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Neurological Assessment Using a Physical-Virtual Patient (PVP)

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Abstract

Background. Simulation has revolutionized teaching and learning. However, traditional manikins are limited in their ability to exhibit emotions, movements, and interactive eye gaze. As a result, students struggle with immersion and may be unable to authentically relate to the *patient*.

Intervention. We developed a new type of patient simulator called the **Physical-Virtual Patients** (PVP) which combines the physicality of manikins with the richness of dynamic visuals. The PVP uses spatial **Augmented Reality** to rear project dynamic imagery (e.g., facial expressions, ptosis, pupil reactions) on a semi-transparent physical shell. The shell occupies space and matches the dimensions of a human head.

Methods. We compared two groups of third semester nursing students (N=59) from a baccalaureate program using a between-participant design, one group interacting with a traditional high-fidelity manikin versus a more realistic PVP head. The learners had to perform a **neurological assessment**. We measured authenticity, urgency, and **learning**.

Results. Learners had a more realistic encounter with the PVP patient (p=0.046), they were more engaged with the PVP condition compared to the manikin in terms of authenticity of encounter and cognitive strategies. The PVP provoked a higher sense of urgency (p=0.002). There was increased learning for the PVP group compared to the manikin group on the pre and post-simulation scores (p=0.027).

Conclusion. The **realism** of the visuals in the PVP increases **authenticity** and engagement which results in a greater sense of urgency and overall learning.

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Background

With the widespread adoption of traditional simulation (i.e. high-fidelity manikins) in healthcare programs, we are witnessing innovative ways to educate nurses and healthcare professionals. Simulation has revolutionized the way we teach and learn as the pedagogy of simulation continues to mature. Despite these advances, current manikin-based technology does have limitations such as the inability to exhibit emotion, move idly, or gaze interactively. Educators often use *workarounds*, to mitigate the manikins' shortcomings. For example, the educator may introduce a picture, graphic, or video of a wound or skin rash, etc. or provide some artifact that the simulator cannot depict (Garside et al., 2012). To further underscore this point, Freeland et al. (2016) engaged standardized patients in addition to a high-fidelity manikin to overcome the manikin's inability to swallow which was a crucial aspect of the stroke simulation and the student learning outcomes.

Students struggle with the suspension of disbelief and may find it difficult to relate to the *patient* authentically. Authentic learning is involving real world case presentations that are relevant to the learner (Kunst et al., 2018). Power et al. (2016) enhanced simulation with the use of video-vignettes prior to the simulation-based experience (SBE) and found this resulted in greater student engagement. This technique gives the simulated patients more context, thereby increasing the realism and, by proxy, the learner engagement (Power et al., 2016).

When developing objectives for SBE, the knowledge and affective objectives may be more complex and necessitate greater realism. At times, this results in the need to cue the student. The facilitator can verbally cue the learner that the patient is *grimacing in pain* to overcome the manikin's static appearance. In healthcare simulation, a cue is defined as information provided to help the learner reach the objectives; this is also known as conceptual cues (Lioce et al., 2020). Cues can be provided directly or indirectly. Direct cues are experienced without facilitator intervention. Indirect cues are obtained verbally through the facilitator. We are interested in comparing the effects of cueing using two different experimental conditions: indirect verbal cueing from the facilitator versus direct dynamic visual cues from the physical virtual patient (PVP).

The PVP belongs to a new class of patient simulators which combines the physicality of manikins plus the richness of dynamic imagery (Hochreiter et al., 2016). This PVP can show dynamic imagery, (e.g. blink, smile, and other facial expressions) on a translucent shell. The patient's speech supports synchronized lip movement displayed on a human-like form. Similar technology has been used previously for cranial nerve assessment (Rivera-Gutierrez et al., 2012). This class of simulator could prove useful for other healthcare scenarios beyond neurological assessment.

Concepts Under Consideration

Urgency. Urgency happens when you recognize that a situation requires immediate attention. The magnitude of urgency may be under-represented when using a traditional manikin. Traditional manikin technology is limited in its ability to evoke a sense of immediacy. In fact, researchers found that standardized patients were superior to traditional manikins when teaching clinical deterioration in patients (Alsaad et al., 2017). Nurses may unwillingly miss rescue events when they do not recognize, act on or report signs of clinical deterioration. These findings have been linked to lack of nursing knowledge and critical thinking skills (Schubert, 2012).

Not all SBE require high fidelity, in fact fidelity requirements vary according to the learning context (Hamstra et al., 2014). However, there may be a deficit in the learners' engagement if the SBE does not tap into the learners' emotional triggers, such as the visual, auditory and tactile elements (Choi et al., 2017). Mills et al. (2016) reported that greater psychological fidelity engendered a realistic sense of urgency among paramedic students. With the advent of newer technologies, such as PVP and augmented reality, a sense of realism may be better recreated, which can lead to an enhanced sense of urgency for learners (Butt et al., 2018; Hochreiter et al., 2016).

Authenticity. An authentic encounter provides context that reflects the way knowledge and skills would be used in a complex world, this applies to both the physical and virtual worlds. Authenticity in the context of simulated learning is associated with realism of which fidelity is a potential attribute (Bland et al., 2014). In an effort to increase engagement educators may rely on moulage to increase realism. Moulage is the use of special effects such as make-up in the form of wounds, cuts, abrasions on the manikin to add realism (Stokes-Parish et al., 2018). The goal is to bring the SBE closer to the complexity of the real world leading to better learning engagement. Engagement can lead to a deeper understanding and improved knowledge retention overall (Schuller et al., 2015).

Learning. The goal of nursing education is to teach students how to appraise clinical information and prioritize in terms of most pressing concerns (Benner et al., 2010) quickly and correctly. For learning to occur, there must be knowledge in the form of facts and information, the ability to think critically and have self-confidence (Kim & Kim, 2015). Learning occurs when the learner is equipped with the information and the background to make sense of a situation. This allows for the learner to contextualize the event and carry it forward thereby, transforming knowledge. Nursing education is based in part on experiential learning in the clinical setting, the skills laboratory, and the simulation arena. For our purposes we define learning as the combination of clinical reasoning, and knowledge acquisition. In order to foster clinical reasoning and knowledge acquisition the SBE must be engaging and authentic.

Engagement is a component of learning, and it is defined as involving oneself in an activity and therefore, a requisite for a meaningful activity. Furthermore, learner motivation is the driving force behind the learner activity (Appleton et al., 2006).

Engagement is multidimensional and includes knowledge, skills and attitudes. Ideally, SBE focuses on the engagement of the learner through activities that simulate clinical situations in order to maximize students' interest, attention and learning (Choi et al., 2017). One of the goals of any SBE is to simulate encounters that possess physical, emotional and conceptual fidelity (Choi et al., 2017).

Intervention

At our university we developed a new type of physical-virtual patient (PVP) simulator for research purposes (Daher et al., 2018, 2020). The PVP combines physicality with rich virtual content using a 3D virtual patient. The simulated patient is modeled using Autodesk Maya and exported to unity game engine. The graphical user interface in unity consists of buttons and sliders to control the patient's reactions in real time using a human in the loop. The camera images from the unity scene are sent to an aaxa P300 projector. The imagery is rear projected on a semi-transparent plastic shell that is formed to represent a simplified human head with a matching scale. The patient's audio came from a speaker located under the plastic shell of the head. This physical-virtual head uses spatial augmented reality (AR). The physical component of the PVP can be touched and occupies volume similar to the dimensions of a human head. The virtual component is computer controlled and consists of the patient's appearance and their physiologic manifestations which includes verbal and non-verbal responses. The verbal responses were pre-recorded and featured synchronized lip movement during speech using LipSync pro unity asset. The non-verbal responses include blendshapes for animating eyebrow movement, mouth movement (open/close, smile), tongue fasciculation, eye movement (eye gaze and blink), and pupil changes to support different symptomatology. The PVP could communicate and react to touch, such as when checking for sensation. The PVP allowed for manipulating the representation of different cues in a controlled environment (see Figures 1 and 2). The apparatus for the *intervention* consisted of the PVP head atop of a Laerdal SimMom™ manikin (see Figure 4). The apparatus for the *control* consisted of a full-body high fidelity Laerdal SimMom™ manikin. A human behind the curtain (Wizard of Oz) (Lu & Smart, 2011) controlled both conditions from a separate room and informed participants when to start the simulation. In the manikin condition, the controller offered verbal cues per participant request to compensate for missing visuals (e.g. ptosis, facial asymmetry).

Methods

Our research objective was to study the effect of the PVP on learning by measuring urgency, authenticity, learner engagement, and knowledge acquisition with third semester nursing students. This research study contained two parts, the initial intervention, and a follow up assessment. Study 1 compared engagement, clinical reasoning (learning), urgency, and authenticity of patient encounters between those using the

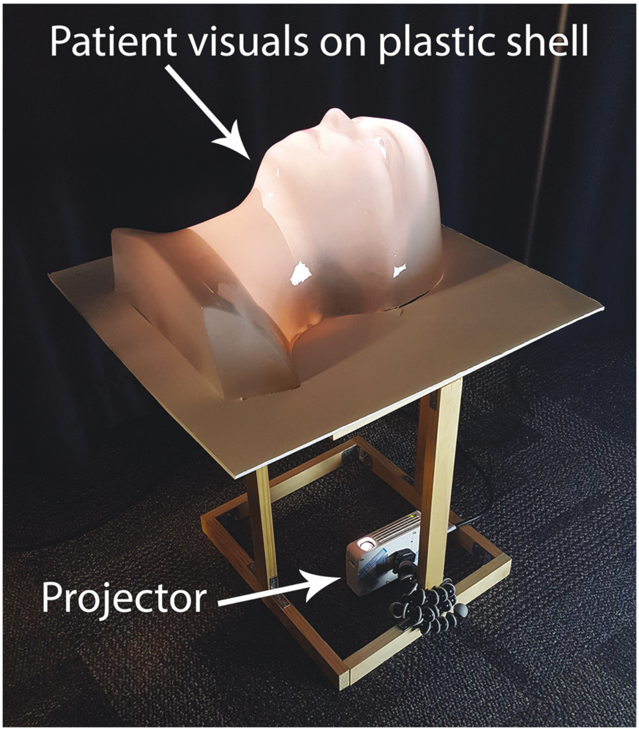

Figure 1. Apparatus for the physical virtual patient head.
Note. Figure showing a wooden rig with a projector and a shell. The visuals are rear-projected on the physical shell of a human head.

traditional manikin and those using the PVP technology. Study 2 assessed learning in the form of a pre and post question.

Research Questions

Question 1 (Urgency): Will the students who interact with the PVP demonstrate greater urgency when compared to those who interact with the manikin?
Question 2 (Authenticity): Will students who interact with the PVP perceive a more authentic encounter when compared to those who interact with the manikin?
Question 3 (Learner Engagement): Will the students who interact with the PVP demonstrate greater learner engagement when compared to those who interact with the manikin?

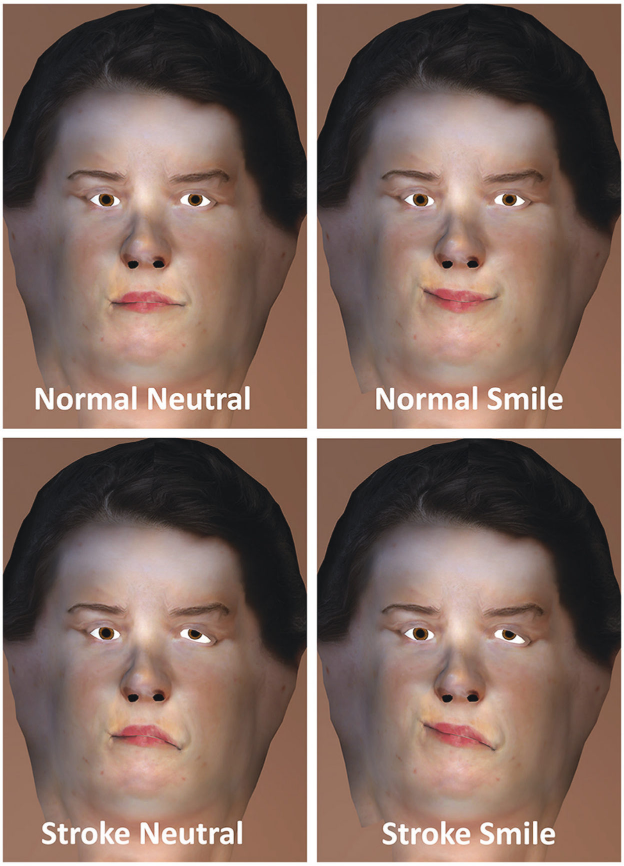

Figure 2. Normal face v. stroke face.
Note. Figure showing different states of the patient's face (i.e. normal vs stroke, neutral vs smile) that was sent to the projector.

Question 4 (Knowledge Acquisition): Will the students who interact with the PVP demonstrate enhanced knowledge retention when compared to those who interact with the manikin?

Sample

This research was approved by our university's Institutional Review Board. For Study 1 students (N=59) were exposed to the PVP as a component of the Medical-Surgical curriculum in a baccalaureate nursing program. Simulation is introduced early on in semester one and occurs throughout the curriculum with simulations becoming more

Figure 3. Learner engaging with PVP.
Note. Learner assessing patient's reaction to touch.
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complex. This study took place with semester three students during their adult health II simulations. Content for the early recognition and management of the stroke patient is delivered in didactic and reinforced during the SBE. For Study 2, students (N=25) chose to participate in the follow up which involved completion of the neurological assessment question.

Research protocol. The studies took place at the University of Central Florida, College of Nursing. The type of encounter (PVP vs. manikin) alternated based on assigned simulation days which were pre-determined at the beginning of the semester (4 days for manikin, 3 days for PVP). The researchers had no prior knowledge of the student composition. In a between-participant design study, seven student cohorts were assigned to the condition that was running that day. In this IRB exempt study, completion of the instruments was considered consent. Study 1 and Study 2 included two conditions (See Figure 4). Condition 1: Assess a high-fidelity manikin (26 interacting and 10 participants observers [PO]) or Condition 2: Assess the physical-virtual patient (18 interacting and 5 PO). All participants for both studies were asked to complete demographics. Immediately after the SBE Participants of Study 1 were asked to complete the VPEval Instrument (Huwendiek et al., 2015) and Urgency and Realism questions. Participants of Study 2 were asked to answer the following question prior to entering the SBE and again at 6 weeks, "*When performing a neurological exam what are all the potential findings you can remember?*"

Participants entered the scenario in either pairs or triplets, in each group two students interacted with the patient and the remaining student sat in a chair in the role of

Figure 4. Physical virtual patient v. traditional manikin.
Note. Figure showing the two conditions: full body Manikin (Top) and

participant observer. The participant observer role is an active learning assignment which requires the learner to take notes and make observations during the SBE (Leigh et al., 2017). All subjects were familiar with high-fidelity simulator (Laerdal™ SimMom) capabilities from previous exposure. Those interacting with the PVP viewed a two-minute video of a healthy patient with normal findings to familiarize themselves with the PVP capabilities. The objectives of the simulation were for the learners to complete a physical assessment and make recommendations for treatment using the Situation, Background, Assessment, Recommendation (SBAR) format. Participants had 15 minutes to complete the assessment. All participants were debriefed by a qualified facilitator with CHSE-A certification using the Debriefing for Good Judgement (DGJ) framework (Rudolph et al., 2007).

We developed the scenario using the INACSL Standards of Best Practice: Simulation Design℠ (INACSL Standards Committee, 2016). Vera Real was a 42-year-old female (see Figures 2 and 3) who presented to the emergency department with acute visual loss and right upper and lower hemiplegia. She had a remote history of transient ischemic attacks and atrial fibrillation. She complained of a headache, which progressively worsened. She admitted to being irritable and could not focus. Past medical history consisted of depression, and hypothyroid disease. She denied any surgeries. Medications included a long history of oral contraceptive use, Lexapro 10mg once a day, and levothyroxine 0.75 mcg once a day. She smoked 1 pack per day and tried to quit on multiple occasions. The participants entered the scenario with an SBAR handoff and were required to do an immediate assessment.

Instruments. This section describes the measures used to assess urgency, authenticity, and learning. We used a combination of researcher developed questions, and validated instruments.

Urgency. We developed the following question to assess urgency: When assessing the head, did it provoke a sense of urgency? (on a 1 - 7 scale with 7 for highest urgency).

Authenticity and learner engagement (clinical reasoning). We developed the following question to assess the authenticity and realism of the patient head: *How close to a real patient did the patient feel? (on a 1 - 7 scale with 7 for greatest realism).* We also used the Virtual Patient Design Evaluation (VPEval) questionnaire to measure authenticity and learner engagement (Huwendiek et al., 2015). This questionnaire uses a twelve item Likert scale with 3 open ended questions and is intended to evaluate virtual patients and to ensure the design fosters clinical reasoning of learners via an authentic encounter. The scale ranges from strongly disagree (1) to strongly agree (5). The domains include (1) authenticity of patient encounter, (2) cognitive strategies on the consultation, (3) coaching during consultation, and (4) learning effect of consultation. We removed two questions from domain (3) coaching during consultation because participants were not allowed to ask questions during the encounter. We did not perform our own validity and reliability testing for the instrument, instead we chose to rely on previously documented reliability and validity. Cronbach's α per domain ranged from 0.74-0.82 indicating high inter-item reliability (Huwendiek et al., 2015).

Knowledge acquisition (learning). **Study 2**: To quantify participants' prior knowledge regarding neurological assessment, we included a second question. This was treated as a standalone assessment. Students were asked the following question prior to the SBE, *"When performing a neurological assessment, what are all the potential findings you can remember?"* At the end of the semester, they were asked the same question in an optional extra credit question for their final exam. In total, 25 students responded (PVP = 13, manikin= 12). For the pre- and post-question, responses were analyzed for inclusion of the following words: Facial (e.g. droop, ptosis, asymmetry, facial expressions), Tongue (e.g. deviation), Pupils (e.g. irregular), Touch (e.g. sensation), Speech (e.g. slurred). For example, if the student mentioned unequal pupils, they received

1 point for the Pupil category; if the pupil was not mentioned the participant received zero points for that category. Therefore, in order to get a perfect score, the participant would have to mention one item per category. Each of the pre and post categories were combined to represent an individual maximum score of 5. There were 13 participants in the PVP condition, if all the participants answered correctly the maximum combined group score would be 65. There were 12 participants in the manikin condition, if all participants answered correctly the maximum combined group score would be 60.

Statistical Analysis

Given the small sample size, we used the non-parametric test Mann-Whitney U for the Likert scale responses, and the score differences obtained from the pre-simulation and post-simulation answers to assess learning. We used the statistical analysis software JASP ("JASP - A Fresh Way to Do Statistics," 2020).

Results

In this section, we present results for urgency, authenticity, and learning.

Urgency

Participants in the PVP condition indicated a significantly higher sense of urgency (Mdn=5) compared to participants in the manikin condition (Mdn=3.0) U=207.50, p=0.002.

Authenticity

Participants in the PVP condition felt the simulated patient was significantly closer to a real patient (Mdn=4.0) compared to participants in the manikin condition (Mdn=3.0), U=271.0, p=0.046. The VPEval (Huwendiek et al., 2015) measures authenticity, and learner engagement which are components of clinical reasoning. The results of the VPEval are detailed in the Learning section below (see Table 1).

Learning

In this section we present the VPEval results from Study1, and knowledge acquisition results from Study 2.

Study 1: The VPEval scores of the participants in the PVP condition were significantly higher compared to participants in the manikin condition. The statistics from the Mann Whitney U test are reported in Table 1. Participants in the PVP condition felt they had to make the same decisions a doctor/nurse would make in real life (p=0.038), felt more as if they were the doctor/nurse caring for the patient (p =0.067), were more actively engaged in gathering the information (e.g., history questions, physical exams, lab tests) they needed to characterize the patient's problem (p=0.049), were more

Table 1. Virtual Patient Evaluation Results (VPEval).

	Mann-Whitney U		PVHead				Mannequin			
Question	U	P	N	Mean	Mdn	SD	N	Mean	Mdn	SD
1) I felt I had to make the same decisions a doctor/nurse would make in real life.	228	0.038	20	5.8	6.0	1.3	34	5.1	5.0	1.3
2) I felt as if I were the doctor/nurse caring for this patient.	239.5	0.067	20	5.6	6.0	1.6	34	4.9	5.0	1.4
3) I was actively engaged in gathering the information (e.g. history questions, physical exams, lab tests) I needed to characterize the patient's problem.	232.5	0.049	20	5.7	6.0	1.7	34	4.9	5.0	1.7
4) I was actively engaged in revising my initial image of the patient's problem as new information became available.	217.5	0.025	20	6.0	6.0	1.2	34	5.1	5.0	1.5
5) I was actively engaged in creating a short summary of the patient's problem using medical terms.	233.5	0.052	20	5.7	6.0	1.3	34	4.9	5.0	1.4
6) I was actively engaged in thinking about which findings supported or refuted each diagnosis in my differential diagnosis.	197	0.009	20	5.9	6.0	1.2	34	5.0	5.0	1.2

Note. Questions 1 and 2 belong to the domain of authenticity of patient encounter and the consultation. Questions 3-6 belong to the domain of cognitive strategies in the consultation

actively engaged in revising their initial image of the patient's problem as new information became available (p=0.025), had greater engagement when thinking about which findings supported or refuted each diagnosis in their differential diagnosis (p=0.009) than participants in the manikin condition. Also, we saw a trend towards significance with participants in the PVP condition demonstrating greater engagement

Table 2. Knowledge Acquisition Results From the Pre-Simulation and Post-Simulation Question.

Pre and post score difference	Mann-Whitney U		PVHead				Mannequin			
	U	P	N	Mean	Mdn	SD	N	Mean	Mdn	SD
Face	12.0	0.36	6	0.67	0.50	1.21	6	0.00	0.00	0.98
Tongue	10.5	0.21	6	0.33	0.50	0.82	6	–0.17	0.00	0.41
Pupils*	4.0	0.023	6	1.33	1.50	0.82	6	0.00	0.00	0.63
Touch*	7.0	0.070	6	1.00	1.00	0.89	6	0.00	0.00	0.63
Speech	17.0	0.93	6	0.33	0.50	0.82	6	0.33	0.00	0.52
Total*	4.0	0.03	6	3.67	5.00	2.16	6	0.17	0.50	1.47

Note. Results from analyzing the text answers for the question When performing a neurological exam what are all the potential findings you can remember?
The * denotes significant results.

when creating a short summary of the patient's problem using medical terms than the participants in the manikin condition ($p=0.052$).

Study 2: Students went into the simulation in teams of 2 or 3, therefore we erred on the side of caution and decided to assess the knowledge acquisition of the team as opposed to the individual learner. We examined the change in scores between the pre-simulation question and the post-simulation question. Since we were examining the difference in scores, the number of participants per team would not affect the results. We had 6 teams (total of 13 participants) in the PVP condition, and 6 teams in the Manikin group (total of 12 participants). In the PVP condition, we observed that 83% (5 out of 6 teams) gained knowledge, 16.7% (1 out of 6 teams) neither gained nor lost knowledge. In the manikin condition, we observed that 50% (3 out of 6 teams) gained knowledge, 16.7% (1 out of 6 teams) neither gained nor lost knowledge, and 33.3% (2 out of 6 teams) regressed. In light of these findings we ran a MannWhitney U test to check for significance. There was greater overall knowledge acquisition when the participants were in the PVP condition compared to the manikin condition ($p=0.027$). Under the sub-categories (i.e. Face, Tongue, Pupils, Touch, Speech) PVP participants acquired significantly more knowledge in the Pupils category ($p = 0.023$) and approached significance in the Touch category ($p = 0.07$) compared to those in the manikin condition. There was no difference in the progress for the individual sub-categories: Face, Tongue, and Slurred Speech ($p > 0.05$) (see Table 2).

Discussion

In this study, we compared urgency, authenticity, and learning among nursing students who performed a neurological assessment on a simulated patient in one of two conditions: high-fidelity manikin versus a Physical-Virtual Patient (PVP). Results showed a greater sense of urgency, a more authentic encounter, and increased learning for those who interacted with the PVP compared to the manikin condition. Students who interacted with the PVP demonstrated greater engagement which resulted in greater knowledge acquisition (learning). This is not surprising, since engagement has been linked to learning (Schuller et al., 2015).

Our results from the VPEval were significantly higher for the PVP than the manikin condition. Participants felt that they were making the same decisions doctors and nurses would make in real life suggesting the encounter had a greater level of authenticity. In addition, participants used better cognitive strategies, such as gathering information, updating initial impressions, and making recommendations. Furthermore, the PVP felt closer to a real patient and evoked a higher sense of urgency than the manikin condition. Participants acquired greater overall learning when interacting with the PVP. In the post-test, participants recalled more assessment findings with the PVP as compared to the manikin. The assessment sub-categories included Face, Tongue, Pupils, Touch and Speech. Our scenario required visual inspection to identify key physiologic assessment findings. The ability to appreciate facial asymmetry is more powerful when visualized as opposed to cueing the learner (e.g. facilitator says *the patient has facial drooping*). However, the researchers were not surprised that facial asymmetry was not significant in the PVP since facial asymmetry as an indicator of stroke is one of the most commonly recognized symptoms among lay people (American Stroke Association | A Division of the American Heart Association, n.d.). The animated imagery (e.g. blink, eye gaze, lips movement for speech. . .etc.) provided real-time feedback on the patient's changing condition. Also, the PVP could alter its eye gaze prompting the learner to re-engage. These dynamic visuals may have made the scenario more realistic which enhanced learning. We speculate that touch was close to being significant due to the ability to observe the visual facial changes (i.e. facial expressions, lip movement) on the PVP as a response to touch when compared to the static manikin.

Limitations and Suggestions for Future Research

Both Studies had a small sample size; these findings are not generalizable beyond our population. We are confident that a larger sample size would have strengthened our findings. This study used the head of a Physical Virtual Patient (PVP); the assessment findings were limited to the head. We recognize that a thorough assessment would include extremities and grip strength at a minimum. Given that these findings were not supported by current technology, facilitators provided those cues verbally upon request.

Technical limitations include the virtual imagery being bound to the physical surface allowing only small movements without distortion, for example large movements on the virtual side such as a head shake could break the synchronization with the physical part that could lead to visual distortions in the imagery.

Not every SBE requires this level of sophistication. The decision to use a particular simulator such as the PVP is dependent on the learner objectives. The value of the PVP is its ability to portray dynamic imagery, especially when inspection and visualization of the patient is important (e.g. stroke, sepsis, burns, measles).

Future work includes extending the PVP to a full-body simulator, adding multisensory experiences, automating certain responses, and developing a library of different scenarios.

Conclusion

Simulation has changed how we teach and learn. Traditional manikins are limited in their ability to exhibit emotions, use idle movements, and gaze interactively. As a result, students may struggle with immersion and may be unable to authentically relate to the *patient*. PVPs combine the physicality of manikins with the richness of dynamic visuals. Our results show that participants had a more authentic encounter with the PVP condition, and they expressed a greater sense of urgency compared to the manikin. When measuring the change between the pre-and post-simulation tests the results indicate an increase in learning for the students interacting with the PVP condition compared to the manikin condition. In summary, the realism of the visuals in the PVP increases authenticity and engagement which results in a greater sense of urgency and overall learning.

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