$See \ discussions, stats, and author \ profiles \ for \ this \ publication \ at: \ https://www.researchgate.net/publication/317297785$ 

# The effect of instructional priming on postural responses to virtual crowds

READS

67

Conference Paper · March 2017

DOI: 10.1109/VHCIE.2017.7935622

citations 5							
3 authors, including:							
٢	Naman Gupta Indraprastha Institute of Information Technology 2 PUBLICATIONS 26 CITATIONS SEE PROFILE						

Some of the authors of this publication are also working on these related projects:

BTP A firewall for Internet of Things View project Project

All content following this page was uploaded by Naman Gupta on 24 March 2018.

# The effect of instructional priming on postural responses to virtual crowds

Naman Gupta<sup>\*</sup> IIIT-Delhi New Delhi 110020, India Email: naman13064@iiitd.ac.in Anmol Singh<sup>\*</sup> IIIT-Delhi New Delhi 110020, India Email: anmol13021@iiitd.ac.in Sachit Butail Northern Illinois University DeKalb, IL 60115, USA Email: sbutail@niu.edu

Abstract—In this paper, we study the effect of instructional priming on postural responses to virtual crowds using a headsetbased virtual reality (VR) platform. Specifically, we instruct VR participants that one of the virtual agents in a simulated crowd represents the movement of a real person, and reinforce this instruction by having a single role player present in the experimental arena. Our results show that while VR participants who were primed did not move significantly more when threedimensional movement was considered, they exhibit significantly more movement in the direction perpendicular to the crowd flow indicating possible collision avoidance maneuvers. These results indicate that manipulation of instructions to participants with the intent of impacting pre-exposure expectations may be used to increase engagement with virtual crowds.

#### I. INTRODUCTION

With rising populations and migration to cities, the frequency and size of pedestrian crowds witnessed in urban environments is increasing every year [1]. This increased incidence of crowding also puts humans under a higher risk of disasters [2], which may take place due to a variety of reasons including sudden alarms [3], turbulence in crowd flow, and unseen bottlenecks [2]. Several studies over the past decade have utilized agent-based models to understand and predict situations that may lead to such disasters (see review in [4]). However, the inherent difficulty in conducting experiments with human crowds due to factors such as safety and the impracticality of gathering large crowds has resulted in more models [5] than empirical data [6].

In this context, a virtual reality (VR) environment may serve as an alternative platform to actual human crowds for testing individual response to crowded scenarios [7]. At the same time, it is difficult to reproduce a rich VR environment such as a pedestrian crowd that integrates multiple sensory modalities in real time. For example, depending on the crowd psychological state [8], the participant may expect to see a large number of people walking in different directions, hear sounds over a wide range of frequencies and loudness, and possibly brush shoulders and get pushed intermittently. In a visual display itself, the virtual agents in the crowd must respond to the participant's movements in real time [9], and not collide or move through each other [10]. With the goal of making immersive virtual crowds that can be used to study crowd behavior, previous studies have focused on mimicking human behavioral rules using Belief-Desire-Intention models [11], and with incorporating realistic interactions between virtual pedestrians [9].

Here, we investigate if pre-exposure conditions can be manipulated through priming to vary participant response to virtual crowds. Priming is the behavioral effect of an event or action in the past that have bearing on subsequent responses of an individual through an implicit memory recall [12], [13]. Specifically, the priming experiment involves presenting the subject with a stimulus, and then assessing the response of that subject to reduced perceptual information that is related to the stimulus [14]. The stimulus constitutes the priming material which can range from printed booklets [15] to pictures and videos [16] and instructional cues [17]. Priming has been shown to increase presence in high-fidelity virtual environments [15], and the number of keywords in participant response to topical questions in visual exposure therapy [16]. Instructional priming, which refers to providing instructional cues related to the exposure content, has been shown to produce significant changes in VR tasks [18], and modify user expectancies about the efficacy of an aroma in aromatherapy [17]. In [18], participants were primed through different instructions from different characters related to the seriousness of the VR task, and in [17], priming instructions related to the effects of an aroma were found to affect user relaxation patterns.

In this paper, we investigate if participant postural response, used as a measure of participant engagement [19], is affected by manipulating the instructions to the participant to believe that an individual in the virtual environment is reconstructed from the real world. Prior work in immersive environments has shown that interpersonal distance is a robust indicator of interaction with virtual humans [19]. Further, controlled experiments with pedestrians have shown that participants exhibit collision avoidance maneuvers form of a left-right movement relative to an oncoming pedestrian direction of motion with a side preference [20]. We apply this notion to quantify engagement with a virtual crowd using joint movement. Differently, however, our participant is quasistationary as the virtual crowd passes by. We test the following

<sup>&</sup>lt;sup>\*</sup>Naman Gupta and Anmol Singh contributed equally to this work

hypotheses [19], [20]:

- H1 Postural response will be enhanced for the participants who are primed with an instruction that one of the walking agents in the environment represents a real person
- H2 Participants who are primed will respond by demonstrating increased collision avoidance maneuvers; these maneuvers will manifest themselves in the form of larger movements in the left-right direction perpendicular to the ambient virtual crowd flow

The paper is organized as follows: In Section II we describe the experimental setup, briefly detailing the crowd simulation model, and the experimental procedure. Section III presents the results of the study. Finally, in Section IV, we discuss the results along with possible applications and future work.

#### II. METHODS

### A. Experimental setup

The experimental setup consisted of the VR headset and a Kinect<sup>TM</sup> depth sensor (Microsoft Corporation, Redmond, WA, USA) for capturing the participant movement (Fig. 1). The VR headset consisted of a smartphone (Xiaomi Redmi 1S, running Android 5.1.1 operating system) inserted into the Google cardboard viewer (Dreamviewer virtual reality headset, Google, Moutain View, CA, USA). The virtual environment was developed using the Google Cardboard Software development kit (version 0.5.0) with automatic gyroscope bias correction, and Unity game engine (version 5.1.1, Personal Edition). The VR source code and a pre-built application package are hosted on a github repository (https: //github.com/naman/VirtualCrowds).

The experimental arena was 10 m long, 5 m wide, and 3.5 m high. The Kinect sensor was placed on a table at a height of 0.6 m and connected to a laptop (HP Compaq 15s006TU Notebook, running Windows 10 Operating System). The Kinect depth sensor was oriented such that the depth axis was approximately aligned with the long side of the virtual environment. The participant was positioned within the 0.5-3m recommended range of the sensor to attain sub-cm accuracy [21]. We used a software development kit (SimpleOpenNI, version 1.96) to convert the color and depth image into joint tracking data of participants. A Processing programming language (version 2.2.1) script running on the laptop (HP Compaq 15-s006TU, Windows 10 Operating System), wrote three-dimensional (3D) joint data into a data file at an average sampling rate of 8 frames per second (fps). This was the maximum attainable sampling rate on our system with the computational load of writing joint data as well as video data (at a subsampled rate of 2 fps) for verification to the computer.

The Kinect sensor has been found to be accurate within a few millimeters for large movements such as trunk and lower limb kinematics, to several centimeters for small movements such as hand grasping and flexions [22]. To further characterize the errors in our analysis of joint movement for participants who may demonstrate constant bodily motion, we tracked a single individual as she moved within the Kinect field of view for 125 seconds. We then computed the error as the absolute difference between four pairs of limb lengths (right and left forearms, upper arms, lower legs and upper legs) measured as the distance between 3D joint positions, and ground truth values measured using a measuring tape. We found that the error was largest for the left and right forearms was 4.66  $\pm$  1.73 cm and 4.79  $\pm$  1.58 cm respectively. The error for the left and right upper arms was 0.47  $\pm$  3.3 cm and 1.2  $\pm$  2.8 cm; for left and right upper leg 0.82  $\pm$  0.35 cm and 0.57  $\pm$  0.56 cm; and for left and right lower leg 0.55  $\pm$  1.03 cm and 0.67  $\pm$  1.4 cm respectively. Based on these errors we excluded hands from the joint data used to analyze postural responses. The remaining errors were found to be less than 5% of the range of joint movements witnessed in the experimental data.

#### B. Virtual environment

The virtual environment played in real-time on the VR headset, simulated a 16 m long  $\times$  8 m wide  $\times$  3.5 m high public place (Fig. 2). The environment was designed to align with the Kinect frame so that participant movement in a given direction could be mapped to movement within the virtual world. Crowds were simulated in the form of 24 virtual agents walking towards the general direction of the participant and interacting non-verbally among themselves and the VR participant. The participant herself was represented as a stationary avatar in the virtual environment with no animation corresponding to the limb movement.

The virtual agents interacted between themselves and the avatar via the social force model [23]. Briefly, the social force model is a dynamic two-dimensional multi-agent model where each agent is driven by a goal force towards the goal direction, social interaction force with all other agents, and a boundary interaction force. The goal direction for all virtual agents was set in the general direction towards the participant (Fig. 1) so that, to a participant, it gave an appearance of standing still facing a crowd moving from front to back. Denoting the two-dimensional position and velocity of agent *i* by  $\mathbf{r}_i$ , and  $\mathbf{v}_i$  respectively, where i = 1, ..., N, the total force experienced  $\mathbf{f}_i$  in Newtons is  $m_i \ddot{\mathbf{r}}_i = \mathbf{f}_g + \sum_{j=1, j \neq i}^N \mathbf{f}_{ij} + \sum_W \mathbf{f}_{iW}$ , where  $m_i$  is the mass in kg,  $\mathbf{f}_g$  is the goal force,  $\mathbf{f}_{ij}$  is the social interaction force with agent j,  $\mathbf{f}_{iW}$  is the interaction force with the wall boundary. The goal force is computed as  $\mathbf{f}_{e} = (s_i \mathbf{e}_i - \mathbf{v}_i) / \tau_i$ , where  $\mathbf{e}_i$  is the desired direction,  $s_i$  is the desired speed in m/s, and  $\tau_i$  which affects the acceleration towards goal, is the relaxation time to achieve the desired direction in seconds. The social interaction force has the form  $\mathbf{f}_{ii} = (A_i \exp(w_{ii} - d_{ii})\mathbf{n}_{ii}) / B_i$ , where  $A_i$  and  $B_i$  are the interaction strength in Newtons and interaction range in meters respectively,  $w_{ij}$  is the sum of agent sizes in meters denoted by their radii,  $d_{ij}$  is the distance in meters between agent positions, and  $\mathbf{n}_{ij} = (\mathbf{r}_i - \mathbf{r}_j)/d_{ij}$  is the unit vector in the direction from agent *i* to *j*. The wall interaction force  $\mathbf{f}_{iW}$ is modeled in the same way as the social interaction force by replacing *j* with an immovable wall location.

The social force model includes automatic collision avoidance based on a minimum distance threshold, and has been



Fig. 1. The experimental setup consisted of a VR headset and a Kinect 3D motion sensor. The motion sensor recorded the participant movements as they interacted with virtual crowds displayed via the headset. The orientation of the participant in the real environment aligned with the horizontal-facing direction in the virtual environment. Experimental conditions corresponded to primeVR (a) where individuals experienced virtual environment experienced in either scenario is shown in the middle with the black box corresponding to the position of the participant.



Fig. 2. A snapshot of the virtual environment consisting of crowds interacting among themselves and with the participant through social force.

shown to reproduce emergent phenomena often witnessed in human crowds [23]. Note that while an alternate crowd motion model that incorporates anticipatory collision avoidance would be more realistic [24], it would require estimating and projecting the direction of motion of all agents—a computational burden that would cause significant frame delays in our current setup. Implementing such a model is being considered as part of future work.

Model parameters used for simulation were set as  $A_i = 2000$  N,  $B_i = 0.2$  m,  $s_i = 0.6$  m/s,  $m_i = 70$  kg, and  $\tau_i = 0.1$  s for all *i*. The goal direction for each agent was uniformly sampled from several candidate directions, all within an angle of 25 degrees with respect to the horizontal-facing direction. Note that although the virtual agents experienced the social force from the participant's avatar, the reverse was not true and any movement by the participant was only due to their response to the virtual environment.

The virtual agents interacted with three out of four walls in the environment according to the social force model and thus moved away from them if they reached closer than 0.5 m. With the wall directly behind the avatar, the virtual agents experienced a periodic condition such that they were repositioned to appear on the far end in front of the participant at a random location. The artificiality caused by the reappearing agents was mitigated by the crowd density where agents closer to the participant tended to occlude such reappearances. This gave an effect of seeing a continuous crowd of people at all times at https://youtu.be/5J-N\_4zF400

## C. Experimental procedure

Human participants for this study were undergraduate and graduate students aged between 18–24 years. Nine out of the twenty-six subjects were female. A between-subject design was followed to avoid affecting participant response due to exposure to virtual environments [25] as well as priming material.

The experiment began by requesting each participant to stand within a 1 m  $\times$  1 m box on the floor approximately 2.5 m in front of the Kinect to enable high tracking accuracy [26]. This was followed by additional instructions depending on the experimental condition described next. Once the Kinect sensor started tracking the skeletal joints, participants were then requested to wear the VR headset and experience the VR environment while staying within the 1 m  $\times$  1 m box, which was rendered in the VR environment as well. Accordingly, a participant was rendered as a stationary avatar in the VR environment. Restricting the movements served two additional purposes: first, it ensured that the participants stayed within the tracking range of the Kinect; and second, it excluded the possibility of confounding the results due to individual tendencies to explore and walk around the environment. Note that the participants were allowed to exercise possible body movements to interact with a crowd such as turning their heads to look around and taking small steps in any direction without walking out of the Kinect range.<sup>1</sup>

The experiment consisted of two different conditions, assigned randomly to each participant. These corresponded to additional instructions given to the participant prior to wearing the VR headset. In the first condition called no prime virtual reality (noprimeVR) that served as the control, no additional instruction was given, whereas in the second condition, called prime virtual reality (primeVR), before putting on the headset the participant was informed that "During the experiment, one of the virtual people in the crowd will correspond to an actual person in the real world who will be moving in the experimental arena". This instruction was given while pointing to one of the experimenters, hereafter referred to as role player. The role player walked within the experimental arena on either side or behind the participant while maintaining a distance of at least 1.5 m from the participant so as not to interfere the Kinect field of view (Fig. 1). The role player wore rubber soled shoes and walked softly to avoid making any noise from the footsteps. Note that the role player was not actually visible in the virtual environment, which was simulated with the same parameters for both conditions. For both conditions, the participant was asked to experience the virtual environment for approximately 3 minutes. During this time, sound recorded from a real-world crowded environment was played on the phone speakers.

After experiments, participants were asked how they felt including questions related to virtual reality sickness. These included: How was your experience in the virtual environment? How realistic did you think the crowd simulation felt? How realistic were the interactions with agents? Participants in primeVR condition were additionally asked if they could identify or feel the role player movement, and if yes, how? Most participants described their experience to close to being in a real crowd; a few participants who wore spectacles faced minor discomfort after the experiments were over. A few participants in primeVR mentioned that they attempted to guess the agent in the virtual environment that may have corresponded to the role player but could not arrive at a specific choice. A total of 26 participants were selected, 13 (8 male, 5 female) for the noprimeVR condition, and 13 (9 male, 4 female) for the primeVR condition. Three trials from the primeVR condition were later ignored after it was found that the participants did not comprehend the instructions properly. Data from one participant from each of the noprimeVR and primeVR condition was further invalidated after it was found that the depth sensor had failed to track movement consistently throughout the experiment. This resulted in a total of 12 participants for noprimeVR and 9 participants for primeVR condition that were finally used for analysis.

<sup>1</sup>Per instructions from the Institutional ethics committee, the recording procedure was explained to each participant and written consent was obtained prior to conducting the experiment.

Position data for 10 out of 17 joints, corresponding to head, torso, arms, elbows, legs, knees, and feet was processed for analysis. Position data from fingers was found to be noisy and inconsistent due to occlusions, position data from hands was ignored since it had the maximum error in our preliminary analysis, and position data from neck and hips was not considered as these values could be interpolated from torso and leg joint movement if needed. To prevent inclusion of body movement caused due to the participants adjusting the VR headset, orienting themselves in the VR space, and removing the VR headset in the end, each recording was trimmed to 60 seconds of video. Specifically, depending on the time it took for the participants to wear the headset and orient themselves in the VR space, the initial 20-50 seconds were removed . The remaining dataset was further trimmed to a consistent 60 seconds across all participants for analysis, which automatically eliminated the final samples where the participants were removing the headset.

Data analysis consisted of computing the distance traveled by each joint for a participant. The trajectory data for joint position was filtered using moving average with a window of 8 samples corresponding to 1 second (to ensure robustness of results to moving window size, data was also filtered using 4 and 16 samples corresponding to 0.5 and 2 seconds). End conditions on either side of the sequence were smoothed using a shorter window until the number of samples were available. The total distance traveled in 3D by a joint *j* with position at frame *k* as  $\mathbf{p}^{j}(k) \in \mathbf{R}^{3}$  was computed over 60 seconds as

$$d^{j} = \sum_{k=2}^{480} \left\| \mathbf{p}^{j}(k) - \mathbf{p}^{j}(k-1) \right\|,$$
(1)

where  $\|\cdot\|$  is the Euclidean norm that computes the distance between two successive joint positions.

To determine if there was an effect of the role player's footsteps on the participants in the primeVR condition the following observational analyses was conducted. First, color (RGB) videos from Kinect were observed as they played in sync with the torso trajectory movement in all three directions; instances where role player was seen in the video were used to indicate times when the role player was in closest proximity to the participant at about 1.5 m (Fig. 1), and could therefore influence distinct changes in the movement. Second, to further quantify this notion, the total distance traveled per second (with joint position filtered using a moving average of 8 samples) during the instances where the role player was spotted in the video was used as a threshold to indicate higher than typical movement. If maximum movement occurred during this time, and no other section of the trajectory came within 80% of that value, a role player effect was considered. Note that the role player did not interfere with the Kinect tracking during any of the trials.

#### **III. RESULTS**

Primed participants did not exhibit significantly more joint movement (H1): Figure 3 compares the total distance in 3D traveled by each joint in 60 seconds across all participants



Fig. 3. Distance traveled by each joint across all participants for noprimeVR (blue) and primeVR (red) experimental conditions. Circles denote mean and the bars denote  $\pm$  standard error.

 TABLE I

 EFFECT OF PRIMING (REPEATED MEASURES ANOVA)

	3D		2D		horizontal-across	
window size	р	F(1,20)	р	F(1,20)	р	F(1,20)
4	0.32	1.01	0.14	2.35	0.03	5.23
8	0.17	2.02	0.08	3.35	0.02	5.95
16	0.11	2.74	0.06	3.87	0.03	5.20

for the two conditions. Statistical comparison using repeated measures ANOVA and significance level set to p < 0.05 did not reveal a significant difference between the two conditions when considering the joint movement in 3D or horizontal plane (2D) irrespective of the moving window size of the smoothing filter (Table I).

Primed participants exhibited significantly different joint movement in the direction perpendicular to the crowd flow (H2): Distance traveled across all joints in the direction perpendicular to the crowd flow (horizontal-across in Fig. 1) was significantly different in primed participants irrespective of the moving window size (Table I). However, post-hoc comparisons using ten separate one-way ANOVA comparisons, corresponding to each of the ten joints, with Bonferroni correction (p < 0.005), showed that none of the joints of primeVR participants had significantly higher movement than noprimeVR.

Variation in torso movement along the horizontal plane was more in primed participants: The average  $\pm$  standard deviation of the absolute torso movement for noprimeVR (resp. primeVR) condition was  $8.09 \pm 8.02$  cm (resp.  $18.40 \pm 16.60$ ) in the horizontal-facing,  $9.63 \pm 10.67$  (resp.  $22.76 \pm 24.34$ ) in the horizontal-across, and  $5.11 \pm 4.39$  (resp.  $3.75 \pm 3.45$ ) in the vertical direction. With Bonferroni correction (p < 0.005), a two-sample F-test for equal variances revealed that only the average torso movement in horizontal plane had significantly different variation in the noprimeVR condition than primeVR



Fig. 4. Mean trajectories of the torso for across all participants for noprimeVR (blue) and primeVR (red) experimental conditions. One standard deviation spread of all trajectories shown in lighter envelopes. Horizontal-across and horizontal-facing directions (solid double arrow) refers to participant movement with respect to the virtual crowd flow (dashed single arrow) in the horizontal plane. The position values are relative to the first sample of the 60-second window considered for all participants.

condition (horizontal-facing: p = 0.001, horizontal-facing p = 0.005). Figure 4 visibly compares torso trajectories for the two experimental conditions along each of the three directions in the Kinect frame. These correspond to horizontal-facing in the direction opposite to the crowd flow, horizontal-across in the direction perpendicular to the crowd flow, and vertical. The variation across multiple torso trajectories show larger movement for the primeVR condition along the horizontal-facing and horizontal-across directions. Since the participants experienced the VR environment in a plane, there was no visible difference between the two conditions along the vertical movement of the torso.

The role player movement did not have a visible effect on torso movement: Figure 5 shows the torso distance traveled per second in 3D by each participant for the two experimental conditions. The role player was spotted in only three out of nine trials in the primeVR condition. Shaded regions correspond to the time during which the role player was spotted in the video. In two out of three of these trials, the maximum

TABLE II							
DISTANCE TRAVELED	by each joint; mean $\pm$	STANDARD DEVIATION.					

Joint	total distance traveled in 3D (m)		horizontal distance traveled in 2D (m)		across distance traveled (m)		facing distance traveled (m)	
	noprimeVR	primeVR	noprimeVR	primeVR	noprimeVR	primeVR	noprimeVR	primeVR
head	$5.0 \pm 1.7$	$6.1 \pm 2.9$	$4.6 \pm 1.6$	$5.9 \pm 2.9$	$2.7 \pm 1.2$	$4.3 \pm 1.9$	$3.1 \pm 1.1$	$3.1 \pm 1.8$
torso	$3.6 \pm 1.4$	$5.4 \pm 2.6$	$3.0 \pm 1.5$	$5.2 \pm 2.6$	$1.9 \pm 1.0$	$3.7 \pm 1.7$	$1.9\pm0.9$	$2.9 \pm 1.7$
left shoulder	$4.6\pm1.6$	$6.1 \pm 2.6$	$4.1\pm1.5$	$5.9 \pm 2.5$	$2.4\pm1.1$	$4.2 \pm 1.8$	$2.7\pm1.0$	$3.3 \pm 1.5$
left elbow	$5.4 \pm 1.9$	$6.8 \pm 2.4$	$4.7 \pm 1.7$	$6.4 \pm 2.4$	$2.7 \pm 1.2$	$4.4 \pm 1.9$	$3.2 \pm 1.1$	$3.7 \pm 1.3$
right shoulder	$4.8\pm1.7$	$6.1 \pm 2.8$	$4.2\pm1.7$	$5.9 \pm 2.7$	$2.5 \pm 1.2$	$4.1\pm1.8$	$2.9\pm1.0$	$3.4 \pm 1.8$
right elbow	$5.5 \pm 2.1$	$6.7 \pm 2.7$	$4.8\pm2.0$	$6.3 \pm 2.6$	$2.7 \pm 1.4$	$4.3 \pm 1.7$	$3.3 \pm 1.3$	$3.8 \pm 1.8$
left knee	$4.3\pm1.7$	$5.6 \pm 2.3$	$3.5 \pm 1.7$	$5.2 \pm 2.2$	$2.0 \pm 1.0$	$3.4 \pm 1.5$	$2.5 \pm 1.2$	$3.2\pm1.5$
left foot	$4.0 \pm 2.1$	$5.2 \pm 2.4$	$3.1 \pm 1.9$	$4.8 \pm 2.2$	$1.6 \pm 1.0$	$2.9 \pm 1.5$	$2.2 \pm 1.6$	$3.1 \pm 1.6$
right knee	$4.2\pm1.7$	$5.5\pm2.5$	$3.4 \pm 1.7$	$5.1 \pm 2.5$	$2.0 \pm 1.1$	$3.4 \pm 1.7$	$2.4\pm1.1$	$3.2\pm1.6$
right foot	$3.9 \pm 1.7$	$5.2\pm2.7$	$3.0 \pm 1.7$	$4.6 \pm 2.5$	$1.6\pm0.9$	$2.7\pm1.7$	$2.2 \pm 1.3$	$3.1 \pm 1.6$

distance traveled per second occurred at a different time than when the role player was seen in the video, and in the third trial, there were multiple instances where similar movement occurred with no role player visible in the video.

# IV. DISCUSSION AND CONCLUSION

Our results show that participants moved differently in one particular direction when they were given the instructions that a random agent in the virtual environment will represent a real person while having a role player present in the room. Specifically, we find that the movement of primed participants was significantly different in the direction perpendicular to the crowd flow, with the torso showing maximum, albeit nonsignificant, difference among all joints. While our expectations that instructional priming will result in larger postural movements on the whole were not met (H1), the hypothesis that a majority of such movements will be perpendicular to the ambient flow of the virtual crowd (H2) was found to be true.

It is possible that even though the role player was careful not to make any walking sound, the difference in the postural response was due to the role player's footsteps instead of a memory recall attributed to the effect of priming. However, this scenario is not supported by the video and trajectory data analysis. Specifically, the role player was spotted far from the participant in only three out of the nine trial videos, and in those three videos, there was no indication of the role player eliciting responses that were distinctly different from the rest of the trial. In this context, considering that the participants were unaware of the role player's position and actions, it is also possible that just having the role player pointed to in the beginning of the experiment would have sufficed to produce the priming effect. In other words, the effect of the walking of the role player in the approximate trajectory of the ambient crowd flow was minimal. These differences will be explored in future work, where participant response will be compared when (i) only instructions are given without a role player, and (ii) when the role player does not actively move within the environment. The second case will remove any ambiguity related to the participant awareness of the role player once she is experiencing the virtual environment. Alternative priming materials such as videos and pictures of crowded scenarios will also be used to compare the effectiveness of the approach described here.

The experimental setup was limited in that it did not allow the participant to walk freely within the virtual environment due to the limited range of the Kinect sensor. A walkable virtual environment must also be implemented with no delay in the display response time as it would otherwise cause postural instability and dizziness. Implemented well, a walkable virtual environment would lend itself more towards a comparison with a respond-as-if-real (RAIR) study and could have induced distinct responses in horizontal-facing direction in addition to the horizontal-across direction with left-right preference [20]. Such responses must be investigated as a function of the orientation of the participant herself with respect to the ambient crowd flow. These and related questions will be addressed as part of future work.

It is likely that the effect of priming is dependent on the type of the crowd simulation model used to simulate the virtual agent motion. A change in direction of motion to avoid collision within the social force model depends on the distance between two agents, which often results in quicker unrealistic turns than those that observed in real pedestrian motion [24]. Such turns from virtual agents may have resulted in exaggerated participant movements when they believed that one of the agents could be real. At the same time, prior studies have shown that the quality of the virtual environment amplifies the effect of conceptual priming [15]. It is therefore also possible, that a more realistic simulation of crowd motion, one that incorporated computationally expensive time-based collision avoidance strategy [24], would have supported the results obtained in this study. We are upgrading our VR system to enable incorporating such crowd motion models on a head-mounted display that will allow us to compare their effectiveness.

The movement of torso is a reliable indicator of full body movement of the participant since unlike most other joints (arms, legs, head), it cannot be moved independently. Torso movement has been used previously to quantify postural movement to differentiate between motor-coordination patterns [27] and to quantify motion sickness experienced by playing console video games [28]. Further, the absolute torso movement in each of the horizontal-facing and -across directions is well above the error range of the Kinect motion capture system. Future experiments will focus on capturing the joint movements with higher frame rate to enable computing accelerations that in turn can directly relate to the social forces experienced by the participants.

Although past studies have discounted postural movement as an indicator of increased presence or behavioral realism, such inferences have been drawn on the basis of noisy position data [29]. More recent studies have shown that participants tend to react to virtual environments in the form of changes to body posture [30] and interpersonal distance [19]. In this context, it is likely that the 3D joint data may be a more robust indicator of user engagement than presence questionnaires that may have wider interpretations. A future aspect of our work will include a presence questionnaire to investigate if postural responses captured by joint movement correlate well with presence ratings in a virtual crowd environment.

In this paper, we investigate the effect of instructional priming on the postural response of participants to a virtual environment of a crowded scene. We used a Kinect based motion capture setup to quantify the postural response of participants. The priming material included an instruction and a role player. These simple priming materials were able to produce a significant difference in the activity of primed participants along at least one dimension. This result conveys promise in terms of including priming in varied intensities in VR beyond crowd behavior studies, such as for example as part of VR exposure therapy for treating anxiety disorders [31]. However, several open questions need to be addressed before we do so. For example, dissecting the effect of the instruction and the role player in priming, and how it compares to classical priming methods of using videos, pictures, and text. These comparisons can be used to create a more effective priming material for crowd behavior studies using VR.

#### ACKNOWLEDGMENT

The authors would like to acknowledge Dr. Alexander Fell for the VR headset. The experiments in this study were conducted while Sachit Butail was with IIIT-Delhi. Naman Gupta and Anmol Singh were partly supported in Summer 2015 through an internship from Microsoft. The authors are grateful to the anonymous reviewers of an earlier version of this paper for their feedback and comments, which have been instrumental in improving the manuscript.

### REFERENCES

- A. Johansson, M. Batty, K. Hayashi, O. Al Bar, D. Marcozzi, and Z. A. Memish, "Crowd and environmental management during mass gatherings," *The Lancet Infectious Diseases*, vol. 12, no. 2, pp. 150– 156, 2012.
- [2] D. Helbing, D. Brockmann, T. Chadefaux, K. Donnay, U. Blanke, O. Woolley-Meza, M. Moussaid, A. Johansson, J. Krause, S. Schutte, and P. Matjaž, "Saving human lives: What complexity science and information systems can contribute," *Journal of Statistical Physics*, vol. 158, no. 3, pp. 735–781, 2015.

- [3] T. Bosse, M. C. A. Hoogendoorn, M.and Klein, J. Treur, C. N. van Der Wal, and A. van Wissen, "Modelling collective decision making in groups and crowds: Integrating social contagion and interacting emotions, beliefs and intentions," *Autonomous Agents and Multi-Agent Systems*, vol. 27, no. 1, pp. 52–84, 2013.
- [4] K. M. Zeitz, H. M. Tan, M. Grief, P. C. Couns, and C. J. Zeitz, "Crowd behavior at mass gatherings: a literature review," *Prehospital and Disaster Medicine*, vol. 24, no. 01, pp. 32–38, 2009.
- [5] D. C. Duives, W. Daamen, and S. P. Hoogendoorn, "State-of-the-art crowd motion simulation models," *Transportation Research Part C: Emerging Technologies*, vol. 37, pp. 193–209, 2013.
- [6] N. Shiwakoti, M. Sarvi, G. Rose, and M. Burd, "Animal dynamics based approach for modeling pedestrian crowd egress under panic conditions," *Transportation Research Part B: Methodological*, vol. 45, no. 9, pp. 1433–1449, 2011.
- [7] M. Moussaïd, M. Kapadia, T. Thrash, R. W. Sumner, M. Gross, D. Helbing, and C. Hölscher, "Crowd behaviour during high-stress evacuations in an immersive virtual environment," *Journal of The Royal Society Interface*, vol. 13, no. 122, p. 20160414, 2016.
- [8] C. McPhail, "Blumer's theory of collective behavior," *The Sociological Quarterly*, vol. 30, no. 3, pp. 401–423, 1989.
- [9] A. Olivier, J. Bruneau, G. Cirio, and J. Pettré, "A virtual reality platform to study crowd behaviors," *Transportation Research Procedia*, vol. 2, pp. 114–122, 2014.
- [10] J. Bruneau, A. Olivier, and J. Pettre, "Going through, going around: a study on individual avoidance of groups," *IEEE Transactions on Visualization and Computer Graphics*, vol. 21, no. 4, pp. 520–528, 2015.
- [11] A. Shendarkar, K. Vasudevan, S. Lee, and Y.-J. Son, "Crowd simulation for emergency response using BDI agents based on immersive virtual reality," *Simulation Modelling Practice and Theory*, vol. 16, no. 9, pp. 1415–1429, 2006.
- [12] D. E. Meyer and R. W. Schvaneveldt, "Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations." *Journal of Experimental Pssychology*, vol. 90, no. 2, p. 227, 1971.
- [13] D. C. Molden, "Understanding priming effects in social psychology: What is "social priming" and how does it occur?" *Social Cognition*, vol. 32, pp. 1–11, 2014.
- [14] E. Tulving and D. L. Schacter, "Priming and human memory systems," *Science*, vol. 247, no. 4940, pp. 301–306, 1990.
- [15] D. Nunez and E. Blake, "Conceptual priming as a determinant of presence in virtual environments," in *Proceedings of the ACM International Conference on Computer graphics, Virtual Reality, Visualisation and Interaction*, 2003, pp. 101–108.
- [16] C. Qu, W.-P. Brinkman, P. Wiggers, and I. Heynderickx, "The effect of priming pictures and videos on a question–answer dialog scenario in a virtual environment," *Presence*, vol. 22, no. 2, pp. 91–109, 2013.
- [17] S. Howard and B. M. Hughes, "Expectancies, not aroma, explain impact of lavender aromatherapy on psychophysiological indices of relaxation in young healthy women," *British Journal of Health Psychology*, vol. 13, no. 4, pp. 603–617, 2008.
- [18] A. Rizzo, J. F. Morie, J. Williams, J. Pair, and J. G. Buckwalter, "Human emotional state and its relevance for military vr training," DTIC Document, Tech. Rep., 2005.
- [19] J. N. Bailenson, J. Blascovich, A. C. Beall, and J. M. Loomis, "Interpersonal distance in immersive virtual environments," *Personality and Social Psychology Bulletin*, vol. 29, no. 7, pp. 819–833, 2003.
- [20] M. Moussaïd, D. Helbing, S. Garnier, A. Johansson, M. Combe, and G. Theraulaz, "Experimental study of the behavioural mechanisms underlying self-organization in human crowds," *Proceedings of the Royal Society B: Biological Sciences*, vol. 276, no. 1668, pp. 2755–2762, 2009.
- [21] B. Molnár, C. Toth, and A. Detrekoi, "Accuracy test of microsoft kinect for human morphologic measurements," *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. 3, pp. 543–547, 2012.
- [22] B. Galna, G. Barry, D. Jackson, D. Mhiripiri, P. Olivier, and L. Rochester, "Accuracy of the microsoft kinect sensor for measuring movement in people with parkinson's disease," *Gait & Posture*, vol. 39, no. 4, pp. 1062–1068, 2014.
- [23] D. Helbing, I. Farkas, and T. Vicsek, "Simulating dynamical features of escape panic." *Nature*, vol. 407, no. 6803, pp. 487–90, 2000.
- [24] I. Karamouzas, B. Skinner, and S. J. Guy, "Universal power law governing pedestrian interactions," *Physical Review Letters*, vol. 113, no. 23, p. 238701, 2014.

- [25] J. Peña, J. T. Hancock, and N. A. Merola, "The priming effects of avatars in virtual settings," *Communication Research*, vol. 36, no. 6, pp. 838–856, 2009.
- [26] K. Khoshelham and S. O. Elberink, "Accuracy and resolution of kinect depth data for indoor mapping applications," *Sensors*, vol. 12, no. 2, pp. 1437–1454, 2012.
- [27] S. D. Ringenbach and J. C. Kao, "Torso movement constraint in stability of bimanual coordination," *Perceptual and Motor Skills*, vol. 107, no. 1, pp. 231–245, 2008.
- [28] T. A. Stoffregen, E. Faugloire, K. Yoshida, M. B. Flanagan, and O. Merhi, "Motion sickness and postural sway in console video games," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 50, no. 2, pp. 322–331, 2008.
- [29] J. Freeman, S. E. Avons, R. Meddis, D. E. Pearson, and W. A. IJsselsteijn, "Using behavioral realism to estimate presence: A study of the utility of postural responses to motion stimuli," *Presence*, vol. 9, no. 2, pp. 149–164, 2000.
- [30] M. V. Sanchez-Vives and M. Slater, "From presence to consciousness through virtual reality," *Nature Reviews Neuroscience*, vol. 6, no. 4, pp. 332–339, 2005.
- [31] M. Krijn, P. M. G. Emmelkamp, R. P. Olafsson, and R. Biemond, "Virtual reality exposure therapy of anxiety disorders: A review," *Clinical Psychology Review*, vol. 24, no. 3, pp. 259–281, 2004.



Fig. 5. Individual torso movement in 3D per second for the twelve noprimeVR (top) and nine primeVR (bottom) participants. Shaded regions in grey indicate where the role player was spotted in the video of primeVR participants. Dashed lines indicate the maximum movement and 80% of that value.