Gerontology

Patient Acceptability of a Novel Technological Solution (Ambient Intelligent Geriatric Management System) to Prevent Falls in Geriatric and General Medicine Wards: A Mixed-Methods Study

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Abstract

Introduction: As effective interventions to prevent inpatient falls are lacking, a novel technological intervention was trialed. The Ambient Intelligent Geriatric Management (AmbI-GeM) system used wearable sensors that detected and alerted staff of patient movements requiring supervision. While the system did not reduce falls rate, it is important to evaluate the acceptability, usability, and safety of the AmbIGeM system, from the perspectives of patients and informal carers. *Methods:* We conducted a mixed-methods study using semistructured interviews, a pre-survey and post-survey.

The AmbIGeM clinical trial was conducted in two geriatric evaluation and management units and a general medical ward, in two Australian hospitals, and a subset of participants were recruited. Within 3 days of being admitted to the study wards and enrolling in the trial, 31 participants completed the pre-survey. Prior to discharge (post-intervention), 30 participants completed the post-survey and 27 participants were interviewed. Interview data were thematically analyzed and survey data were descriptively analyzed. *Results:* Survey and interview participants had an average age of 83 (SD 9) years, 65% were female, and 41% were admitted with a fall. Participants considered the AmbIGeM system a good idea. Most but not all thought the singlet and sensor component as acceptable and comfortable, with no privacy concerns. Participants felt reassured with extra monitoring, although sometimes misunderstood the purpose of AmbI-

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GeM as detecting patient falls. Participants' acceptability was strongly positive, with median 8+ (0–10 scale) on pre- and post-surveys. ***Discussion/Conclusion:*** Patients' acceptability is important to optimize outcomes. Overall older patients considered the AmbIGeM system as acceptable, usable, and improving safety. The findings will be important to guide refinement of this and other similar technology developments.

Introduction

Falls, a hospital-acquired complication, account for 40% of all safety incidents reported [1]. Falls are costly to the health system, with an Australian study reporting that patients who fall in hospital have an increased average length of stay compared to those who have not fallen, with an additional cost of AUD \$6,669 [2]. To date, multifactorial interventions following falls risk screening remain the cornerstone of falls prevention in hospital, but at best, risk may be reduced by 20% [3].

As the majority (86%) of inpatient falls are unwitnessed, occurring mostly in the patient's room (85%), followed by the bathroom [4, 5], our approach has been to explore providing extra monitoring through technology, with patients wearing sensors that detect risk movements and alert staff via a mobile phone carried by staff, providing staff with the opportunity to provide supervision when required to patients who are moving in the room, bathroom/toilet, and corridor.

Currently, inpatients can use the call bell to request supervision or support to move, though when people have fallen, very few have used the call bell (3%) [5]. The use of passive technology systems to alert staff can play an important role in preventing falls. Community-dwelling older adults have a positive view toward real-time monitoring technology related to falls detection, believing it helped them to feel safer knowing that they would receive assistance if they fell [6, 7]. Patients also had a positive view toward pressure sensor mats, with some feeling safer [8]. However, other patients limited their movement or deactivated the system to avoid feeling embarrassed or annoyed when alerts were triggered [8]. There is a paucity of research reporting the perceptions and acceptability of older inpatients using wearable sensors that detect risk movements with the aim of alerting staff and preventing as opposed to detecting falls [9–11]. Evaluating the acceptability of such an intervention from the user's perspective in a real-world setting is important as this

would allow system refinement in response to findings from the research, increasing the likelihood of future adoption of such systems in hospital settings, and increasing the likelihood of this type of intervention reducing inpatient falls.

To the best of our knowledge and when it comes to the use of wearable sensors to prevent falls, this is the first clinical trial that has explored the perspectives of patients and informal carers. The aim of this paper therefore was to report on our evaluation of the acceptability, usability, and safety of the Ambient Intelligent Geriatric Management (AmbIGeM) system from the perspectives of patients before and after they had used it (and their informal carers for patients with cognitive impairment). In the context of this paper, acceptability is defined as the extent to which recipients of an intervention consider it to be appropriate [12] and usability is defined as the extent to which recipients of an intervention can achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context [13].

Materials and Methods

Ethics
Human Research Ethics Committees and governance departments of two participating hospitals (TQEH [HREC/15/TQEH/17 and CALHN: Q20161007] and SCGH [HREC 2015-110]) and universities (University of Adelaide and Curtin University) granted Ethics Approval.

Setting
The effectiveness of the AmbIGeM system in reducing falls rate was investigated in two Geriatric Evaluation & Management Units (GEMU) and one general medical ward (Gen Med) at The Queen Elizabeth Hospital (TQEH), Adelaide, South Australia (SA), and Sir Charles Gairdner Hospital (SCGH), Perth, Western Australia (WA) [14]. The GEMU is a subacute ward providing comprehensive geriatric assessment and management to patients. The median length of stay for participants enrolled in the AmbIGeM intervention from the SA GEMU ward was 19 [IQR13–28] days, from the WA GEMU was 15 [IQR11–21] days, and from the WA Gen Med was 9 [IQR5–15] days [15]. Although the principles applying to GEMU are similar across Australia, length of stay can vary, in part influenced by the availability of discharge options. For example, between October 2020 and September 2021, the national Health Roundtable Benchmarking report provided for a GEMU national average length of stay of 17.1 days and a wide range of 4–26.1 days.

AmbIGeM Clinical Trial
A pragmatic stepped wedge trial was used to investigate the effectiveness of the AmbIGeM system in reducing falls. In brief, the AmbIGeM intervention consisted of a wearable sensor worn under hospital clothing, and a sensor attached to the patient's walking aid (where used), to detect patient movement. Sensor readings were transmitted to the ceiling located base stations in patient rooms,

Table 1. Outline of embedded acceptability study data collection in the intervention period of stepped wedge study design

Ward	Wedge1 25 weeks	Wedge2 25 weeks	Wedge3 25 weeks	Wedge4 25 weeks
SA GEMU 28 beds	Control (25 weeks)	Intervention (75 weeks) *Acceptability study* Pre-survey $n = 11$ Post-survey $n = 10$ Post-interview $n = 10$		
WA GEMU 14 beds	Control (50 weeks)		Intervention (50 weeks) *Acceptability study* Pre-survey $n = 10$ Post-survey $n = 10$ Post-interview $n = 10$	
WA Gen Med 32 beds	Control (75 weeks)			Intervention (25 weeks) *Acceptability study* Pre-survey $n = 10$ Post-survey $n = 10$ Post-interview $n = 7$

SA, South Australia; WA, Western Australia; GEMU, Geriatric Evaluation and Management; Gen Med, General Medicine.

doorway, and bathroom, which in turn relayed this to the AmbIGeM server. Staff identified and entered individual patient risk movements (getting out of bed, sitting to standing, walking without supervision, walking without aid) and locations (patient room, toilet, corridor) into the system, to alert when sensors detected those risk movements. Alerts were sent to clinical staff via handheld mobile phones (vibration and or sound mode) (see Visvanathan et al. [14, 15] for further description). The trial consisted of 4×25-week blocks, commencing on July 10, 2017, with all three wards being control (usual care) as shown in Table 1. Every 25 weeks, one ward transitioned to intervention until in the final 25 weeks, all three wards were intervention. Patients and families were given an information sheet about the trial and posters were placed around the ward. In SA, an opt-out consent process was in place where participants were included in the trial unless they opted out by signing the information sheet or telling the clinical or research staff. In WA, a consent waiver process was in place which waived the requirement to obtain informed consent, and if they did not want to participate, they withdrew by telling the clinical or research staff. During the intervention period, within 3 days of entering the ward, staff put the snug fitting singlet (also known as a vest, cami top, or sleeveless undershirt) with the sensor positioned over the patient's sternum (see Fig. 1), on patients who met the inclusion criteria (aged 65+ years, not receiving palliative management). In this clinical trial, the AmbIGeM system did not reduce falls rate, injurious falls rate, or proportion of fallers, although a post hoc analysis revealed that falls and injurious falls rates were reduced in participants in the GEMUs [15].

Acceptability Study

The acceptability studies used a concurrent mixed-methods approach to evaluate the acceptability, usability, and safety of the AmbIGeM system, with interview and survey data collected in the intervention periods of the stepped wedge study design (see Table 1) [7].

Consent

Patients gave written informed consent before being surveyed or interviewed. At TQEH, if participants could not provide informed consent, a person responsible (relative/guardian) was approached to provide consent, while at SCGH, if participants could not provide informed consent, they were excluded (ethics requirement).

Participant Recruitment

Nonprobability sampling was used to recruit 10 participants per ward (or less if data saturation was reached for the interviews) as shown in Table 1. Sampling was spaced to enable research staff to concurrently recruit and collect data for the three acceptability studies. The nursing team leader (independent of the research team) provided information about patients selected for the acceptability studies on whether patients had the capacity to understand what the research entailed (informed consent) and whether it was appropriate for research staff to approach them (e.g., patient too unwell). In SA GEMU only, for patients who were unable to provide informed consent, the nursing team leader could suggest the next of kin to be approached and interviewed.

Semistructured Interview

Every seventh participant enrolled in the AmbIGeM intervention was invited to participate in the interview approximately 3 days before expected discharge and after at least 2 days of experiencing the AmbIGeM system.

Surveys

Participants did not need to complete both the pre- and post-intervention surveys. Every fifth participant enrolled in the AmbIGeM intervention was invited to complete the pre-survey within 3 days of admission to the ward. Every fifth participant enrolled in the AmbIGeM intervention was invited to complete the post-sur-

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Fig. 1. Wearable sensor in the customized envelope pocket sewn onto inside of plain designed, 100% cotton white singlet.

vey approximately 3 days before expected discharge and after at least 2 days of experiencing the AmbIGeM system.

Data Collection

Demographic Information. Age, gender, a dementia diagnosis, and if admitted to hospital with a fall data were gathered as part of the trial.

Semistructured Interview. Participants' experience with the AmbIGeM system was explored through a short semistructured interview, being conscious of the need to minimize fatigue and excessive burden on patients recovering from the health problems causing their admission. Using an interview guide with open-ended questions about patient experience, what they liked or did not like, as well as any effects on their privacy, developed de novo by the research team (online suppl. Table 1; for all online suppl. material, see www.karger.com/doi/10.1159/000522657), it was pilot tested on the first interview and was considered appropriate. Interviews were conducted face-to-face at a time convenient to participants, avoiding scheduled ward routines, and at a location convenient and appropriate to participants, which was usually the participant's single- or multi-bedroom. Interviews were digitally recorded.

Six research staff collected data. They did not work as clinicians on the study wards and did not have a clinical relationship with staff or patients. Research staff included registered nurses, medical students, and health services researchers. Research staff conducting the interviews received an orientation to the protocol and the interview guide. The interviewers conducted or observed one interview with the lead researcher (A.W.) or the coordinator (J.D.) to receive feedback on their interview techniques and ask questions. Three research staff conducted interviews in SA GEMU (J.D. conducted 4 interviews [an interview each observed by A.Z. and N.N.], A.Z. conducted 5 interviews [1 interview observed by A.W. and N.N.; 2 interviews observed by J.D.], and N.N. conducted 1 interview [observed by J.D.]). Two research staff conducted interviews in WA GEMU (both E.M.B. and K.J. conducted 5 interviews [1 interview observed by K.J. and A.W.]) and one research staff conducted interviews in WA Gen Med ward (K.J. conducted 7 inter-

views). Audio files were professionally transcribed verbatim, deidentified, and checked for the topics covered in the interview guide.

Pre-Intervention Survey. A 6-item pre-survey was used to evaluate patient's expectations of acceptability prior to the intervention. These items were used in our previous research (online suppl. Table 2) [16, 17] and adapted from a validated questionnaire [18]. The response scale ranged from 0 to 10, with the highest positive rating being 10.

Post-Intervention Survey. A 24-item post-survey covering the domains of physical activity, hygiene, privacy, equipment, and anxiety was used to evaluate patient acceptability of the AmbIGeM intervention. These items were used in our previous research (online suppl. Table 3) [16, 17] and adapted from a validated questionnaire [18]. Two items from the post-survey had very minor wording changes and five items were added examining the acceptance of extending this technology for other groups of older adults at risk of falls, and in other settings (items 20–24). The response scale ranged from 0 to 10, with the highest positive rating being 10.

Research staff left the deidentified survey and envelope with consenting participants to complete before being collected. If participants preferred, research staff assisted participants to complete the survey by reading out the survey questions and response items and writing their responses.

Data Analysis

Semistructured Interviews. We took a realist epistemological approach, guided by Braun and Clarke's [19] approach to thematic analysis to analyze interview data. A deductive approach was used to explore the acceptability, usability, and safety as well as an inductive approach to developing other themes. M.Z., A.W., and J.D. read the interview transcripts multiple times to become familiar with the data. Initial codes were generated to organize data, phrase by phrase across the whole dataset, coding at the semantic level. Three researchers coded separately and then coded together as a group. Codes were added to a table in Microsoft word, with a column for the interview text, codes, and subthemes. Analysis was also conducted in Excel. Disagreement between coding was discussed by the three researchers to reach consensus. The list of codes was sorted and grouped together, like with like, to form seven subthemes, which the three researchers contributed and agreed to. These subthemes were reviewed, labeled, defined, and linked to the a priori themes of acceptability, usability, and safety to answer the research aim, as well as forming additional inductive themes. A.Z. then coded the rest of the transcripts using the coding framework.

Data saturation occurred when no new information was obtained by the 27th interview. Participant quotes support the themes and edited to remove unnecessary detail. Description of the ward, age range, gender, and participant type (patient or family) provides context for each quote.

Pre-Intervention Survey and Post-Intervention Survey. N.N. entered and J.D. rechecked all survey data into SPSS version 26.0. Pre- and post-survey item scores were not normally distributed; therefore, medians and 25th/75th percentiles were reported. The Kruskal-Wallis test was used to test for differences in the distribution of total scores between the three wards. The Mann-Whitney U-test was used to test for difference in pre-intervention acceptability (6 items) and also post-intervention acceptability (24 items) between participants who had or had not fallen prior to hospitalization.

Table 2. Demographic, fall history, and dementia diagnosis for pre-survey, post-survey, and post-interview participants

	Total (N = 88)[a]	Pre-survey (N = 31)[a]	Post-survey (N = 30)	Post-interview (N = 27)
Age, years				
M (SD)	83 (9)	84 (9)	84 (9)	82 (9)
Sex, n (%)				
Male	31 (35)	7 (23)	14 (47)	10 (37)
Female	57 (65)	24 (77)	16 (53)	17 (63)
Admitted with a fall, n (%)				
Yes	36 (41)	12 (39)	9 (30)	15 (56)
Dementia diagnosis, n (%)				
Yes	7 (8)	2 (7)	2 (7)	3 (11)

M, mean; SD, standard deviation; [a] Missing n = 1 as participant withdrew from the trial before further data were collected.

Results

Demographic Information

Approximately, two-thirds of all participants were female (cf., 55% for the trial) and the mean age was 83 years (i.e., similar to the trial) (Table 2). Only 8% had a diagnosis of dementia (cf. 17% in the trial). More than half of those interviewed, and one-third of those surveyed, had been admitted with a fall in the last 7 days (cf., 29% in the trial). On average, participants recruited for the post-survey and interview had been on the ward for 7.9 (SD = 4.5) days and 7.0 (SD = 3.6) days, respectively. No participants had fallen in hospital prior to completing the post-survey. Two participants had fallen in hospital prior to being interviewed. The 27 interviews ranged from 5 to 16 min (except for one interview lasting 36 min), with a total of 288 min of data recording.

Semistructured Interview

Of the 56 participants in the trial invited to participate in the interview, 27 participated (48% recruitment rate), three of which were family of patients from SA GEMU. Reasons to not participate included: declined (unwell) (n = 3), approached but discharged without interview (n = 15), or consent was not able to be gained (n = 11). The a priori themes of acceptability, usability, and safety of using the system and one inductive theme Information and Understanding about the system and trial were developed (online suppl. Table 4 for thematic map).

Theme 1: Preventing Falls Using the AmbIGeM System Was Appropriate and Valuable (Acceptability)

Participants found the AmbIGeM system and its purpose to be beneficial, appropriate, and valuable and indicated that they would value implementation in health care. Minor concerns were expressed about the singlet, but the sensor was acceptable and suggestions were made to expand capabilities of the sensor.

Subtheme: Acceptable

Participants and families understood the potential risk of falling in hospital, the impact of falls as an issue for older adults, and that falls were potentially preventable. The system was viewed as a good idea and will benefit those who needed supervision when moving.

> "Occasionally he might get up and go to the toilet. […] It's a good idea that the monitor is on there" (SA GEMU P5, son/wife of patient, male, aged 85–89).

The sensor size and location were acceptable with participants describing the wearable aspect of the system as being discrete, and the size of the sensor was small and noninvasive. One participant compared the sensor to another larger wearable monitor commonly encountered, the Holter monitor.

> "That's a good spot to have it (sensor), out of the way" (SA GEMU P7, wife of patient, male, aged 90–94).

Views on the singlet however varied. Positive comments included the singlet being viewed as ordinary wear

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that some participants already wore at home. Negative comments included the style of the singlet for women, though the few other negative comments about the look of the garment (e.g., not glamorous, pretty, or stylish) did not create much personal bother for these participants. Some participants acknowledged that the singlet sometimes became visible above their clothing.

> "I wear a singlet like this all the time; all my life" (WA Gen Med P6, male, aged 70–74).
> "It's such a big heavy ungainly thing for a woman. It always comes up above all your clothes and doesn't look exciting […]." (WA GEMU P7, female, aged 85–89).

Subtheme: Valuable

Participants mentioned that having a system that monitors participant movement and alerts staff provided a sense of reassurance and safety. This was particularly so when participants did not or could not use the call bell.

> "It's reassuring to know that someone is looking out for you. If you get into strife that you don't have to worry about a call bell […], that someone will come" (WA Gen Med P2, female, aged 70–74).

Participants indicated that they would like to see the implementation of the system across the health system, including in the wards, particularly with patients who are prone to falling or who are frail, and into other settings such as residential aged care or for older adults living in their own at home.

> "I can see it being rolled out across the wards […] where you've got more frail people" (WA Gen Med P2, female, aged 70–74).

There were two suggestions to enhance the capability of the sensor. These were to add vital sign monitoring such as heart rate and to add an emergency alert to the sensor that could be pressed, for those times the call bell could not be reached in an emergency.

> "Something that can also monitor the heart rate of the patient […] so it comes back to when the people are in trouble they can get the medical assistance right away" (SA GEMU P4, male, aged 75–79).
> "Call button, it's always on fixed places […] if I'm walking between here and there and fall over, well I want a nurse. How can I get a nurse? There's no button on the floor" (WA Gen Med P5, male, aged 65–69).

Theme 2: Experiencing Little Impact on Patient Experience (Usability)

Participants considered the system as usable, being in the main comfortable to wear, with little personal impact, privacy concerns, or disruption to the ward experience or routine.

Subtheme: Comfort

The majority of the participants thought that the sensation from wearing the singlet and sensor was negligible. There were varied responses in relation to the comfort of the singlet which was often related to their thermal comfort. The singlet was reported to be comfortable and some participants even reported improved sensory comfort level of the clothes or hospital gowns they wore from wearing the singlet. As participants generally found hospital rooms to be quite cold, the added warmth of the singlet added a positive impact to thermal comfort. However, for some, the singlets were too warm to wear, particularly in summer. Further, the singlet was not comfortable when the singlet was too small.

> "When I had the smaller one (singlet), it (the sensor) bothered me" (WA Gen Med P1, female, aged 80–84).
> "You can't feel it (singlet) […] It just fits the body" (WA GEMU P1, male, aged 90–94).
> "The singlet is very warm […] I feel very cold before" (WA GEMU P5, female, aged 80–84).

Subtheme: Personal Impact

For a few participants, their mobility and range of movement caused difficulties for them to put the singlet on independently. Participants considered that there was no invasion of privacy impacting on their actions, thoughts, conversations, and communications from the system. Many participants reported that they had forgotten that they were wearing the singlet or the sensor. Two participants experienced the sensor nearly falling out of the sensor pocket. One participant requested that the sensor be removed as they thought it might contribute to their vomiting.

> "I can't see how it can be intrusive […] Doesn't record our discussion, does it" (SA GEMU P7, wife of patient, male, aged 90–94).
> "I was having a vomiting attack and I was really unwell and I didn't want to have anything extra on me […]. That it [sensor] would contribute to vomiting, prolonging it" (WA GEMU P8, female, aged 65–69).

Theme 3: Enhanced Patient Safety (Safety)

Some participant's perceived sense of safety was enhanced by the system monitoring participant movement and location, as participants believed nurses would be able to quickly attend to them if needed and prevent falls. Participants and their families thought that the system was potentially a useful backup system when participants were unable or forgot to press the call bell.

"I feel safe with it, […] it works, and I feel secure" (SA GEMU P9, female, aged 90–94).

"Make people alert, know where he is […] and if something does happen, they can get there a little bit quicker. Won't have to rely on him pushing a button, because he might not be up to that" (SA GEMU P5, son/wife of patient, male, aged 85–89).

Participants identified that staff monitoring and response were key in the functionality of the system, and described variability in staff engagement. Some participants noticed staff checking on them and linked this with the sensors triggering alerts and nurses responding to the alerts, whereas others reported that staff did not check on them, with one example being a nurse attending 20 min after the family used the call bell and only after the family walked the participant to the toilet and back. Furthermore, some participants reported that staff sometimes did not put the singlet (and the sensor) on them.

"I think it's a very good idea […]. As long as the nurses attend" (WA GEMU P4, female, aged 80–84).

"When I was walking from the bed – about two feet – the nurse was there before I could really even steady myself […] they come running as quick as anything yes. […] a feeling of security" (WA GEMU P6, female, aged 80–84).

"Nobody came […] Well if the sensor goes off, they'll have to come and see what's going on. […] pop their head in and see" (SA GEMU P1, husband of patient, female, aged 75–79).

Theme 4: Insufficient Participant Information and Understanding

Not all participants thought that the patient information provided to participants in the clinical trial was adequate. Further, some participants' understanding of the purpose and mechanism of the system was incorrect.

Subtheme: Participant Information

Some participants thought that verbal or written information about why patients were wearing the singlet and sensor in the trial was inadequate, including for participants with English as their second language.

"The lady that was explaining this to me, she disappeared, and I never really heard any more about it. […] I know what it for, coz I read a little bit about it somewhere. But I wasn't aware that it's currently being used. […] until you mentioned it, I haven't really realised it's for falls" (SA GEMU P8, male, aged 75–79).

"She said it was just put on her and she didn't really understand the concept behind it. She is quite happy to wear it but it would have been really good if someone had told her, 'ok this is what we are going to do and why'" (SA GEMU P6, friend of patient, female, aged 80–84).

Also, some participants were unable to remember why they were wearing the singlet and sensor or what the sin-

glet and sensor does, possibly because of their inability to remember information communicated to them.

"I can't remember now quite what it's for" (WA GEMU P1, male, aged 90–94).

Subtheme: Participant Understanding

Participants understood the purpose of the system as monitoring patient's movements and to alert staff to provide supervision when patients were moving, in order to prevent falls.

"I think monitors his movement, that is a good idea. Because, his wife can't keep an eye on him 24/7" (SA GEMU P7, wife of patient, male, aged 90–94).

"It gives you a peace of mind […] you know that somebody's alerted if you are about to fall" (WA GEMU P5, female, aged 80–84).

"If you go out or the dining room or you go for a walk, and something happen to you, straight away they can come and help you" (SA GEMU P2, female, aged 85–89).

However, some participants misunderstood that the system had the capability to detect patient falls and immediately alert staff who would be able to provide immediate assistance. There was also a misunderstanding that the system allowed staff to locate patients in real time more than if the patients fell but also if they were wandering or missing, the misperception being that patients could be located wherever they may be as opposed to just in the patient room, toilet, or corridor. These understandings, particularly the belief that staff could immediately detect a fall, locate the patient and respond to the fall, which were associated with a strong sense of reassurance.

"Yes it is reassuring to know that if I fell over or something that someone would come running" (WA Gen Med P2, female, aged 70–74).

"Patients get up and start to wander, they go look for them but got no idea where they can be. With the sensor on them, they can actually see where they are" (SA GEMU P4, male, aged 75–79).

"If someone turns up missing, it's another method of finding them. I assume that is what it's for" (SA GEMU P8, male, aged 75–79).

Pre-Intervention Survey

Of the 46 participants in the trial invited to participate in the pre-survey, 31 participated (67% recruitment rate), one of which were family of a patient from SA GEMU. Reasons to not participate included: declined (not up to par, unwell) ($n = 3$), approached but discharged before completing survey ($n = 5$), or consent was not able to be gained ($n = 7$).

The median for all six items ranged between 8 and 10 (Table 3). The items that did not have a median of 10 were

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Table 3. Median and percentiles for pre- and post-intervention survey items

Item number	Item	Median [25, 75]
Pre-intervention items		
1	I expect this investigation can help prevent falls	8 [7, 10]
2	I believe if I wear this device I will have difficulties doing daily activities	10 [8, 10]
3	I am worried that the equipment will not give good enough signals for the research	9 [8, 10]
4	I am afraid that the equipment will fall from its attached position if I move too much	9 [8, 10]
5	I am afraid that the equipment will break if I move too much	10 [9, 10]
6	I am afraid that the equipment will harm me	10 [9, 10]
Post-intervention items		
1	How did you experience wearing the equipment while performing activities?	10 [9, 10]
2	How did you experience wearing the equipment attached to a special garment?	10 [9, 10]
3	How did you experience wearing the equipment knowing that someone could be aware of some of your activities?	10 [9, 10]
4	Were you hindered by the equipment while walking?	10 [10, 10]
5	Were you hindered by the equipment while sitting?	10 [9, 10]
6	Were you hindered by the equipment while lying?	10 [9, 10]
7	Did you experience a feeling of sweat and discomfort while wearing the equipment and garment?	10 [8, 10]
8	Wearing the device was no problem	10 [10, 10]
9	I was frightened by this technology	10 [10, 10]
10	I just forgot I am wearing it	10 [9, 10]
11	I don't want the equipment to be seen by others	10 [8, 10]
12	I don't like the feeling of being monitored	10 [9, 10]
13	I am afraid the equipment might suddenly stop working	10 [4, 10]
14	I am satisfied using the equipment	10 [9, 10]
15	I find the equipment easy to use	10 [10, 10]
16	I am comfortable being monitored if it can prevent injuries	10 [10, 10]
17	I am comfortable with being monitored even if there is no medical reason for this	10 [8, 10]
18	I am comfortable being monitored if I was able to get earlier help after a fall	10 [9, 10]
19	I am comfortable with being monitored if I was forgetful and forgot to ask for help	10 [10, 10]
20	I feel that this technology will benefit older people with dementia	10 [10, 10]
21	I feel that this technology will help me or others care better for a family member or friend with dementia	10 [10, 10]
22	I feel that this technology may help frail older people live independently in their own home longer	10 [8, 10]
23	I am comfortable with being monitored if I was at risk of falling	10 [10, 10]
24	I feel that this technology may prevent falls in nursing homes	10 [9, 10]

Response scale: scale 0–10; highest positive rating per item = 1.

expecting that the intervention can prevent falls, being worried the equipment would not give good enough signals and being afraid the equipment will fall from its attached position. Acceptability measured that pre-intervention (six items) was not statistically significantly different between those who had or had not fallen prior to hospitalization (all $p > 0.05$).

Post-Intervention Survey

Of the 55 participants in the trial invited to participate in the post-survey, 30 participated (55% recruitment rate), one of which were family of a patient from SA GEMU. Reasons to not participate included: declined (not up to par, unwell) ($n = 3$), approached but discharged before completing survey ($n = 15$), or consent was not able to be gained ($n = 7$).

The median for all 24 items was 10, indicating very strong endorsement of all domains of the technology system evaluated in the survey, including not being hindered by the equipment, being comfortable, being monitored, and benefits of technology for other people at risk of falls (Table 2). Acceptability measured that post-intervention (24 items) was not statistically significantly different between those participants who had or had not fallen prior to hospitalization (all $p > 0.05$).

Discussion

The key findings from this aspect of the trial were that participants were positive about the technology system, with qualitative evaluation revealing most but not all finding the system acceptable, usable, and improving safety. These findings suggest that wearable sensor-based health information systems may find a place in clinical practice where refinement of the system and technology advancement results in the system cost-effectively preventing falls (and injurious falls), which unfortunately was not the case in our recent trial [15].

There appears to be an appetite for consumers for technology systems to improve their safety. Prior to commencing the intervention, participants rated their expectations of the system positively and ratings were also positive for those having experienced the intervention. This was despite whether participants had a recent prehospital fall or not, likely because falls are already common in this population [20]. These ratings were more positive than two previous studies, where similar older patients admitted to a GEMU wore wearable (W_2ISP) sensors for a shorter duration than our study (less than 90 min vs. our study of approximately 1 week) [16, 17], the likely explanation being the wearable sensor in the current study was smaller and less visible, and hence more acceptable. The purpose-built, small coin cell battery powered BLE sensor used in this study was rated more positively than the obtrusive batteryless W_2ISP sensors used in the earlier version of the AmbIGeM system [16, 17], "I just forgot I am wearing it" (median of 10 vs. 7/8). However, further improvements or alternatives to the singlet are worth future investigations, with user involvement. The emergence of patch systems may provide a suitable alternative [21].

Patients and their families viewed the system as improving patient safety. As reported elsewhere, monitoring systems give older adults a sense of reassurance and security, which they value [8, 22]. Participants recognized the importance of a timely staff response for the AmbIGeM system to work. Staff engagement in the system is paramount and the system cannot replace clinical management, as participants and carers expressed feelings of security from staff checking in on them. Participants did not mention that being monitored decreased their movement in hospital, as has been reported with pressure sensor alarms [8]; as importantly, mobility restriction can contribute to deconditioning [23].

The use of wearable sensors to detect movement in the hospital setting did not raise concerns about privacy (confirming survey and interview data), similar to our previous pilot study [16, 17]. Privacy concerns have previously been raised about other types of monitoring in hospital [24], and the difference may be explained by monitoring via real-time video versus the use of wearable sensors supported by predictive algorithms. Even though privacy was not reported as a concern, there may be an implicit trade-off for the perceived increase in safety of hospitalized older adults who were in an unfamiliar environment and personally may have viewed falls as a major concern, with 41% in this study having very recently experienced a fall.

An important benefit perceived by participants was the fact that call bells were not the sole method for alerting staff. Some older adults forget to use, cannot use, or are reluctant to use the call bell [25, 26], and in any case, the majority of falls occur unwitnessed [4, 5]. There was support for translation of this strategy outside of hospital to residential aged care as well as people's homes, and benefit was seen for older adults, particularly those at risk of falling, with frailty and dementia.

A suggestion included expanding monitoring from movement to include vital signs such as heart rate [27] as well as to function as an alert pendant following a fall and a location monitor for wandering patients [28], a possibility with the evolution of sensor technology [29]. Some participants misunderstood that the system worked by detecting patient falls in all locations rather than being limited to where readers were placed, understandably because other alarm systems exist to address commonly known problems in older adults such as falls detection or wandering alarms [30]. Other studies have also found that older participants had limited understanding of the technology monitoring system they had used [8, 22]. In this study, opt-out and consent waiver processes were in place for the study trial with information sheets provided to patients on admission and posters displayed on the ward walls [14]. This might have contributed somewhat to participant misunderstanding.

A strength of this study was that acceptability of the AmbIGeM system was explored prior to and after an average of being on the ward for 7 days, in a real-world context addressing a knowledge gap in the research field of wearable sensors [31]. Our study incorporated mixed-methods that allowed for the development of a more complete understanding of patient acceptability of this novel sensor system [32]. Limitations of the study include that the post-survey and interview only included participants who were retained in the trial (i.e., not those who had withdrawn from the participa-

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tion and may hold differing opinions), and the surveys included a relatively small sample size. The interviews were quite short, and with some interviews being held in multi-bedrooms, it is unknown if participants' responses were influenced by the presence of others. Further, research staff being in the role of interviewers could have biased findings.

Participants experienced the AmbIGeM system for an average of a week on a study ward and overall found it to be an acceptable, usable, and safe to monitor patient movement to prevent or reduce falls in hospitalized older adults. Participants provided suggestions for extending the system to detect falls, measure vital signs, and for use in other settings where older adults are cared for. The findings from this study may guide the refinement of the system with other options for monitoring such as using sensor patches rather than sensors in singlets [27]. It is however clear that there are optimism and hope from participants that such systems may improve their safety in health care, which bodes well and provides a basis for further research.

Statement of Ethics

Procedures were followed as assessed by the Human Research Ethics Committees and governance departments of the two participating hospitals (TQEH [HREC/15/TQEH/17 and CALHN: Q20161007] and SCGH (HREC 2015-110]) and universities (University of Adelaide and Curtin University) granted ethics approval. Participants gave written informed consent. The person depicted in Figure 1 gave written informed consent for publication of their picture.

Conflict of Interest Statement

A patent titled "System, method, software application and data signal for determining movement" was filed by the Associate Professor Ranasinghe and Professor Visvanathan (lapsed 2015). Professor Visvanathan is the Director of Aged & Extended Care Services at The Queen Elizabeth Hospital in South Australia within which SA GEMU sits. The remaining authors have no conflicts of interest to declare.

Author Contributions

R.V., A.W., K.D.H., K.L., and D.C.R.: substantial contribution to conception, design, and oversight of the work including securing grant funding; analysis or interpretation for the work; drafting the work or revising it critically for important intellectual content; final approval of the version to be published; and agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. J.D., K.J., E.M.B., M.Z., and N.N.: substantial contributions to acquisition, analysis, or interpretation of data for the work; drafting the work; final approval of the version to be published; and agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Data Availability Statement

The data that support the findings of this study are not publicly available as this was not requested of and therefore approved by the Ethics Committee. Given the smaller number of participants, the available information could compromise the privacy of research participants.

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