On The Necessity of Multi-disciplinarity in The Development of At-home Health Monitoring Platforms for Older Adults: Systematic Review

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Abstract. *Background* - The growth in ageing populations globally has increased the demand for new models of care. At-home, computerized healthcare monitoring is a growing paradigm which explores the possibility of reducing workloads, lowering the demand for resource-intensive secondary care and providing more precise and personalised care. Despite the potential societal benefit of autonomous monitoring systems when implemented properly, uptake in healthcare institutions is slow and a great volume of research across disciplines encounters similar common barriers to real-world implementation. *Objectives* - The goal of this review is to 1) construct an evaluation framework that can assess research in terms of how well it addresses already identified barriers to application and 2) to then use that framework to analyse the literature across disciplines and identify trends between multi-disciplinarity and the likelihood of research being developed robustly. *Methods* - This paper introduces a scoring framework for evaluating how well individual pieces of research address key development considerations using 10 identified common barriers to uptake found during meta-review from different disciplines across the domain of healthcare monitoring. A scoping review is then conducted using this framework to identify the impact that multi-disciplinarity involvement has on the effective development of new monitoring technologies. Specifically, we use this framework to measure the relationship between the use of multi-disciplinarity in research and the likelihood that a piece of research will be developed in a way that gives it genuine practical application. *Results* - We show that viewpoints of multi-disciplinarity; namely across computer science and medicine alongside public and patient involvement (PPI) have a significant positive impact in addressing commonly encountered barriers to application research and development according to the evaluation criteria. Using our evaluation metric, multi-disciplinary teams score on average 5.43/10 compared to 3.5 for teams made up of medical experts and social scientists, and 2.68 for technical-based teams, encompassing computer science and engineering. Also identified is the significant effect that involving either caregivers or end-users in the research in a co-design or PPI-based capacity has on the evaluation score (2.93 without any input and 4.83/3.67 for end-user or caregiver input respectively, on average). *Conclusion* - This review recommends that, to limit the volume of novel research arbitrarily re-encountering the same issues in the limitations of their work and hence improve the efficiency and effectiveness of research, multi-disciplinarity should be promoted as a priority to accelerate the rate of advancement in this field and encourage the development of more technology in this domain that can be of tangible societal benefit.

Keywords: Multi-disciplinarity · Gait Assessment · Machine Learning · At-home Health Monitoring · Older Adults

1 Introduction

With the general increase in global life expectancy and the ever-increasing ratio of retirement-age to working-age people, research in the scope of health and social care for older people is greatly increasing. As people live longer and the ageing population grows, governments and international organisations are recognizing the need for a paradigm shift in the way we care for our older populations [32]. Current methods of care typically include a social care system to look after the most vulnerable and frail older adults, but as the size of this population increases at a faster rate than the working population, these institutional models of care at the country level become progressively less practical and more costly. In response to this growing crisis, one solution researchers have sought to employ is the use of novel health monitoring technologies to tackle the problem of labor shortages in healthcare systems and to improve productivity and efficiency in care [3, 14, 19, 21, 23, 24, 31, 38, 40, 44]. This can be in direct terms, for example monitoring systems that assist care professionals carrying out their duties within care settings [39] and also indirectly with at-home monitoring devices designed to reduce the occurrence of injuries by, for example, assessing gait [5, 13] and predicting fall events [14, 20], with the goal of reducing the potential burden on secondary care and ultimately reducing the burden on the care-home sector and keeping people at home, healthy and independent for longer [12, 16, 38].

The goals of this work can be summarized by the following two research questions:

- Can we construct an evaluation framework for at-home health monitoring research and justify that a positive score in said framework broadly correlates with a higher likelihood of the research being effective in real-world use.
- Can we identify the trends if they exist, between the method of research (single-discipline, multi-discipline, the use of PPI or co-design) and the increase or decrease in effectiveness of said research?

In the context of this paper, "effective research" can be defined as research that is more efficient by being less prone to making oversights already identified in the existing literature across disciplines. We assert that research that addresses the already existing issues in the literature (and therby scoring highly on our proposed metric) leads to more effective research and ultimately leads to products and platforms more likely to be usable in real-life applications (see 2.3 for evidence of this).

To answer these questions, this research is split into two phases, a scoping phase and evaluation phase. In the scoping phase, an overview is provided of the various systematic reviews across disciplines in the field of at-home healthcare monitoring for older adults. In doing this, we synthesize an evaluation framework based on the consensus and concatenation of these studies to measure the degree to which individual pieces of research encounter similar common problems. By defining this framework, observations can be made about the degree to which these problems are acknowledged by different types of research teams operating with or without multi-disciplinarity, which types of issues are likely to be identified by which types of research, and how stakeholder involvement can improve the likelihood of developing an effective product. To justify this evaluation criteria and to address the first research question, examples of existing technologies in commercial use are positively evaluated by this approach to assert the positive relationship between a high evaluation score and the generation of more effective research, considerate to existing identified issues with real-world use(see section 2.1). To our knowledge, there is currently no evaluation methodology designed to measure research application effectiveness, based on multidisciplinary metrics.

In the evaluation phase. a review of individual works in the application of computerized at-home health-monitoring systems is then presented, with these works evaluated against the metric developed in the scoping phase, with the results analysed to address the second research question (see section 3.3 .

For this evaluation phase, a total of 350 papers were found from the IEEE Explore, PubMed and ArXiv databases, of which 60 papers were ultimately used, with the inclusion constraints being that the papers had to be individual pieces of original research relating either to the development of technology associated with the various applications of at-home older adult health monitoring or a review into the effectiveness of existing at-home health monitoring applications. This is including but not limited to: development and deployment of disease diagnosis and progression analysis, fall detection and prevention, lifestyle monitoring, vital-sign monitoring and smart-home systems. Candidate papers must present methods that have the prospect of or are already actively being tested in an at-home environment in whole or in part.

The contributions of this paper are:

- A review of the recent literature of at-home healthcare monitoring. This is achieved by providing a 2-stage review of the literature, with the first (scoping phase) being a meta-review of reviews in the relevant literature, and the second (evaluation phase) being a scoping review of individual works across multiple disciplines in the area of at-home health monitoring.
- The introduction of a comprehensive evaluation framework for assessing the likely real world effectiveness of health monitoring application research, based on 10 key issues consistently identified in the overview of systematic reviews of 15 literature reviews in the field across disciplines.
- The identification and demonstration of various links between the manner of research and the effectiveness of research. Namely, we find that multi-disciplinarity has a consistently positive effect in this respect, reflected by

higher scores on the evaluation framework. We also find a convincing uptick in score where PPI and co-design methods are used.

Section (2.1) contains the scoping phase and provides an overview of the literature in health monitoring technologies, constructing from them a concise evaluation framework in the form of a 10-point checklist criteria for research application effectiveness based on consensus drawn from these works. Section (3.1) presents the evaluation phase, reviewing individual pieces of research across disciplines using this evaluation framework. The trends between multi-disciplinarity and stakeholder involvement via PPI and co-design and the effectiveness of research are also analysed here. Finally, Section (4) summarizes the findings of this research and makes recommendations for how future health monitoring research should be conducted in order to improve the effectiveness of research in this field.

2 Methods

2.1 Scoping Phase: Overview of At-home Health-monitoring in Older Adults

To identify the most common barriers to uptake in this field, an overview of 12 systematic and other review papers from 2014 onwards was conducted to identify and concatenate the common issues within some of the common sub-disciplines of at-home healthcare monitoring: encompassing any autonomous monitoring methods used in a domestic context such as camera-based applications, wearable sensors, remote sensors and ensemble smart-home systems. Table 1 provides a concise summary of the main reviews investigated, and the presence of each of the commonly identified barriers among them. Broken down in 1 are the makeup of the teams involved in the research: multi-disciplinary, Technical or Application-based. In the context of this work, "Technical" concerns research conducted by engineering and/or computer science teams, with "Application" making up all other types of research team, but predominantly teams in the fields of medicine and social science. 10 core barriers are identified across these reviews and synthesized to be inclusive of all the barriers identified in all the systematic reviews evaluated in this section. An exact breakdown of the presence or absence of the 10 points in each review is available in the supplementary materials (see Table 1 in the supplementary materials).

Beyond these key reviews from which the evaluation framework was constructed, there are numerous other reviews and surveys whose findings are inclusive of the framework outlined at the end of this section (see Table 2 in the Supplementary materials for a full breakdown of the x reviews). Only the core 12 are included here for brevity, with these 12 being selected as they 1) encompass all of the core at-home healthcare methodologies, 2) they include examples of all 10 key points that make up the framework and 3) they represent a roughly equal variety of research teams, namely multidisciplinary teams (n = 3), computer science (n = 3) engineering (n = 2), medical (n = 2) and social science (n = 2).

Table 1: Overview of systematic reviews and their evaluation score according the the evaluation metric. "Research Team" denotes whether the teams conducting the research were technical or medical-based. See further in this section for a breakdown of the 10 common identified points, and see the supplementary material for a specific breakdown of which barriers are present in each.

Paper	**Description**	**Research Team**	**Score**
Are Active and Assisted Living applications addressing the main acceptance concerns of their beneficiaries? [7]	Overview of concerns with AAL technologies	Multi-disciplinary	5/10
A critical review of smart residential environments for older adults with a focus on pleasurable experience [21]	Older adult opinions on monitoring tech	Multi-disciplinary	3/10
Smart homes and home health monitoring technologies for older adults: A systematic review [23]	Overview of smart home applications	Application	7/10
Health Monitoring Using Smart Home Technologies: Scoping Review [31]	Overview of smart home applications	Application	5/10
Older persons have ambivalent feelings about the use of monitoring technologies [3]	Older adult opinions on monitoring tech	Application	6/10
Older adults' perceptions of technologies aimed at falls prevention [14]	Older adult opinions on monitoring tech	Application	4/10
Unobtrusive sensing and wearable devices for health informatics [44]	Overview of 4 main sensor-based monitoring technologies	Technical	4/10
Wearable sensors for remote health monitoring [24]	Overview of wearable health monitoring technologies	Technical	4/10
Unobtrusive health monitoring in private spaces: The smart home [40]	Overview of smart home applications	Technical	2/10
Detection and assessment of Parkinson's disease based on gait analysis: A survey [13]	Overview of gait assessment monitoring	Technical	0/10
Remote patient monitoring using artificial intelligence [38]	Overview of AI in patient monitoring	Technical	2/10
Factors Determining the Success and Failure of eHealth Interventions [12]	Overview of smart home applications	Multi-disciplinary	7/10

[10] present a number of insights in their review of the literature regarding older adults using smart-homes, such as identifying solutions to the problems in most research applications. For example, they assert that gradual introduction of smart-home technology combined with the ability to 'pause' it at will to provide 'emotional release' is highly desired in end-users for a more pleasant experience. They also find that more tech-literate people tend to have less concerns with the technology due to an improved understanding of the data being collected and the privacy risks involved, if any. One other concern identified was transmission of data and the insecurities associated with this, leaning to a user-preference that data should be handled manually instead of via remote connection. These findings are all further reinforced by the findings in [26], which similarly conduct interview sessions with 20 older adults regarding which aspects of health-monitoring systems concern them. These findings inform points 4 and 5 in the evaluation metric, defined in section 2.2.

Regarding data access, [36] find that older adults could in some cases want control of data access to withhold the data from certain parties, namely their family and friends, for fear of burdening them, informing points 6 and 8 of the framework. Cost was also an identified challenge (informing point 3), for example focus group attendees in [3] were concerned by the cost of long-term use of monitoring devices, with the implication being that they would have to buy them outright.

[15] discovers that when surveyed, there is a broad perception that older people view new advancements in smart-home related technology as good but 'unnecessary for them', as they don't perceive themselves as being 'unhealthy enough' to merit using what they see as a drastic action toward greater care. [25] found in their study of 661 older people that a slim majority (56.3%) perceived smart-home technology as not being of use to them specifically. [10] identify a series of factors through their investigation with older participants which are crucial to account for when considering the integration of new technology into real life. These factors range from societal stigma to technical reliability, covering points 1, 2, 3 and 6 in the evaluation framework. Research in [3, 23] also point to the issues surrounding the implication of autonomous monitoring being a decline in human contact, addressed by point 7. In the systematic review conducted by [10], observations were made regarding the progression of smart-home technologies. Regarding patient acceptability, they note that less than half of the papers reviewed take into consideration the acceptability of their technology where privacy is concerned: with the focus of the paper instead being explicitly about the functions of the novel technology. Some steps taken toward improving privacy in certain papers included encrypting collected data [2] and locking data access behind authorization [29].

Regarding medical professionals, their main concerns with smart-home technology and healthcare monitoring concern the feasibility of use. Unlike patient acceptability, acceptability by medical professionals is under-researched, where many papers will either focus on the technology being developed and not address it in application or they will focus only on the opinions of the end users and how they will use and accept the technology [28]. This finding is echoed in the lack of surveys found in the scoping review in section 3.3, where the focus is on medical professionals rather than patients. Of the 60 papers in the scoping review, only 7 made any explicit use of external medical caregivers in their research development.

2.2 Evaluation Framework Criteria

Across the review papers both in table 1 and the other reviews referenced in this section, the following list of 10 factors were collated to encompass all of the common considerations identified when designing and implementing novel monitoring technology for use with older adults in a domestic environment. They are segmented by category of concern (technical, application or multi-disciplinary), where the technical are purely engineering or computer-science implementation concerns and application are concerns involving human interaction with the technology and any adjacent concerns important to medical and social science-based disciplines. The framework is as follows:

1. **Usability** - *technical*: concerning the usefulness of the technology and how feasible it is to be used by caregivers and end-users.
2. **Accessibility** - *technical*: this concerns the ease of use by laymen of the computer technology and the barriers for entry in terms of effectively using the technology.
3. **Reliability** - *technical*: covers issues relating to the long-term viability of the application e.g. is it expensive, does it require upkeep, charging or maintenance.
4. **Control** - *multi-disciplinary*: concerns the level of access and control both patients and medical staff should have to the application and the data it records.
5. **Privacy** - *multi-disciplinary*: constitutes issues relating to the intrusiveness of the data being collected, and the manner in which it is collected.
6. **Stigma** - *application*: anything relating to the societal stigma people may feel by using monitoring technologies for the purposes of personal health.
7. **Lack of human response** - *application*: concerns the issue of the perception that increased autonomous monitoring would result in a decrease in human interaction as a result.
8. **Burden to others** - *application*: regarding the perception of older adults that additional at-home monitoring is representative of applying additional burden to their caregivers.
9. **Lack of perceived need** - *application*: concerns a commonly identified phenomenon in the literature that people have a tendency to think a technology is useful but unnecessary for them personally.
10. **Affordability** - *application*: this concerns the cost both on a personal and institutional level to implement solution applications in real life.

Table 2: Scoring of two current at-home monitoring projects being developed with the intention of widespread use. The Attributes are numbered corresponding to the attribute list given in the attribute list above.

Project Name	**Year**	**Description**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
SPHERE [6, 30, 45]	2018	Smart-home system for behaviour monitoring, under development for several years and the feature of multiple research studies.	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
HALLEY [9]	2023	IoT-based Smart-home development project currently in commercial development.	Y	Y	Y	N	Y	Y	Y	N	N	Y

2.3 Evaluation Framework Justification

To demonstrate the descriptive power this evaluation system has to the likelihood of success in application, Table 2 provides an overview of papers concerning 2 technologies being developed for commercial use (Sphere [45] and HalleyAssist [9]), and the degree to which the prior research and development of these systems adhere to the criteria in the evaluation metric. Both have demonstrated a commitment to addressing barriers relating to both technical and human elements, addressing 90% and 70% of the evaluation metrics respectively (The average score across the scoping review in section 3.1 is 36.2% for comparison). They also both were developed by a multidisciplinary research team from computer science and signal processing to nursing, geriatric medicine and social care. The relationship between the absence of certain metrics such as multi-disciplinarity and the lack of consideration for common barriers to uptake is further concretely illustrated during the analysis in Section 3.1.

3 Results

3.1 Evaluation Phase: Scoping Review and Parameters

Figure 1 illustrates the selection process for papers considered for the scoping review. From the three databases, the following search term was used:

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((healthcare monitoring) AND (older adult)) AND ((home) OR
(at-home) OR (domestic)) AND ((obtrusive) OR (unobtrusive) OR
(intrusive)) AND ((machine learning) OR (AI) OR (artificial
intelligence))
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with the exception of the Arxiv database, where the

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((obtrusive) OR (unobtrusive) OR (intrusive))
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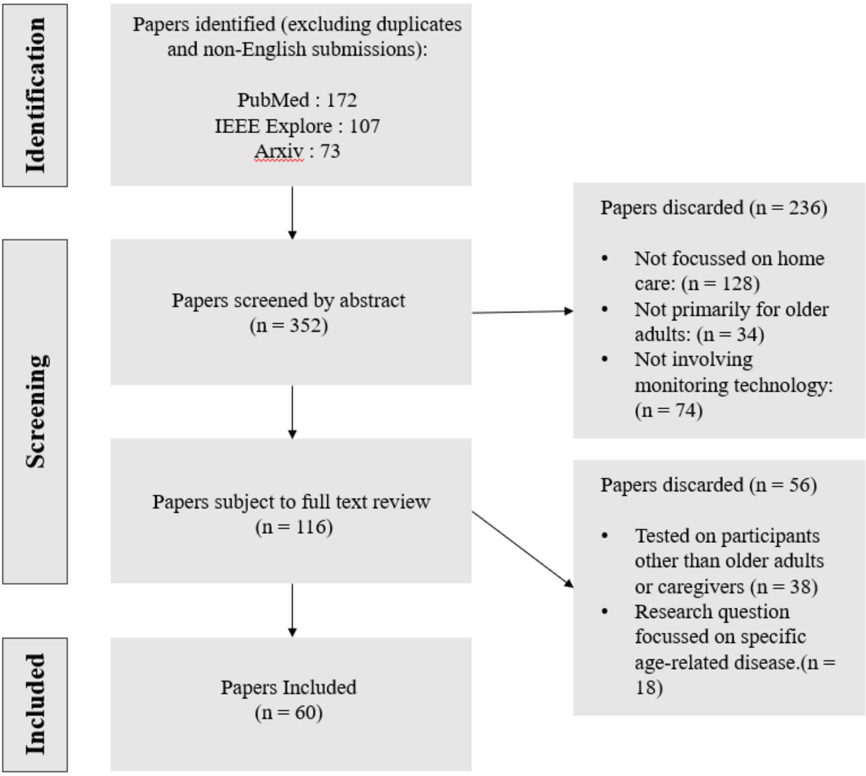

Fig. 1: Screening process illustration for the scoping review portion of this research.

section was omitted for a larger range of initial texts. Language was restricted to English and the date was restricted to 2014 or later, with the search commencing on January 7th - 24th 2024. Excluded were papers that didn't in whole or in part reference older adult monitoring as the purpose of their application or review, and papers where the application was specifically designed for care homes or hospitals. The initial search yielded a total of 352 papers. Paper title analysis excluded 236 papers, and assessment of the remaining abstract resulted in 116 remaining, with the final count being 60 papers after a full-paper review resulting in 56 more deletions (see figure 1.

The following section is broken down by technical and application-based research, following the definitions for both established in the beginning of section 2.1. Papers defined as multi-disciplinary are those in which the research team consist of at least one from each of the first two categories.

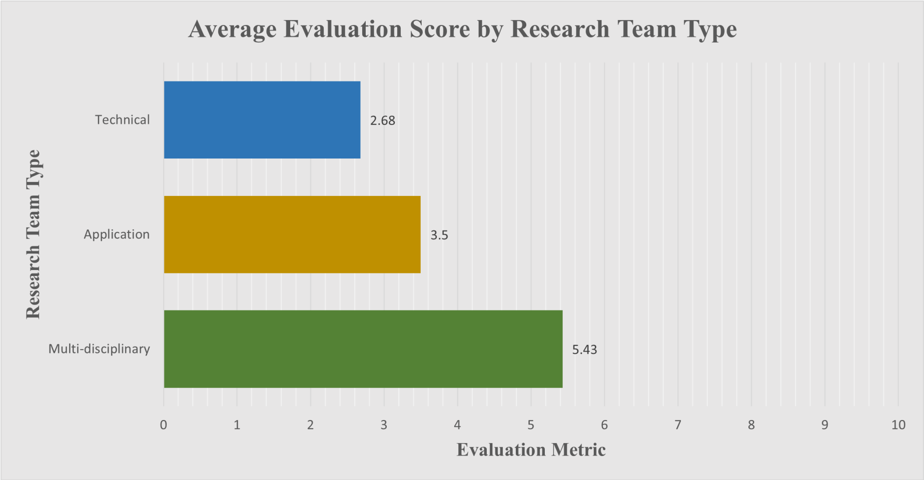

Fig. 2: Comparison of relative average performance, broken down by the category of team conducting the research.

3.2 Technical Research

The majority of research in this space relies either on traditional or neural-network based machine learning (ML) methods to make their systems effective and largely automatic. [1] constructs a model that can differentiate between regular, pre-frail and frail gait within a population of 50 older adults at an accuracy of 88.5% based on wearable accelerometer signals. They rely on traditional methods of AI such as support vector machines (SVM), Random Forest (RF) and basic single-layer neural networks (NN).

With vision-based applications on the other hand, [22] use a novel 3D convolution neural network (CNN) with multi-temporal-scale pooling to process gait silhouettes taken from the CASIA-B dataset [43] to achieve a person-recognition accuracy of 97.6%. While the question of gait identification can be fairly trivially solved with modern CNN frameworks, the question of gait analysis, or assessing health requires a more nuanced approach and is still an active research area.

[37] use a Spatio-temporal Graph Convolutional Network (ST-GCN) [41] framework to assess Parkinson's severity as classified under the Unified Parkinson's Disease Rating Scale (UPDRS) [11]. As this is a far more complicated problem than simple person-identification or even traditional action recognition, they achieved 53% f1 score using a dataset of 53 participants.

Recently, in [42], the Spatio-temporal joint adjacency GCN (STJA-GCN) was developed that utilises 3 streams for joints, bones and velocities, a novel joint attention module and a streamlined joint graph architecture to achieve state-of-the-art results (93.17% and 92.08%) on the domain of recognizing and classifying different types of abnormal gaits compared to other ST-GCN-based methodologies. This was tested on a pair of datasets totalling 22 participants

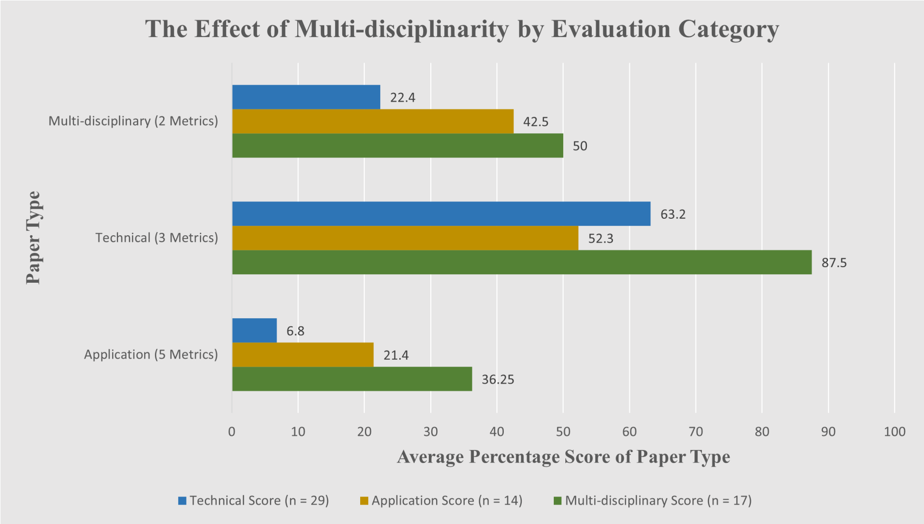

Fig. 3: Illustration of evaluation performance per-evaluation category.

and 8600 instances of gait data collected from a total of 7 sensors across the two datasets.

Demonstrably then, ML methods are extremely capable in multiple healthcare monitoring applications. The issue with the papers in this field however is that they score poorly on the evaluation framework due to an overt focus on technical innovation at the expense of concerns applicational concerns (see figure 2). This analysis indicates a narrow focus purely on the effectiveness of the technology at the expense of an omission of application considerations, such as cost or perceived need by end-users and medical stakeholders (see figure 4 for a per-category breakdown). To take a more concrete example of this narrowed focus, [5] is explicitly geared toward the development of a decision-support algorithm for medical professionals, complete with visual aids. However, there is no evidence of consideration of the requirements of medical professionals being employed in the design of the system itself. Similar issues were found in several studies where technical teams sought to develop assistive tools for caregivers or patients without direct involvement of prospective caregivers [8, 17, 27, 33, 34].

3.3 Application and Multi-disciplinary Research

Of the surveyed technical papers (n = 29), they scored an average 6.8% on the application-centred metrics in the evaluation framework (see figure 3). In contrast, the application papers (n = 14) mainly authored by medical researchers scores 21.4% on application-based metrics. While this indicates that application-focused papers typically address more concerns with real-life deployment of research solutions, there is also a notable trend that this focus on application comes at a slightly increased tendency to neglect technical aspects of research (with

Table 3: This table denotes the presence or absence of caregivers and end-users in the co-design of research across the review, split by research team type. Values are not mutually exclusive and some papers have both caregivers and end-users involved. As a result, values may not necessarily add up to 100%.

Team Type	**Caregivers (CG) (%)**	**End-users (EU) (%)**	**CG & EU (%)**
Multi-disciplinary	37.5	56.25	*37.5*
Application	38.4	64.2	14.2
Technical	0	13.7	0

both technical and multi-disciplinary papers outperforming application-based papers on technical metrics). A clear trend can be seen in multi-disciplinary papers consistently outperforming specialist papers, even on their metrics specific to their own discipline (see Figure 4).

In [35], 5 focus groups were conducted with both older adults and caregivers; namely family and care staff, to help synthesize a consensus on the design of future at-home sensor-based systems, with a focus on acceptability, respect for privacy and how to best provide control of care to the end-users themselves. Scoring 5 out of 10, the authors neglect aspects such as system reliability at the expense of greater privacy, and other application-driven barriers such as societal stigma and the threat of greater isolation resulting in the deployment of remote monitoring technology. Expanding on this focus-group style research, [4] conduct a series of interviews with both formal and informal caregivers to identify the key parameters which need to be addressed to achieve effective at-home lifestyle monitoring systems. Scoring 6, their strengths come from the inclusion of both medical and end-user input, however they similarly lack extensive consideration for how the parameters being set by stakeholders would affect the performance of the monitoring systems themselves. [18] investigate issues of application from a medical perspective but score only 4. Not only does their investigation consist only of testing an existing technology without the intention of developing said technology further, they also concern their research only with application concerns as far as the caregivers and medical stakeholders are concerned, with no involvement being afforded to the end-users and patients. As a result, issues around stigma and even privacy are completely unaddressed.

Table 4: Breaking down again by research team type, here denotes the average evaluation score out of 10 when caregivers and end-users are included or not in research.

Team Type	**Neither (Score)**	**Caregivers (CG) (Score)**	**End-users (EU) (Score)**	**CG & EU (Score)**
Multi-disciplinary	3.57	7	6.8	7
Application	2.75	4	4.2	4.3
Technical	2.48	0	3.5	0

As can be seen in table 3, there is a clear lack of involvement in research and application design from the medical community and caregivers. 13.7% and 64.2% of single-discipline papers involve end-user participation vs a mere 0% and 14.2% exhibiting caregiver or medical participation in the development of the research (for application and technical based papers respectively). While the likelihood of involving both types of stakeholders (caregivers and end-users) is more than double when multi-disciplinary teams are involved (14.2% vs 37.5%), this cannot be considered conclusive due to the relatively small number of papers in each category when divided by the inclusion of different stakeholder types (end-user and caregiver). Likewise, there is a definite trend across all research team types that exhibit lower evaluation scores when neither caregivers nor end-users participate in the design or evaluation of research. However, discerning the differing impact between the two stakeholder types is difficult due to the small positive sample size (with only 0.2 separating end-user only and caregiver only scores for both research team types, see table 4). The trend in the research, especially in survey-style research seems to be to focus on end-users rather than caregivers or other medical stakeholders with only 7/60 papers involving medical stakeholders and 22/60 involving end-user input.

The strongest scores using the evaluation framework come from those where interdisciplinary teams are utilised (see Figure 2, further strengthened by the presence of caregiver and end-user involvement in development, shown in table 4.

In general, as shown in figure 4, different categories of research team tend to neglect certain aspects identified in the evaluation framework. Technical papers struggle with 'Stigma' and 'Human Response', and application-based papers, mostly led by medical teams often omit factors such as 'Accessibility' and 'Burden to Others' from their consideration. Both tend to struggle particularly with addressing societal stigma, possibly due to the varying levels and types of stigma for at-home monitoring from researcher's home countries, or potentially due to considerations for more general issues not directly related to their specific research being deemed as outside of the scope of their work.

A common theme across all of these works is the tendency to make assumptions on the necessity of their application in the eyes of end-users (seen in Figure 4), as the lack of perceived need is seldom addressed regardless of the make-up of the research team. Technical issues are generally well addressed such as usability and reliability, however broader human issues such as societal stigma and feelings of end-users becoming a burden, or the technology itself being a burden to use by caregivers are likewise rarely addressed. Across the entire evaluation phase, there is a consistent trend of greater representation of every attribute when multi-disciplinary teams are involved in the research, with specifically technical teams being especially susceptible to a lack of focus on application-based concerns.

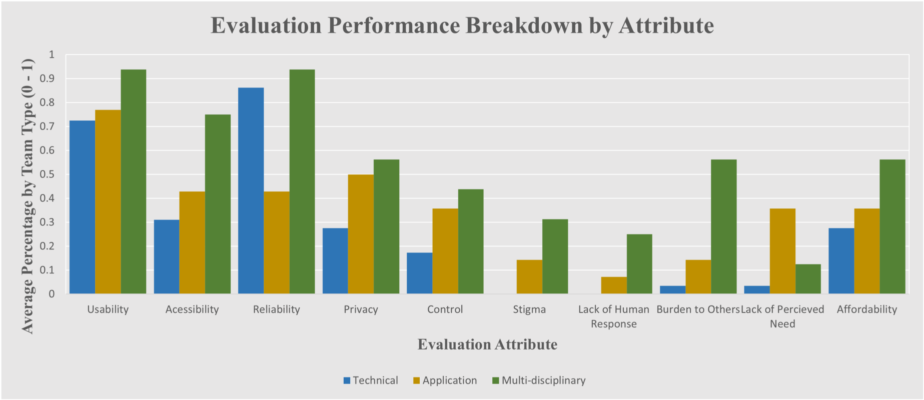

Fig. 4: Breakdown of the average presence of each evaluation attribute by research team type.

4 Discussion

The research presented here concludes that a root problem underlying the issues affecting real-life uptake of research applications is the lack of multi-disciplinarity in the research. Using a novel evaluation metric based on the 10 key barriers to uptake identified in the literature, a concrete trend can be observed that that multi-disciplinarity between engineers, computer scientists, medical experts, and social scientists, alongside co-design/PPI-based inclusion of caregivers and end-users is highly beneficial to the effective development of technology that has direct practical application and tangible social benefit. The evaluation framework itself was also justified by the demonstration of a trend of extremely high evaluation scores on research projects that had reached the point of sucessful practical application, namely HalleyAssist and SPHERE. Using this evaluation metric, we find a boost of between 19.3-27.5% for multi-disciplinary teams vs single discipline, and between 7.4-19% boost when research includes the use of caregivers or end-users in a PPI or co-design capacity.

The main limitation of this study is that the results can only demonstrate the lack of multi-disciplinarity is *a* root issue, not necessarily *the* root issue. For example, many extenuating factors not included in the research itself can explain why effective technology was researched but not developed, such as personal material conditions for the researchers, leading them to be uninterested or unable to develop effective research further. One other limitation is in the methodology of the framework itself. Ways to improve the descriptive power and nuance of the framework could be to introduce more criteria, break the criteria down into further sub-disciplines or introduce criteria weighting so that criteria deemed more "vital" or less common are weighted higher when calculating the score. To our knowledge their is no comparable work in quantitatively assessing the effects of multi-disciplinarity on research in at-home health monitoring, so in general, more research is needed to saturate the domain and allow for trends to be more concretely identified.

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Conflicts of Interest

This research was funded by the Legal & General Group (research grant to establish the independent Advanced Care Research Centre at University of Edinburgh). The funder had no role in the conduct of the study, interpretation or the decision to submit for publication. The views expressed are those of the authors and not necessarily those of Legal & General. To the authors knowledge there are no conflicts of interest during the undertaking of this research.

Supplementary Materials

The following link contains a .xlsl file containing all referenced supplementary materials including source tables and score-breakdowns for all of the reviewed works: [Supplementary Materials]

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Abbreviations

ML: Machine Learning PPI: Public and Participant Involvement ST-GCN: Spatio-temporal Graph Neural Network STJA-GCN: Spatio-temporal Joint Adjacency Graph Neural Network