Radiography 29 (2023) 641–646

Contents lists available at ScienceDirect

Radiography

journal homepage: www.elsevier.com/locate/radi

A comparison of perceived image quality between computer display monitors and augmented reality smart glasses

A. England [a,*], J. Thompson [b], S. Dorey [c], S. Al-Islam [d], M. Long [a], C. Maiorino [a], M.F. McEntee [a]

[a] Discipline of Medical Imaging & Radiation Therapy, University College Cork, Cork, Ireland
[b] University Hospitals of Morecambe Bay NHS Foundation Trust, Barrow-in-Furness, UK
[c] Tameside and Glossop Integrated Care NHS Foundation Trust, Tameside, UK
[d] East Lancashire Hospitals NHS Trust, Blackburn, UK

ARTICLE INFO

Article history:
Received 28 November 2022
Received in revised form
28 March 2023
Accepted 14 April 2023
Available online 30 April 2023

Keywords:
Augmented reality
Smart glasses
Wearable device
Image quality comparison
Fluoroscopy

ABSTRACT

Introduction: Augmented-reality (AR) smart glasses provide an alternative to standard computer display monitors (CDM). AR smart glasses may provide an opportunity to improve visualisation during fluoroscopy and interventional radiology (IR) procedures when there can be difficulty in viewing intra-procedural images on a CDM. The aim of this study was to evaluate radiographer perception of image quality (IQ) when comparing CDM and AR smart glasses.

Methods: 38 radiographers attending an international congress evaluated ten fluoroscopic-guided surgery and IR images on both a CDM (1920 × 1200 pixels) and a set of Epson Moverio BT-40 AR smart glasses (1920 × 1080 pixels). Participants provided oral responses to pre-defined IQ questions generated by study researchers. Summative IQ scores for each participant/image were compared between CDM and AR smart glasses.

Results: Of the 38 participants, the mean age was 39 ± 1 years. 23 (60.5%) participants required corrective glasses. In terms of generalisability, participants were from 12 different countries, the majority (n = 9, 23.7%) from the United Kingdom. For eight out of ten images, the AR smart glasses demonstrated a statistically significant increase in perceived IQ (median [IQR] 2.0 [-1.0 to 7.0] points) when compared to the CDM.

Conclusion: AR smart glasses appear to show improvements in perceived IQ when compared to a CDM. AR smart glasses could provide an option for improving the experiences of radiographers involved in image-guided procedures and should be subject to further clinical evaluations.

Implications for practice: Opportunities exist to improve perceived IQ for radiographers when reviewing fluoroscopy and IR images. AR smart glasses should be further evaluated as a potential opportunity to improve practice when visual attention is split between positioning equipment and image review.

Introduction

Advances in technology have created new opportunities for the increased utilisation of virtual reality (VR) and augmented reality (AR) applications in medicine.[1] Growth of the VR and AR sector is evident, spending in this area exceeding $215 billion in 2021[2] and growth is expected to continue within the VR/AR market. In terms of AR/VR technologies, Uppot and colleagues in 2019, explored the use of VR and AR within radiology.[3]

VR relies on the creation of a fully immersive environment[3] whereas in AR the user is not completely immersed in a virtual world, instead hologram-style images are superimposed on a real-world background.[4] AR environments are typically generated for the user by a head-up display (HUD) which may be more commonly termed 'smart glasses'.[5]

Applications for both VR and AR systems have been reported extensively across radiology. Elsayed and colleagues reported on the potential applications for VR and AR in radiology.[5] Within this work the authors describe potential roles for these technologies in

* Corresponding author. Medical Imaging & Radiation Therapy, Assert UG 16, Brookfield Health Sciences, University College Cork, College Road, Cork, T12 AK54, Ireland.
E-mail address: aengland@ucc.ie (A. England).

https://doi.org/10.1016/j.radi.2023.04.010
1078-8174/

interventional radiology (IR), patient consent processes, education and training, relaxation and distraction therapy and image interpretation. Many reports within the literature have focused on the potential of VR/AR in IR/fluoroscopy-guided applications.[6–10]

Within the fluoroscopy environment, a potential advantage of AR smart glasses is that the clinician's gaze is not directionally fixed or predetermined by the location of the computer display monitor (CDM).[11] Dorey and colleagues, in 2019, suggested based on their IR study using phantoms and lead protection glasses, that there could be benefit from modified leaded AR smart glasses in terms of reducing eye lens dose to the operator.[11] A report by Elsayed and colleagues[5] further argued that VR and AR technologies have the potential to revolutionise image-guided interventions and improve patient outcomes. Reducing operator head movement, by reducing the frequency in which eye gaze is switched between the intervention site (patient) and CDM, could result in lower radiation exposure and could potentially make procedures shorter.

A study by Devcic and colleagues[12] demonstrated that viewing AR reconstructions of splenic artery aneurysms before embolization improved operator confidence. Nicolau and colleagues[13] suggest that AR has growing promise in percutaneous interventions, such as biopsies and ablations. Reports have, however, argued that objective evaluations of the benefits of AR over conventional image review methods in IR are limited and more robust research is needed to validate clinical utility.[5]

Whilst favourable reports of both radiology-based VR and AR technologies exist there is a lack of research evidence surrounding the displayed image quality (IQ) on such devices. Within radiology, high IQ has a longstanding link with diagnostic and operational performance. Within fluoroscopy-guided and IR procedures procedural success is likely to have a strong relationship with IQ and radiation dose (patient and staff). IQ is of upmost importance to the operating clinician but also the radiographer. Radiographers have a requirement for high-quality images to help ensure that relevant anatomy is appropriately presented, and that accurate collimation is applied ensuring optimal radiation protection. To the authors' knowledge no studies have sought to evaluate the differences between IQ perception on CDM against AR smart glasses and this is the primary aim of this study.

Methods

Participants

Image quality evaluations were conducted with 38 radiographers attending the European Congress of Radiology (ECR) in Vienna, Austria in July 2022. Eligible participants were all radiographers who would be familiar with clinical fluoroscopy-guided procedures and IR. Participants were invited by social media and personal invites via members of the research team. Participation was voluntary and everyone was invited to read a participant information sheet and complete a series of online consent questions. Ethical approval for the study was granted by University College Cork Social Research Ethics Committee (2022-118). All participants were asked to provide details on their age, gender, current country of practise and to indicate whether they wear corrective lenses.

Images

Images were chosen by study researchers from those in the public domain accessed via the internet. Images were selected by members of the research team and were designed to cover a range of fluoroscopy and interventional radiology procedures across a range of image quality domains (Table 1). Images were presented to participants as a series of MS Powerpoint (Microsoft Inc, Redmond, WA) slides which would be accompanied by a series of image-specific IQ questions. Digital Communication in Medicine (DICOM) format images were not displayed to participants as study researchers wanted to provide a convenient method for reviewing the images within the research environment. Since both viewing modalities (CDM/AR glasses) used the same Powerpoint presentation this was felt unlikely to result in any bias against a single image review modality. To further reduce the effects of either fatigue or favouring the image display device presented first participants were switched between starting image review with the CDM or AR glasses.

Computer display monitor (CDM)

A laptop was connected to a Eizo 22.5" FlexScan EV2360-BK (Eizo Corp, Hakusan, Japan) colour computer monitor running the default parameters (contrast and brightness). The monitor has a 16:10 aspect ratio and 1920×1200 pixel resolution (2.3 megapixel). Using MS Powerpoint, a series of fluoroscopy and IR images were presented to participants. Participants first evaluated a slide (Snellen Eye Chart) which was designed to assess near distance vision. The line with the smallest text that a participant could read was recorded (large = 1 and smallest = 9). Participants then proceeded to provide evaluations of their perceived IQ via a series of verbally presented questions from a study researcher. Participants were invited to review a total of ten images and each image had between 4 and 6 specific IQ questions. In total each participant responded to 55 questions. Participants were permitted to only review the images on Powerpoint, there was no possibility to window or zoom images.

AR-smart glasses

The Powerpoint presentation was also presented to participants on a pair of Epson Moverio BT-40 (Epson, Nagano, Japan) smart glasses (1921×1080 pixels) also setup using the default parameters. The smart glasses were connected to the laptop computer using a USB-C connection and provided a contrast ratio of 500,000:1 and a full HD 1080p colour display, similar to an external CDM. The manufacturer specification stated that the screen size (projected distance) is 120 inches at 6 m.

Viewing environment

Participants undertook review of the fluoroscopy and IR images in the EFRS Research Hub room within the Austria Centre conference facility (ECR2022). The room was free from distraction, computer equipment was displayed on a standard office desk, room lighting was ambient, and participants were sat directly opposite the CDM. For the AR glasses participants were asked to gaze on a neutral background. The research team considered that the ambient lighting in the room was not dissimilar to an IR suite or operating theatre environment. Participants were able to review the images at a time convenient to the individual. The first display device (either AR smart glasses or CDM) that the participants used for image review was selected randomly. Due to time restrictions each participant was asked to review images on both devices at the same sitting. Participants were given a short break between evaluations.

Image quality questions

For each display device each participant was asked to review the series of images in a fixed order. For each image, a researcher asked the participant to respond to a series of bespoke questions on IQ (device and anatomical visibility, contrast, density and sharpness);

Table 1
Summary of summative IQ Scores by modality for the ten images.

Modality		Image A	B	C	D	E	F	G	H	I	J
		Aortic DSA using a calibrated catheter.	Coronary angioplasty image with an inflated balloon.	Selective cerebral DSA with embolization coils.	DSA of the carotid arteries.	DSA of the left pulmonary artery.	Cerebral DSA demonstrating the Circle of Willis.	Intra-operative femoral nailing. AP knee projection with guidewire.	Intra-operative femoral nailing. Lateral knee projection with guidewire	Intra-operative dynamic hip screw. AP hip projection with prothesis.	Left nephrostogram. Inferior vena cava contains a filter.
Computer Display Monitor	Median	15.0	8.5	10.0	5.0	8.0	8.5	10.5	12.0	9.5	9.5
	IQR	11.3 to 17.0	4.0 to 12.0	8.0 to 11.0	3.0 to 8.8	4.3 to 10.0	8.0 to 11.0	8.0 to 14.0	10.0 to 15.8	6.3 to 11.0	6.0 to 11.8
AR Smart Glasses	Median	15.0	10.0	11.5	8.0	10.0	9.0	13.0	15.0	12.0	13.0
	IQR	12.3 to 18.0	8.0 to 12.8	9.3 to 14.0	6.0 to 11.0	8.0 to 11.8	8.0 to 11.0	11.0 to 15.0	12.3 to 16.0	9.3 to 13.0	11.0 to 14.0
Difference		0.0	+1.5*	+1.5*	+3.0*	+2.0*	+0.5	+2.5*	+3.0*	+2.5*	+3.5*
P value		0.205	<0.001	0.002	<0.001	0.004	0.186	0.004	0.001	<0.001	<0.001

IQR, inter-quartile range. *indicates statistical significance ($p < 0.05$) determined by the Wilcoxon signed rank test. DSA, digital subtraction angiogram. AP, anteroposterior.

different images could have different maximum IQ scores. For each question the participant provided an evaluation of image quality using a four-point Likert scale (0 = inadequate, 1 = adequate, 2 = good and 3 = excellent). Bespoke IQ questions were determined by members of the research team based on prior experience of image perception experiments. Participants were also asked to comment on whether the image set represented a range of fluoroscopy and IR cases likely to be experienced within current clinical practice. Participants were asked to grade the suitability of each device for image display and to indicate the likelihood of AR smart glasses becoming part of routine clinical practice.

Data analysis

Data acquired from the participants was inputted into Microsoft Forms (Microsoft Cor, Redmond, WA) by a study researcher. Data within the Microsoft Forms system was then downloaded as a Microsoft Excel (Microsoft Corporation, Redmond, WA) spreadsheet for further analysis. Descriptive statistics were used to provide an overview of the data. Median and interquartile range values (IQR) were reported for the summative image quality scores. This method has been widely documented when considering multiple responses to an attitudes survey.[14–16] Absolute numbers and percentages were given for binary and categorical variables. The Wilcoxon signed rank test was used to investigate the statistical significance of any differences between the CDM and AR smart glasses. P values of less than 0.05 were considered significant. Fleiss' kappa was used to determine if there was agreement between the participants on the displayed images. The statistical computer software R[17] was used to calculate Fleiss' kappa (κ) using the *irr* package.[18] Confidence intervals (95%) were generated using a bootstrapping technique and the *boot* package.[19] Kappa (κ) statistics were interpreted according to the categories suggested by Landis and Kock.[20] A Chi-square test statistic was calculated for general questions relating to the overall viewing modality preferences of participants (hypothesis - no difference between AR glasses and the CDM). A subset of the collected, fully anonymised, research data, based on individual consent, has been made available to other researchers at the Zenodo Digital Repository under a Creative Commons Attribution 4.0 licence thus supporting the FAIR

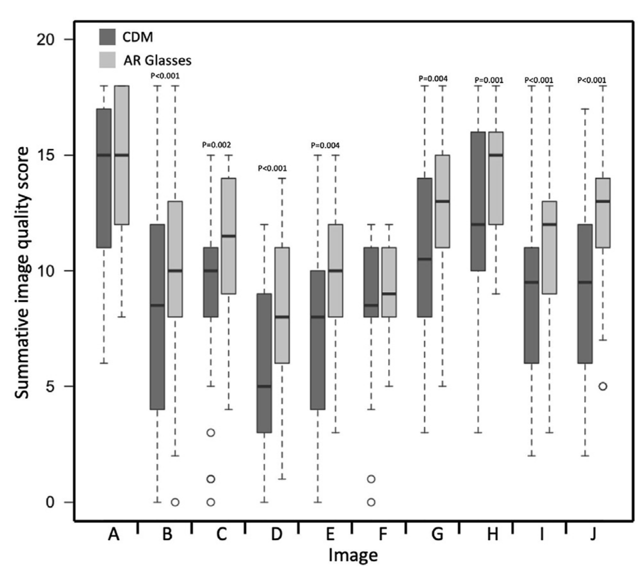

Figure 1. Boxplot illustrating the summative IQ scores by viewing modality (circles indicate outlier values).

principles (Findable, Accessible, Interoperable and Reusable) of Open Research Practices.[21]

Results

Of the 38 participants, 17 (44.7%) identified as male and 21 (55.3%) as female. The mean (SD, range) age of the participants was 39 (10, 25 to 60) years. Twenty-three (60.5%) participants required a prescription of corrective glasses and 15 (39.5%) did not require corrective lenses. Participants originated from 12 different countries with the majority (9, 23.7%) from the United Kingdom.

Across the CDM and the AR smart glasses the 38 participants recorded a total of 4180 individual IQ evaluations on the ten images. 35 (92.1%) participants achieved an eye test score of >8 (out of 9) with the CDM whereas 27 (71.1%) achieved the same with the AR glasses ($P < 0.001$). Summative image quality scores for the 38 for each image were compared between the two display devices (Table 1, Fig. 1). For eight out of ten images (A to J) the AR smart glasses consistently demonstrated a statistically significant increase in perceived IQ when compared to the CDM. Scores for the AR glasses were a median (IQR) 2.0 (−1.0 to 7.0) higher than those for the CDM.

Study data were analysed according to IQ domains and included radiographic appearances of the device and visualised anatomy. Image contrast, density and sharpness were also evaluated between devices. The AR smart glasses provided a statistically significant improvement in the perceived IQ according to domains (Table 2, Fig. 2). Image sharpness and contrast showed the greater increase in perceived IQ (Table 2, Fig. 2). Radiographic appearances of the visualised device and image density showed the lowest increase in perceived IQ (Table 2, Fig. 2).

Fleiss' kappa indicated that there was poor[20] agreement between the participants' rating of IQ, $\kappa = 0.095$ (95%CI, 0.069 to 0.124), $p < 0.001$ (Table 3).

In terms of the expressed preferences of the display devices by participants; the CDM had a rating of four or five stars (out of five) for 29 (76%) participants, whereas the AR smart glasses had ratings of four or five stars for 27 (71%) participants (Chi-squared test, $P = 0.70$). Thirty-four (90% of participants felt that the images provided represented a good spectrum of fluoroscopy-guided or IR procedures. Twenty-seven (71%) felt that AR smart glasses will have a future role for the radiographer/surgeon/radiologist whereas the remainder, 11 (29%), felt that there may not be a role for AR smart glasses for radiographers/surgeons/radiologists.

Discussion

The use of AR smart glasses in medicine and radiology has been widely reported within the literature.[1–5] Many studies have focused on reporting and evaluating clinical applications and not specifically focussing on comparisons of IQ against traditional computer display monitors. Additionally, studies have had a

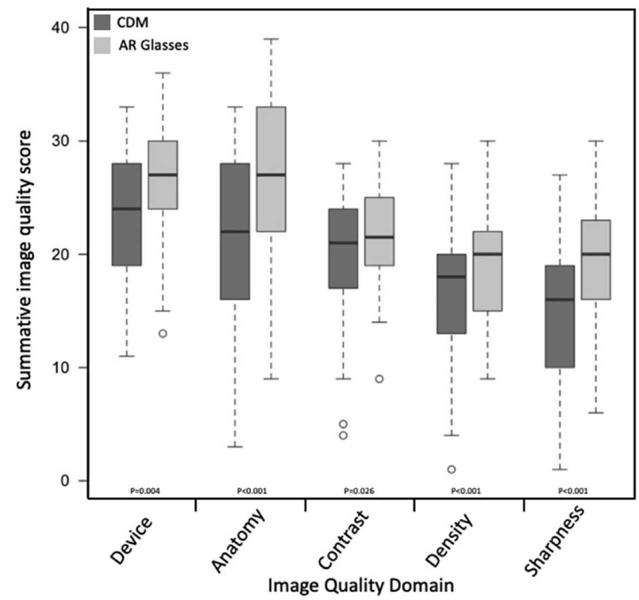

Figure 2. Boxplot of summative IQ scores for the different image quality domains stratified by viewing modality (circles indicate outlier values).

tendency to focus on the role of AR smart glasses for the primary operator, i.e. radiologist or surgeon performing the intervention and not ancillary staff involved in providing the image-guidance, i.e. the radiographer. To the authors' knowledge this is the first study to compare a traditional computer display monitors against AR smart glasses for providing image-guidance using fluoroscopy images. The primary study methodology focused on an individual visual grading analyses for the CDM and the AR smart glasses. A key strength of the methodology was that participants acted as their own controls (CDM) when evaluating the intervention (AR smart glasses).

In terms of the comparison, the AR smart glasses demonstrated a consistent improvement in terms of perceived IQ when compared to the CDM. For all ten images reviewed the participants indicated IQ superiority for the AR smart glasses compared to the CDM (Fig. 1; Table 1); this was statistically significant in eight out of ten cases ($p < 0.05$). In terms of sub-analysis, five IQ domains were evaluated in our study (Table 2). This included the visibility of medical devices, anatomy together with contrast, density, and sharpness. Again, the AR smart glasses provided superior IQ perception across all five domains but was greater for anatomy and sharpness. Questions could arise as to why two images did not show statistically significant differences between CDM and AR smart glasses. These were an aortic angiogram (A) and a cerebral angiogram (F). Interestingly, images C was also a cerebral angiogram and demonstrated statistically significant ($p = 0.002$). Image A would

Table 2
Summary of the differences in IQ perception by domain.

		Radiographic appearances				
		Device	Anatomy	Contrast	Density	Sharpness
Computer Display Monitor	Median	24.0	22.0	21.0	18.0	16.0
	IQR	19.0 to 27.8	16.0 to 28.0	17.0 to 23.8	13.0 to 20.0	10.3 to 19.0
AR Smart Glasses	Median	27.0	27.0	21.5	20.0	20.0
	IQR	24.0 to 29.8	22.0 to 32.5	19.3 to 25.0	15.3 to 22.0	16.3 to 23.0
Difference		+3.0*	+5.0*	+0.5*	+2.0*	+4.0*
P values		0.004	<0.001	0.026	<0.001	<0.001

IQR, interquartile range. *indicates statistical significance ($p < 0.05$) according to the Wilcoxon signed rank test.

Table 3
Sub-analysis of the inter-rater variability between the participants.

	Combined		Computer Display Monitor		AR Smart Glasses	
	κ	P value	κ	P value	κ	P value
Inadequate (0)	0.129	<0.001	0.119	<0.001	0.066	<0.001
Adequate (1)	0.056	<0.001	0.049	<0.001	0.054	<0.001
Good (2)	0.037	<0.001	0.050	<0.001	0.023	<0.001
Excellent (3)	0.182	<0.001	0.201	<0.001	0.140	<0.001
Combined	κ = 0.095 (95%CI, 0.069 to 0.124)		κ = 0.098 (95%CI, 0.061 to 0.137)		κ = 0.073 (95%CI, 0.039 to 0.111)	

have been presented to observers first and thus there might have been some customisation to the AR glasses. Alternatively, the density of the contrast presented on the digitally subtracted aortogram (A) was very high and thus may have reduced perceived differences between viewing modalities. It is difficult to be sure of an exact reason why Image F did not show statistical significance. No medical device was present and thus evaluations would have been based on visualised anatomy, contrast, density and sharpness.

Both the differences in the resolution of the CDM and AR glasses should be considered together with the results of the initial eye tests. The available pixels (1921 × 1080) for the AR glasses were lower than the CDM (1920 × 1200), this could generate surprises given that the AR glasses performed more favourably. Resolution is an important consideration but only one factor in terms of perceived image quality. The display brightness, background and environmental viewing conditions[22] could have also played a part. Initial eye test values were lower for the AR glasses when compared to the CDM. Multiple reasons could exist for these differences, possible the task of looking at high contrast black letters on a white background could have favour the CDM. Again, these would have been the initial image presented on the AR glasses and could have resulted in lower values due to the unfamiliarity of the display modality to the participant. For future work, it might be useful to assess other elements of vision e.g. low contrast details and include an eye test at the beginning and end of the assessments for each modality.

Only static images were provided. Generally, images were selected for inclusion if they provided a range of criteria for IQ evaluation by the participant. Image-guidance often requires the dynamic evaluation of real-time imaging and thus such datasets should be the focus of further evaluations. Both the environment and background would have had some differences to either an IR suite or operating theatre environment and this could induce differences if our study was repeated in a clinical setting. Further evaluations of AR smart glasses in these environments are recommended. The use of AR smart glasses might aid radiographers when review of CDM in the operating theatre or IR suite is difficult. It is also important to conduct further evaluations of the primary operators' (surgeons/radiologists) perceived IQ of AR smart glasses. AR smart glasses, if combined with lead, could provide some additional attenuation of scattered radiation and thus may also reduce eye doses to staff within the controlled area. Again, this is a potentially novel point and would be worthy of further research. Undertaking lengthy procedures with AR smart glasses could induce eye strain and fatigue and thus would warrant further investigation.

Clinically, the option to review fluoroscopy images using AR smart glasses may provide numerous benefits for radiographers and other health care professionals involved in image-guided procedures. Whilst a promising technology and our data provides a favourable impression of perceived IQ improvements, visualisation within these environments is complex and must be considered holistically within the framework of the procedure being performed. Patient experiences of practitioners' wearing AR smart glasses should be considered if a decision is made to formally implementing them into clinical practice. It is of note that 29% of participants felt that there may not be a role for AR smart glasses. Multiple factors could be response for this result, these may include that the participant did not perceive a problem with the viewing of fluoroscopy/IR images as a radiographer (i.e. glaze obstacles). Setup and integration options into existing equipment may have also been a factor. The availability, portability and weight (ergonomics) of current CDMs mean that more viewing options are and will continue to become available in the theatre/IR environments potentially further limiting the opportunities for AR glasses.

Several limitations of our study are evident. Inter-rater variability was evaluated using Fleiss' kappa statistic and when using the scale by Landis and Koch[20] would indicate poor agreement between participants. This could cause concern, but observer variability is a part of image perception studies.[23,24] In our study, it is important to consider that methodology compared scores, for the same participant, between the CDM and AR smart glasses. As previously stated, the participant acted as their own control and thus a difference in the ratings of an individual between display devices was the primary outcome. Whether there was agreement between participants was less important as the aim of the study was to understand whether there was a difference in perceived IQ, for individual participants, between the viewing modalities. It could be argued that fatigue or recall bias had some impact on our results. Images on both the CDM and AR glasses were presented to participants in the same sitting. It would be useful to know, regardless of display modality, as to whether there were differences between the first or second set of IQ scores. Within our data there were no statistically significant differences between the first and second set of IQ scores.

Conclusion

When compared to a 2.3-megapixel standard display monitor AR smart glasses appear to offer improvements in the perceived IQ of radiographers reviewing fluoroscopy/IR images. Further research is required to explore whether this would bring benefits during clinical image-guided procedures and with dynamic imaging. It would also be useful to consider whether such an innovation would be of benefit to different personnel within the theatre/IR environment (i.e. primary operator - surgeon or radiologist).

Conflict of interest statement

None.

Acknowledgement

This study was supported by the European Federation of Radiographer Societies, together with the European Society of Radiology, through the EFRS Research Hub at ECR 2022.

References

1. Sutherland J, Belec J, Sheikh A, Chepelev L, Althobaity W, Chow BJW, et al. Applying modern virtual and augmented reality technologies to medical images and models. *J Digit Imaging* Feb 2019;**32**(1):38–53. https://doi.org/10.1007/s10278-018-0122-7.
2. Pensieri C, Pennacchini M. *Virtual reality in medicine. Handbook on 3D3C Platforms.* Springer; 2016. 353–401.
3. Uppot RN, Laguna B, McCarthy CJ, De Novi G, Phelps A, Siegel E, et al. Implementing virtual and augmented reality tools for radiology education and training, communication, and clinical care. *Radiology* 2019;**29 1**(3):570–80. https://doi.org/10.1148/radiol.2019182210.
4. Khor WS, Baker B, Amin K, Chan A, Patel K, Wong J. Augmented and virtual reality in surgery—the digital surgical environment: applications, limitations and legal pitfalls. *Ann Transl Med* 2016;**4**(23).
5. Elsayed M, Kadom N, Ghobadi C, Strauss B, Al Dandan O, Aggarwal A, et al. Virtual and augmented reality: potential applications in radiology. *Acta Radiol* Sep 2020;**61**(9):1258–65. https://doi.org/10.1177/0284185119897362.
6. Garg T, Loya MF, Shrigiriwar A. Virtual reality and its applications in interventional radiology. *Acad Radiol.* Oct 2020;**27**(10):1495. https://doi.org/10.1016/j.acra.2020.05.043.
7. Park BJ, Hunt SJ, Martin C, Nadolski GJ, Wood BJ, Gade TP. Augmented and mixed reality: technologies for enhancing the future of IR. *J Vasc Interv Radiol.* Jul 2020;**31**(7):1074–82. https://doi.org/10.1016/j.jvir.2019.09.020.
8. Solbiati LA. Augmented reality: thrilling future for interventional oncology? *Cardiovasc Intervent Radiol.* May 2021;**44**(5):782–3. https://doi.org/10.1007/s00270-021-02801-9.
9. Ayp Gelmini, Duarte ML, Silva MOD, Guimarães Junior JB, Santos LRD. Augmented reality in interventional radiology education: a systematic review of randomized controlled trials. 2022 *Sao Paulo Med J.* Jul-Aug 2022;**140**(4):604–14. https://doi.org/10.1590/1516-3180.2021.0606.R2.27122021.
10. Auloge P, Cazzato RL, Ramamurthy N, de Marini P, Rousseau C, Garnon J, et al. Augmented reality and artificial intelligence-based navigation during percutaneous vertebroplasty: a pilot randomised clinical trial. *Eur Spine J* Jul 2020;**29**(7):1580–9. https://doi.org/10.1007/s00586-019-06054-6.
11. Dorey S, Gray L, Tootell A, Higgins R, Al-Islam S, Baxter H, et al. Radiation protection value to the operator from augmented reality smart glasses in interventional fluoroscopy procedures using phantoms. *Radiography (Lond)* Nov 2019;**25**(4):301–7. https://doi.org/10.1016/j.radi.2019.02.008.
12. Devcic Z, Idakoji I, Kesselman A, Shah R, AbdelRazek M, Kothary N. 4:03 PM Abstract No. 30 Augmented virtual reality assisted treatment planning for splenic artery aneurysms: a pilot study. 2022/09/ *J Vasc Intervent Radiol* 2018;**29**(4):S17.
13. Nicolau SA, Pennec X, Soler L, et al. An augmented reality system for liver thermal ablation: design and evaluation on clinical cases. *Med Image Anal.* Jun 2009;**13**(3):494–506. https://doi.org/10.1016/j.media.2009.02.003.
14. Champion V. Development of a benefits and barriers scale for mammography utilization. *Cancer Nurs.* Feb 1995;**18**(1):53–9.
15. Peabody D. Two components in bipolar scales: direction and extremeness. *Psychol Rev* 1962;**69**(2):65.
16. Willits FK, Theodori GL, Luloff A. Another look at Likert scales. *Journal of Rural Social Sciences* 2016;**31**(3):6.
17. *R: a language and environment for statistical computing. R Foundation for Statistical Computing*. 2010. http://www.R-project.org.
18. *Irr: various coefficients of interrater reliability and agreement. R package version 0.84.1*. 2019. https://CRAN.R-project.org/package=irr.
19. *Boot: bootstrap R (S-Plus) Functions. R package version 1.3-28*. 2021. https://CRAN.R-project.org/package=boot.
20. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics.* Mar 1977;**33**(1):159–74.
21. Holub P, Kohlmayer F, Prasser F, Mayrhofer MTh, Schlunder I, Martin GM, et al. Enhancing reuse of data and biological material in medical research: from FAIR to FAIR-health. *Biopreserv Biobank* Apr 2018;**16**(2):97–105 (Accessed Apr 2018), https://doi.org/10.1089/bio.2017.0110.
22. Papathanasiou S, Thompson JD, Walton LA. Survey of monitor specification and viewing conditions in breast screening units in the North West of England. *Radiography* 2021;**27**(2):546–53.
23. Krupinski EA. Current perspectives in medical image perception. *Atten Percept Psychophys* Jul 2010;**72**(5):1205–17. https://doi.org/10.3758/APP.72.5.1205.
24. Börjesson S, Håkansson M, Båth M, Kheddache S, Svensson S, Tingberg A, et al. A software tool for increased efficiency in observer performance studies in radiology. *Radiat Protect Dosim* 2005;**114**(1–3):45–52. https://doi.org/10.1093/rpd/nch550.