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ORIGINAL ARTICLE

The use of augmented reality for patient and significant other stroke education: a feasibility study

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Abstract
Background: Stroke education is a key factor in minimising secondary stroke risk, yet worldwide stroke education rates are low. Technology has the potential to increase stroke education accessibility. One technology that could be beneficial is augmented reality (AR). We developed and trialled a stroke education lesson using an AR application with stroke patients and significant others.
Methods: A feasibility study design was used. Following development of the AR stroke education lesson, 19 people with stroke and three significant others trialled the lesson then completed a customised mixed method questionnaire. The lesson involved narrated audio while participants interacted with a model brain via a tablet. Information about participant recruitment and retention, usage, and perceptions were collected.
Results: Fifty-eight percent ($n = 22$) of eligible individuals consented to participate. Once recruited, 100% of participants ($n = 22$) were retained. Ninety percent of participants used the lesson once. Most participants used the application independently (81.82%, $n = 18$), had positive views about the lesson (over 80% across items including enjoyment, usefulness and perception of the application as a good learning tool) and reported improved confidence in stroke knowledge (72.73%, $n = 16$). Confidence in stroke knowledge post-lesson was associated with comfort using the application ($p = 0.046$, Fisher's exact test) and perception of the application as a good learning tool ($p = 0.009$, Fisher's exact test).
Conclusions: Technology-enhanced instruction in the form of AR is feasible for educating patients and significant others about stroke. Further research following refinement of the lesson is required.

Keywords: Augmented reality; stroke; stroke education; feasibility; prevention

Introduction
Stroke is the second highest cause of death globally and the third most common cause of disability (Feigin, Norrving, & Menash, 2017). The risk of stroke recurrence is high, with the accumulated risk of a second stroke at 43% over ten years (Hardie, Hankey, Jamrozik, Broadhurst, & Anderson, 2004). The chronic and pervasive consequences of stroke can negatively impact an individual's quality of life, social engagement and ability to work. Stroke education about the mechanisms of stroke and prevention is a key factor in minimising secondary stroke risk. Consequently, stroke education features prominently in clinical guidelines and best practice recommendations for stroke worldwide (Cameron et al., 2016; Stroke Foundation, 2020).

While a number of researchers have explored stroke education, there is a lack of consensus about the critical ingredients and optimal delivery format. At a broad level, stroke education is divided into two types: stroke education targeting the general population and/or people at high risk of stroke (Chan et al., 2015; Marto, Borbinha, Filipe, Calado, & Viana-Baptista, 2017; Williams et al., 2019), and stroke education targeting stroke survivors and their significant others. This paper will focus on stroke education provided to stroke survivors and their significant others for the purpose of secondary stroke prevention. Given the high risk of secondary stroke (Hardie et al., 2004) and the preventable nature of stroke with a reduction in risk factors (Kim, Lee, & Kim, 2013), the aim of stroke education after admission to hospital for stroke is typically focused on secondary stroke prevention (Kim et al., 2013), recovery/recognition of stroke (Stroke Foundation, 2020) and informed choice about health care decisions (Forster et al., 2012).

Stroke education is diverse in depth and breadth and can be provided in various formats, including; paper-based leaflets, workbooks, computer programs or websites, or verbally (Forster et al., 2012). In the current digital age, there is also a vast array of online resources available to stroke survivors and their significant others (e.g., See https://www.cdc.gov/stroke/materials_for_patients.htm; https://enableme.org.au/). Forster et al. (2012) suggested that stroke education can cover a plethora of content but typically includes information about one or more of the following areas: stroke causes and type; management and recovery from stroke; secondary stroke prevention; and information about resources or services available. The timing of stroke education varies, with no single ideal time identified. However, it is recognised that stroke education should not be a single isolated event and should instead occur across the continuum of care (Cameron et al., 2016). With respect to outcomes, the effects of stroke education are typically measured in terms of patient satisfaction (Meighan, 2018), knowledge about stroke or services (Forster et al., 2012; Johnson, Handler, Urrutia, & Alexandrov, 2018), or the impact on mood (Forster et al., 2012). However, other outcomes have also been briefly explored, including activities of daily living, participation, social activities, health status and quality of life, service use, risk reduction, death, carer outcomes and the costs to health and social services (Forster et al., 2012).

Despite the recognised importance of stroke education, current stroke education provision is challenged by a number of issues. Access to stroke education is a major barrier. A 2017 Stroke Foundation audit found that approximately 30% of stroke patients in Australia did not receive education about preventing risk factors for stroke while in hospital (Stroke Foundation, 2017). This result has been echoed internationally, with 40% of stroke patients in the United States of America (USA) reporting that they receive inadequate stroke education (Meighan, 2018). There is a need to develop new approaches to stroke education that are accessible on multiple occasions. Current access to stroke education is in direct contrast with the recommendation that stroke education should occur across the continuum of care (Cameron et al., 2016). Additionally, people with stroke report low levels of satisfaction with the education when it is provided (Yonaty & Kitchie, 2012). Questions have also been raised about optimal ways to enhance retention of stroke education (Johnson et al., 2018). Consequently, there is an urgent need to provide stroke education to people with stroke and their significant others in an accessible, engaging and effective way. This thought has been echoed by the Canadian Best Practice Guidelines for Stroke, which recommend that stroke education needs to '. . . be interactive, current, ongoing, repetitive, evaluative and available in a variety of languages and formats . . . it should address varying levels of health literacy and ensure access to communication . . . ' (Cameron et al., 2016, p. 812).

In the rapidly growing digital age, technology may help meet this need and there has been an exploration of stroke education using technology. Delivering stroke education using technology has the potential to increase not only the accessibility of stroke information for people with stroke and their significant others but also their level of engagement with the education. A Cochrane review by Forster et al. (2012), which was an update on an earlier 2009 review, found that stroke education with active stroke information provision (i.e., the active inclusion of patients and significant others in the education with multiple opportunities for them to ask questions) had a greater positive impact on patient mood than more passive information provision (i.e., the information was provided on a single occasion only to patients and significant others). Technology can provide a novel modality to facilitate active information provision. Therefore, there is a need to explore technologies that involve interaction and engagement with education to increase active stroke information, rather than the passive reading of website materials.

Thompson-Butel et al. (2018) conducted a small qualitative study with four people with stroke and significant others. Following a three-dimensional virtual reality (VR) stroke education lesson, participants reported improvements in stroke knowledge, risk factors and management, as well as increased motivation to manage stroke risks. While this is a promising result, VR may be limited by potential nausea, dizziness and headache as side effects (Feng, González, Amor, Lovreglio, & Cabrera-Guerrero, 2018), a requirement for expensive VR equipment and infection control concerns with cleaning VR equipment. Consequently, there is a need to explore the use of less expensive and more scalable mobile technologies, such as participants' own devices for delivering stroke education. Kang et al. (2019) trialled the use of a Stroke Health Education Mobile App (SHEMA) compared to a stroke health education booklet. Both approaches significantly improved participants' knowledge of stroke risk factors, with no significant difference between the two modalities. Neither approach significantly improved health-related quality of life (Kang et al., 2019). As the application presented the electronic information passively, rather than requiring active engagement through information-based activities, there is a need to explore technology-based stroke education methods that require active engagement.

An alternative technology that may meet this need is augmented reality (AR). AR is the use of a tablet or smartphone with a camera to view items in the real world as a digital model. The person using the tablet or smartphone can interact with the digital model and the real-world item (Moro, Stromberga, Raikos, & Stirling, 2017). One advantage of this approach is that individuals can use their own devices. This is particularly relevant when considering sterile clinical settings. AR has been found to be useful in medical education (Moro et al., 2017); however, it is unknown whether the technology can improve the accessibility and effectiveness of education to people with stroke. AR has facilitated learning in healthy students by increasing engagement, immersing the learner in the experience (Birt, Stromberga, Cowling, & Moro, 2018) and increasing knowledge gain (Albrecht, Folta-Schoofs, Behrends, & Von Jan, 2013). Studies with healthy young adults have revealed that AR can effectively teach medical students brain anatomy without the potential side effects of VR (Moro et al., 2017). As knowledge of brain anatomy and the mechanisms of stroke are often important ingredients in stroke education, AR may be a salient modality for providing this content to people with stroke. As yet, no research has explored whether AR can be used to teach people with stroke and their significant others about brain anatomy and the mechanisms of stroke. AR is ideally situated as a potential learning tool in stroke education. AR has the ability to enable active participation in the education (as active stroke education has been found to promote greater benefits than passive stroke education) (Forster et al., 2012), lack of specialised equipment (unlike VR, AR can be used with the participant's phone or tablet, rather than requiring a specialised headset), ability to localise the learning within a real-world context, and fewer adverse effects than VR. There is a need to explore whether AR can enhance stroke education for patients and their significant others. If found to be beneficial, AR could be used to teach people with stroke and their significant others about the brain and mechanisms of stroke as part of a suite of stroke education resources. This is important because stroke education that involves multiple methods has been found to promote better information retention than one method alone (Chan et al., 2015).

Aims and hypotheses

The overall aim of the study was to develop and trial the delivery of a stroke education lesson using an AR application on a computer tablet with people with stroke and their significant others.

Specifically, the study aimed to (1) explore key parameters relevant to a subsequent more extensive study (including usage and recruitment rate and retention), and (2) explore people with stroke and their significant others' perceptions of the stroke AR education lesson and confidence in their knowledge of stroke after the stroke education AR lesson. It was hypothesised that the AR stroke education would (1) have favourable recruitment, retention and engagement, (2) be perceived favourably by end users, and (3) improve the stroke-specific knowledge and confidence of people with stroke and their significant others.

Materials and methods

Design

The project used the Medical Research Council framework for developing complex healthcare interventions (Craig et al., 2008). Within the framework, the current project represented the development and trialling of a novel intervention (stroke education lesson via AR) in the form of a feasibility study to inform a subsequent larger-scale evaluation project. According to Bowen et al. (2009), feasibility studies help determine which interventions should progress to large-scale evaluation. As such, the current study was a critical step in developing a new healthcare intervention to help meet stroke education needs. Additionally, feasibility studies are ideal when there is limited existing data for the specific intervention or when the target population has unique considerations (Bowen et al., 2009). The current study trialled a novel intervention in a patient population with unique considerations (i.e., people with stroke who can experience stroke-related changes in areas such as communication, cognition and physical function). A convergent parallel mixed methods study design was used within the feasibility study, which involved the simultaneous collection of quantitative and qualitative data (Creswell & Plano Clark, 2011).

Participants

Participants were recruited in one of two groups. The first group had experienced a stroke and were a current or past inpatient at the recruiting hospital. The second group comprised significant others (family members or friends) of someone admitted to the recruiting hospital with a stroke. A convenience sample of 19 people with stroke and three family members was recruited. Participant demographic details were collected (see Table 1). The study inclusion criteria were: adequate English skills to complete the study questionnaires and aged over 18 years (with no upper age limit). Participants with post-stroke communication and cognitive impairments or a non-English speaking background were included if they could communicate with support. This communication support was provided by the study research assistant, a qualified speech pathologist with training in facilitating communication in people with communication difficulties. Stroke-related physical impairments, such as hemiplegia, did not preclude participation in the study. Each tablet was placed on a stand on the table, which enabled participants to interact with the lesson using one hand only. Individuals admitted with a diagnosis other than stroke were excluded. Due to the study being a feasibility study, participants were not stratified according to any measure or demographic feature.

Procedure

Ethical approval was obtained from the relevant Human Research Ethics Committee. All participants provided informed written consent. The study involved two stages:

Stage 1 (Development of the stroke education lesson AR application). The research team created a tablet-based AR application using Unity 3D (Unity Technologies, San Francisco, California, USA) with C# coding for the interactive elements. The 3D brain model was created using 3D Studio Max (Autodesk Inc., California, USA) and further colorised and labelled using

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Table 1. Participant Demographic Information

Demographic characteristic	People with stroke ($n = 19$), n (%)	Significant other ($n = 3$), n (%)
Gender		
Female	7 (37%)	2 (67%)
Male	12 (63%)	1 (33%)
Age range (years)		
26–40	1 (5%)	–
41–65	10 (53%)	2 (67%)
66–73	5 (26%)	1 (33%)
74–81	2 (11%)	–
>82	1 (5%)	–
Science degree or formal training about the brain		
Yes	2 (11%)	0 (0%)
No	17 (89%)	3 (100%)
If yes, how would you describe your knowledge of the brain?	($n = 2$)	N/A
I do not know much about the brain	2 (100%)	–
I know the anatomy of the brain well	0 (0%)	–
Prior experience using a tablet device		
No	7 (37%)	2 (67%)
Yes – rarely (less than once per week)	3 (16%)	0 (0%)
Yes – more than once per week	9 (47%)	1 (33%)

Note: Percentages are rounded to the nearest whole number.

Cinema4D (Maxon Computer, Friedrichsdorf, Germany). The file was exported to SM-T810 Galaxy S3 Tablets (Samsung, Seoul, South Korea). The handheld markers (multicoloured cubes) were created using a Replicator 5 3D Printer (Makerbot Industries, New York, United States). The participant was able to navigate freely through the software. As the model was attached to the marker (multicoloured cube) in the participant's hand, the model of the brain rotated by moving the marker (i.e., the multicoloured cube). Whenever the participant moved the cube, the image of the brain on the tablet moved in the same manner. This enabled visibility of all angles and viewpoints of the brain. By moving the marker (multicoloured cube) closer to the camera, the image on the screen was enlarged. Tapping on the screen over the brain highlighted that visible region and provided its name in a text box anchored to the lower portion of the screen. Once highlighted, the participant could tap a 'dissect' button and remove that layer to view the underlying features of the brain (Fig. 1).

Once the participant had familiarised themselves with the software, the interactive audio lesson commenced. This was narrated from a stroke education script developed and refined by the research team based on information currently provided to patients in written form through resources such as the Stroke Foundation's My Stroke Journey (Stroke Foundation, 2019). A readability analysis within Microsoft Word indicated that the script was at an appropriate reading level for the general population. The script was designed to explain brain anatomy and physiology, mechanisms of stroke, and potential post-stroke difficulties. This became the guiding audio

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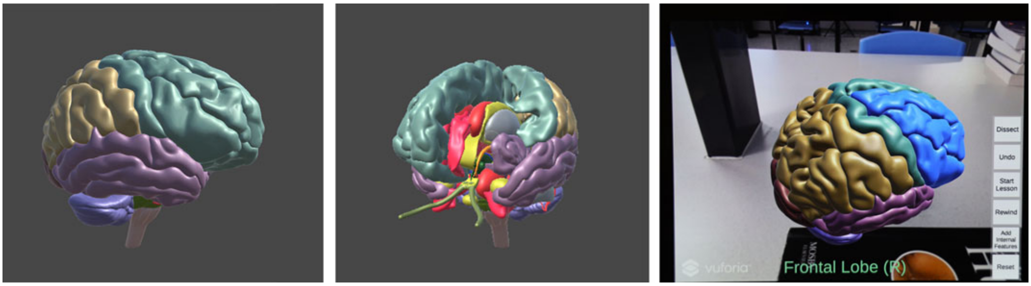

Figure 1. Model of the brain created for the study. The participant can freely navigate the model and remove layers to view the labelled underlying features.

narration played through the tablet speakers. As the narration advanced, the relevant areas of the brain being discussed were highlighted in different colours to guide the participant's attention during the lesson. If the participant had previously removed (dissected) the part of the brain being described, the software would automatically return this part of the model to view and then highlight as appropriate. The participant could also pause or rewind the audio stream at any time in order to explore the model at their own pace during the lesson.

Stage 2 (Evaluation of the stroke education lesson AR application). This stage involved trialling the lesson with people with stroke and their significant others at the recruiting hospital. A research team member set the participant up with the stroke education lesson AR application running on a tablet. This research team member provided communication or physical support (e.g., holding the cube) if participants had any stroke-related communication or physical impairments. Participants were instructed by the research team member that they could access the lesson on the tablet as many times as they desired. Participants completed the customised mixed methods questionnaire following the education lesson.

Outcome measures

The primary outcome measure was the participants' frequency of use of the lesson. The secondary outcome measures included: (1) whom participants used the application with (e.g., visitors, hospital staff), (2) participant recruitment (rate and retention), (3) completion rate of the questionnaire and (4) participants' responses on a customised mixed method questionnaire exploring their perceptions of the application, usage, confidence with stroke knowledge, empowerment and confidence telling other people about stroke. Responses to the mixed methods questionnaire were a combination of 11–13 dichotomous rating scales (the number of questions depended on participant's answers) and four free text open-ended responses. The open responses were: *please state any symptoms or feelings experienced during the lesson (if applicable); the parts of the application which I found most useful were; the parts of the application which I found least useful were; and suggestions for improvements*. A research team member (a qualified speech pathologist) provided communication support if participants had any stroke-related communication impairments. Management and support of post-stroke communication disorders is common practice for speech pathologists. As the researchers in direct contact with participants were speech pathologists with experience working with patients post-stroke, communication strategies were provided in the form of non-verbal (i.e., gesture) and compensatory prompts (simple sentences, slower rate of speech, emphasis on key words and phrases). The presence of communication impairments was recorded throughout data collection. To facilitate the involvement of participants with post-stroke communication impairments, dichotomous (yes/no) rating scales were used where possible.

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Data analysis

Quantitative dichotomous scale data, recruitment information and participant usage data were analysed descriptively using counts (and percentages where appropriate). Free text open-ended questions were analysed using inductive qualitative content analysis (Graneheim & Lundman, 2004). This process involved the repeated reading of participants' responses to the questions, generating codes and then grouping the codes into categories and sub-categories. Rigour in the qualitative analysis was ensured through the following processes: (1) the coding process was completed by a member of the research team, (2) another member of the research team then checked it, (3) field notes were kept by the study research assistant when collecting the data and (4) an audit trail was kept of decisions related to the qualitative analysis. This enabled a further level of methodological rigour and triangulation of the quantitative and qualitative responses. To explore the association between different responses to the dichotomous questions, a series of Fisher's exact tests were conducted using IBM Statistical Package for the Social Sciences (SPSS version 26) to explore whether there was an association between prior experience using a tablet device, enjoyment using the application, feelings of comfort with using the application, confidence with knowledge about stroke and perceptions towards the application as a good learning tool. Fisher's exact tests were used due to cell counts of less than 5 for over 20% of cells.

Results

In terms of participant recruitment and retention, 58% of eligible individuals consented to participate in the study ($n = 22$); however, once recruited 100% of participants ($n = 22$) were retained. Two participants (one person with a stroke and one significant other) used the application more than once. The remaining participants (people with stroke $n = 18$; significant others $n = 2$) reported using the stroke education lesson AR application only once. The majority of participants reported using the application independently (people with stroke $n = 16$; significant others $n = 2$). Four participants reported showing the application to family members or friends (people with stroke $n = 3$; significant others $n = 1$).

All participants completed the customised mixed methods questionnaire. Fifteen participants required the research assistant to enter the answers due to communication or physical impairments.

Dichotomous responses

Participant responses (counts and percentages) to the dichotomous rating scale items are presented in Table 2. According to the dichotomous responses, the majority of participants enjoyed using the stroke education lesson AR application and thought it was a useful learning tool. The majority of participants also found the information useful and thought it was easier to understand brain anatomy when presented in three dimensions (e.g., during the application). Approximately three-quarters of people with stroke and two-thirds of significant others believed that they were more confident in their knowledge of stroke after using the application.

Participants generally thought the lesson would help their family and friends better understand stroke if they used the application; however, more people with stroke believed this was the case compared to significant others (See Table 2). All of the significant others and over half of people with stroke thought that they were better able to explain stroke to other people after using the application. The majority of participants felt better prepared for the next conversation with their family member's medical team after using the application. Approximately three-quarters of people with stroke and two-thirds of significant others believed that the software was user friendly and felt comfortable using the application.

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Table 2. Participant Perceptions of the AR Application According to Dichotomous Rating Scale Responses

Question	People with stroke ($n = 19$)		Significant other ($n = 3$)		Combined ($n = 22$)	
	Yes	No	Yes	No	Yes	No
I enjoyed using this application	17	2	2	1	19	3
	89.47%	10.53%	66.67%	33.33%	**86.36%**	13.64%
This application provided useful information	17	2	3	0	20	2
	89.47%	10.53%	**100.00%**		**90.91%**	9.09%
It is easier to understand anatomy when I can see it in 3D	16	3	3	0	19	3
	84.21%	15.79%	**100.00%**		**86.36%**	13.64%
This is a good learning tool	15	4	3	0	18	4
	78.95%	21.05%	**100.00%**		**81.82%**	18.18%
The software was user friendly	14	5	2	1	16	6
	73.68%	26.32%	66.67%	33.33%	72.73%	27.27%
The instructions and labels were clear	15	4	3	0	18	4
	78.95%	21.05%	**100.00%**		**81.82%**	18.18%
The spoken words were too long and detailed	10	9	2	1	12	10
	52.63%	47.37%	66.67%	33.33%	54.55%	45.45%
I felt comfortable using this application	15	4	2	1	17	5
	78.95%	21.05%	66.67%	33.33%	77.27%	22.73%
The content was easy to understand	12	7	2	1	14	8
	63.16%	36.84%	66.67%	33.33%	63.64%	36.36%
I am more confident in my knowledge about stroke	14	5	2	1	16	6
	73.68%	26.32%	66.67%	33.33%	72.73%	27.27%
I am better able to explain stroke to other people	11	8	3	0	14	8
	57.89%	42.11%	**100.00%**		63.64%	36.36%
I am better prepared for my next conversation with my medical team after using this application	14	8	3	0	17	8
	73.68%	42.11%	**100.00%**		77.27%	36.36%
It would help my family and friends to better understand stroke if they used this application	17	2	2	1	19	3
	89.74%	10.53%	66.67%	33.33%	**86.36%**	13.64%

Note: Responses with over 80% yes response are bolded.

Regarding changes to the lesson, over half of all participants reported that the spoken words were too long and complicated (See Table 2). At the same time, approximately only two-thirds thought that the content was easily understandable. In contrast, the majority of participants thought that the instructions and labels were clear.

Open-ended responses

Table 3 presents the qualitative analysis of participants' open-ended responses, including categories, sub-categories and exemplar quotes. Responses were grouped into four categories: *Symptoms or feelings experienced*; *The aspects I found useful*; *The aspects I found least useful*; and *Suggestions*

Table 3. Qualitative Analysis of Participants' Open-Ended Responses

Category	Sub-category	Exemplar quotes
Symptoms or feelings experienced	Felt informed ($n = 2$)	*I understood much better how the brain worked. I felt more informed [P01]*
	Felt more confident ($n = 1$)	*I feel a bit more confident knowing what I'm looking at. After you have had a stroke, you can look at things, and it doesn't register but having labels is useful [P03]*
	Felt stressed due to my time in hospital ($n = 1$)	*I feel stressed because I've been in hospital too long. I didn't feel stressed about the app[lication] [P04]*
	Sleepiness ($n = 2$)	*Tired but not necessarily because of the app[lication] [P19]*
	I became annoyed and disengaged ($n = 3$)	*The further it went, the more disengaged I felt. I didn't understand what is being talked about. Limited explanation. I was engaged at the start, and I was enthusiastic at the start [P14]* *Overwhelmed [P12]*
	Felt interested ($n = 2$)	*Interested [P11]*
	Felt like an idiot ($n = 1$)	*Because it was using terms you're not familiar with you can feel like a bit of an idiot [F03]*
	I felt ok ($n = 2$)	*Felt ok [P06] [P08]*
The aspects I found useful	The interactive dissection ($n = 5$)	*Dissection. It was great to be able to see the different sections and relate them to their primary functions [F01]*
	Seeing the brain ($n = 5$)	*Having a look at where my stroke affected me in terms of part of the brain [P15]*
	Learning about the brain and stroke ($n = 6$)	*The general explanation of how the brain works and various areas of the brain responsible for thinking, speech and walking [P14]*
	Nothing was useful ($n = 2$)	*Nothing was useful [P06]*
	The technology ($n = 3$)	*The 3D was superb [P18]*
The aspects I found least useful	The labelling could have been clearer ($n = 2$)	*No arrows pointing to which parts we were talking about [P11]*
	More variety ($n = 2$)	*That it is one set diagram instead of being all segregated. It would be better if the diagram was broken up [P03]*
	More information ($n = 1$)	*I would like to explore more about clots and see the clots [P04]*
	Technological issues ($n = 2$)	*Application froze [F01]*
	The language was too complicated ($n = 4$)	*Some words were hard to understand [P09]*

(*Continued*)

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Table 3. (*Continued*)

Category	Sub-category	Exemplar quotes
	It was too long ($n = 2$)	*The speed of the lesson [P13]*
	More interaction ($n = 2$)	*Not being able to interact or replay certain parts. It wasn't entertaining enough [P10]*
	Wasn't delivered in a quiet area ($n = 3$)	*Using it in this environment because of the noise [P19]*
Suggestions for improvement	More information and features ($n = 7$)	*Highlighting more areas with information available on touch. I'd like to see difference between the strokes, more written information and more visually appealing in terms of colour scheme. Maybe look more realistic. I want pop up quizzes to ask simple questions like does this mean a, b, or c. That would be reinforcement in a pleasant way. I'd like to see a little person give examples of deficits. I want to see the haemorrhaging happening [P10]*
	Easier to understand ($n = 4$)	*It might be useful to pause after each section of the brain so that the user can explore before moving on to the next section. There is a lot of information to take in at once [F01]*
	Technology-related suggestions ($n = 2$)	*Speakers [P16]*
	Change the project location ($n = 1$)	*Used in quieter area [P19]*

for improvement. Each category contained a number of component sub-categories, which are discussed in more detail below.

Within the category *symptoms or feelings experienced*, participants' feelings ranged from positive emotions (including feeling more confident, interested and informed) to negative emotions (including feeling annoyed and disengaged, overwhelmed, or feeling like an idiot). Three participants reported states (sleepy or stressed) that were unrelated to the application. No participants reported adverse side effects from the application (See Table 3).

Regarding the category, *the aspects I found useful*, participants reported various benefits from enjoying the interactive dissection to seeing the different parts of the brain and learning about the brain and stroke. Participants also enjoyed using the technology. Two participants reported that no element of the application was useful. In terms of *the aspects I found least useful*, participant feedback included unclear labelling of brain regions, a lack of variety, insufficient information about clots, complicated language, excessive length and not enough interaction with the application. Two participants commented about technological issues (device ceasing to work) and three participants commented that they would have preferred a less noisy environment for the lesson (See Table 3).

For the final category, *suggestions for improvement*, participants suggested a range of areas, including more information and features, increased ease of understanding (e.g., reduced rate and more straightforward language), improved technology (speakers and more reliable equipment) and a quieter project location. Five participants provided no suggestions for improvement.

Association analyses

Prior experience using a tablet device was not significantly associated with enjoyment using the application ($p = 0.642$, Fisher's exact test), perception of the value of the application as a good learning tool ($p = 0.450$, Fisher's exact test), comfort using the application ($p = 0.316$, Fisher's exact test), or confidence in knowledge about stroke ($p = 0.477$, Fisher's exact test). Enjoyment using the application was not significantly associated with perception of the application as a good learning tool ($p = 0.073$, Fisher's exact test). Feeling comfortable using the application and perception of the application as a good learning tool were significantly asscociated with feeling more confident in knowledge about stroke after using the application ($p = 0.046$ and $p = 0.009$, Fisher's exact test).

Discussion

The overall aim of the project was to develop and trial the delivery of a stroke education lesson using an AR application with stroke inpatients. Both the development and trial of the stroke education lesson using an AR application occurred successfully. In line with the study hypotheses, the stroke education AR lesson had reasonable participant recruitment (58%) and excellent participant retention (100%); however, usage was below projected. As expected, the majority of participants had positive views about the stroke education AR lesson and reported improved confidence in their knowledge of stroke after the lesson. Interestingly, previous experience with tablet devices was not significantly associated with enjoyment or comfort using the application or perceptions towards the application as a learning tool.

Increasing evidence suggests that people with stroke and their carers find technology beneficial during rehabilitation (Ownsworth et al., 2020; Pallesen, Andersen, Hansen, Lundquist, & Brunner, 2018). The current study supported this by finding that the majority of participants enjoyed using the stroke education lesson AR application and thought it was a useful learning tool. The results also suggest that technology may be beneficial during the acute or sub-acute stages of recovery. Additionally, approximately three-quarters of people with stroke and two-thirds of significant others believed that they were more confident in their knowledge of stroke after the stroke

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education AR lesson. This finding is also in line with Thompson-Butel et al. (2018), who found that a VR stroke education lesson improved participants' knowledge of stroke, risk factors and management, along with an increased reported motivation to manage stroke risk. Active information provision, embedded in stroke education, is more beneficial than passive information provision (Forster et al., 2012). Therefore, AR and VR technologies may facilitate active information provision through increased opportunities for engagement and interaction.

End-user engagement is a key aspect in developing technological interventions (Fuller et al., 2020; Pithara et al., 2020). The present study found that feeling comfortable using the application was associated with increased confidence with stroke knowledge, which in turn was associated with perception of the application as a good learning tool. The majority of participants were positive about the stroke education AR lesson. Some suggested modifications for future trials, including more information and features, increased ease of understanding (e.g., reduced rate and more straightforward language), improved technology (speakers and more reliable equipment) and a quieter project location. As a number of participants identified that the language used was too complicated, it highlights that modifications, particularly around the script, are required before further testing of the stroke education AR lesson. Given the high prevalence of aphasia following stroke (Pedersen, Stig Jørgensen, Nakayama, Raaschou, & Olsen, 1995), co-design support from people with aphasia and their families will be an important future step to ensure that the complexity of language meets consumer needs in order the maximise the feasibility and usability of the lesson. Additionally, this is also an opportunity to explore different language capabilities. This highlights an additional benefit of using technology in stroke education, as it may be adapted to increase accessibility by having a broad number of language translations.

Given the multidisciplinary and stroke specialisation of members of the research team, it should be noted that stroke and disciplinary expertise was likely embedded in the lesson created and in the delivery of the trial. It is possible that the materials and delivery may be different from those developed by a technology-based team without stroke, allied health and hospital-based expertise. It is possible that the research team was supporting the use and acceptability of the lesson by supporting communication and functioning in ways that were not detected.

Initially, the AR stroke education lesson was to be loaded onto each participant's device and their usage tracked. However, this was not possible as the initial application was only available on android devices, so participants were given the stroke education AR lesson to use on a device associated with the study. Due to this, most participants only used the lesson once (although they were informed that they could repeat the lesson), and thus usage was below the projected level. Additionally, it is possible that if the lesson had been offered routinely that uptake may have increased, as stroke-related memory or initiation difficulties could have been a factor. Future studies could load the stroke education AR lesson onto participants' own devices and use an application compatible with both Android and Apple operating systems to maximise the useability of the lesson.

The majority of participants used the application by themselves, with four participants reporting that they showed the application to family members or friends. This may have been impacted by the length of time each participant had with the device, therefore impacting on the length of time the application was accessible to show visitors and hospital staff. Factors such as visiting times, availability of family and/or quantity of time the device was accessible may have impacted how participants were able to engage with and share the application with their support people.

While the majority of participants reported positive reactions towards the stroke education lesson, a subset of participants reported the opposite reaction (such as feeling overwhelmed or disengaged). This lends support to the notion that technology could be used to personalise stroke education according to patient and significant other literacy/education levels, preferences (including the length of exposure), perceptual needs (including vision and button responsiveness) and content. While the education lesson in the current study was not personalised for each participant, future iterations could be personalised, including focusing on the location of the participant's stroke and concerns and providing scaffolded learning to help revisit things that participants find unclear. This potential for personalisation is in accordance with recommendations that stroke education should be interactive, repetitive, accessible and usable with varying levels of health literacy (Cameron et al., 2016). This would likely maximise the feasibility and useability of the lesson.

It is possible that AR may not meet the stroke education needs of all stroke patients and their significant others. It is acknowledged that some people may prefer a low or no technology education option over a high technology-based education format, such as AR. Indeed, researchers have suggested previously that a combination of education formats may be optimal for meeting the information needs of stroke patients and their significant others (Chan et al., 2015). AR may therefore be one element in a comprehensive stroke education package.

Beyond demonstrating that it is possible to develop and trial a novel AR stroke education lesson with people with stroke in a hospital setting, the present study affords a number of lessons for people conducting education research with people with stroke using novel technologies. The study highlights the critical importance of understanding the ward environment (or context) before embarking on different types of education and identifies some barriers to participation/engagement in AR-focused stroke education. These barriers include the complexity of language and consideration to which devices the technology is available on. Future research could explore the barriers and facilitators to the use of innovative technology in stroke education in a ward environment in more detail. The study also highlights that a multidisciplinary approach to novel technology development is an important element in ensuring that the technology is suitable and able to be trialled in the targeted setting. The study suggests that it is feasible to adapt and customise educational materials according to education levels and communication and support needs, but that further customisation is required. It is also worth noting that technological interventions are not desirable to all patients. This was evident in the 58% recruitment rate but the 100% retention rate which suggested that the intervention appealed to some people who were then engaged in the lesson. Technology therefore needs to be an adjunct rather than a replacement for other forms of stroke education for all patients.

Limitations and future directions

The present study represents feasibility work in this embryonic field and consequently has a number of limitations. The absence of a comparison group with an alternative method of stroke information provision means that the results may not be solely due to the technology. Future, large-scale research could include a comparison education method, such as paper-based information. We also acknowledge that not including formal communication assessments as part of the study may have further limited the results. However, as the focus of the study was a feasibility study designed to explore the application, future research could include communication assessments as part of the study design. To minimise the communication load for participants, a survey with a dichotomous response format was used for several questions related to perceptions. We acknowledge that this may have limited the results; however, the open-ended questions were also included to give participants the opportunity to express their thoughts in more detail. We also acknowledge that the questions did not explore actual knowledge, attitude, intention or behaviour change. As the focus of the current study was on perceptions of the lesson and technology, these types of questions were not included. Future research could explore these areas. We also note that the findings may be limited by the use of repeated testing on a small sample. Additionally, participants may have responded favourably to the study questions as they did not want to be critical of a new technology given to them. Future research could explore this in detail using a technology acceptance model, such as the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh, Morris, Davis, & Davis, 2003).

The key issues identified in the current study involved lesson uptake, rate of usage, rate of sharing with others and complexity of language. Future research could target these issues in a number of ways. One key issue was that the application was only developed for Android devices. Due to

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this, participants used the lesson on a tablet provided by the research team. Future research could focus on use of the lesson with both Android and Apple devices, which would enable the lesson to be uploaded on participants' own devices. This may in turn increase the uptake, usage and sharing of the lesson with other people. The complexity of the language of the lesson could be further modified (and potentially simplified) through consultation and feedback from people with stroke and their families. This could include people with and without communication difficulties and focus on the content and language provided in the lesson. It is also critical for future research to explore the comparison between AR stroke education lesson compared to other education materials, such as written materials or videos.

Conclusion

This feasibility study used a novel and innovative approach by using an AR application to enhance stroke education to make it more accessible and engaging for people with stroke and their significant others. The majority of participants enjoyed using the stroke education lesson AR application and thought it was a useful learning tool. The majority of participants also believed that they were more confident in their knowledge of stroke after using the application. The findings suggest that the stroke education AR lesson is feasible and warrants modification and further testing to enhance feasibility and useability further. The study adds to the growing body of evidence supporting the use of technology in stroke education. The next step is to modify the application and seek funding to conduct a more extensive, multisite evaluation of the application.

Data availability statement. The data pertaining to this study are available on request from the corresponding author. The data are not publicly available due to privacy and ethical restrictions.

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Conflicts of interest. The authors have no conflicts of interest to disclose.

Ethical standards. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008. The study was approved by Metro South Human Research Ethics Committee (HREC/18/QPAH/161).

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