

On the Importance of Providing a Tangible Haptic Response for Training Cardiopulmonary Resuscitation in Virtual Reality

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Abstract

The current approach to train *Cardiopulmonary Resuscitation (CPR)* is to employ a mannequin device replicating the physical properties of a real human head and torso. This aims to ensure a correct transfer of the cardiac massage location, amplitude and frequency in a real situation. However, this type of training does not replicate the stress that may be elicited in the presence of a real victim ; this may result in reduced *CPR* performances or even errors. *Virtual Reality (VR)* may alleviate this lack by adding visual immersion with a *Head-Mounted Display (HMD)* so that the trainee is cut from the potential distractions of the real surrounding and can fully engage in a more faithful training scenario. However, one must ensure in the first place that using this technology maintains the quality of the *CPR*. Hence, we have conducted an experimental study to evaluate the potential of visual immersion in such a training context (limited to the cardiac massage). One important requirement was to ensure a correct hand tracking while executing the standard *CPR* two-hands pose. In the present paper we describe first how we assessed a simple approach using two HTC-Vive trackers. Results show that the proposed minimal setup based on a single hand tracking is validated for frequency and, with correction, for amplitude. Then, to assess the quality of the training, we performed an evaluation study considering the following two factors: Haptic feedback with the mannequin device (with/out) and Real-time Performance feedback (with/out) in the *HMD*. We observed that the visually immersive experience proposed in this paper delivers a sufficient level of spatial presence, involvement and agency. Integrating the real *CPR* mannequin in *VR* has a significantly positive impact on the massage performance quality whereas displaying the real-time performance in the virtual environment tends to be only useful for the frequency when no mannequin is used.

1. Introduction

It is now well accepted that human intelligence relies on Embodiment as defined in [PB06] as "the idea that the body is required for intelligence". Likewise computed-mediated interaction has evolved from the traditional desktop metaphor to integrate embodied interaction as a powerful means to achieve new classes of tasks leveraging on our full-body synergies and skills [Dou01]. This is one of the core contributions of *VR* to take advantage of users full-body movements while displaying a plausible scenario within a virtual world ; the goal is to make them behave as if they were experiencing the real situation [MTL*05]. Such an approach is particularly useful to train individuals to react correctly to stressful situations, e.g. an emergency requiring to perform first aid in case of sudden cardiac arrest [Lem18]. In that specific context, the full training includes mastering two types of knowledge: the procedural knowledge of the correct sequence of actions to perform, e.g. first calling the emergency service if the victim is not responding, and the coordinated movement knowledge (skill), e.g. the cardiac massage. However the question remains as to whether the sole visual immersion is sufficient for the skill training or whether the haptic component provided by a tangible mannequin is necessary.

The feasibility of such skill training has been shown to be possible in [SFBC09]. In the present paper we focus on the cardiac massage skill training in immersive *VR* by examining the impact of the two following factors : Haptic feedback (with/out) with the mannequin device from Brayden [bra19] (Figure 1) and Real-time Performance feedback (with/out) in the *HMD* (Figure 2 right). The performance criteria mainly consist in the amplitude and frequency of the cardiac massage during a standardized two minutes duration. This duration is recognized by rescuers as the best duration to reduce turnovers breaks while maintaining a good quality of the movement.

Beyond assessing the impact of training with a tangible mannequin we wish to ensure that, if really necessary for ensuring a correct skill transfert, such a piece of hardware remain the simplest possible. In that frame of mind, we chose to track the location of the top hand (Figure 2 left) with an HTC-Vive tracker so that the same low-cost measurement system can be used independently from the mannequin device. Many studies used such an approach using trackers to acquire performance data but surprisingly few studies took care to assess the fidelity of the measured data. For instance, [BCV20] used an instrumented mannequin tracked in *VR* but did not analysed the probe data assuming the match between

the tracker data and the probe one as proposed by [SRG*19]. Thus, to address this lack of validation, we calibrated the internal probe of the mannequin and compared its results with the one from the HTC-Tracker.

The mannequin location itself is tracked with a second tracker (Figure 1) to ensure consistency with the victim virtual body location.

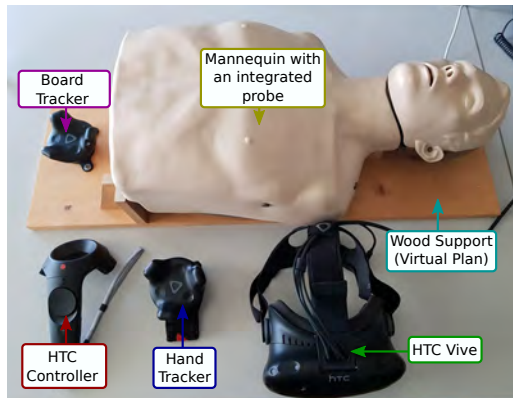


Figure 1: The CPR mannequin [bra19] is tracked through the HTC-Vive tracker mounted on the wooden support to align the virtual victim body with the mannequin. The same type of tracker is attached to the dominant hand. Finally an HTC controller is only used to launch the application.

The purpose of the chosen setup is twofolds. Firstly we want users to benefit from a sufficient level of *presence* [SKHH19] through the HMD visual immersion by cutting them from the potential distractions of their real surroundings. As advocated in [Lem18] the presence dimension is critical for training to reduce fears and taboos related to the action of resuscitation. Secondly, we want to ensure that users also feel a high level of *agency*, i.e. the Embodiment component characterizing the feeling of *being in control* [KGS12] of the user avatar hand movement. This is achieved by tracking and displaying the top hand during the massage performance (Figure 2 left). With only two trackers our approach contributes to reduce the cost and the complexity of the complete setup as only a non-instrumented, hence more affordable, mannequin with a regular VR kit is then sufficient.

Inspired by [CB16] we expect this minimal immersive setup to be sufficient to elicit presence. Likewise we expect it to elicit a sufficiently high level of Embodiment through the agency component.

Our additional hypotheses associated to the evaluation experiment are the following: first that the use of the tangible mannequin benefits to the quality of the performance, second that the combination of the mannequin use with performance feedback in VR leads to a performance increase and third that the performance display reduces the level of presence compared to the context without the performance feedback.

The remainder of the paper is organized as follows : After the related work section, section 3 presents the system overview with a special emphasis on the validation of the tracked hand measurements for evaluating the cardiac massage performance. It is fol-

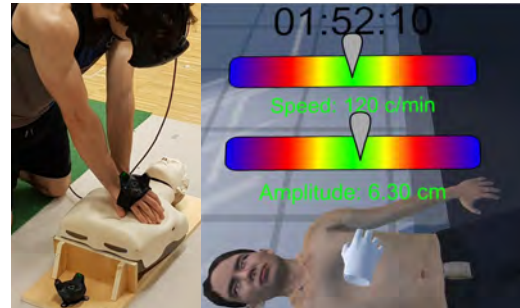


Figure 2: Cardiopulmonary Resuscitation training in VR : setup with the tracked mannequin device and tracked hand (left) and 1PP view with performance feedback provided in the HMD (right)

lowed by the pilot evaluation experiment description and results in section 4 prior to the concluding discussion.

2. Related Work

In 2004 the pioneer work from [MTL*05] demonstrated the interest of VR for first aid training in a virtual environment populated with virtual agents. The immersive display consisted of a vertical stereo retro-projected 3m x 3m screen. The user could navigate, interact with virtual agents and react to events representative of a stressful situation under the global supervision of an external operator. An evaluation based on two scenarios demonstrated the ability of the system to instil a sense of presence. However, at the time the technology was not mature enough to involve the user to the point of performing the first aid actions on the virtual victim. Instead, they would interact with other virtual agents present in the scene to instruct one of them to perform the CPR. As a consequence this system was more suited for training the first aid procedural knowledge rather than the CPR skill itself.

The medical education field has offered a wide range of simulation solutions [MG03] with some degree of success in offering applications displaying haptic feedback in VR such as with laparoscopic simulators or for training breast exams by employing a mannequin together with a virtual agent in VR [RKLL09]. Yet CPR training has been limited to the non-immersive manipulation of instrumented mannequin [bra19] or immersive VR without mannequin [Lem18]. In 2014 [KLJK14] proposed to use a mannequin with Augmented Reality to deliver information about the scenario and the user performance. However the solution remains mostly 2D hence reducing the sense of presence. A similar approach was also proposed in [JGM*18].

More immersed simulations were studied in [KVA*14] where authors compared a regular face-to-face team training against VR enhanced approaches and observed a similar learning experience. However this study focuses more on the team training rather than on the CPR massage in itself. [APY*19] mixed VR with a real mannequin but focused more on benefits from gamification and training availability rather than technical validation of the approach or on the training quality. In [YLLL20] authors also used a similar approach but replaced the mannequin with a tangible "force sensitive

model" and only used a piezoelectric element to capture compression rate thus they do not have access to the real depth compression range.

The contributions of the approach we propose are the following: ensure a sufficient level of presence while allowing a correct skill training through the interaction with a mannequin dedicated to CPR training, prevent break in presence by applying a deformation to the virtual victim torso consistent with the user hand movement, ensure a high level of agency over the interaction with the virtual victim body through a minimal embodiment while using only a consumer ready VR setup plus a generic mannequin providing haptic feed-backs.

To ensure the fidelity of the system, we took advantage of the integrated probe inside of the mannequin to use it as a ground truth. Compared to [Ber19] where an external visual motion analyzer is used as reference, using the inner side of the mannequin give more straight forward information with less risk of errors due to occlusions, and is more natural in the sense that the heart, during CPR is compressed by the inner side of the body. In the same paper, authors provide a higher granularity for hand and finger movement using a Leapmotion. However they do not use this information to compute performance, instead their setup uses an additional accelerometer to achieve this goal.

3. System Overview

In immersive VR the users are visually cut from the real world, i.e. they do not even see their own body. For cost and efficiency reasons we adopted a minimal embodiment strategy of tracking a single hand to allow users to adopt the standardized CPR hand postures that include both hands. For this reason the tracker was attached to the back of the top hand (Figure 2 left). This choice guarantees a good stability and visibility of the tracker without impeding the user comfort.

Likewise the alignment of the virtual victim body with the CPR mannequin from Brayden [bra19] was enforced through the same type of tracker. Initial tests revealed that the cardiac massage performance would transmit oscillations to the tracker when attached directly to the mannequin. Hence it was decided to attach both the mannequin and the tracker to a wooden plate to prevent this issue (Figure 1).

The main idea of these initial design decisions is that a simple non-instrumented mannequin is sufficient to infer the user massage performance. The remaining requirement for the mannequin is to offer a similar resistance/deformation and shape as a real human for CPR training. The information of location, amplitude and frequency of the massage can then be deduced from the tracker data as detailed now in subsection 3.1.

3.1. Data Acquisition

Our use of the HTC Vive trackers is compatible with their latency of 22ms (sampling frequency of roughly 45Hz) as measured by [NLL17]. This paper also reported their relatively good accuracy and precision without occlusions for static positions, at least for our quite small and well located interaction area preventing tracking

loss [NLL17] and allows us to obtain hands height in the referential of the mannequin (Figure 3).

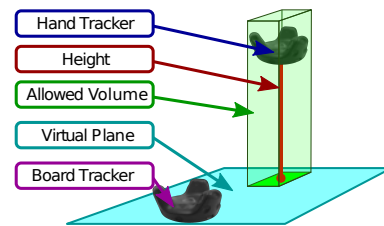


Figure 3: Hand height and allowed interaction area are deduced from the tracker's data

3.1.1. Frequency

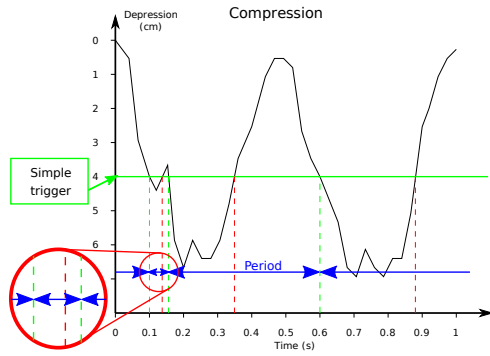
Once the heart stops to beat, the blood circulation ceases immediately. If we consider that the heart beat of a healthy person is near 60bpm, the expected heart beat during a CPR massage is around 120bpm (i.e. 2 Hz) to compensate the fact that it is externally induced. So it is mandatory to provide the user an accurate and stable frequency feedback for proper training. Despite the good aforementioned tracker characteristics, we nevertheless observed some tracker measurement variations when the cardiac massage was changing direction (actual measurements are provided in subsection 3.2). We explain these artefacts by the movement dynamics that may induce some wobbles to the tracker through the hand tracker fixation (Figure 2 left). The immediate consequence is that using a single threshold on the hand height signal is not appropriate for robustly counting the massage periods. This is illustrated on the conceptual drawing of Figure 4a where each successive pair of green-red vertical lines delimit a trigger to compute a beat. To fix this issue we applied a hysteresis filter with two fixed thresholds (Figure 4b) : one use to set the trigger and the other one for the release. Thus, to start counting a period, the height signal has to fall below a low triggering value first. Conversely, the period end is reached when the next trigger is reached.

3.1.2. Amplitude

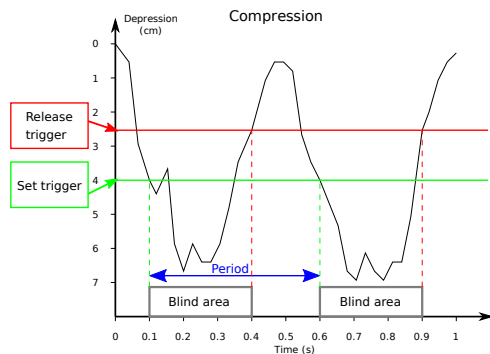
This information requires a short user-specific calibration stage to define the highest hand location while in contact with the virtual victim torso as each user may have a different hand thickness. The resulting hand height defines the zero of the depression signal plotted in black in Figure 4. The amplitude is computed by subtracting the current hand height from the calibrated zero height and retaining only positive values.

3.2. Hand Tracking Validation

In order to ensure that the hand height data acquired using the HTC Vive trackers match the actual torso compression depth, we conducted a validation study to compare our tracker-based measurement with the output of the mannequin internal depth sensor. For this we connected the output of the integrated depth sensor to an external microcontroller. In our case we used a simple at-Mega328 [Mic18] connected on a development board (an Arduino Uno) to use the integrated power section, resonator and USB \iff



(a) Hand height data artefacts induce false positive beat detection when using a single threshold



(b) A two-thresholds hysteresis approach makes the massage frequency measurement robust to reasonable artefacts induced by the movement dynamics

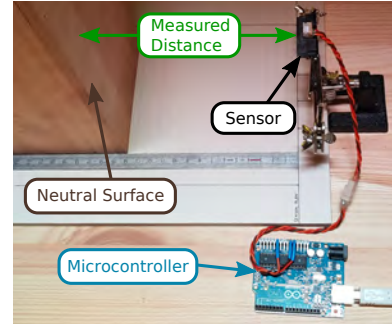
Figure 4: Conceptual illustration of the frequency count without (a) and with (b) a hysteresis filter

Serial adapter [Ard19]. The integrated depth sensor is an analogical Time-Of-Flight sensor: it is a Laser device composed with an emitter and a receiver. It measures the time required for the light to achieve the way out, way back between the sensor and the inner part of the mannequin torso. As the data-sheet of this sensor does not gives the manufacturer tolerance, we had to perform a test to calibrate our ground truth (Figure 5a).

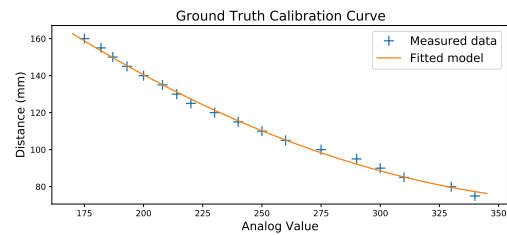
In order to link the analog value and the distance measured by the sensor we measured several time the equivalence Distance \leftrightarrow Analog value on the whole range of distance allowed by the mannequin, compute point means, and fit a second order polynom using `scipy.optimize.curve_fit`. We obtained

$$h = (1.708 \cdot 10^{-3}) \cdot v^2 - 1.373 \cdot v + 346.8$$

where v is the analog value and h the associated distance in millimeters. The regression plot is illustrated in Figure 5b. As the sensor is fixed on the bottom of the mannequin h directly represents the height of the inner part of the torso. The compression depth induced by the hand movement is then $d = r - h$, with r the rest position height described in subsection 3.1.2.



(a) Calibration bench used to calibrate the integrated mannequin depth sensor used as ground truth



(b) The calibration curve of the Time Of Flight Sensor. Analog values refer to the image of the voltage with the linear mapping $0 = 0V$ and $1023 = 5V$.

Figure 5: Calibration of the internal probe covering the whole set of possible compression for this mannequin

3.2.1. Tracker data evaluation setup

We programmed the microcontroller to output the raw computed height through the serial port clocked at 115200 bauds in a continuous stream used as an input for the Unity3D application. As the data stream from the microcontroller and the Unity3D application are not synchronized and have different refresh rates, we run the algorithm handling sensor values in a separated thread to avoid to completely fill the Serial port buffer or introducing time mismatching (Figure 6). The raw data are then exported into two separated files but with the same time reference shared between the two output files.

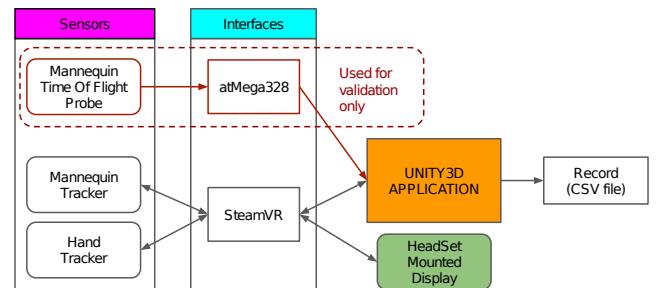


Figure 6: System architecture

These data from this sensor are only used to assess our setup and are just stored for post analysis.

As we can see in Figure 7b, we configured a refresh rate for the

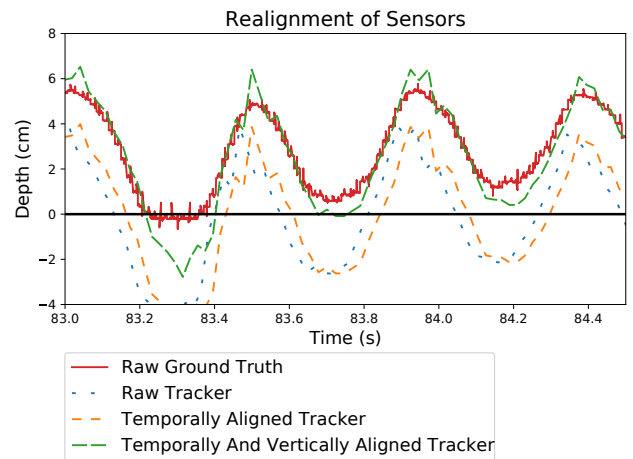
integrated sensor much higher (~ 887 Hz) than the one we have from the HTC Vive tracker (~ 40 Hz). As both samples have a different refresh rate and as a short delay still exists between the two samples, a pre-processing had to be applied on these raw data. To temporally re-synchronize both samples we started by under-sampling the sensor data and extracted a short sub-sample of 5s from the tracker and sensors data the beginning of the sample. Then we computed the cross correlation between these two curves and kept the maximum point defining the best number of frames to shift to get the best alignment (corresponds to the orange dashed curve from Figure 7a). A second pass removes the vertical offset by subtracting the difference of the means over the sub-sample (in dashed green Figure 7a).

Then we went back to raw inputs and, as the values from the internal probe are over-sampled compared to the tracker values, they are uniformly averaged, for a second time, but this time around each synchronized tracker sensor values timestamp to smooth the curve and get a sample with only one time grid reference shared by both sensors curves (in orange on Figure 7b). For a fair comparison the tracker value is capped to zero (dashed green Figure 7b) when hands are above the mannequin surface as the internal probe cannot measure their position in such a context. As we measured the same frequency information with both sensors, we were able to sliced samples into single "pushes" sub-samples using local lower extrema from the sensor probe as a "push" delimitation (vertical orange lines in Figure 7b). Then we computed each push amplitude from both sensors and obtained an average absolute error of 1.20 cm (i.e. the tracker measures an amplified movement) with a standard deviation of 0.60 cm based on a dataset of 1758 pushes. This represents a mean ratio Tracker Amplitude over Sensor Amplitude of 1.30 with a standard deviation of 0.18.

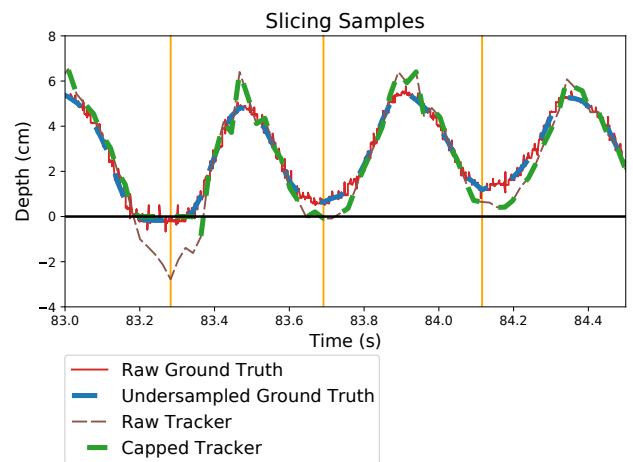
A noticeable artifact visible on the tracking curves (Figure 8a) is the presence of spikes especially when the direction of the movement changes as previously described in subsection 3.1.1. Indeed, spikes are visible on the the tracker curves (in orange) when the direction of the movement changes whereas the reference value (in blue) does not present this issue.

This might be explained by the fact that when we wear the tracker, it is fixed with a slightly deformable strap, and when we change the direction of the movement we can see that the tracker moves due to its inertia.

The difference between the maximum value read from the reference and the tracker for each push is plotted in red in Figure 8b. Likewise the difference between the minima of both sensors is plotted in green and the filling areas represents the standard deviation. As we can see, both curves follow a similar trend giving hint about a drift occurring over the number of pushes ; the tracker erroneously reports getting closer to the ground as the number of pushes increases. These drifts led us to change the computation of frequencies for the offline analysis using the extrema delimitation described in subsection 3.2.1 as it is more robust than the hysteresis method (Figure 4) used to display the online feedback.



(a) Realignment process. The black horizontal line represents the height when the mannequin is not pressed.



(b) Under-sampling and splitting process. The black horizontal line represents the height when the mannequin is not pressed.

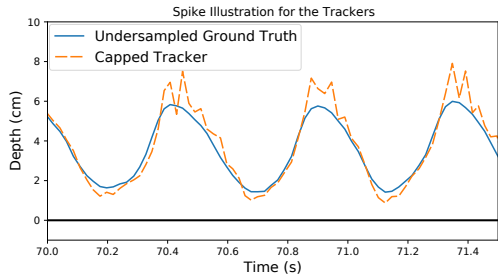
Figure 7: Illustration of the pre-processing applied on the raw data from the analysis of the results of the experiment

3.3. Visualization

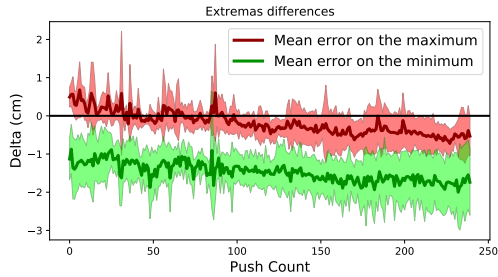
We use Unity3D for integrating the components of our CPR training system (Figure 6). Our system offers two visualization choices depending on the training focus on either emphasizing the sense of presence or finely guiding the CPR skill acquisition process. The minimal scene consists in the 3D environment including at least the virtual victim body and the user tracked virtual hand. An additional display of performance indicators for the frequency and the amplitude can be generated in real-time within the 1PP field of view (Figure 2 right).

3.3.1. Motivation for computing the virtual victim torso deformation

We consider that displaying a moving user virtual hand during the massage is critical for inducing a strong agency. Indeed seeing such



(a) Spikes



(b) Extrema drifts between mannequin integrated probe values and tracker data on 7 sessions

Figure 8: Illustration of artifacts on the tracker curve

a movement is the main information the user has about the massage process ; for this reason we chose to display the user virtual hand collocated with the actual hand location. An immediate consequence is the necessity to deform the virtual victim torso accordingly to prevent the virtual hand to sink-in a rigid virtual torso thus potentially creating a break in presence [BRP*06].

3.3.2. Torso deformation

The amplitude signal is used to drive the torso deformation as it faithfully expresses the compression depth achieved by the user on the virtual torso. We retained a purely geometric approach for the compression as the searched key effect is to prevent interpenetration rather than computing a physically-realistic shape deformation (Figure 9). The full deformation reflecting the current amplitude is only applied to the torso mesh center.



Figure 9: Hand-torso interaction without (left) and with the simplified geometric deformation (right). Note that the displayed hand is the on top of the (undisplayed) other hand for performing the cardiac massage. See the video for the 1PP viewpoint.

3.3.3. Performance indicators

The cardiac massage amplitude and frequency can be displayed on-the-fly with individual gauges fixed above the virtual victim, as visible in Figure 2 right. The optimal values are centered for gauges and colored with green. Gauge markers are initialized at zero and are refreshed after each compression. If the user stops to perform CPR, a timer will automatically reset these markers to zero. Gauges indicates values between 100 and 140 compression per minutes, and between 1 and 11 cm for the amplitude.

4. Experimental Evaluation

4.1. Hypotheses

The purpose of this study is firstly to assess whether the minimal immersive setup that we have retained is sufficient to elicit a sufficient level of presence and Embodiment (through the agency score). We used the IPQ (IPQ) presence questionnaire [SKHH19] and the embodiment questionnaire, adapted from [GFP18], to match our specific haptic interaction context (available in appendix) to assess these hypotheses. Scores are then normalized by summing and dividing the result by the maximum score possible to ensure that normalized scores are within [0, 1].

The second goal of the study is to determine the impact of two factors on the massage skill Performance (frequency and amplitude) : Haptic feedback with a CPR mannequin (without and with) and CPR Performance feedback (without and with) in the HMD (Figure 10b).

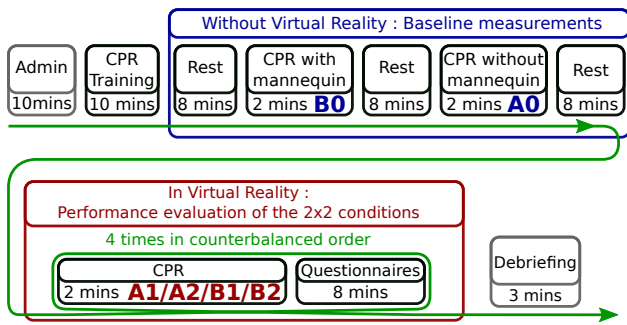
Thus we formulate the following hypotheses :

- H1** - We expect a normalized presence score to be ≥ 0.5
- H2** - We expect a normalized agency score to be ≥ 0.5
- H3** - The use of the mannequin leads to better performance than without the mannequin because the haptic interaction induced by the mechanical property of the mannequin sustains more the regularity of the movement compared to a movement in free-space
- H4** - The combination of the mannequin use with the real-time performance indicators leads to a better performance compared to no performance indicators
- H5** - Displaying the performance within the HMD reduces the level of presence compared to the context without the performance indicators

4.2. Method

Given the potentially wide differences among subjects in terms of initial expertise in CPR massage, we decided to first provide a training session to all of them with the CPR mannequin in the regular context of such a training, i.e. without VR. We then measured the performance (amplitude and frequency) in two successive contexts, with and without the mannequin, to establish their baseline (Figure 10a top line).

After establishing the two baselines (A0 and B0), the subjects enter a sequence of four CPR massage sessions in VR, each consisting of a two minutes massage (corresponding to A1, A2, B1 or B2 from Figure 10b) followed by 8 minutes rest (Figure 10a bottom line). Massage order is counterbalanced in order to prevent bias



(a) Experimental protocol

Haptic Feedback (Mannequin)	Visual Feedback	
	Without	With
Baseline (no VR)		
No live performance display	A0	B0
Trial (in VR)		
No live performance display	A1	B1
Live performance displayed	A2	B2

(b) Experimental evaluation with two factors: Haptic feedback (without and with the physical mannequin) and Performance feedback (without and with the amplitude and frequency gauges)

Figure 10: Experimental main timeline and conditions

from a potential training effect. Each rest period is dedicated to the filling of questionnaires described previously.

5. Results

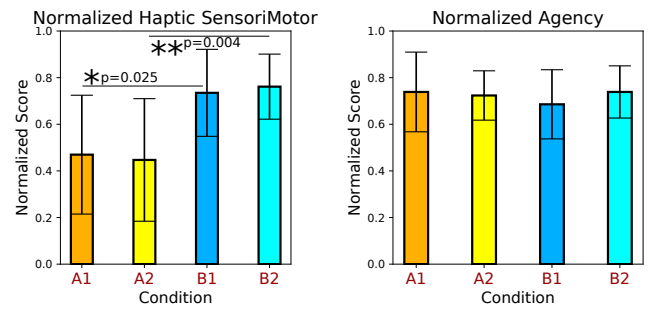
A total of twelve subjects participated in the experimental evaluation (age within [16,56], median 27.5, four female). One subject sample was corrupted and one female subject stopped the experiment due to insufficient physical force to interact with the CPR mannequin. All subjects were right-handed and six reported being familiar with VR while only two indicated an average experience of CPR massage.

5.1. Presence and embodiment levels

We used non parametric RankSum tests with a Bonferroni correction on p -values to determine whether the aforementioned hypotheses were verified.

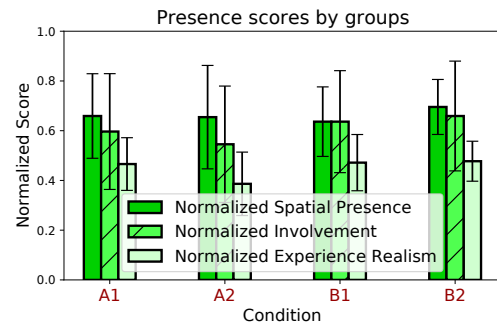
Results of these tests are plotted in Figure 11a for the assessment of the haptic feedback, Figure 11b for the agency (both based on [GFP18]), and Figure 11c for the three presence components from the IPQ [SKHH19].

As expected, significant differences found for haptic scores (A1 - B1, $p = 0.025$ and A2 - B2, $p = 0.004$) show the positive impact of the physical mannequin on haptic feedbacks perceived by participants. Surprisingly, haptic scores in non-mannequin conditions are higher than expected. We suspect that a combination of multiple factors, including the deformable avatar and the self hands contact, might explain such scores.



(a) Haptic SensoriMotor scores

(b) Agency scores



(c) Presence scores

Figure 11: Distributions of normalized scores from questionnaires (labels from Figure 10b)

5.2. Performance quality

Concerning the evaluation of the performance : the Shapiro test rejected the hypothesis of the normality of samples across all conditions from the dataset (cf. Appendix). Thus we also applied non-parametric tests (RankSum) with corrections for p -values (Bonferroni). Results are displayed in Figure 12.

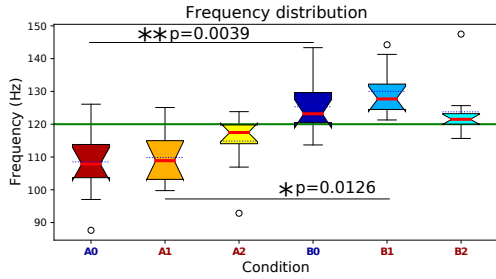
In all conditions without the live displayed performances we observed a significant difference between with and without the tangible mannequin (A0 - B0, $p = 0.0039$ and A1 - B1, $p = 0.0126$). Conversely, when live performance is displayed we did not observe a significant difference (i.e. A2 - B2). This suggests that whenever guided with the displayed performances, the performed frequency is closer to the target value.

For the amplitude the difference observed (A1 - B1, $p = 0.0019$ and A2 - B2, $p = 0.0003$) shows that, even guided, used still struggle to reach the correct amplitude without the help of the mannequin.

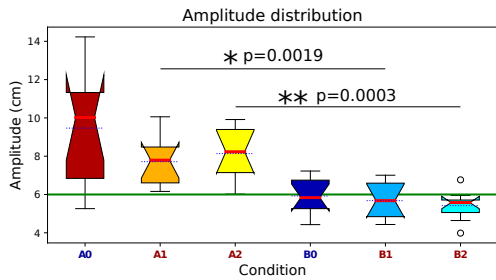
6. Discussion

Regarding the experimental evaluation with subjects, our hypotheses were partially confirmed as follows:

H1 - The presence level delivered by the IPQ questionnaire is decomposed into three components: experience realism, spatial presence and involvement. Only the scores of spatial presence and involvement succeed to be in the upper half (i.e. ≥ 0.5) of the pres-



(a) Frequency distribution of the result by groups



(b) Amplitude distribution of the results by groups

Figure 12: Plot of scores obtained by group (labels from Figure 10b). Horizontal green lines represent the targeted value for the best CPR and noches represent the 95% confidence interval of the median (the red line, dashed blue one represents the mean).

ence scale hence offering only a partial confirmation of H1. Indeed, the proof of concept design was far from being realistic (e.g. single hand display).

H2 - As this single hand representation did not penalize the embodiment score through its agency component, showing a consistently high level across all conditions, this hypothesis is accepted.

H3 - This hypothesis was validated as the integration of the real CPR mannequin in VR has a significantly positive impact on the massage performance quality compared to the conditions without mannequin (cf Figure 12). Indeed, in a real world context the weight of the user combined with the resistance of the victim torso constitute a dynamic system where the user only need to give downward impulses to perform CPR. Additionally this system links frequency and amplitude; thus given the right frequency it is easier to achieve the right amplitude as the former is more easily mastered. In the non mannequin conditions there is no such dynamic coupling, thus after each impulse users have to use more their back muscles to lift up. Also the amplitude/frequency link is different explaining the observed wrong amplitude range while the frequency was correct. Thus even in the presence of the live displayed performance factor it remains difficult to reach both target (amplitude and frequency) at the same time.

Finally, no significant differences were found between the performance baseline B0 and the mannequin conditions (B1 and B2). This should not be interpreted negatively though ; simply put, one can see that performances were as good without and with VR, hence VR does not degrade performance. On the other hand the

presence scores show that VR has some potential to immerse the participant in a situation much closer to real life (but this was out of the scope of the present submission).

H4 - This hypothesis was initially hinted from the outcome of prior works from [SFL*13] where authors noticed a significant difference between CPR performance with and without performance feedback. Surprisingly it was not validated in the mannequin condition as the performance display in the HMD was not bringing any added value to the performance quality.

H5 - Only the frequency performance quality shows a correct target value in the no-haptic condition which suggests this partial benefit from the displayed information. Likewise no significant reduction of presence level can be linked to the display of the massage information in the user field of view ; this invalidates this hypothesis.

7. Conclusion

7.1. Limitations

As this study is a proof of concept, many scenario events were not implemented (e.g. warnings if the hand is badly placed). Moreover we only secured a minimal embodiment level with a single rigid hand representation rather than dealing with the whole body integration. Results observed Furthermore performing CPR remains a physically demanding task, a point this study was not designed to address.

7.2. Tracking reliability

Our results show that the proposed minimal setup with single hand tracking is sufficient to provide accurate frequency feedback. Unlike [SRG*19], our results also show that the raw amplitude from the tracker needs to be scaled down by 0.77 (in our setup) to achieve a sufficient level of fidelity for the amplitude measurement. Thus, if we take this into account, the measurement of both performance criteria of a CPR massage can be done with a low-cost non-instrumented mannequin which offers the standardized haptic response.

7.3. Experimental assessment

As expected this experiment clearly shows that the presence of a tangible mannequin provide better haptic feedback than without.

Finally, unlike our observation that a tangible mannequin is not necessary for training the correct frequency, this study strongly implies that a mannequin is required to train the correct amplitude range for a CPR massage.

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