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Does Repeated Exposure to Critical Situations in a Screen-Based Simulation Improve the Self-Assessment of Non-Technical Skills in Postpartum Hemorrhage Management?

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Abstract

Background. **Postpartum hemorrhage** (PPH) is the leading cause of maternal death in the world. **Non-technical skills** (e.g. communication) are now recognized as a contributing factor to medical safety. In the field of simulation, **screen-based simulations** are currently very popular with computer/technological development. This study evaluates a screen-based simulation device, *PerinatSims*, developed to improve technical and non-technical skills in PPH situation. This experiment hypothesized that **exposure and repetition** of training with *PerinatSims* would **improve the self-assessment of non-technical skills**, and therefore increase the ability to manage PPH.

Methods. The primary endpoint was a self-assessment of non-technical skills during **simulation session of PPH on a digital simulator**. Twenty French midwives performed three of nine 25 minutes sessions of PPH screen-based simulation. Four self-assessment questionnaires were administered at the end of each simulation session: a leadership/team working questionnaire (**BAT**), a negative feelings/emotional questionnaire (**DASS-21**), a **Flow questionnaire** and a mental load questionnaire (**NASA-TLX**). Results between sessions were compared using a repeated measures ANOVA followed by a Bonferroni post hoc test.

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Results. The study showed a **positive evolution during the three screen-based simulation sessions**: an increase of leadership and team working self-assessment, an increase of Flow sense, and a decrease of negative emotions (anxiety and depression in the DASS-21 score). Significant decrease of stress was found only between the second and the third sessions, and significant differences in the NASA-TLX were observed only in two dimensions, Performance and Frustration.

Conclusion. A repeated exposure to PPH situations with a screen-based simulation tool improved the midwives' self-assessment, **especially for leadership, team working, emotion management and Flow sense**. Furthermore, midwives had a very positive feedback on the device. They highlighted the desire to use *PerinatSims* more often to be trained to PPH management, for technical as well as non-technical skills.

Keywords
education, human factors, medicine, non-technical skills, screen-based simulation, simulation

Introduction

Postpartum Hemorrhage (PPH) is the leading cause of maternal death, with more than 100,000 women dying each year in the world, mainly in developing countries (AbouZahr, 2003). In France, 85 women per year die from complications during pregnancy, delivery or after (10 maternal deaths per 100,000 births; INSERM report[1]). The leading cause is PPH, it is admitted that during the postpartum period 80% of the deaths could be avoided (Bouvier-Colle, 2007). The management of PPH is based mainly on procedure,[2] but many unexpected situations may occur (e.g. absence of a specialist during crucial minutes). Technical and procedural knowledge are insufficient, and they must be complemented with other dimensions such as organization and cooperation between professionals of different specialties and situation awareness.

Many medical errors are clearly related to insufficient mastery of Non-Technical Skills (NTS). The report *To Err Is Human* (Donaldson, Corrigan, & Kohn, 2000) underlines that shortcomings of teams' technical skills cannot explain the occurrence of incidents or accidents. Organizational and human factors are crucial to prevent maternal mortality. Communication imposed by the multidisciplinary aspect of this situation appears to be a critical factor in the proper management (Dreyfus, Beucher, Mignon, & Langer, 2004). Education, practical workshops and simulation can train practitioners to improve their skills and abilities to deal with PPH situations. In healthcare and medical professions, the non-technical skills such as communication, stress management, teamwork, and situation awareness must now be integrated in the curriculum and specific training modules (Cornthwaite, Edwards, & Siassakos, 2013; Fransen et al., 2012).

Table 1. Medical Definitions of Non-Technical Skills.

Situation awareness: *"Developing and maintaining a dynamic awareness of the situation in theatre based on assembling data from environment" (Flin, Youngson, Paterson-Brown, Yule, & Maran, 2006).*
Decision Making: *"Skills for reaching a judgement to select a course of action or make a diagnosis about a situation, in both normal conditions and in time-pressured crisis situations" (Flin, Glavin, Maran, & Patey, 2003,).*
Communication: *"Quality and quantity of information exchanged among team members" (Hull, Arora, Kassab, Kneebone, & Sevdalis, 2011).*
Teamwork: *"Skills for working in a team context to ensure that the team has an acceptable shared picture of the situation and can complete tasks effectively" (Flin et al., 2006).*
Leadership: *"Leading the team and providing direction, demonstrating high standards of clinical practice and care, and being considerate about the needs of individual team members" (Flin et al., 2006).*
Managing emotion/stress: *"Acute stress is sudden, novel, intense and of relatively short duration, disrupts, goal-oriented behavior requires a proximate response" (Flin, O'Connor, & Crichton, 2008).*

As an educational tool, simulation appears specifically as a "method that would allow training of medical personnel without involvement of a real living patient could improve functioning and, in the long run, would likely reduce errors, save lives" (Streufert, Satish, & Barach, 2001, p. 172). In the field of simulation training, feedback and debriefing are considered as determining factors for effective learning because it helps learners to develop a reflective approach that is conducive to the development of individual and collective professional skills (Fanning & Gaba, 2007). To reduce PPH mortality and morbidity, simulation is a validated learning tool associated with the improvement of technical and non-technical skills (INSERM report;Bantz, Dancer, Hodson-Carlton, & Van Hove, 2007; Maslovitz, Barkai, Lessing, Ziv, & Many, 2008).

NTS and Simulation: Origin and First Developments in Medicine

Non-technical skills are "cognitive, social and personal resources skills that complement technical skills and contribute to safe and efficient task performance" (Flin, O'Connor, & Crichton, 2008, p. 1). They have been categorized in seven skills: Situation awareness, Decision making, Communication, Teamwork, Leadership, Managing stress and Coping with fatigue (see Table 1).

The NTS framework found its roots in the Crew Resource Management (CRM) developed in aviation to improve safety, after many fatal accidents in the 70's, like the Tenerife accident (Wiener, 1980). The main objective of CRM is to evaluate/and improve the ability of practitioners to work with their co-workers (e.g. communication or leadership), to pay attention to the work environment (e.g. situation awareness) and to manage physiological or psychological states (e.g. stress or fatigue).

In the beginning of 1990, Gaba and his colleagues developed the concept of CRM in medicine (called Crisis Resource Management or ACRM). They developed a simulator in a real operation room to investigate decision making and human performance during critical situations in anaesthesia (Gaba & DeAnda, 1988). This simulator helped improve technical skills but also NTS in the theater: "I stay calm in crises", "I focus on priorities", "I assume the role of team leader" (Holzman et al., 1995).

The healthcare sector has a long tradition of using simulation for training. In this field, simulation is defined as the "use of a device, such as a mannequin, a task trainer, virtual reality, or a standardized patient, to emulate a real device, patient, or patient care situation or environment to teach therapeutic and diagnostic procedures, processes, medical concepts, and decision making to a health care professional."[3] In obstetrics, some artefacts like the dolls of Angélique du Coudray or William Smellie were designed at the end of 18th century to teach delivery in order to reduce mortality (Dubois et al., 2004; King, 2007; O'dowd & Philipp, 2000). Since then, the use of mannequins has broadened in the 20th century (Cooper & Taqueti, 2004). However, even if mannequin-based simulation has many advantages, the cost of training on this type of equipment remains very high.

In parallel to these innovations, new technologies have recently emerged in medical simulation such as virtual environments (Ma, Jain, & Anderson, 2014). Software simulation (also called screen-based simulation or digital simulator), including virtual environments, were created and are used in many medical specialties such as resuscitation (Wattanasoontorn, Magdics, Boada, & Sbert, 2013) or emergency (e.g. road accidents, Jouffroy et al., 2016). Several advantages are generally cited to justify the development of digital simulators over High-Fidelity simulation: they replicate the global environment (e.g. war situation, Pasquier et al., 2016), they allow learners to train regularly and remotely which also improves motivation (de Ribaupierre et al., 2014; Garris, Ahlers, & Driskell, 2002), and finally they offer a more cost-effective solution, especially for healthcare professionals with poor access to high-end medical equipment (Taekman et al., 2017).

Many medical researches are conducted in the Second Life platform and focused on learning and/or the transmission of knowledge (e.g. McGrath et al., 2015; Stewart & Davis, 2012; Wiecha, Heyden, Sternthal, & Merialdi, 2010). In a recent study, screen-based simulation impacted positively the self-efficacy of medical students, the retention of knowledge and focus (Creutzfeldt, Hedman, Medin, Heinrichs, & Felländer-Tsai, 2010).

In the obstetrics field, independent software are designed, in particular with the expansion of computer technology (Barré et al., 2018), including virtual reality environment (e.g. Dit Gautier et al., 2016). However, the study of the impact of simulation in virtual environments have received little attention, especially in the critical situation of PPH.

Research Question

This paper presents a project, which aim is to improve non-technical skills of medical practitioners in postpartum hemorrhage. This study is a part of the MacCoy Critical project[4] (Models for Adaptative feedback enriChment and Orchestration based virtual realitY in Critical situations). This project aims at studying and improving training systems, designed for NTS development, through the use of simulation and virtual environments. A screen-based simulation *PerinatSims* was designed to manage postpartum hemorrhage critical situations and offered a deliberate and repetitive practice that could improve and maintain practitioner's skills (Cannon-Diehl, 2009).

This experiment hypothesized that the repeated exposure to *PerinatSims* would positively influence the participants' self-assessment of non-technical skills for the management of PPH (via 4 questionnaires: BAT, Flow, DASS-21 and NASA-TLX); particularly leadership, team working and stress. Indeed, this repeated exposure would lead to an increase of the BAT scores (improved leadership and collaborative work, etc.) and the Flow scores (higher concentration, less stress, etc.), and also a decrease in the DASS scores (stress and anxiety reduction at each trial) and NASA-TLX scores (decrease of mental load with training).

Materials and Methods

Participants

Twenty midwives participated in an individual two-hour training session on the PPH digital simulator (*PerinatSims*). They were undergoing their last year of training in France or first year as a qualified professional, less than a year after graduation (women only, between 22 and 39 years old; Mean age of 24.05 ± 3.97 SD years). They had never used digital simulators during their curriculum and none of them had followed a training on NTS, CRM or Human Factors previously. Participants were all volunteers and received no financial remuneration for their participation. Recruitment was made from a mailing list of midwifery schools. The experimental design used in the present study was approved by the ethical committee of SFAR (Société Française d'Anesthésie et de Réanimation, N°IRB 00010254-2017-008) and the experimental data were collected with the approval and written consent of each participant.

Digital Simulator

The screen-based simulation *PerinatSims* has been designed by the Medusims company.[5] It reproduces the virtual environment in 3 dimensions of a delivery room during various PPH situations. Avatars in the virtual environment represent the parturient and the medical staff (nurse, gynecologist and anesthetist; see Figure 1). It is a first-person perspective, the midwife's view, and the navigation inside the digital simulator is a "point-and-click" type. The interface offers various actions, such as hygiene gestures, consultation of the patient's file or therapeutic actions (see Figure 1).

There are nine different scenarios developed on the basis of a compromise between what is plausible as an event external to the medical algorithm, based on opinions gathered from medical experts in obstetrics, midwifery, anesthesiology and human factors, and what is technically possible to implement in this type of virtual environment (given the constraints of computer experts). Each scenario differs depending on the patient's profile (e.g. age, number and type of delivery) and some specific medical or organizational events (e.g. the husband of the patient who knocks at the delivery room door during PPH; the anesthetist of the medical team who is busy and cannot help the midwife when called upon). Every scenario allows learners to test their ability to manage

Figure 1. *PerinatSims* software (screenshots). Above, different possible actions on the parturient: speak to the patient, observe the bleeding, etc. (left); avatars of team work (right). Bottom, a medical action is featured (uterine massage), with different graphic representations of possible actions (e.g. telephone, drugs administration).

PPH, and especially regarding NTS by integrating actions as phone calls to train communication skills, calibrated delivery drape verification to train with situation awareness or also drug administration according to time to train decision making.

Each exercise begins with an introduction about the medical case: e.g. *"Mrs Dinechin, 29 years old, has just given birth to her first child. She does not feel well in the birth room. Mrs. Dinechin has no history, no known allergy, no criteria for difficult intubation. She has her complete blood group card (AB +) and updated antiglobulin testing"*.

Through an educational approach, a debriefing on technical skills after each exercise is integrated into the software. A color code indicates the technical actions that were done well (green), the ones that could be improved (orange) and the ones that were not done / or poorly done (red).

Material

Four self-assessment questionnaires were selected in relation with the evaluation of non-technical skills.

Table 2. Example of a Rating Form of BAT.

3. Assumption and Leadership Role				
Fails to clearly identify himself/herself stands hack, takes a "hands off" approach; appears nervous, "rattled", uncomfortable; fails to inspire confidence.		*Identifies self after questioned; enters the situation and takes "hands on " approach when asked to; assumes leadership role but does not clearly coordinate activities of team.*	*Clearly identifies himself/herself as responsible for patient care; readily enters the situation, takes a "hands on" approach when necessary; coordinates activities of all team members; calmly inspires confidence in leadership.*	
Poor/Novice (0 points)	Partially/Acceptable (1 point)	Acceptable/Competent (2 points)	Above/Average (3 points)	Excellent/Expert (4 points)

The first one is the BAT (Behavioural Assessment Tool; Anderson & Warren, 2011; Le Flore, Anderson, Michael, Engle, & Anderson, 2007), designed as a leadership and collaborative teamwork questionnaire used in medical studies on specific and/or direct past situation. In the literature many surveys about leadership/followership topics are based on global management: "the senior leaders in my hospital listens to me and cares about my concerns", not usable in this study (Pronovost et al., 2003). Although BAT is traditionally used with a blinded expert on video evaluation, the ten stated dimensions are suitable for behaviors during PPH situations (e.g. connection is established between the team members as midwife, anesthetist, nurse or gynecologist; the algorithm was respected by each member of the team, the leader delegates tasks, etc.). Furthermore, BAT is based on Dreyfus model of skills acquisition to assess behaviors in simulation-based education (Anderson & Warren, 2011). It was therefore decided to use it as a self-assessment tool, the midwife evaluates her own performance after each exercise. The BAT includes 10 questions on leadership and team work (see Table 2), on a 5-point Likert scale, from Poor/Novice (0) at Excellent/Expert (4). The final result was calculated as the mean value of these 10 items (/5).

The Flow questionnaire was selected as the second self-assessment tool (Csikszentmihalyi, 1997; Ghani, 1995). Flow state is defined as an intense and focused concentration, or an involvement and absorption in an ongoing activity. If the level of challenge is mismatched with the current stage of development then either boredom or anxiety will result. In the medical field, Flow "could refer to the ease and fluidity with which an operation progresses" (Shouhed, Gewertz, Wiegmann, & Catchpole, 2012), and is reported to facilitate learning and encourage one to attempt a difficult task (Ahlborg, Hedman, Rasmussen, Felländer-Tsai, & Enochsson, 2012; Creutzfeldt et al., 2010). At last, Flow can be correlated with medical performance (Ahlborg, Hedman, Nisell, Fellânder-Tsai, & Enochsson, 2013). The Flow questionnaire includes 12 questions (e.g. *I had the skills to do this activity* or *I did not see the time pass*), on a 7-point Likert scale, from “Not agree at all” (1) to “Totally agree” (7). The final result is calculated as the mean value of these 12 items (/7).

Third, the NASA-TLX was selected to assess the perceived workload (Hart & Staveland, 1988) during a specific task. Many factors contribute to workload in medical situation, as risk, stress and unexpected events (like PPH situation), communication, fatigue / sleep deprivation or the ability to lead a team / delegate tasks (Leedal & Smith, 2005). An excessive workload can increase the risk of errors (Yurko, Scerbo, Prabhu, Acker, & Stefanidis, 2010) and lead to failures (Vincent, Taylor-Adams, & Stanhope, 1998). Even if NASA-TLX was initially developed in aviation, it appears to be a validated tool to assess workload perceptions in the medical CRM field (Young, Zavelina, & Hooper, 2008). The NASA-TLX include 6 questions/dimensions (e.g. Mental Demand; *How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex?*), rated on a 100-points range for each dimension. Raw Task Load Index was used to analyze our results, without weighting phase (RTLX; Byers, Bittner, & Hill, 1989).

Finally, the DASS-21 version was selected to assess participants’ emotions and stress (e.g. *I was worried about situations in which I might panic and make a fool of myself*). The DASS questionnaire evaluates emotion management according to three axes of stress, anxiety and depression (Lovibond & Lovibond, 1995). Traditionally used in clinical context, DASS are also used as self-report in professional/learning context, for example to evaluate communication performance when a novice is breaking bad news during a consultation (Brown et al., 2009). Twenty-one questions compose the score using a 4-point Likert scale, from 0, “Did not apply to me at all/Never”, from 3, “Applied to me very much, or most of the time/Almost/Always”. DASS final scores classification are as follows: *Normal, Mild, Moderate, Severe* and *Extremely severe*, on a 21-points scale in each axis.

In order to ensure the usability of the system, an evaluation was carried out by the means of the System Usability Scale questionnaire (SUS; Brooke, 1996). Its score is composed of ten-items with a Likert scale on the criteria of usability, in line with the ISO 9241 standard about Ergonomics of Human-Computer Interaction: e.g. *I think that I would like to use this system frequently; I thought the system was easy to use; I felt very confident using the system*. Bangor, Kortum, and Miller (2009) defined a categorization to evaluate the system from SUS global score with some adjectives: *Worst Imaginable, Horrible, Poor, OK, Good, Excellent*, and *Best Imaginable.*

Open-ended question was also added to the study to gather participants’ perceptions of the major strengths and weaknesses of the simulator (*What are the major strengths and weaknesses of the simulator? and Did you learn anything*? *Please explain what*).

In addition, demographic information (gender, age, year of training, simulation experience) was collected to ensure consistency in the characteristics of the population studied.

The sessions were conducted in an experimentation room at *Ilumens Simulation lab* (Paris Descartes University) on a Desktop Computer (23-inch screen with 1920*1080 resolution).

Procedure

After a brief tutorial, each learner underwent a short practice session to navigate in the virtual environment of the delivery room, interact with the patient and perform some actions (e.g. to install the calibrated delivery drape, administering drugs, call colleagues). Then, learners began the two-hour simulation with three 25 minutes software sessions on three different scenarios. Scenarios were randomly distributed over the three sessions. After each exercise a computer debriefing on technical skills was included in the software. No information on NTS were included in this computer debriefing.

At the end of each screen-based simulation session, learners were asked to fill in the 4 self-assessment questionnaires: leadership questionnaire (BAT), the emotion/stress questionnaire (DASS-21), the Flow questionnaire and the NASA-TLX. Regarding the specific interest to NTS, participants were blinded to the endpoints of the experiment before and during the exercises. In addition, a demographic survey and the SUS questionnaire with open question were completed by the participants. Data were collected on paper and participants themselves completed the questionnaires.

Finally, in addition to the computer debriefing on technical skills after each exercise, a 10 minutes debriefing on non-technical skills was conducted by a senior physician face-to-face with each midwife at the end of the sessions. This last debriefing covered the three sessions and included the presentation of the NTS shown in the Table 1. Technical and non-technical debriefings were standardized: seven categories were integrated in the computer debriefing (e.g. Medical hygiene topics), and six categories in the skilled facilitator debriefing based on the Table 1. The debriefings, including the computer debriefing on technical skills, allowed midwives to capitalize their experience by a reflective practice on the events in the screen-based simulation sessions about feedback on actions/decisions, and to promote the multidisciplinary approach required for NTSs learning (e.g. importance of collaborative working, impact of leadership/followership, etc.; Fletcher et al., 2003; Flin et al., 2008; Hull, Arora, Kassab, Kneebone, & Sevdalis, 2011).

Data Analysis

Results from the four measurement scales were compared using a repeated measures ANOVA to analyze the data changes along the sessions, followed by a Bonferroni post hoc test, for a pairwise comparison. Data was analyzed with SPSS version 23 software (IBM, USA).

A thematic analysis of the open-ended question was used to identify and quantify participants' positive and negative views of the simulator.

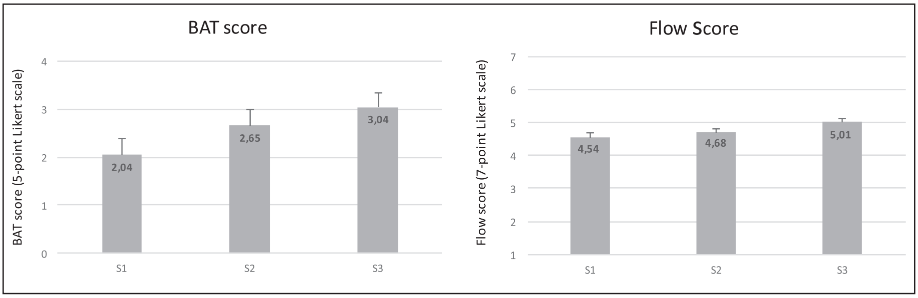

Figure 2. Results of BAT score (left) and Flow score (right) in each session (mean and standard error).

Results

This section presents the significant differences between sessions (noted [S1], [S2] and [S3] below), regarding BAT, Flow, DASS and NASA-TLX scores.

Concerning the **BAT score**, a difference of 1 point (on a 5-point Likert scale) was found between S1 (M = 2.04; SD = 0.66) and S3 (M = 3.04; SD = 0.59), with an intermediate result for the session two (M = 2.65; SD = 0.67; Figure 2). Self-evaluation changed from “Acceptable” performance to close to “Excellent” (see Table 2). Differences were significant between sessions (ANOVA, F(2/38) = 50.209, $P < .001$; Bonferroni post hoc, [S1/S2] $P < .001$, [S1/S3] $P < .001$, [S2/S3] $P < .05$). These results suggest that the participants perceived an improvement after each session concerning the leadership and the team working dimensions.

Similar results were observed with the **Flow score**. Participants rated a high score on the Flow scale, which increased after each session ([S1] M = 4.54; SD = 0.61 < [S2] M = 4.68; SD = 0.50 < [S3] M = 5.01; SD = 0.54; see Figure 2). Differences were significant between sessions (ANOVA, F(2/38) = 8.048, $P < .001$; Bonferroni post hoc, [S1/S2] NS $P = .835$, [S1/S3] $P < .05$, [S2/S3] $P < .05$). In accordance with the concept of Csikszentmihalyi (1997), the ratio between digital simulator challenge and personal skills appeared to be high. Participants were gradually in a Flow sense, intense and focused concentration and an involvement, and absorption in ongoing task achievement.

Self-assessment of **DASS** showed a stress score considered as “mild”[6] in the first and second session (M > 7; see Figure 3), and a stress score considered as “normal” in the third simulation session (M < 7). General differences between sessions were not significant, except between S2 and S3 (Bonferroni post hoc, $P < .05$). Concerning the anxiety score, a score considered as “mild” in S1 and S2 was found (M > 3), but a “normal” score was found in the last session (M < 3). Differences were significant between sessions (ANOVA, F(2/38) = 12.599, $P < .001$; Bonferroni post hoc, [S1/S2] NS $P = .063$, [S1/S3] $P < .05$, [S2/S3] $P < .05$). Finally, on the depression axis, a

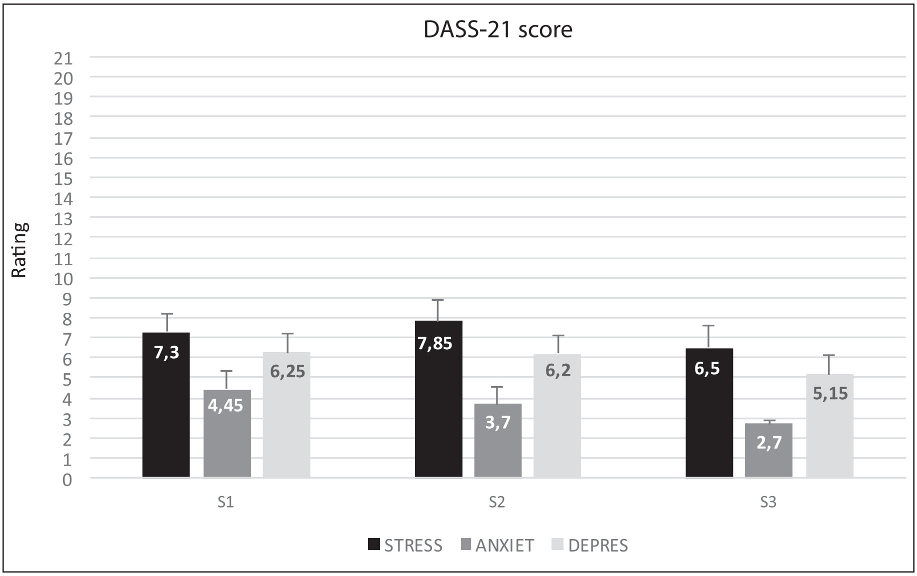

Figure 3. DASS-21 mean score and standard error in each simulation session (S1/S2/S3), in view of the three axes of DASS dimension (Stress/Anxiety/Depression).

"moderate" score was found in the first and second simulation (M > 6), and a score considered as "mild" was found in the last session (M = 5.15; SD = 4.28). General differences were significant between sessions (ANOVA, F(2/38) = 3.238, $P < .05$; Bonferroni post hoc, [S1/S2] NS $P = 1$, [S1/S3] NS $P = .219$, [S2/S3] NS $P = .060$). Although these scores are relatively low in view of DASS, simulation sessions can be considered as mildly to moderately stressful to the participants,[7] especially in the first and second simulation sessions. In the last session, stress, anxiety and depression scores decreased to a normal level.

Finally, concerning the **NASA-TLX**, mental load in the three sessions was high (M > 50; see Figure 4), but there were no significant differences between sessions (ANOVA, F (2/38) = .822, NS; Bonferroni post hoc, [S1/S2] NS $P = 1$, [S1/S3] $P = 1$, [S2/S3] $P = .397$). The mental load in the PPH screen-based simulation can be considered as important, but it remained stable despite the training sessions. Each dimension was analyzed below (see Figure 5).

High mean scores especially on the Mental demand (M > 80) and Effort dimensions (M > 70), were found without significant differences between sessions. Physical demand was the dimension assessed as the lowest (M < 20; indeed, the physical activities were quite low in the simulation). However, a slight increase in the last session on this scale was observed, certainly due to participants' fatigue after more than one hour of simulation, but the differences were not significant although close (ANOVA, F (2/38) = 3.024, $P = .060$). The same observation was described for the Temporal demand, which could be related to an increased fatigue. Concerning the Frustration

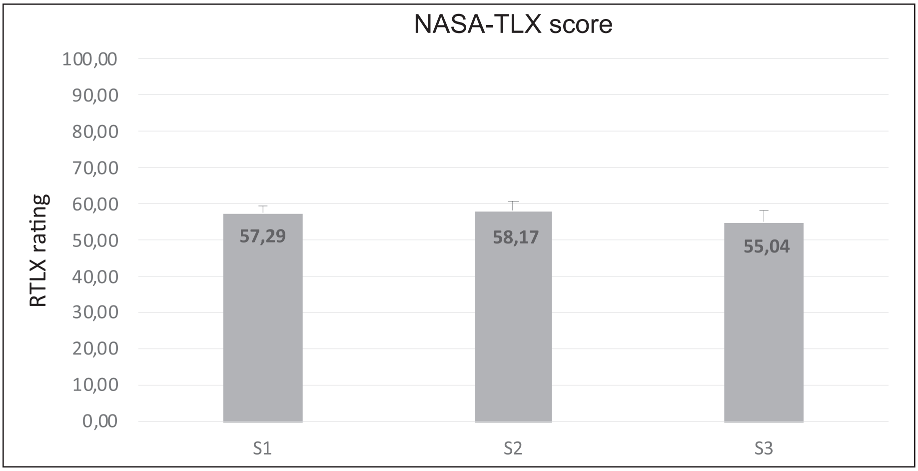

Figure 4. NASA-TLX results between session (RTLX mean score and standard error).

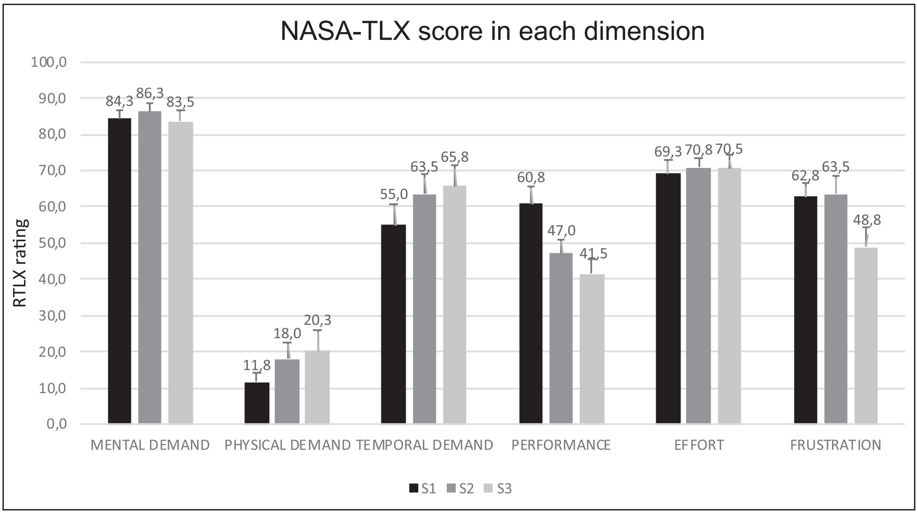

Figure 5. NASA-TLX results (RTLX mean score and standard error), in each dimension and session.

scale, a significant decrease between sessions was observed (ANOVA, F(2/38) = 4.688, $P < .05$), except between S1 and S2 (Bonferroni post hoc, [S1/S2] $P = 1$, [S1/S3] $P < .05$, [S2/S3] $P = .053$). The decrease of Frustration could be explained by an improved mastery of the software (e.g. understanding of icons/pictograms), but also a better management of the medical situation. Finally the scoring of the Performance scale showed a similar trend (ANOVA, F(2/38) = 10.724, $P < .001$), except between the session 2 and 3 (Bonferroni post hoc, [S1/S2] $P < .05$, [S1/S3] $P < .05$, [S2/S3] $P = .367$). This could be explained by a perception of a better control of PPH situation after each session, participants being more comfortable and confident.

Finally, participants filled the SUS open questionnaire on the software experience, to give a global and subjective view on the usability and interest in the *PerinatSims* software. A mean score of 78.25 points was obtained (min = 60; max = 100; SD = 9.49). It was considered as a "good" software (Bangor et al., 2009).

Concerning open question, the 20 midwives formulated 91 opinions on the simulator (M = 2.27, SD = 1.55). Of these opinions, the majority were positive (68/91; 74.7%). They highlighted the novelty of this tool compared to their traditional curriculum and the value of such a device for learning or training PPH management from repeated exposure of critical situations: "*training courses of PPH, with unknown situations*", "*useful for studying the algorithm*", "*good immersion / as in reality / realistic*", "*improve the management of PPH*", "*opportunity to train regularly / repeat actions*". Midwives also emphasized the benefits of perceived stress in situation: "*it helps to manage stress*" and "*to be more serene*". Nevertheless, they noted some negative elements concerning improvement of the software: "*the software requires some learning*", "[it] *does not give immediate feedback on my mistakes*", "[it allows] *only one action at a same time*", "*interaction with the other game avatars could be improved*" and "*the rhythm is a little bit different from reality (slower)*". Although improvements to the device would be worth implementing, participants perceived the virtual environment simulator experience to be largely beneficial for PPH training.

Discussion

In healthcare, previous research on virtual environments has shown that learning can be positively impacted by this kind of technology. Creutzfeldt et al. (2010) carried out measurements of self-efficacy, concentration, and mental strain in a cardiopulmonary resuscitation training for medical students in virtual environment. The authors found an increase of subjects' self-efficacy after the training. In another study, self-confidence was tested in a screen-based simulation (Taekman et al., 2017) and the results showed that subjects improved confidence in their ability to perform task. These findings are closed with those of Kanthan and Senger (2011), who evaluated satisfaction of student using digital games-based learning: better satisfaction and engagement, enhanced personal learning, and a lower stress perceived.

In this study a positive evolution during repeated exposure of *PerinatSims* simulator was observed with an increase of leadership and team working self-assessment, an increase of Flow sense, and a decrease of anxiety and depression dimensions of the DASS-21. Concerning stress dimension, a significant decrease was found only between the second and the third sessions. The decrease of negative emotions was in accordance with the heart rate measures realized in addition of self-rating. In NASA-TLX, significant decreases were found only in Performance (*How successful do you think you were in accomplishing the goals… How satisfied were you with your performance?)* and Frustration (*How insecure, discouraged, irritated, stressed and annoyed… did you feel during the task?*) dimensions, a better mastering of PPH situation is certainly the cause. Indeed, obstetric emergencies are stressful mainly in student midwives, and simulation reinforces confidence, improves communication and team working and reduces stress (Hughes, Anderson, Patterson, & O'Prey, 2014; Norris, 2008; Scholes et al., 2012). Self-assessment results are concordant with spontaneous opinions of the participants. For example, one of them said in open question: "*I feel I have learned a lot. I have felt better as I went through the scenarios, more confident in my skills. It will improve my personal management of real situations*".

These positive effects on participants' self-assessment of NTS is an important outcome. In this virtual environment, midwives exposed to repeated unexpected critical situations could have created a sentiment of failure or stress, especially because midwives were confronted to different scenarios with different levels of difficulty (randomly distributed). On the contrary, it seemed to reinforce a positive perception towards their NTS over time.

Because of the particular learning situation, the screen-based simulation of PPH, and the relatively small sample of participants (n = 20), these results would need to be replicated and confirmed in other situations and/or with a larger cohort. However, statistical analysis showed significant differences in scores despite the small sample. These findings argue that screen-based simulation improves midwives' self-assessment in their ability to manage critical situations of PPH more effectively, particularly with regard to the NTS.

According to Weick and Sutcliffe (2011), these results suggest that these simulations, by developing the ability of practitioners to cope with the unexpected would be relevant for training. This skill is a fundamental feature of a resilient organization. Algorithms can be revised by practitioners (e.g. accuracy of blood loss estimation, role of each team members, timing of medicine administration, etc.) but also many unexpected situations included in the software (e.g. allergy, external events as the husband who knocks at the delivery room door, etc.) to help midwives to manage PPH.

However, the role of debriefing on learning is fundamental. Screen-based simulation can be considered as a support or vector because "learning comes from the debriefing, not from the game" (Crookall, 2010). Debriefing with learners cannot be separated from simulators (Fanning & Gaba, 2007; Gordon & Buckley, 2009). Same observations can be performed with High-Fidelity simulation: discussion on the training session is essential to capitalize knowledge and know-how (Barry Issenberg, McGaghie, Petrusa, Lee Gordon, & Scalese, 2005; Guillén-Nieto et al., 2012).

The study has some limitations. Self-assessment questionnaires used here evaluate indirectly NTS, and under this condition validity and reliability of each instrument must be studied and independently tested. For example, in Nakamura and Csikszentmihalyi (2002) the state of Flow was categorized by an "Intense and focused concentration", a "Merging of action and awareness" and a "Sense that one can control one's actions", and can be compared to Situation awareness and Decision making definitions of Table 1, but no study analyzed specifically the correlation between Flow and non-technical skills. In the future, further analyses will have to be carried out to confirm these results, for example by resorting to non-technical skills checklists (e.g. ANTS, Fletcher et al., 2003; OTAS, Hull et al., 2011) or by measuring effective learning scores (e.g. the changes during trials in the number and types of errors committed, the duration of the task performed). Positive correlations between self-assessment tools used in this study and NTS checklists or learning outcomes would be expected.

Finally, one last point seems important for future research: the retention of knowledge within a longitudinal approach, as repeated exposure to screen-based simulation is not sufficient to ensure knowledge appropriation and transfer. A new experiment could test skills and knowledge of midwives before practicing in the simulator, when using the screen-based solution *PerinatSims*, and after a delay of one month. This experimentation could also evaluate the retention of knowledge in a variety of critical situations unknown to participants. Although it is difficult to anticipate critical events, interviews with midwives who followed screen-based simulation and who later encounter a PPH case could be carried out to assess how the simulation impacted their professional performances.

Conclusion

PPH is an emergency situation considered as complex and critical. Technical skills are required to manage efficiently this situation (e.g. rapid identification; Marshall, Vanderhoeven, Eden, Segel, & Guise, 2015), non-technical skills are however also essential to prevent incidents or accidents especially in unforeseen situations (Cornthwaite et al., 2013; Donaldson et al., 2000; Fransen et al., 2012). Simulation and screen-based simulation offer several opportunities essential for enhanced learning (Cannon-Diehl, 2009; de Wit-Zuurendonk & Oei, 2011), due to the diversity of exercises with various scenario, level of difficulty and specific and timely feedback on learner's decision making (e.g. success, errors). It therefore allows the retention of knowledge, with the possibility of repetition mainly during initial training or deliberate practice (e.g. voluntary and distance learning; Ericsson, 2009).

Some authors suggest that digital simulators could be an effective training method in healthcare (de Wit-Zuurendonk & Oei, 2011), but screen-based simulation cannot replace traditional training. In order to be able to use the digital simulator, midwives must have completed their curriculum. The software then appears as a support tool during the initial training of midwives, or as a training tool throughout their career. A digital simulator cannot either replace the High-Fidelity training in regards with the multidisciplinary aspect. As already mentioned, High-Fidelity is a technique that is still not widespread: "[High-Fidelity simulation] is currently constrained by a number of factors including cost, the adequacy of facilities and equipment, and the availability of staff with the required expertise and experience in simulation" (Vermeulen et al., 2017). In France, many midwives in practice or even recently graduated, have never received High-Fidelity training. So, screen-based simulation is proving to be an interesting alternative for PPH teaching and training, by allowing several midwives to be trained simultaneously, promoting distance learning (initial and continuing), and can also be used in developing countries. This last point appears to be important as PPH is the most common type of obstetric hemorrhage and accounts for the majority of the 14 million cases that occur each year (World Health Organization, 2007; World Health Organization & United Nations International Children's Emergency Fund, 2012).

The next step will be to test if those training advantages are confirmed in real interaction, ensuring that it is not just a learning effect of the simulator. With this aim in mind, the midwifes could perform a PPH High-Fidelity simulation session after this

PerinatSims training. Another midwives group could perform only a PPH High-Fidelity simulation without *PerinatSims* training. An improvement of NTS self-assessment in the group *PerinatSims*/High-Fidelity simulation would be expected, compared to the control group.

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Notes

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2. Collège National des Gynécologues et Obstétriciens Français : http://www.cngof.fr/
3. H.R. 855 To amend the Public Health Service Act to authorize medical simulation enhancement programs, and for other purposes. 111th Congress, USA, 2009. Available from: gpo.gov/fdsys/pkg/BILLS-111hr855ih/pdf/BILLS-111hr855ih.pdf
4. N°ANR-14-CE24-0021: https://maccoy.hds.utc.fr
5. This present work is done as part of an ANR research project where Ilumens, LATI and Medusims are technical and scientific partners. These three partners are not bound by financial issues, but only by scientific issues related to NTS learning in virtual environment. Medusims' technical expertise has enabled the implementation, in the PPH virtual environment management system, of criticality elements for atypical care situations. This implementation was conducted according to the recommendations resulting from preliminary analyses by LATI and Ilumens researchers.
6. In coherence with Lovibond and Lovibond (1995). DASS final scores classification are as follows: Normal, Mild, Moderate, Severe and Extremely severe.
7. The heart rate monitor Polar M400 associated with the chest belt H7 (Polar Electro Oy, Finland) were also used in this study to measured beats per minute (bpm) of midwives during simulation sessions in addition of self-assessment questionnaires. Decrease of heart rate (HR_{mean}) was observed between each session: [S1] 94.99 $\pm$ 11.5 (bpm) $>$ [S2] 90.04 $\pm$ 13.26 (bpm) $>$ [S3] 85.41 $\pm$ 12.6 (bpm), in accordance to the results of DASS-21 ($P < .01$).

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