

What was already known on the topic

- Technologies aimed at fall detection, assessment, prediction and prevention are emerging.
- There are difficulties in comparing the efficacy of studies due to a lack of consistency in the language used.
- A common language and classification system is required for describing and reporting studies using technologies.

What this study has added to our knowledge

- Studies using technologies can be classified using a common language.
- The pace of technological development requires a classification system that can be modified and expanded.
- The FARSEEING Taxonomy of Technologies online classification system presents an accessible tool for ensuring consistency in describing and reporting studies using technologies.

Conflict of interest

The authors declare that they have no proprietary, financial, professional, or other personal competing interests of any nature or kind.

Authors contributions

EB wrote the first draft of the paper with input from KP and CT for the introduction; HHH, AH, SM and AB for the methods and results; FC for the online application; BV, AC and NG for the discussion. All subsequent drafts were prepared by EB. EB and HHH managed the development of the different versions of the taxonomy and the handbook. All authors critically revised the paper for publication.

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References

[1] K. Rapp, E. Freiberger, C. Todd, J. Klenk, C. Becker, M. Denkinger, C. Scheidt-Nave, J. Fuchs, Fall incidence in Germany. Results of two population-based studies, and comparison of retrospective and prospective falls data collection methods, BMC Geriatr. 14 (2014) 105, http://dx.doi.org/10.1186/1471-2318-14-105.

[2] T.A. Soriano, L.V. DeCherrie, D.C. Thomas, Falls in the community-dwelling older adult: a review for primary-care providers, Clin. Inter. Aging 2 (4) (2007) 545.

[3] I.D. Cameron, L.D. Gillespie, M.C. Robertson, G.R. Murray, K.D. Hill, R.G. Cumming, N. Kerse, Interventions for preventing falls in older people in care facilities and hospitals, Cochrane Database Syst. Rev. 12 (2012) CD005465.

[4] L.Z. Rubenstein, Falls in older people: epidemiology, risk factors and strategies for prevention, Age Ageing 35 (Suppl 2) (2006) ii37–ii41, http://dx.doi.org/10.1093/ageing/afl084.

[5] R.A. Marottoli, L.F. Berkman, L.M. Cooney, Decline in physical function following hip fracture, J. Am. Geriatr. Soc. 40 (9) (1992) 861–866.

[6] R.S. Braithwaite, N.F. Col, J.B. Wong, Estimating hip fracture morbidity, mortality and costs, J. Am. Geriatr. Soc. 51 (3) (2003) 364–370.

[7] C. Todd, D. Skelton, What are the Main Risk Factors for Falls Among Older People and what are the most Effective Interventions to Prevent these falls?

[Internet]. WHO Regional Office for Europe (Health Evidence Network Report), Copenhagen, 2004 [cited 2015 September 19]; Available from: <http://www.euro.who.int/__data/assets/pdf_file/0018/74700/E82552.pdf?ua=1>.
[8] American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention: Guideline for the prevention of falls in older persons, J. Am. Geriatr. Soc. 49(0002–8614 (Print)) (2001) 664–672.
[9] L.D. Gillespie, M.C. Robertson, W.J. Gillespie, C. Sherrington, S. Gates, L.M. Clemson, S.E. Lamb, Interventions for preventing falls in older people living in the community, Cochrane Database Syst. Rev. 9 (2012) CD007146. DOI:10.1002/14651858.CD007146.pub3.
[10] N.A. Guldemond, M.D. Hercheui, Technology and care for patients with chronic conditions: the chronic care model as a framework for the integration of ICT, in: M.D. Hercheui et al. (Eds.), HCC10 2012, IFIP Advances in Information and Communication Technology, vol. 386, 2012, pp. 123–133.
[11] A.J. Campbell, M.C. Robertson, Comprehensive approach to fall prevention on a national level: New Zealand, Clin. Geriatr. Med. 26 (4) (2010) 719–731, http://dx.doi.org/10.1016/j.cger.2010.06.004.
[12] V. Scott, B. Wagar, A. Sum, S. Metcalfe, L. Wagar, A public health approach to fall prevention among older persons in Canada, Clin. Geriatr. Med. 26 (4) (2010) 705–718, http://dx.doi.org/10.1016/j.cger.2010.06.003.
[13] J. Howcroft, J. Kofman, E.D. Lemaire, Review of fall risk assessment in geriatric populations using inertial sensors, J. Neuroengineering Rehab. 10 (1) (2013) 91, http://dx.doi.org/10.1186/1743-0003-10-91.
[14] K.S. van Schooten, M. Pijnappels, S.M. Rispens, P.J.M. Elders, P. Lips, J.H. van Dieën, Ambulatory fall-risk assessment: amount and quality of daily-life gait predict falls in older adults, J. Gerontol. Ser. A Biol. Sci. Med. Sci. (2015) 608–615, http://dx.doi.org/10.1093/gerona/glu225.
[15] L. Schwickert, C. Becker, U. Lindemann, C. Maréchal, A. Bourke, L. Chiarifor the FARSEEING consortium and the FARSEEING meta database consensus group, Fall detection with body-worn sensors: a systematic review, Z Gerontol Geriatr. 46 (8) (2013) 706–719, http://dx.doi.org/10.1007/s00391-013-0559-8.
[16] N. Pannurat, S. Thiemjarus, E. Nantajeewarawat, Automatic fall monitoring: a review, Sensors (Basel, Switzerland) 14 (7) (2014) 12900–12936, http://dx.doi.org/10.3390/s140712900.
[17] C. Becker, L. Schwickert, S. Mellone, F. Bagalà, L. Chiari, J.L. HelbostadFARSEEING Meta Database Consensus Group, Proposal for a multiphase fall model based on real-world fall recordings with body-fixed sensors, Z. Gerontol. Geriatr. 45 (8) (2012) 707–715, http://dx.doi.org/10.1007/s00391-012-0403-6.
[18] F. Bagalà, C. Becker, A. Cappello, L. Chiari, K. Aminian, et al., Evaluation of accelerometer-based fall detection algorithms on real-world falls, PLoS ONE 7 (5) (2012) e37062, http://dx.doi.org/10.1371/journal.pone.0037062.
[19] L. Cattelani, P. Palumbo, L. Palmerini, S. Bandinelli, C. Becker, F. Chesani, L. Chiari, FRAT-up, a web-based fall-risk assessment tool for elderly people living in the community, J. Med. Internet Res. 17 (2) (2015) e41, http://dx.doi.org/10.2196/jmir.4064.
[20] N. Skjæret, A. Nawaz, K. Ystmark, Y. Dahl, J.L. Helbostad, D. Svanæs, B. Vereijken, Designing for movement quality in exergames: lessons learned from observing senior citizens playing stepping games, Gerontology 2015 (61) (2015) 186–194.
[21] A. Nawaz, N. Skjæret, K. Ystmark, J.L. Helbostad, B. Vereijken, D. Svanæs, Assessing seniors' user experience (UX) of exergames for balance training, ACM Digital Libr. 2014 (2014) 578–587.
[22] M. van Diest, C.J.C. Lamoth, J. Stegenga, G.J. Verkerke, K. Postema, Exergaming for balance training of elderly: state of the art and future developments, J. Neuroengineering Rehab. 10 (2013) 101, http://dx.doi.org/10.1186/1743-0003-10-101.
[23] P.M. Deshmukh, C.M. Russell, L.E. Lucarino, S.N. Robinovitch, Enhancing clinical measures of postural stability with wearable sensors, Conf. Proc.: Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. (2012) 4521–4524, http://dx.doi.org/10.1109/EMBC.2012.6346972.
[24] L. Allet, R.H. Knols, K. Shirato, E.D. de Bruin, Wearable systems for monitoring mobility-related activities in chronic disease: a systematic review, Sensors (Basel, Switzerland) 10 (10) (2010) 9026–9052. DOI:10.3390/s101009026.
[25] V. Power, P. Van de Ven, J. Nelson, A. Clifford, Predicting falls in community-dwelling older adults: a systematic review of task performance-based assessment tools, Physiother. Pract. Res. 35 (1) (2014) 3–15, http://dx.doi.org/10.3233/PPR-130027.
[26] S. Martin, G. Kelly, W.G. Kernohan, B. McCreight, C. Nugent, Smart home technologies for health and social care support, Cochrane Database Syst. Rev. 4 (2008) CD006412, http://dx.doi.org/10.1002/14651858.CD006412.pub2.
[27] S.E. Lamb, C. Becker, L.D. Gillespie, J.L. Smith, S. Finnegan, R. Potter, K. Pfeifferfor the taxonomy investigators, Reporting of complex interventions in clinical trials: development of a taxonomy to classify and describe fall-prevention interventions, Trials 12 (2011) 125, http://dx.doi.org/10.1186/1745-6215-12-125.
[28] M.A. Habib, M.S. Mohktar, S.B. Kamaruzzaman, K.S. Lim, T.M. Pin, F. Ibrahim, Smartphone-based solutions for fall detection and prevention: challenges and open issues, Sensors (Basel, Switzerland) 14 (4) (2014) 7181–7208.
[29] S.E. Lamb, E.C. Jørstad-Stein, K. Hauer, C. Becker, Prevention of Falls Network Europe and Outcomes Consensus Group: development of a common outcome data set for fall injury prevention trials: the Prevention of Falls Network Europe consensus, J. Am. Geriartr. Soc. 53 (9) (2005) 1618–1622.
[30] Centre for Reviews and Dissemination: Systematic Reviews: CRD's Guidance for Undertaking Reviews in Healthcare. York, University of York [Cited 2014, March 19]. Available from: <http://www.york.ac.uk/inst/crd/>.
[31] L. Demers, R. Weiss-Lambrou, B. Ska, The Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST 2.0): an overview and recent progress, Technol. Disabil. 14 (3) (2002) 101–105.
[32] B. Hensel, G. Demiris, K.L. Courtney, Defining obtrusiveness in home telehealth technologies: a conceptual framework, J. Am. Med. Inform. Assoc. 13 (2006) 428–431.
[33] H. Hawley-Hague, E. Boulton, A. Hall, K. Pfeiffer, C. Todd, Older adults' perceptions of technologies aimed at falls prevention, detection or monitoring: a systematic review, Int. J. Med. Inf. 83 (2014) 416–426.
[34] P. Silveira, E. van het Reve, D. Daniel, F. Casati, E.D. de Bruin, Motivating and assisting physical exercise in independently living older adults: a pilot study, Int. J. Med. Inform. 82 (2013) 325–334.
[35] S. Brownsell, M.S. Hawley, Automatic fall detectors and the fear of falling, J. Telemed. Telecare 10 (2004) 262–266.
[36] B. Heinbüchner, M. Hautzinger, C. Becker, K. Pfeiffer, Satisfaction and use of personal emergency response systems, Z. Gerontol. Geriatr. 4 (2010) 219–223.
[37] S.T. Londei, J. Rousseau, F. Ducharme, A. St-Arnaud, J. Meunier, J. Saint-Arnaud, F. Giroux, An intelligent videomonitoring system for fall detection at home: perceptions of elderly people, J. Telemed. Telecare 15 (2009) 383–390.
[38] R. Steele, A. Lo, C. Secombe, Y.K. Wong, Elderly persons' perception and acceptance of using wireless sensor networks to assist healthcare, Int. J. Med. Inform. 78 (2009) 788–801.
[39] G. Wu, L.M. Keyes, Group tele-exercise for improving balance in elders, Telemed. J. E Health 12 (2006) 561–570.
[40] J. Brender, J. Talmon, N. de Keizer, P. Nykänen, M. Rigby, E. Ammenwerth, STARE-HI – Statement on reporting of evaluation studies in Health Informatics: explanation and elaboration, Appl. Clin. Inf. 4 (2013) 331–358.
[41] J. Talmon, E. Ammenwerth, J. Brender, N. de Keizer, P. Nykänen, M. Rigby, STARE-HI—statement on reporting of evaluation studies in Health Informatics, Int. J. Med. Inform. 78 (2009) 1–9.
[42] L.D. Gillespie, M.C. Robertson, W.J. Gillespie, S.E. Lamb, S. Gates, R.G. Cumming, B.H. Rowe, Interventions for preventing falls in elderly people, Cochrane Database Syst. Rev. 15 (2009) CD007146.