eCULTURE

Volume 7 2014 *Article* 2

Using eye tracking, time-to-action, heart-rate and perceived task difficulty to assess level of distraction and performance of entry-level paramedicine students in low- versus high-fidelity simulation

Owen Carter[*] Brennen W. Mills[†] Cobie Rudd[‡]
Natalie Strobel[**] Louise Claxton[††] Nathan Ross[‡‡]

[*]Edith Cowan University, o.carter@ecu.edu.au
[†]Edith Cowan University, b.mills@ecu.edu.au
[‡]Edith Cowan University, cobie.rudd@ecu.edu.au
[**]Edith Cowan University, n.strobel@ecu.edu.au
[††]Edith Cowan University, l.claxton@ecu.edu.au
[‡‡]La Trobe University, n.ross@latrobe.ecu.edu.au

Using eye tracking, time-to-action, heart-rate and perceived task difficulty to assess level of distraction and performance of entry-level paramedicine students in low- versus high-fidelity simulation

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Abstract

Introduction

There is limited research investigating the usefulness of high-fidelity simulations (HFS) for early-stage students. Some argue the additional expense of HFS over low-fidelity simulation (LFS) is unnecessary as early-stage students are too easily distracted by non-relevant stimuli inhibiting student's ability to focus on the core task. However, the extent to which this is true is yet to be empirically tested.

Methods

First-year paramedicine students were randomly assigned to complete either a LFS or HFS involving a collapsed patient with an obstructed airway. Level of distraction was measured via eye-tracking, arousal via heart-rate (HR), task difficulty via the NASA TLX, and clinical decision making via time-to-action. Student's perceptions of HFS and LFS were also explored via in-depth interviews immediately following simulations.

Results

Proportion of time attending to non-relevant stimuli was greater for HFS than LFS students (8.1% vs. 0.9%, *p*pp=.001). More students from the HFS group revived the patient than the LFS group (58% vs. 30% respectively). Students from the HFS condition achieved time-to-action significantly quicker than those in the LFS condition (*p*=.010), a trend that remained constant when isolating those removing the obstruction (*p*<.05).

Conclusions

Students in HFS suffered from greater distraction, perceived the task as being more difficult and were more aroused than students in LFS. However, HFS students outperformed LFS students with respect to clinical decision making and patient outcomes.

KEYWORDS: Simulated-learning environments; early-stage students; paramedicine; eye-tracking; clinical decision making

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The increased global demand for health professionals has resulted in a marked increase in the intake of undergraduate students in Australian universities in the past decade. Clinical placements are an integral part of the learning curriculum but the number of students requiring undergraduate placements within Australia now exceeds supply [1]. This is the result of a number of factors, including increased demand, declining inpatient populations, concerns for patient safety, limited funding for training, staff shortages, and competition for placements between health care disciplines [2]. This has led many tertiary education providers to seek avenues for reproducing clinical experiences through innovative approaches. Simulation-based learning is widely suggested as part of the solution. Its advantages include experiential learning in a secure environment [3], avoidance of any risk to patients and students [4] and recreation of important but rare clinical situations that most students would miss in random clinical encounters [5].

For early-stage students the extent to which simulations should attempt to replicate the dynamic aspects of real-world environments remains contentious. Low-fidelity simulations (LFS) focus on replicating the essential components of a clinical scenario so as to allow skills to be practiced in a safe environment with minimum extraneous distraction. High-fidelity simulation (HFS) incorporates the use of realistic environments, live standardised patients or sophisticated and often computerised manikins, other actors and elaborate scripts, generally resulting in increased costs compared to LFS [6 7].

Given the substantial additional expense, there is surprisingly little robust research to demonstrate an additional positive effect of HFS on student learning outcomes in comparison to LFS. While it has been convincingly demonstrated that HFS training results in high levels of student satisfaction [2 8 9] systematic reviews are consistently critical of the quality of most published research investigating simulation-based learning. This is largely due to the propensity to rely on single-group analyses with no comparison group data or infer benefits of HFS over LFS with comparisons to variants of didactic learning [2 10 11]. In addition, Cant and Cooper also criticise most simulated-learning-environment research for relying upon indirect and self-reported measures of improvements in clinical competency [11] that have been shown to vary considerably from ratings by clinical assessors [12].

Given the paucity of robust evidence for the effectiveness of HFS training to date, it is difficult to establish when throughout the undergraduate curriculum the use of HFS, as opposed to LFS, is most appropriate. A study by Reischman and Yarandi used paper-based simulations to demonstrate that the development of diagnostic expertise is associated with an ability to focus on highly relevant cues and ignore non-relevant ones [13]. This is generally in line with the views of Maran and Glavin who proposed the use of a progressive continuum of low- to high-fidelity simulation for health profession education [14]. However, they provided little empirical evidence to support the progressive continuum.

The Challenge Point Framework (CPF) proposed by Guadagnoli *et al.* supports this progression of low- to high-fidelity simulation, as it recommends an appropriate level of challenge aligning with student experience to maximise experiential learning [15]. According to the CPF early-stage students should be provided new information in limited amounts in a controlled practice area, with minimal outside distractions, so as to avoid cognitive overload (i.e. LFS). However, students later in their training should be able to process information more efficiently and therefore are better suited to more dynamic learning environments more closely emulating real-world settings (i.e. HFS). The concept of ‘distraction’ is often referred to as the main contributing factor leading to increased difficulty in HFS with extraneous items being inserted into the environment and thus more accurately imitating real-world settings [16 17]. The CPF aligns with other adult learning theories from the health profession literature, such as the information processing theory—which posits that as practitioners become more experienced, processing of information becomes quicker leading to increased clinical decision-making capability [18]. Similarly, the descriptive theory of skill acquisition suggests that with increased expertise an elaborate knowledge-base is compiled into a few high-level concepts, improving the efficiency of short-term memory processing freeing up space for active problem solving [19].

Evidence to support a progressive continuum of low- to high-fidelity simulation includes a study by Girzadas *et al.* who demonstrated HFS-based assessments are good at discerning novice from experienced emergency medical residents [20]. Similarly, Thompson *et al.* demonstrated that as the fidelity of simulations increases it makes it more difficult for nursing students to separate important clinical symptoms from non-relevant distractors [21]. A directly relevant paper is by Brydges *et al.* who used the ‘scaffolding theory’ to demonstrate that allowing medical students to train through simulations of progressively increasing fidelity led to a superior transfer of clinical skills compared to HFS training only [22]. However, students receiving only HFS-based training undertook approximately half the total training of students receiving a progression from low- to high-fidelity, providing an alternate explanation for their data being attributable to differing training dosages.

To date, there exists limited evidence supporting progression from lower to higher fidelity simulation-based training for undergraduate health professionals. We sought to conduct an investigation focussing on HFS for early-stage students, for whom the CPF suggests would experience a heightened cognitive burden due to greater distraction in HFS leading to a diminished ability to perform clinical tasks. Reischman and Yarandi assessed students' attention to relevant vs. non-relevant stimuli in clinical scenarios by analysing audio-recordings of students' verbal recounts of written clinical scenarios (LFS) [13]. However, no studies have provided objective measurements assessing differences in level of distraction between HFS and LFS environments. We sought to (1) objectively compare the extent to which early-stage students were distracted by extraneous/non-relevant item cues in HFS compared to LFS; (2) investigate how levels of distraction related to task difficulty and (3) investigate how task difficulty impacted on performance in each environment. The aim of the present study was to test these study aims via the following hypotheses utilising a mixed-methods study design:

Early-stage students undertaking the same clinical task in either HFS or LFS will:
H_1: attend to more non-relevant cues in HFS than LFS
H_2: find HFS more challenging than LFS.
H_3: perform worse in HFS than LFS.

METHODS

Participants

Our participant pool included all students (n=52) enrolled in a first-year paramedicine clinical skills unit entitled "Introduction to Paramedical Practice" in 2013 at Edith Cowan University (ECU), Western Australia. Participation in the study was voluntary. Recruitment took place during a presentation at one lecture as well as online postings on the faculty website. The study was approved by the ECU Human Ethics Committee (#9834).

Materials

The scenario

Paramedicine teaching staff at ECU identified a standard clinical condition that could be simulated in both HFS and LFS environments, while still maximising discrimination between students' varying levels of clinical competency. The resultant clinical scenario involved the student paramedic being dispatched to a nightclub for a lacerated arm. When attending to the patient, another man collapses on the dance floor with an obstructed lower airway, is non-responsive, not breathing and gradually becomes pulseless after three minutes. Visual assessment of the airway with standard triple-airway manoeuvre reveals no obvious obstruction. No chest rise results from use of the bag-value mask. Use of a laryngoscope reveals a bottle cap easily removed with Magill forceps resulting in breathing and recovery. Students had been taught the skill in class three weeks prior to data collection. Both fidelity environments utilised a Laerdal SimMan 3G manikin (Laerdal, Oakleigh, Australia) as the collapsed patient with obstructed airway. A 'confederate' actor played the role of 'assistant paramedic' throughout the scenario whose role was to assist and respond to requests from the participant. All scenarios took place within the ECU Health Simulation Centre. Both versions of the scenario were piloted with n=3 visiting paramedicine instructors as well as a sub-sample of n=4 paramedicine students randomly selected from the participant pool. Pilot testing suggested students were unfamiliar with some functions of the manikin, so a 5-minute training protocol was developed for participants to be conducted prior to the start of the experiment.

Differences in fidelity

While the simulated patient and clinical symptoms remained constant between study groups, the HFS included multiple distractors comprising of: a darkened setting, loud music, flashing lights, projected background dancers and multiple interactive bystanders played by live actors, including a distressed girlfriend, a bouncer and a cantankerous drunk. In contrast, the LFS environment was in a well-lit room devoid of environmental distractions. As the HFS contained bystanders that—when prompted by the participant—provided pertinent information regarding timeframes and medical history, in the LFS this information was provided—again only when prompted—by the confederate.

Measures

Distraction

Participants wore Mobile Eye-XG (Applied Science Laboratories, Bedford MA, USA) eye-tracking goggles to measure visual fixations of relevant and non-relevant stimuli (see Figure 1). Holmqvist *et al.* suggests fixations are generally considered a measure of attention to that position [23]. Finke *et al.* validated visual attention as a neurological measure of actual attention by finding significant correlations between visual parameters and four established clinical tests of attention [24].

The level of distraction amongst study participants was quantified by a paramedic clinical supervisor who reviewed the eye-tracking videos and recorded the amount of time (in split seconds) participants fixated on relevant and non-relevant stimuli. A fixation was defined as a students' eye remaining on a single object for more than 500 milliseconds [23].

[INSERT FIGURE 1 HEREBOUTS]

Perceived Difficulty

The National Aeronautics and Space Administration Task Load Index (NASA-TLX) is a self-completed paper-and-pencil instrument that evaluates a participants' perceived difficulty of undertaking a set task. It measures six dimensions each rated on 21-point scales—namely mental, physical and temporal demand, performance, effort and frustration. The index was rigorously tested during its three-year development period [25] and has since appeared in over 2,850 studies [26]. It has previously been used in simulation studies in the field of aviation [27] and perceived workloads in the health industry [e.g. 28 29 30]. Xiao *et al.* evaluated the NASA-TLX on n=1,268 mental health workers in China and found it to have good re-test reliability, good internal consistency and good structure validity [31].

Arousal

Continuous heart-rate (HR) data were collected from participants at five-second intervals during the task using the Polar s610i watch and chest strap (Polar, Kempele, Finland). Jang *et al.* demonstrated its use as an objective measure of arousal in simulated environments [32].

HR variation was calculated by comparing mean HR throughout simulations against pre-entry baseline recordings (mean HR from 60 seconds immediately prior to simulation entry).

Performance

We assessed participants' performance via two simple objective measures: whether the participant located and removed the obstruction; and time until termination. The simulation had two strict termination procedures: (1) when participants successfully removed the obstruction leading to patient recovery or (2) if the obstruction remained undetected after two bouts of five cycles of cardiopulmonary resuscitation (CPR) and students commenced a third round without further investigation of the airway.

Statistical analysis

For continuous variables (distraction, NASA TLX perceived difficulty ratings, continuous HR data and time to termination) between-group comparisons were made via Independent Samples *t*-tests (α=.05). A Fisher's Exact Test was used to compare proportions of students from each group who located and removed the obstruction (α=.05).

Interviews

Immediately following the simulation participants were taken to a private debriefing room where a face-to-face, unstructured interview was conducted in order to elicit participants' experiences, feelings, beliefs and perceptions of the simulation. The processes of qualitative phenomenology as recommended by Moustakas [33] was conducted, developing a textural and structural description of students' perceptions. As per the recommendations set out by Creswell during the data collection and analysis phases, any prior beliefs, views or judgements from the researcher were recorded or 'bracketed' in order to suspend any bias or presuppositions during the research process [34]. The recorded data were transcribed verbatim. Moustakas' approach was again followed using systematic steps in the data analysis procedure [33]. De-identified data were entered into QST NVivo qualitative software to organise text, coding, identifying themes and displaying findings.

RESULTS

In total, 39 students made up our final sample, providing a consent rate of 80% (after removing those that took part in the pilot study). Our final sample, randomly split into 19 in the HFS group and 20 in the LFS group, consisted of 51% females spread equally across experimental groups, with an average age of 23 years (SD = 5.8).

Distraction

Distraction data were available for 38 out of 39 participants as the eye-tracking hardware malfunctioned for one participant. The proportion of time students fixated upon non-relevant stimuli was higher in HFS than LFS (8.1% vs. 0.9%, $t(28.010)=-5.621$, $p<.001$), equating to 32.5 seconds vs. 4.7 seconds respectively).

Perceived Difficulty

NASA-TLX data were successfully collected from all participants. Analysis of the global NASA-TLX scores suggested no significant differences between groups ($t(37)=-1.183$, $p=.244$). However, the mean score for one subscale item referring specifically to *mental demand* (“how mentally demanding did you find the task?”) was significantly greater for participants undertaking the HFS compared to the LFS ($t(37)=2.145$, $p=.039$). No significant differences were found between-groups for the other subscale items.

Arousal

HR data were successfully recorded for 68% of participants as one day of HR data were lost due to equipment failure. No significant differences in average baseline HR were observed between groups ($t(26)=1.387$, $p=.177$) suggesting no allocation bias to groups for this measure. An analysis of mean HR during the simulation compared to mean HR at baseline suggested the HFS group increased by an average of 11.92 beats per second (bps) compared to the LFS group that decreased by 2.43 bps. This difference was statistically significant ($t(25)=3.679$, $p=.001$). As can be seen in Figure 2, changes in average HR from baseline were consistently greater post-simulation entry for the HFS group compared to the LFS group.

[INSERT FIGURE 2 HEREABOUTS]

Performance

The proportion of students who revived the patient—by removing the obstruction from the airway—was greater in the HFS than LFS group (58% vs.

30% respectively). However, this difference only approached statistical significance (Fisher's Exact Test, *p*=.076).

Simulation termination was achieved significantly quicker by students from the HFS condition compared to those in the LFS condition (6.4 vs. 7.9 minutes respectively; *t*(36)=2.736, *p*=.010). This difference remained significant when isolating those that 'passed' the scenario by removing the obstruction (5.8 vs. 7.9 minutes in the HFS and LFS scenarios respectively; *t*(14)=2.353, *p*=.034).

Interviews

Qualitative interview data generally aligned with the quantitative results. Participants in the HFS condition said the simulation provided substantial distraction that often forced their attention away from the primary patient, e.g., "*I got distracted so easily and my mind was going a mile a minute.*" This seemed primarily due to the bystanders being in the room, loud music and flashing lights, e.g., "*There was just lots of people around with lots of noise, way more than what we usually do with just two people and a manikin*" and "*Yeah the drunk guy and the girlfriend got me.*" In the LFS condition, participants commented that the simulation could have benefited from a heightened level of fidelity, e.g., "*It was quite quiet for me, it was a bit you know…not real"* and "*If for example there was really the patients girlfriend there I think that would have been better.*"

With respect to arousal, it seemed participants in both conditions felt stressed, e.g., "*Yeah wow that was intense*" and "*My heart was pounding really fast.*" HFS participants attributed this to the realistic nature of the scenario, e.g., "*It was pretty, you know, like powerful having all that stuff going on in the background*" and "*I thought I saw him get punched and I was like 'what the hell?'*" LFS participants seemed to focus more on the feelings of being 'assessed' by the confederate, e.g., "*The fact that I was the only one there I really felt like the pressure was on me*" and "*Even though she's there saying 'just tell me what to do' I kind of know she's assessing me.*"

Concerning impact on overall performance, HFS participants generally considered the simulation to be challenging and stressful but were comfortable overcoming this obstacle by narrowing their focus toward the patient, e.g., "*You have to learn to deal with distractions so they were OK*" and "*It was distracting but I guess when you can see that your number-one priority is the patient you can kind of zone all that other stuff out.*" LFS participants on the other hand seemed to be less concerned with helping the patient in a timely manner than ensuring stringent application of processes due to the 'assessment' type feel of the simulation, e.g., "*I psyched myself out in this scenario because I was trying so hard to do everything perfect, which took ages*" and "*In our assessments we have to do everything textbook or we get told off, no matter how long it takes.*"

DISCUSSION

Our measure of eye-fixations to non-relevant stimuli was significantly higher amongst the HFS group compared to the LFS group, confirming that our experimental manipulation of environmental fidelity was successful at providing greater distractions for students in the HFS condition. While perhaps an obvious result, our eye-tracking measure objectively confirms that early-stage students are subject to increased distraction in HFS compared to LFS.

Our second hypothesis, in line with the CPF, predicted that early-stage students would experience greater challenge in HFS than LFS due to greater distractions leading to cognitive overburden. Our NASA-TLX and HR data confirm that HFS students had greater arousal and mental burden than their LFS counterparts. Interview data provide insight into why this may have been the case. Increased psychological 'immersion' due to the realistic nature of the HFS environment is likely responsible for heightening arousal over and above those within the LFS group. It has been suggested participants in immersive simulations can 'suspend disbelief' and speak and act much as they do in real life [35]. It seems participants within the HFS environment were able to suspend disbelief better than the LFS group, whose focus was more on assessment as opposed to being engrossed within the greater scenario. This may explain the differences in mental demand and HR increases from baseline in the HFS compared to the LFS group.

Our next hypothesis sought to test the extent to which greater cognitive burden, brought about by greater distractions in HFS, was a useful vehicle for students' application of the clinical skill, or whether it was predominantly inhibitory. The performance data did not support H_3. Participants in the HFS condition performed the task faster and—although only approaching statistical significance—were more likely to identify and remove the obstruction. This is despite being more distracted and experiencing heightened cognitive demand in HFS compared to LFS. Drawing from the CPF, it appears our HFS scenario elicited extra cognitive demand but not to the point of overload. Rather, it fell within appropriate limits of challenge/difficulty for this sample. If anything, it seems the LFS scenario failed to provide enough challenge, leading students to associate the scenario with basic clinical skill assessments. The apparent lack of immersion within the LFS environment seemed to have a negative effect on performance, particularly when referring to our time measure. This contention has some pedigree in previous literature. A study by Gutierrez *et al.* found greater knowledge improvements amongst medical students exposed to a fully-immersive virtual reality simulation via a head mounted display compared to a partially-immersive simulation on a computer screen [36].

Our data do not support the suggestion that HFS is inappropriate for early-stage students. It seems such students actually appreciate the highly immersive nature of the HFS environment thereby facilitating timely performance of clinical skills. LFS on the other hand may too closely resemble regular clinical assessments which appeared to lessen the need to perform tasks quickly, but heightened the incentive to perform tasks thoroughly.

It should be reiterated that the task students were asked to perform in our simulations was not new to them; students had undertaken regular classroom learning with subsequent opportunities to practice the clinical skill three weeks prior to data collection. It is possible and perhaps even likely had students been asked to undertake a clinical skill at the upper limit of their current scope of practice, the heightened challenges associated with the HFS environment would have hindered performance, as per the CPF [15]. Nonetheless participants *were* early-stage first-year paramedicine students for whom conventional wisdom would suggest have insufficient knowledge and skill to undertake such sophisticated HFS [e.g. 14 22]. Our results suggest that early-stage students can adequately cope with such learning environments after previous exposure to a clinical skill in regular learning environments, to the extent that HFS students actually outperformed students undertaking LFS.

We attempted to minimise methodological weaknesses in our study design by maintaining symmetry across study environments (i.e., manikin, scenario, confederate) thereby isolating the effects of simulation fidelity. Our convenience sample of early-stage paramedicine students were unlikely to possess significant differences in knowledge or competency at baseline, randomly allocated to one of our two study conditions (HFS and LFS).

The results of the present study have implications for curriculum design, particularly for early-stage students, suggesting that the inclusion of HFS for such students may not hinder learning through cognitive overload, but can work to facilitate increased immersion in simulated scenarios expediting timely performance of clinical skills. However, provision of HFS is labour-intensive and often expensive, particularly when simulation infrastructure is not yet established. Determining the extent to which the benefits associated with greater immersion into the simulated environment are cost-effective was beyond the scope of the present study and is an avenue for future research. Future research should also attempt to replicate our results amongst other—preferably larger—samples from other health disciplines as well as consider different aspects of simulation fidelity.

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Figure 1: Mobile Eye-XG eye-tracking glasses

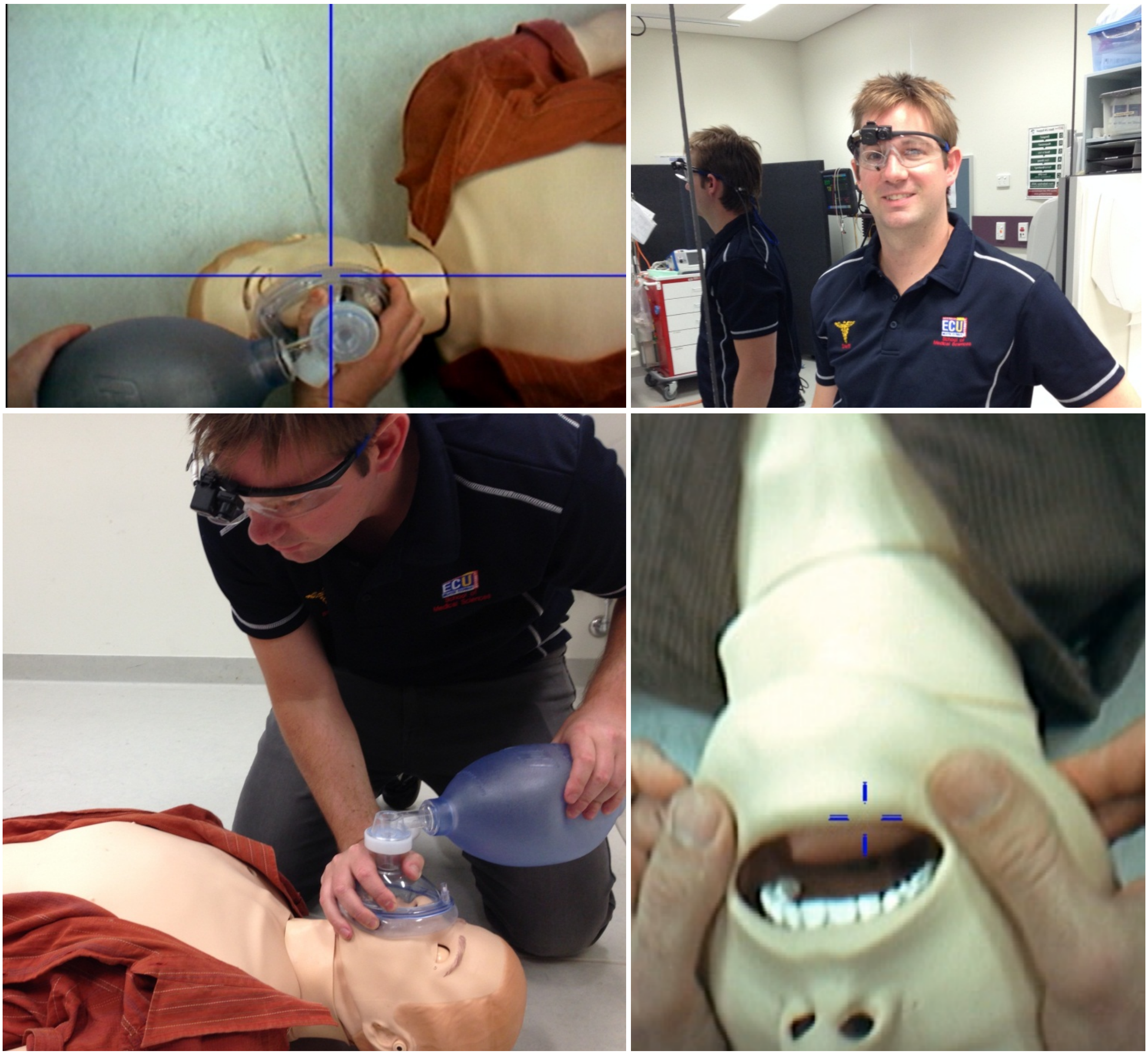

Figure 2: Average heart rate deviation from baseline by experimental condition