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Addressing learning gaps to improve access to assisted reproductive technology in low-resource settings: Development and evaluation of a low-cost oocyte retrieval simulator

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Abstract

Infertility is highly prevalent (20-40%) in sub-Saharan Africa, with limited access to assisted reproductive technology services. This study describes the development and evaluation of a low-cost oocyte retrieval simulator designed for use in resource-constrained environments. We developed and evaluated a low-cost oocyte retrieval simulator in Ghana. The exterior housing consists of a 3D-printed vaginal canal. The interior design supports identifying mature follicles and retrieval skills with a web camera mounted to simulate an ultrasound view of the ovaries. Key considerations were low material cost, material availability in Ghana, and replication of the 'ultrasound view'. The simulator was evaluated across four domains: physical attributes, realism of experience, value, and relevance using 4-point rating scales (4=highest). Ability to perform tasks (5-point scales), and global value were evaluated. Mean ratings are reported. Across the four domains: physical attributes, realism of experience, value, and relevance, we report the evaluation scores using 4-point rating scales (4=highest). The ability to perform tasks was measured using the 5-point scales, and its global value was also scored. Given the ordinal nature of Likert-scale data and the small sample size, non-parametric statistical procedures were used. Group comparisons were conducted using the Mann–Whitney U test. The simulator demonstrated promising preliminary face and content validity, with higher ratings for value and relevance than for physical realism. This low-cost simulator represents an important step toward expanding ART training capacity in sub-Saharan Africa. Further iterative refinement and expanded validation are warranted.. *(Afr J Reprod Health 2026; 30 [8]: 15-22).*

Keywords: oocyte retrieval, simulator, trainer, low-resource setting, assisted reproductive technology

Résumé

L'infertilité est très répandue (20 à 40 %) en Afrique subsaharienne, où l'accès aux services de procréation médicalement assistée est limité. Cette étude décrit le développement et l'évaluation d'un simulateur de ponction ovocytaire à faible coût, conçu pour les environnements aux ressources limitées. Nous avons développé et évalué un tel simulateur au Ghana. Son boîtier externe est constitué d'un canal vaginal imprimé en 3D. L'aménagement intérieur permet d'identifier les follicules matures et de s'exercer à la ponction grâce à une webcam simulant une échographie ovarienne. Les principaux critères de conception étaient le faible coût des matériaux, leur disponibilité au Ghana et la reproduction fidèle de l'image échographique. Le simulateur a été évalué selon quatre critères : ses caractéristiques physiques, le réalisme de l'expérience, sa valeur et sa pertinence, à l'aide d'échelles de notation à 4 points (4 = maximum). La capacité à réaliser les tâches (échelle à 5 points) et la valeur globale ont également été évaluées. Les notes moyennes sont présentées. Pour les quatre domaines (attributs physiques, réalisme de l'expérience, valeur et pertinence), les scores d'évaluation sont rapportés à l'aide d'échelles de Likert à 4 points (4 = note maximale). La capacité à réaliser les tâches a été mesurée à l'aide d'échelles à 5 points, et sa valeur globale a également été évaluée. Compte tenu de la nature ordinale des données de l'échelle de Likert et de la petite taille de l'échantillon, des procédures statistiques non paramétriques ont été utilisées. Les comparaisons entre groupes ont été effectuées à l'aide du test U de Mann-Whitney. Le simulateur a démontré une validité apparente et de contenu préliminaire prometteuse, avec des notes plus élevées pour la valeur et la pertinence que pour le réalisme physique.Ce simulateur à faible coût représente une avancée importante pour le développement des capacités de formation en PMA en Afrique subsaharienne. Des améliorations itératives supplémentaires et une validation plus approfondie sont nécessaires. *(Afr J Reprod Health 2026; 30 [8]: 15-22)*

Mots-clés: ponction ovocytaire, simulateur, formateur, contexte à faibles ressources, procréation médicalement assistée

Introduction

Infertility continues to remain increasingly a major reproductive health and social challenge in sub-Saharan Africa (SSA), with prevalence estimates ranging from 20–40%.[1,2,15] While infertility is a global health issue, the adverse impact of the disorder in many African settings is particularly profound. In several African cultural contexts, fertility is closely linked to social identity, marital stability, inheritance, family lineage continuity, and social and economic security.[16] Notably, women in infertile couples disproportionately suffer a heavier burden of infertility-related stigma, and often experience marital instability, gender-based discrimination, social exclusion, and significant psychological distress.[3-5] In some settings, infertility has been associated with domestic violence, abandonment, and community marginalization.[5] These consequences underscore infertility not merely as a biomedical condition but as a significant public health and developmental concern across the African continent. Despite the magnitude of this burden, access to infertility care and assisted reproductive technology (ART) remains severely limited in most parts of SSA. Since the birth of the first in vitro fertilization (IVF) baby in 1978, ART services have expanded rapidly across high-income countries; however, its distribution remains highly inequitable. In Africa, access is constrained by high treatment costs, inadequate infrastructure, limited appropriate laboratory capacity, regulatory frameworks, and few skilled trained reproductive medicine specialists.[6-7] Even in countries where ART services are available, they are frequently concentrated in urban private centers and remain financially inaccessible to the majority of couples requiring care. The mismatch between the prevalence of infertility and the limited number of fertility centers highlights a substantial service gap. Beyond infrastructure and cost constraints, training capacity represents a critical but under-addressed barrier to ART expansion. Oocyte retrieval is a central procedural component of the IVF cycle. The procedure requires transvaginal ultrasound-guided aspiration of ovarian follicles, usually under sedation or anaesthesia. Successful performance demands coordinated visuomotor skills, accurate interpretation of ultrasound imaging, precise needle guidance, depth perception, and careful avoidance of adjacent vascular structures such as ovarian blood vessels. Inadequate training can increase procedural complications, including bleeding, incomplete follicular aspiration, and patient morbidity. Ensuring competency in ultrasound-guided oocyte retrieval is therefore essential for safe and effective IVF practice. Simulation-based medical education has become an established strategy for enhancing procedural competency and patient safety. Across surgical and interventional disciplines, simulation allows trainees to practice technical skills in a controlled environment without risk to patients. Evidence suggests that simulation-based training can shorten learning curves, improve confidence, and enhance technical precision.[10] However, commercially available IVF simulators, particularly those focused on embryo transfer or ultrasound-guided procedures are often prohibitively expensive and designed primarily for high-resource contexts. Their acquisition and maintenance costs limit their feasibility in low- and middle-income countries (LMICs). Currently, there is no standardized simulator for the oocyte retrieval procedure. The closest such simulator is the embryo transfer simulator program developed by the American Society for Reproductive Medicine.[7-8] While this simulator is high fidelity, it is expensive and focuses primarily on the embryo transfer procedure in IVF, making it inaccessible and not applicable for teaching oocyte retrieval in low-middle income countries (LMICs). This motivates the development of an oocyte retrieval simulator, especially one that is designed to best serve LMICs. A low-cost simulator to train physicians to safely perform this surgical procedure would improve access to IVF treatment in SSA countries, therefore improving the quality of life of women and couples experiencing infertility.

To support this mission, we developed a physical simulator using a combination of 3D-printed components and low-cost and readily available materials. The simulator is comprised of two compartments that that align with two training modules to provide scaffolded learning. The main anatomical landmarks (vulva and the vaginal canal) are 3D printed, along with a 3D printed nonworking model of a transvaginal ultrasound probe. The first

module is an "ovary" constructed of collapsible dark liquid-filled tapioca pearls, also known as "popping boba," that were embedded in a gelatin matrix to simulate the follicles. The tapioca pearls were purchased from a local drink shop and can easily be made from an online recipe available.[9] The tapioca pearls were selected to provide visual feedback as the learner would be able to see the dark-coloured juice flowing out of the follicle as they aspirated the follicle. The second module, with an increased difficulty, included a simulated ovary made of silicon with a thin wire encircling it to simulate the ovarian blood vessels. Powered by a 9V battery, this module was designed so a loud buzzer would provide an auditory alert to the learner when the oocyte retrieval needle touched this wire, erroneously. alerting the learner that they have potentially caused damage to the ovarian blood vessel (Figure 1).

The entire model is mounted to a wooden base plate and covered by a cardboard box. A 3Dprinted vulva is attached to the outside of the box, to provide an important anatomical landmark and offer an opportunity to practice the important skill of probe insertion. (Figure 2) Small holes were made in the top of the box to allow for a camera to be mounted above the ovaries.

The camera is connected to a computer and provides a top-down, black-and-white view to emulate a traditional ultrasound view. (Figure 3).

In resource-constrained environments, contextually appropriate, low-cost simulation solutions are essential to expand procedural training opportunities. Locally developed simulators that utilize accessible materials and simplified engineering approaches may provide sustainable alternatives to imported high-cost systems. Such tools can contribute to strengthening reproductive medicine training programs, improving procedural competency among obstetrician-gynaecologists, and ultimately expanding equitable access to ART services in SSA.

To address this identified training gap, we developed a low-cost, locally reproducible oocyte retrieval simulator tailored specifically for use in resource-limited settings.This study aimed to evaluate preliminary face and content validity

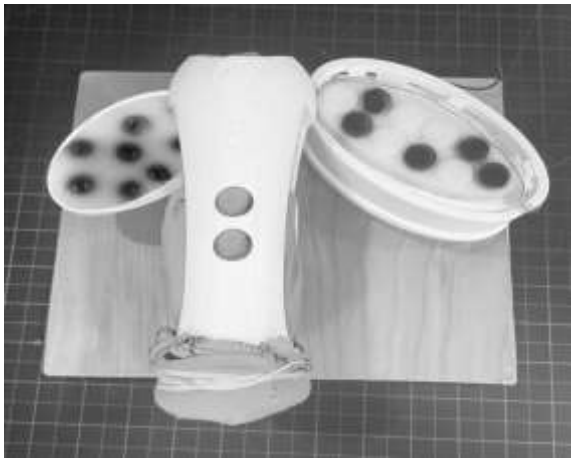

Figure1: Simulated ovaries with follicles, and a thin wire to emulate ovarian blood vessels

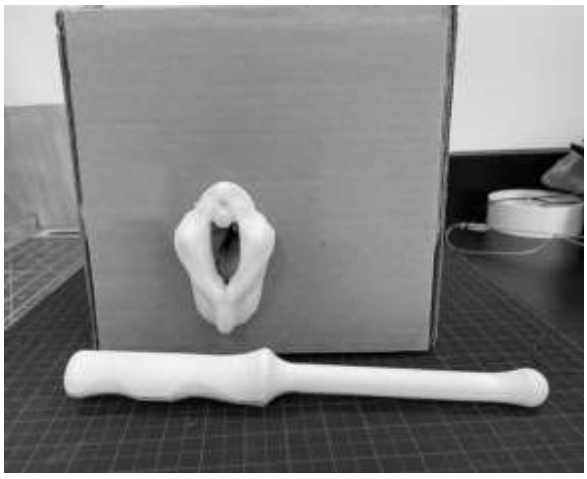

Figure 2: 3D-printed vulva attached to the outside of the box and the vaginal probe

Figure 3: Computer view simulating ultrasound view of ovary with 'follicles'

evidence for this simulator among obstetrician-gynaecologists practicing in Ghana.

Methods

We used this study to evaluate preliminary validity evidence of a novel simulator intended to support obstetrician gynecologists' learning and practice of ultrasound-guided oocyte retrieval, with a focus on low-income countries.

Study setting

This was a cross-sectional validation study assessing preliminary face and content validity evidence. The study focused on evaluating user perceptions of the anatomical realism, procedural fidelity, and educational utility.

Twelve Obstetrician gynecologists, including 2 junior-level residents, 4 senior-level residents, 2 fellows, and 4 attendings, at the University of Ghana Medical School trialed the simulator in January 2024. Participants were categorized as "junior" (n = 6), including all residents, and "senior," including fellows and attendings (n = 6).

Conception and development of the simulator

Following the conception of the idea, the simulator was developed through collaboration between obstetrician-gynaecologists and biomedical engineers. The design process followed iterative prototyping, incorporating clinician feedback to refine anatomical orientation, material selection, and ultrasound visualization. During the design, priority considerations of key focus included affordability, availability of local materials, durability, reproducibility, and simulation fidelity. The final model consisted of 3D-printed female external genital anatomy, two ovary modules (gelatin-based and silicone-based), a simulated vascular alert system powered by a 9V battery, and a web camera mounted above the ovaries to simulate grayscale ultrasound visualization of the pelvis.

Study setting and participants

Twelve obstetrician-gynaecologists (residents, fellows, consultants) from the department of Obstetrics and Gynaecology of the Korle Bu Teaching Hospital, Accra, Ghana, participated in the evaluation in January 2024. Participants represented varying levels of clinical experience in IVF and transvaginal ultrasound-guided procedures. Junior participants had a mean of 21.60 ± 40.2 career oocyte retrievals with an average of 5.2 ± 9.3 in last 12 months, while senior participants had a mean of 48.3 ± 42.7 and 15.7 ± 17.5 estimated career and 12-month transvaginal ultrasound egg retrievals performed.

Table 1: Descriptive ratings of Simulator (4-point scale; n=12)

Domain / Item	Mean	SD
Physical Attributes (Overall)	2.23	0.44
Realism of Experience (Overall)	2.25	0.47
Value as Training Tool	3.17	0.72
Relevance to Practice	3.50	0.52
Global Rating	1.83	0.58

Table 2: Ability ratings for critical tasks (3-point scale; n=12)

Task	Mean	SD
Insertion of ultrasound probe	2.00	0.43
Visualization of ovary	2.08	0.29
Aspiration of follicle	2.08	0.51
Avoiding ovarian artery	2.17	0.58
Ultrasound-guided aspiration	2.08	0.29

Data collection procedure

Participants received a standardized briefing on simulator components and objectives. Each participant performed simulated oocyte retrieval independently. Since all physician participants had previous training in oocyte retrieval, they were able to begin using the simulator with minimal training. Participants then rated the fidelity of the simulator based on both anatomical features and haptic feedback, as well as their ability to perform specific oocyte retrieval tasks.After completion, participants completed a structured 29-item questionnaire that assessed five domains: physical attributes, realism of experience, ability to perform critical tasks, value as a testing and training tool, and relevance to clinical practice.

Statistical analysis

Measures and rating procedure

The simulator was evaluated across five domains: physical attributes, realism of experience, ability to

perform tasks, value, and relevance. Each category was assessed on a 4-point scale, with 4 being the highest value. A score of 2 on this scale would indicate that that specific feature of the model needed improvements before it could be used as an educational training tool. Ability to perform 5 critical tasks was scored using a 3-point scale, ranging from 1 (Too difficult to perform), 2 (Reasonably difficult/easy to perform), and 3 (Too easy to perform). Value and relevance of the simulator was also evaluated on a 4-point scale, ranging from 1 (No value) to 4 (High value).

Given the ordinal nature of Likert-scale responses and small sample size, non-parametric statistical procedures were used. Statistical significance was set, a priori, at $P \leq 0.05$. Statistical analyses were performed using SPSS Statistics version 27 (IBM SPSS Inc. Chicago, IL). Descriptive statistics were calculated. Group comparisons were conducted using the Mann–Whitney U test. Statistical significance was set at $p \leq 0.05$.

Assessment form

The assessment form framework was created by the senior author (DMR), was drafted by first author (RP), and reviewed by the practicing OB-GYN physician (PS) for relevance and clarity. The final 29-item assessment form included 5 domains; demographics (3 questions), physical attributes (9), realism (5), ability to perform tasks (6), Value & relevance (3), and a global (overall) rating. The *physical attributes* domain evaluated both the tactile and visual feedback the simulator provides, particularly with regard to several important anatomical landmarks, while the *realism of experience* domain evaluated the realism of maneuvers and the simulated ultrasound view provided by the model. The *ability* domain evaluated the user's ability to complete the critical steps of the oocyte retrieval process using the model. Beyond the numerical rating system, we also provided a section of the form for reviewers to provide written feedback. Ethical approval was obtained from the IRB of Korle Bu Teaching Hospital (ID No.KBTH-STC00039/2023). Written informed consent was obtained from all participants before evaluation. Participation was voluntary, and responses were anonymized.

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Results

The evaluation of the simulator was performed by twelve Gynaecologists at the Korle Bu Teaching Hospital in Ghana. Participants completed all evaluation items. Descriptive ratings across domains are presented below.

Physical attributes

The overall rating for physical attributes was 2.23 (SD = 0.44) on a 4-point scale. Visualization of ovarian blood vessels received the lowest rating (2.08 ± 0.90). Scale of the model to a live patient (2.17 ± 0.39), tactility of the cervix (2.17 ± 0.83), and visualization of the ovary (2.17 ± 0.58) were similarly rated by participants. Tactility of the ovary received the highest rating (2.42 ± 0.51) within this domain. Although the lowest score was associated with the ovarian blood vessels, the majority of comments on the anatomical markers in this section targeted the haptic feedback of the 3D-printed vulva. Participants largely agreed that the material of the vulva was too rigid to properly accommodate the lateral movements of the transvaginal ultrasound probe. The simulated vulva also did not have enough elasticity to aid in probe insertion.

Realism of experience

The overall realism rating was 2.25 (SD = 0.47). Haptic feedback during needle insertion was rated as 2.00 (± 0.77). Maneuvering of the ultrasound probe was rated 2.27 (± 0.65). The simulated ultrasound view received a rating of 2.45 (± 0.82). Participants stated that the oocyte retrieval needle was difficult to manipulate, taking away from the realism of the experience.

Value and relevance

Value of the simulator as a testing tool was rated as 2.83 (± 0.58), while value as a training tool was rated 3.17 (± 0.72). Relevance to clinical practice received the highest overall rating of 3.50 (± 0.52). Reviewers generally agreed that the simulator had moderate value as a training tool, M = 3.17 (0.72), slightly lower value as a testing tool, and relevant to their practice, M = 3.50 (0.52). Overall, the majority of participants agreed that the simulator needed minor improvements before it can be considered for use in oocyte retrieval training**.**

Ability to perform tasks

Ratings for the five procedural tasks ranged from 2.00 to 2.17 on the 3-point scale. Insertion of the ultrasound probe was rated 2.00 (± 0.43), visualization of the ovary 2.08 (± 0.29), aspiration of follicles 2.08 (± 0.51), avoidance of the ovarian artery 2.17 (± 0.58), and ultrasound-guided aspiration 2.08 (± 0.29). No statistically significant differences were observed between junior and senior participants ($p > 0.05$). Most of the reviewer comments in this section were centered around the orientation of the ovaries within the simulator, with particular focus on how the ovaries appear on the simulated ultrasound view**.**

Discussion

With the increasing need for ART in LMICs, a natural need to implement simulation-based training is necessary. Most simulated training devices are geared toward higher-resource communities, which may not be accessible or affordable for physicians practicing in LMICs. This motivates the need for low-resource, but still relatively high-fidelity, simulators for training in LMICs. This is especially true for simulators for teaching and learning ART. We developed a simulator to address these learning needs, balancing the high-fidelity aspects with many 3D-printed pieces and the low-resource context, using various household materials, including fabric, cardboard, and gelatin**.** The development and evaluation of this low-cost oocyte retrieval simulator trainer aimed at improving access to assisted reproductive technology (ART) in low-resource settings yielded promising but mixed results. While the simulator demonstrated value as a training tool, findings indicate that key refinements are necessary to enhance its realism and usability before it can be effectively integrated into educational settings.

Physical attributes and realism of experience

The moderate ratings observed for physical attributes and realism of experience highlight important areas for refinement. The lower ratings for haptic feedback during needle insertion and visualization of ovarian blood vessels also suggest that anatomical fidelity and tactile realism require further optimization of the device. These findings align with previous studies that emphasize the importance of anatomical accuracy in medical simulators to enhance training effectiveness for clinician trainees.[10-11] In ultrasound-guided procedures, tactile feedback and accurate anatomical representation are critical for building procedural confidence and minimizing complications. Future design iterations should prioritize softer, more elastic materials for external genital structures and improved alignment of the ovary modules to better replicate clinical conditions. Haptic feedback plays a very essential role in medical simulation training, as it allows learners to develop muscle memory and improve procedural proficiency.[12] While maneuvering the transvaginal ultrasound probe and the simulated ultrasound view were rated slightly higher, the feedback suggests that further calibration is necessary to improve tactile feedback and imaging accuracy.

Value and relevance

Participants rated the simulator more highly for its value and relevance than for anatomical realism. This suggests that users recognized the educational utility of the model despite acknowledging its current limitations. In many low-resource settings, moderate-fidelity simulators can provide substantial educational benefit when integrated into structured training curricula. The relatively high ratings for training value demonstrate the device's potential for use in postgraduate residency and fellowship programmes to supplement limited live-case exposure for trainees' skills acquisition. These scores suggest that, with some refinements and modifications, the simulator has remarkable potential as a useful educational tool in ART

training, particularly in low-resource settings where access to real-time oocyte retrieval training is limited. This is consistent with recent research findings that reported that low-cost simulators can be valuable in bridging the training gap in reproductive medicine, especially in developing countries.[13]

Ability to perform critical tasks

The observed ratings for the ability to perform essential procedural tasks clustered around the midpoint of the scale, indicating that the simulator was functional but required refinement. Concerns related to needle manoeuvrability and ovary orientation underscore the importance of ergonomic design in simulation-based training tools. Improving these elements may enhance procedural realism and ultimately facilitate skill transfer to clinical practice. Previous research had similarly suggested that correct anatomical positioning and real-time ultrasound guidance are critical for optimizing oocyte retrieval training.[14]

Implications for ART training in low-resource settings

The findings have important implications for strengthening ART training capacity in sub-Saharan Africa. Given the limited number of fertility centres and trained specialists across many countries in the region, cost-effective simulation tools may support workforce development and improve procedural competency. Embedding such models within structured competency-based curricula may enhance trainee preparedness before performing procedures on patients.

Implications and future directions

The findings have important implications for strengthening ART training capacity in sub-Saharan Africa. These findings highlight the potential of a low-cost simulator to address ART training gaps in resource-limited settings while also underscoring the need for targeted improvements in anatomical fidelity, haptic feedback, and ultrasound visualization.

Addressing these issues will be crucial in ensuring that ART trainees gain a realistic and effective learning experience. Future iterations should prioritize modifications to the material properties of the simulated vulva, the responsiveness of the oocyte retrieval needle, and the alignment of the ovaries with the ultrasound display to optimize usability and training impact.Moreover, the integration of advanced materials and 3D-printing technology could improve the anatomical realism of the simulator at a low cost, a strategy that has been successfully applied in other medical training models.[15]

Additionally, future studies should incorporate objective performance assessments to compare training outcomes using this simulator versus traditional methods to further validate its effectiveness. Given the limited number of fertility centres and trained specialists across many countries in the region, cost-effective simulation tools may support workforce development and improve procedural competency. Embedding such models within structured competency-based curricula may enhance trainee preparedness before performing procedures on patients.

Strengths

A major strength of this work is the development of a contextually appropriate simulator within a sub-Saharan African setting. To the best of our knowledge, the first attempt to develop the oocyte retrieval simulator trainer in a low-resource setting.

This study does have limitations to consider. Although it included a heterogenous sample of training levels, the study was performed at a single institution, and the sample size was relatively small, making it difficult to generalize findings to other institutions. Despite these limitations, our preliminary findings indicate that the simulator has the potential to be used in oocyte retrieval training but will need several modifications prior to its use in such a setting. Some key modifications proposed by the evaluators are: a) reorienting both the ovaries and the cameras to provide a view that more closely mimics an ultrasound, but still provides appropriate haptic feedback in terms of needle insertion and aspiration; b) making the vulva and other external anatomy out of a softer, more flexible material so it can be easily manipulated and stretched to allow for adequate access (this could potentially be done using silicon or fabric); and c) situating the entire simulator model into a manakin to provide a higher degree of anatomical realism. Following the modifications,

reevaluation of validity evidence from a broader global sample will be required. All the OB-GYN physicians who evaluated the model were based in Ghana. Although it is one of the main target communities of use, it is important to ensure that the simulator receives similar ratings from physicians in other areas, not just Sub-Saharan African LMICs. Also, the study is limited by its small sample size and single-centre design. Additionally, the evaluation relied primarily on subjective assessments. Future research should incorporate objective performance metrics and multi-centre validation to strengthen evidence.

Following improvements to the simulator, future work will include more evaluations with an expanded scope, and development and evaluation of a complementary curriculum and competency assessment program.

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Conflict of interest

All authors have declared no conflict of interest

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Data availability

All data supporting the findings of this study are available within the paper and its Supplementary Information.

Authors' contribution

PES and DR conceptualized the project idea. PES developed the project proposal and funding application. RP-1, RP-2, PES and DR built the simulator unit. DR developed the raining/evaluation scoring scale. PES, ASD and SAO supervised the evaluation research and data collection. DR performed the data analysis. RP-1 drafted the initial manuscript. RP-2, DR, CM, SAO, ASD and PES reviewed the draft manuscript.
All authors have read and approved the final manuscript for submission and PES is the corresponding author.

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