# Psychophysiological responses to virtual crowds

## Implications for Wearable Computing

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*Abstract*— **Human responses to crowds were investigated with a simulation of a busy street scene using virtual reality. Both psychophysiological measures and a memory test were used to assess the influence of large crowds or individual agents who stood close to the participant while they performed a memory task. Results from most individuals revealed strong orienting responses to changes in the crowd. This was indicated by sharp increases in skin conductance and reduction in peripheral blood volume amplitude. Furthermore, cognitive function appeared to be affected. Results of the memory test appeared to be influenced by how closely virtual agents approached the participants. These findings are discussed with respect to wearable affective computing which seeks robust identifiable correlates of autonomic activity that can be used in everyday contexts.**

***Keywords—affect; psychophysiology; crowds; proxemics; skin conductance; blood volume pulse; cognitive function;***

## I. INTRODUCTION

There is increasing interest in the field of ubiquitous computing and assistive technologies that can help people as aids to everyday life. This might mean, for example, extending human information gathering, providing timely advice or assessing and aiding neurological disorders. Ultimately this will make human-computer interaction more natural, with adaptive responses based on individual preference and current mood. Related to this is wearable computing which is used in real-world situations not just in the office or laboratory. Wearable technology, as it relates to affective computing, therefore needs to find robust measures of affect that can be used in everyday settings. Ideally an affective wearable is able to sense and recognize signals corresponding to underlying affective states of the user and respond appropriately based on an interpretation of that state [1][2].

Current research is therefore pursuing models of emotion and the development of wearable technology itself, e.g. [3]-[5]. The basic idea is to measure physiological signals produced by the body that are related to emotion and use signal processing, pattern recognition and machine learning to interpret the user's emotional state and make predictions. The challenges include finding reliable models of emotion based on robust biological indices [1] and the removal of artefacts or perturbations in measurement. The most common problem is that of artefacts introduced by movement. Physiological sensors in current use are sensitive to body movement and finding sites for their placement which is unobtrusive but also insensitive to movement is being investigated e.g., [6].

Other perturbations of physiological signals are more subtle and relate to the normal psychological function. One example of this is environmental stress in which the individual's emotional state is influenced by their surrounds. A person on a crowded shopping street, for example, may be more stressed than someone walking through a field of flowers. People are influenced by their environments and more specifically by proximity to other people and this influence may be conscious or unconscious and may vary if someone is surrounded by friends or strangers [7].

Thus, unexpected and context-driven events may make interpretation of physiological signals on their own more difficult. In order to highlight the challenges faced by any system that needs to assess the user's emotional state we investigated the influence of crowds and the proximity of other people on peripheral physiological arousal. We did this in a controlled way using virtual reality (VR) simulation with an epoch-based design whereby changes in the virtual crowd marked transitions from baseline measurements of indices of emotion. Our results show these changes are reflected in physiological measures of arousal. Furthermore we provide evidence for changes in cognitive function that appear to be connected to the proximity of other people (interpersonal distance). We begin by defining our physiological indices of arousal and briefly review the literature relating to the influence of crowds on human psychophysiology.

## II. BACKGROUND

### A. Physiological Indices of Emotion

Physiological or biological stress is a response to a *stressor* that can be either a stimulus or an environmental condition. Stress is the body's way of reacting to challenging situations. According to the stressful event, the body's way to respond depends on the autonomic nervous system (ANS). The ANS is the control mechanism that regulates, for example, heart rate, perspiration, respiration, pupil diameter and digestion. It is comprised of two main subdivisions: the sympathetic and parasympathetic pathways, which serve opposing functions: the sympathetic nervous system (SNS) prepares the body for action, whilst the parasympathetic nervous system (PNS) promotes relaxation and digestion. Changes in the environment are rapidly processed by the brain to allow orienting of resources toward possible threats [8]. This is done by engaging the SNS which increases heart rate to pump more blood around the body and increased sweating to cool the body down. These two

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measurable quantities have therefore been used to indirectly assess emotional arousal, attention and cognitive effort.

*1) Electrodermal Activity*

Electrodermal activity (EDA) is the term used for autonomic changes in the electrical properties of the skin [9]. Skin conductance is determined solely by the SNS. As the SNS is engaged it triggers increased sweating at the skin (sudomotor activity) which can be measured by applying an electrical potential between two points and measuring the resulting current flow between them. Skin conductance is expressed in microsiemens (μS) and increases with the level of arousal. During relaxation, the skin conductance level normally decreases. The EDA signal includes both baseline tonic (skin conductance level, or SCL) and rapid phasic (skin conductance responses, or SCRs) components. The latter occur spontaneously but can also be triggered by external events.

*2) Cardiovascular Response*

The cardiovascular response (CR) is characterised by changes in heart rate and is influenced by both the SNS and PNS and can be measured using either an electrocardiogram or photoplethysmographic (PPG) sensor. Heart rate variability (HRV) has been used in medicine and biofeedback regimes to promote health, cf [10]. HRV includes measures of how heart rate varies and researchers have used the frequency components of the inter-beat interval signal to extract low and high frequencies. Low frequencies have sympathetic involvement. High frequencies have sympathetic and parasympathetic involvement, so ratios of these have been used to quantify the relative involvement of the SNS in psychophysiology [11].

Each heartbeat briefly increases blood volume in the arteries and capillary beds. A more easily accessible measure of affect in terms of heart rate is the amount of blood that gets pumped around the body, measured by blood volume pulse (BVP) amplitude. Arousal and involvement of the sympathetic nervous system increases blood flow to vital organs and reduces blood flow to extremities such as the fingers (vasoconstriction). Thus, sympathetic arousal leads to vasoconstriction which is indexed by reductions in BVP amplitude [12].

## B. Proxemics and Crowds

As social beings much of what we do involves interpreting and responding to non-verbal signals. Non-verbal behaviour includes mutual gaze, voice intonation, body orientation and interpersonal distance. This behaviour is systematic and subconscious [13] and human-computer interaction researchers have begun exploiting such behaviours as novel means of engagement and interaction, e.g. [14][15]. Proxemics, a termed coined by Edward Hall in 1963, is a subclass of non-verbal communication that relates to the distances that people maintain between each other out of personal or cultural preference or in different contexts [16]. Hall distinguished between basic categories of distance including intimate, personal, social and public. For example, a zone of 45cm around a person is considered personal territory and reserved only for close friends. Beyond this is social space in which normal interaction between colleagues and strangers takes place. This does, of course, depend on context. Think, for example, of sharing a crowded lift full of strangers. Our normal boundaries in this case must be changed to accommodate the context. In general however transgression of territorial zones may be considered either alarming or even threatening and our physiology has evolved to make us aware of, and react to, these situations.

Researchers have investigated several factors that may moderate what is considered personal space, including culture [17], race [18] and age [19]. There is also evidence of gender differences with some studies suggesting that preferred male-male interpersonal distances are greater than female-female and female-male [18][20]-[22] and that females are more likely to react to violations of personal space than males [23].

In recent years advances in virtual reality (VR) have facilitated the study of proxemics and non-verbal behaviour in arguably more controlled settings. For example, [21] devised an experiment investigating the relationship between mutual gaze and interpersonal distance. They asked male and female participants wearing a head mounted display to approach a virtual human agent to obtain a name and number written on their front and back for a subsequent memory test. They recorded the participant's movements, minimum distance maintained and performance in the test. They found that participants were prone to respect the agent's personal space keeping longer minimum distances to their front than their back. They also reported an effect of social inhibition on memory in that participant's recall was worse when dealing with a humanoid agent than with a non-humanoid control. In subsequent experiments [22] found that participants make aversive responses when approached by virtual agents, in line with previous findings [23].

These aversive responses suggest the involvement of physiological arousal in response to physical proximity. Ref [24] measured increased skin conductance when participants were approached by a stranger who stood at a distance of 30cm compared with 90cm. Ref [25] reported increases in skin conductance in participants immersed in a virtual environment that correlated with the minimum distance of approach by virtual agents. They used one or four agents of opposite gender who approached male participants. They found SCR correlations with minimum distance as well as the number of agents who approached the participant. Intriguingly, they also found similar physiological responses to non-human 3D objects and this was attributed to a fear of collision rather than a violation of interpersonal distance.

Other consequences of proxemics may be the influence of interpersonal distance on cognitive function. This is suggested by neuroscience literature concerning anxiety and cognitive function [26][27]. This was also suggested by Bailenson's experiment [21]. Ref [28] reported increased levels of stress associated with overcrowding with concomitant negative impact on cognitive function. In [29] it was reported that participants who preferred greater interpersonal distance showed greater stress indexed by skin conductance due to crowding and also showed reduced creativity. Similar results were reported in [30]. Ref [31] reported increased salivary cortisol and performance aftereffects when commuters had to sit close to each other. Cortisol is a marker for adrenocorticotropic hormone (ACTH) which is produced as a result of stress.

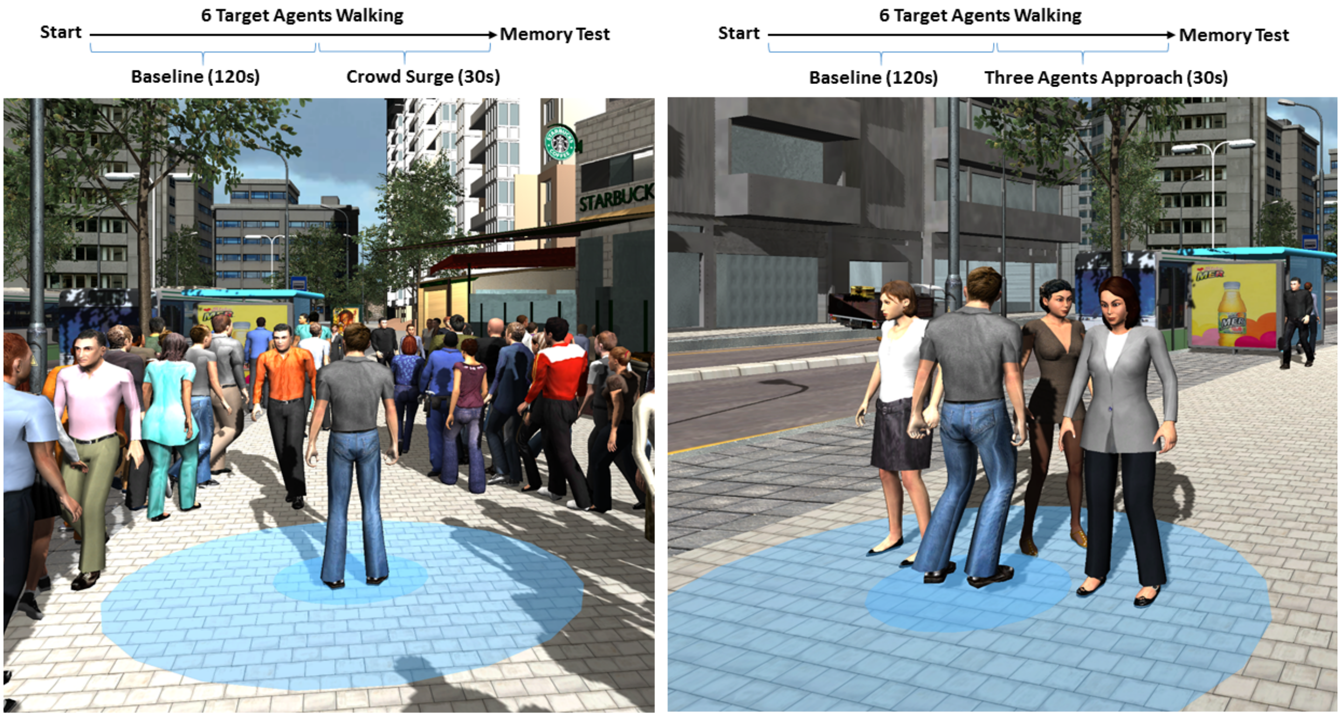


Fig. 1. The two 'stressor' events used in the experiments with timelines. The picture on the left shows a CROWD trial. The participant is in the middle of the concentric circles which depict the distances of 0.5m and 1.5m. Here the crowd does not come within a distance of 1.5m. The picture on the right shows an AGENTS trial. In this instance the 3 agents stand 0.5m from the participant. The circles were not visible during the experiment. Prior to these 'stressor' events participants saw just the 6 target agents walking up and down the street.

In our experiment we wanted to simulate the conditions under which a wearable device might operate while measuring CR and EDA to assess autonomic arousal. A crowded street in an urban area with traffic noise, people and movement was used. Specifically, we wanted to address the following questions:

- Does increase in crowd size increase arousal?
- Is there an effect of interpersonal distance?
- Are there any gender differences?
- Does arousal influence cognitive function?

## III. Method

Static observers immersed in a VR simulation were asked to familiarize themselves with six virtual agents walking around on a pavement for a later recognition test. During this familiarization stage, which lasted for 120s, their EDA and CR were recorded and formed the baseline epochs in the analysis. After the familiarization stage one of two events occurred: In the CROWD condition, 92 agents of different gender and races appeared from nearby locations (shops, bus stop) and walked repeatedly between various randomly chosen positions in front and behind the observer. In the AGENTS condition 3 agents appeared from nearby locations, approached and stopped around the observer. Both events lasted for 30s and formed the stressor epochs in our analysis. The timelines for these events are shown in Figure 1 together with screen captures which illustrate the two conditions.

A memory test followed immediately thereafter. This consisted of the individual presentation of the agents seen during the familiarization stage together with an equal number of 'distractor' agents that were never seen before. Participants used a hand-held mouse to indicate whether they had seen the agents before or whether they were new.

### *A. Design*

A repeated measures design was used with two conditions (CROWD, AGENTS) as described above. Each condition had two levels: In the CROWD condition agents were allowed to come within 50cm or 150cm of the observer on their way to their respective destinations. In the AGENTS condition the agents stopped within either 50cm or 150cm from the observer. These combinations resulted in 4 scenes (trials) for each observer.

To control for order effects participants were assigned to the four scenes according to a Latin square design with the additional provision that scenes from the same condition did not directly follow each other. This resulted in 8 distinct combinations of scene order for each gender.

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## B. Participants

Sixteen participants took part in the experiment (8 male, 8 female). Median ages were 23 and 23.5 for females and males respectively. Participants were recruited by advertisements within the campus and received no payment. They had normal or corrected to normal vision. The only difference in the treatment of gender was that in the AGENTS condition the stressor agents were of the opposite gender.

## C. Equipment

A realistic virtual setting was created using 3D-modelling packages (3DStudio Max & Maya). The game engine Unity3D (www.unity3d.com) was used to present the trials as game levels Unity3D also controlled the sequence of events as well as the presentation and user input in the memory test. The virtual characters were designed, created and rigged using Autodesk Character Generator (charactergenerator.autodesk.com). In total 156 different agents were used for the various parts of the experiment. When agents were not walking they performed 'idle' animations involving movements of their body and head.

The simulation also included audio in the form of background sounds that could be heard in a typical busy pedestrian environment. The audio consisted of traffic noise, incoherent people's voices, bird-song etc. The audio recording was adjusted to make the end seamless with the beginning, thus it could be played in a loop throughout the simulation. Audio was delivered via closed wireless stereo head-phones. The sound level range was 40-60 dB measured at the speakers.

A CAVE™ display was used to present the scenes and consisted of four projection screens: one to the left and right of the user, one on the floor and one in front. Each screen was controlled by a separate workstation, with Intel Xeon 64bit 2.6GHz CPUs and NVidia Quadro 6000 graphics cards. The projection area of each screen was 2.44 x 1.83 m, with 1600 x 1200 pixels resolution. The refresh rate of 120 Hz allowed stereoscopy with the use of active shutter glasses, where the right and left eye's view was displayed alternately with a frequency of 60 Hz. A Vicon tracking system consisting of four infrared cameras tracked the position and orientation of the user's head.

EDA and CR were measured using a Mind Media Nexus 10 device (www.mindmedia.info) recording skin conductance and BVP amplitude at 32Hz. This consisted of electrodes placed on the medial phalange of the left index and middle fingers, using 8mm diameter Ag/AgCl electrodes and CR was monitored using a pulse oximeter placed on the middle finger. Real-time signals from the Nexus were sent wirelessly to a laptop running Mind Media Biotrace software for visual inspection and recording and which also allowed event markers for baselines and stressors to be set.

## D. Procedure

Experimental sessions lasted approximately 45 minutes. Participants initially signed consent forms and read written instructions. They were then fitted with the physiological sensors, stereo glasses and headphones.

The experiment started with a relaxation stage in which participants viewed an infinite horizon scene with clouds lasting 2 minutes without audio. This was followed by a demo phase which was a shortened version of the actually test trials but without the two CROWD or AGENTS events. Audio was present during this phase and continued until the end of the experiment. Participants then performed the four trials with short breaks in between.

Participant's main instruction was 'You will observe 6 individual characters for 2 minutes followed by a memory test. Try to ignore anything else that happens during this time and try your best to memorize the 6 individuals using all of their various features, including clothing, type of clothing, colour of clothing, body shape and face'. Participants were asked to remain still during the learning stage so as not to introduce artefacts but were allowed to rotate their heads as required.

Memory for agents seen during the baseline stage consisted of a one-interval yes-no discrimination task in which participants were presented with either one of the previously seen agents or a 'distractor'. The distractors had similar clothes but differed in various respects including body shape, colour of clothing, face characteristics etc. Different distractors were used in each memory test corresponding to the target agents. The target and distractor agents were unique and did not appear before or in subsequent scenes. Combinations of target agents were randomised between subjects.

## E. Data and Signal Analysis

EDA recordings were analysed by Ledalab Matlab software (www.ledalab.de) [32] using Continuous Decomposition Analysis (CDA) to extract the phasic driver (SCL) from the tonic nerve activity (SCR). Raw data was smoothed by convolution with Hann window of size 16 to reduce noise. The CDA method first fits the data to a bi-exponential Bateman function [9] and then optimizes the fit using conjugated gradient descent to reduce errors between the fit and the internal model. We used the integrated skin conductance response (ISCR) as our dependent variable. The ISCR corresponds to the total average sudomotor nerve activity during a given epoch [33]. We compared log transformed ISCR for stressor epochs with baseline epochs as follows:

- In the CROWD condition – for 20s after the crowd first appeared versus the previous 20s.
- In the AGENTS condition – for 20s after the agents arrived and stopped at the participant versus the previous 20s.

Skin conductance responses were categorized as responses exceeding an amplitude of 0.1 μS.

Cardiovascular response was assessed using blood volume pulse amplitude. Raw signals were first passed through a Butterworth low pass filter with normalized cut-off frequency corresponding to 6Hz. These were then smoothed by convolution with a Gaussian with 64 point window width. Mean BVP amplitudes served as dependent variables and were calculated according to the EDA epochs stated above.

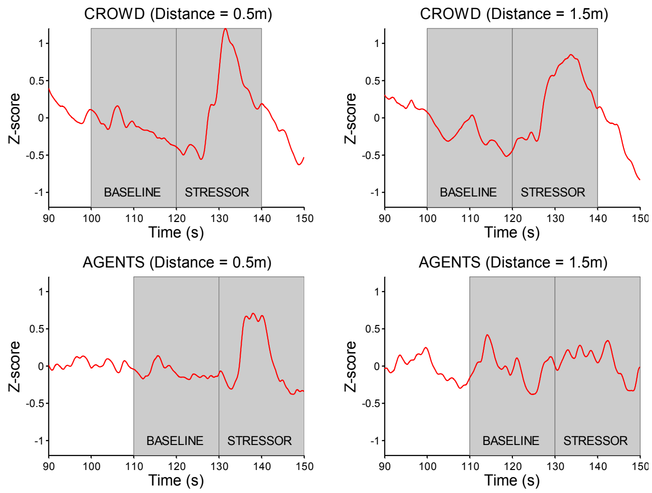


Fig. 2. Mean SCR as z-scores (n=16). The grey areas depict baseline and stressor epochs. Signals were low-pass filtered with a cutoff frequency of 6Hz and smoothed using exponential smoothing (α=0.6) before being standardized and detrended.

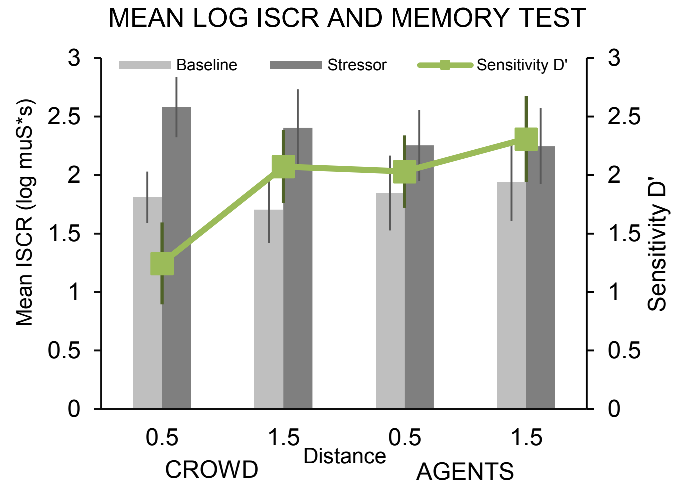


Fig. 3. Mean log integrated skin response (ISCR) for the two conditions (CROWD, AGENTS) each with two minimum distances (0.5m, 1.5m) contrasted against baseline levels. The figure also shows the d' memory results for each condition (line overlay).

Finally, subject responses to the target and distracter agents were tabulated and converted to ratios of hits (correctly identified previously scene agent) and false alarms (incorrectly identified distractor as a previously seen agent). This allowed us to use sensitivity index d', calculated as in (1)

$$d' = Z(\text{hit rate}) - Z(\text{false alarm rate}) \quad (1)$$

Where $Z(p)$, $p \in [0, 1]$, is the inverse of the cumulative Gaussian distribution. D' is a statistic used in signal detection theory and provides a separation between the means of the signal and noise distributions compared to the standard deviation of the noise distribution [34].

## IV. RESULTS

### A. Skin Conductance

Figure 2 shows the SCR as z-scores averaged across all participants. Grey areas mark the baseline and stressor epochs and show increased skin conductance during most stressor epochs. In terms of ISCR Figure 3 shows mean, log transformed, values for stressor epochs compared to baseline for each trial. The CROWD condition at the shortest distance produced the greatest response in ISCR. To analyse the data we performed a repeated measures ANOVA with three within-subjects factors: CONDITION(CROWD, AGENTS), DISTANCE(0.5m, 1.5m), and STRESSOR(ABSENT, PRESENT), and one between-subjects factor: GENDER(M, F). There was no significant effect of CONDITION [$F(1,14)=0.18$, $p=0.67$] or DISTANCE [$F(1,14)=0.12$, $p=0.73$] although the presence of the STRESSOR was highly significant [$F(1,14)=26.1$, $p<0.0005$]. The effect of GENDER also approached our significance level of 0.5 [$F(1,14)=4.2$, $p=0.059$].

We also found a significant interaction between CONDITION and STRESSOR [$F(1,14)=5.97$, $p<0.05$] with CROWD conditions producing greater ISCR responses compared to baseline than the AGENTS conditions. Furthermore, there is some evidence of gender involvement between the two types of conditions (CROWD and AGENTS). Figure 4 suggests males were more influenced by the stressor in the AGENTS condition than females. The ANOVA showed that the interaction between CONDITION, STRESSOR and GENDER approached significance [$F(1,14)=3.65$, $p=0.07$]. A one-tailed paired-samples t-test showed the stressor ISCR for males in the AGENTS condition for both distances was significantly higher than baseline [$t=1.89$, $p<0.05$] whereas a similar comparison for females showed no significant difference between the stressor and baseline [$t=0.40$, $p=0.35$]. All other interactions were not significant.

### B. Blood Volume Pulse Amplitude

Average z-scores obtained from the BVP amplitude data are shown in Figure 5 and suggest vasoconstriction during all stressor epochs. Figure 6 shows log transformed values contrasted to baselines. We performed a similar ANOVA on BVP amplitude as in the previous section, with three within-subjects factors (CONDITION, DISTANCE, STRESSOR) and one between-subjects factor (GENDER), all with two levels.

The effect of CONDITION approached significance [$F(1,14)=3.14$, $p=0.098$] which would have suggested that vasoconstriction was marginally greater for the AGENTS scenario than CROWD. Once again the STRESSOR produced significant deviations from baseline [$F(1,14)=16.6$, $p<0.005$]. The effect of GENDER was not significant [$F(1,14)=0.88$, $p=0.36$] neither was the effect of DISTANCE [$F(1,14)=0.006$, $p=0.98$]. However, we did see approaching significance for the interaction between DISTANCE and STRESSOR [$F(1,14)=3.4$, $p=0.08$] with marginally greater vasoconstriction for closer distances. All other interactions were not significant.

### C. Memory Test

Mean d' results are overlaid as lines in Figures 3 and 6 for each condition. The effective limits of .99 and .01 were used for 100% hit rates and 0% false alarm rates respectively. The maximum d' possible is therefore 4.65. If a subject correctly identified old and new on 69% of trials then d'=1. We see from the means that performance was between these two values.

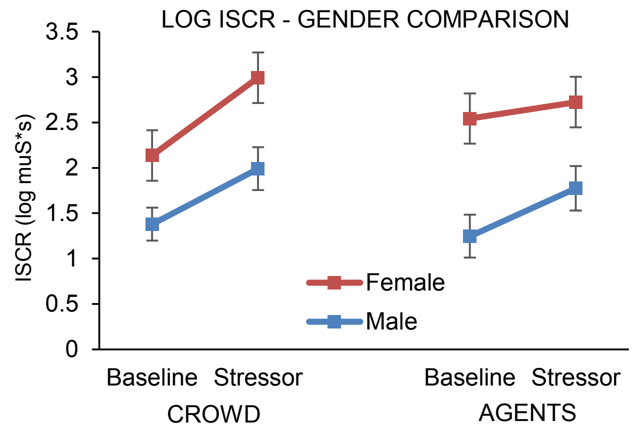


Fig. 4. Mean log ISCR averaged over both distances (0.5m, 1.5m) for male and female subjects. The graph suggests that in the AGENTS condition males were more influenced by interpersonal distance than females.

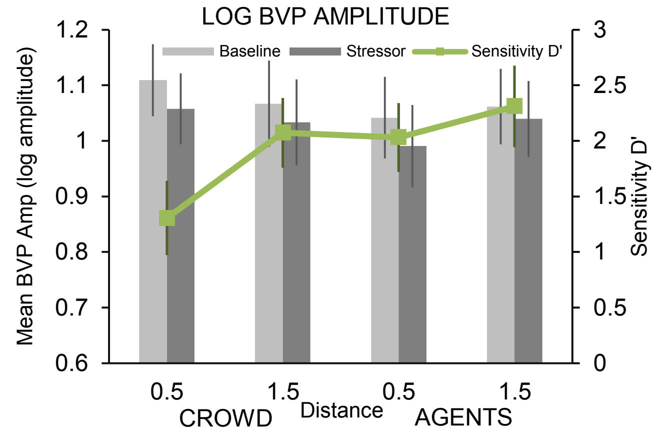


Fig. 6. Mean log blood volume amplitude for the two conditions contrasted against baseline levels. The figure also shows the d′ memory results for each condition (line overlay).

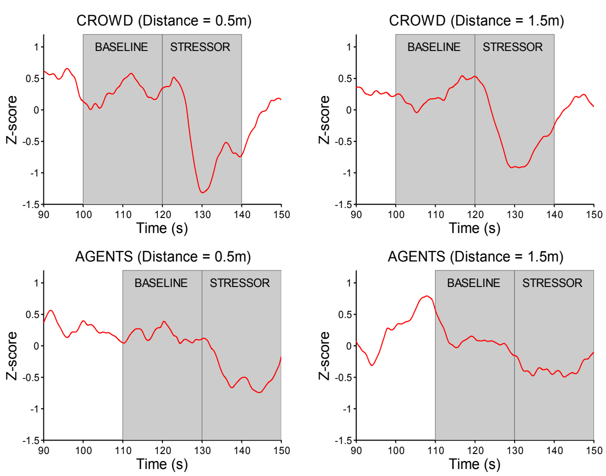


Fig. 5. Mean BVP amplitude. Grey areas show baseline and stressor epochs. Signals were filtered to remove noise and smoothed by Gaussian convolution before conversion to z-scores.

A repeated measures ANOVA with two within-subjects factors of CONDITION(CROWD, AGENTS) and DISTANCE(0.5m, 1.5m) and one between subjects factor of GENDER was used to analyse the data. CONDITION was not significant [F(1,14)=2.48, p=0.14] whereas DISTANCE between agents and the participant was significant [F(1,14)=9.26, p<0.01]. Averaging across CONDITION and GENDER, closer interpersonal distances produced worse performance (m=1.64, s.e.=0.34) than further distances (m=2.19, s.e.=0.34). There was also a significant effect of GENDER [F(1,14)=5.7, p<0.05]. Averaging across conditions shows that females performed better (m=2.45, s.e.=0.31) than males (m=1.38, s.e.=0.31).

## V. Discussion

These results suggest that there is, in general, an effect of other people in a virtual scene on both psychophysiology and cognitive function. We found skin conductance increases and constriction of pulmonary peripheral blood flow, two indices of autonomic arousal, when crowds of people appeared or when individual agents stood next to the participants.

In terms of interpersonal distance the closer distance of 0.5m qualitatively appears to generate a larger average response in EDA and CR than the further distance of 1.5m. We expected to see this especially in the AGENTS condition as this is essentially a replication of the experiment described in [25]. However the analysis of ISCR data did not show a significant effect. There are a number of possible reasons for this. Firstly, technical limitations of the CAVE display meant that the closest distance that could be used without eye strain and diplopia was 50cm. Previous studies have used distances of 40cm or less. Secondly, in [25] they studied only males whereas we employed both males and females. Figure 4 indeed suggests that males are more affected by the stationary agents than females, in line with previous studies e.g., [35]. With sufficient numbers of male subjects it may well be possible to replicate previous results. Our intention here however was to provide data on how a broad range of people respond to crowds and therefore it was important to include both genders.

In the memory tests, performance was significantly worse when agents came closer to participants. This effect was more marked in the crowd condition than the AGENTS condition. We also found gender differences here with females overall performing better than males, although both were affected by interpersonal distance. This suggests a possible influence of arousal on cognition in line with previous studies e.g., [21].

These findings are remarkable considering participants were in the CAVE on their own. The environment and the people within it were just projections. If computers are to understand and adapt to their wearers it seems unlikely they would be able to do this ubiquitously without some information regarding context that can account for fluctuations in affective indices. This might be provided, for example, by visual or other sensory input to provide information regarding the environment in which the wearer is located. These results also suggest wider implications for urban societies in which people are constantly interacting with each other and in which stress and constant sympathetic arousal can lead to disease.

## References


[1] R. W. Picard, E. Vyzas, and J. Healey, "Toward machine emotional intelligence: Analysis of affective physiological state," Pattern Analysis and Machine Intelligence, IEEE Transactions on, vol. 23, pp. 1175-1191, 2001.

[2] R. W. Picard and J. Healey, "Affective wearables," Personal Technologies, vol. 1, pp. 231-240, 1997.

[3] M. A. Williams, A. Roseway, C. O'Dowd, M. Czerwinski, and M. R. Morris, "Swarm," pp. 293-300, 2015.

[4] J. A. Healey, "Wearable and automotive systems for affect recognition from physiology," Massachusetts Institute of Technology, 2000.

[5] M. Chen, Y. Zhang, Y. Li, M. Hassan, and A. Alamri, "AIWAC: affective interaction through wearable computing and cloud technology," Wireless Communications, IEEE, vol. 22, pp. 20-27, 2015.

[6] R. Chellali and S. Hennig, "Is It Time to Rethink Motion Artifacts? Temporal Relationships between Electrodermal Activity and Body Movements in Real-Life Conditions," in Affective Computing and Intelligent Interaction (ACII), 2013 Humaine Association Conference on, 2013, pp. 330-335.

[7] R. Gifford, Environmental psychology: Principles and practice: Optimal books Colville, WA, 2007.

[8] A. Öhman, A. Flykt, and F. Esteves, "Emotion drives attention: detecting the snake in the grass," Journal of experimental psychology: general, vol. 130, p. 466, 2001.

[9] W. Boucsein, Electrodermal activity: Springer Science & Business Media, 2012.

[10] M. Malik and A. J. Camm, "Heart rate variability," Clinical cardiology, vol. 13, pp. 570-576, 1990.

[11] G. G. Berntson, J. T. Bigger, D. L. Eckberg, P. Grossman, P. G. Kaufmann, M. Malik, et al., "Heart rate variability: origins, methods, and interpretive caveats," Psychophysiology, pp. 623-48, 1997.

[12] E. Peper, R. Harvey, I.-M. Lin, H. Tylova, and D. Moss, "Is there more to blood volume pulse than heart rate variability, respiratory sinus arrhythmia, and cardiorespiratory synchrony?," Biofeedback, vol. 35, 2007.

[13] R. B. Zajonc, "Feeling and thinking: Preferences need no inferences," American psychologist, vol. 35, p. 151, 1980.

[14] S. Greenberg, N. Marquardt, T. Ballendat, R. Diaz-Marino, and M. Wang, "Proxemic interactions: the new ubicomp?," interactions, vol. 18, pp. 42-50, 2011.

[15] A. G. Brooks and R. C. Arkin, "Behavioral overlays for non-verbal communication expression on a humanoid robot," Autonomous Robots, vol. 22, pp. 55-74, 2007.

[16] E. T. Hall, "A system for the notation of proxemic behavior," American anthropologist, vol. 65, pp. 1003-1026, 1963.

[17] M. Baldassare and S. Feller, "Cultural variations in personal space," Ethos, vol. 3, pp. 481-503, 1975.

[18] T. J. Rosegrant and J. C. McCroskey, "The effects of race and sex on proxemic behavior in an interview setting," Southern Journal of Communication, vol. 40, pp. 408-418, 1975.

[19] J. R. Aiello and S. E. Jones, "Field study of the proxemic behavior of young school children in three subcultural groups," Journal of Personality and social psychology, vol. 19, p. 351, 1971.

[20] L. L. Adler and M. A. Iverson, "Interpersonal distance as a function of task difficulty, praise, status orientation, and sex of partner," Perceptual and motor skills, vol. 39, pp. 683-692, 1974.

[21] J. Bailenson, J. Blascovich, A. Beall, and J. Loomis, "Equilibrium theory revisited: Mutual gaze and personal space in virtual environments," Presence, vol. 10, pp. 583-598, 2001.

[22] 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, pp. 819-833, 2003.

[23] J. K. Burgoon, L. A. Stern, and L. Dillman, Interpersonal adaptation: Dyadic interaction patterns: Cambridge University Press, 1995.

[24] G. McBride, M. King, and J. James, "Social proximity effects on galvanic skin responses in adult humans," The Journal of psychology, vol. 61, pp. 153-157, 1965.

[25] J. Llobera, B. Spanlang, G. Ruffini, and M. Slater, "Proxemics with multiple dynamic characters in an immersive virtual environment," ACM Transactions on Applied Perception (TAP), vol. 8, p. 3, 2010.

[26] A. F. T. Arnsten, "NEUROSCIENCE: Enhanced: The Biology of Being Frazzled," Science, vol. 280, pp. 1711-1712, 1998.

[27] H. van Steenbergen, "Affective modulation of cognitive control: a biobehavioral perspective," in Handbook of Biobehavioral Approaches to Self-Regulation, ed: Springer, pp. 89-107, 2015.

[28] J. R. Aiello, "Field Experimental Research on Human Crowding," 1975.

[29] J. R. Aiello, D. T. DeRisi, Y. M. Epstein, and R. A. Karlin, "Crowding and the role of interpersonal distance preference," Sociometry, pp. 271-282, 1977.

[30] Y. M. Epstein, R. L. Woolfolk, and P. M. Lehrer, "Physiological, Cognitive, and Nonverbal Responses to Repeated Exposure to Crowding," Journal of applied social psychology, vol. 11, pp. 1-13, 1981.

[31] G. W. Evans and R. E. Wener, “Crowding and personal space invasion on the train: Please don’t make me sit in the middle,” Journal of Environmental Psychology, 27(1), pp. 90-94, 2007.

[32] M. Benedek and C. Kaernbach, "Decomposition of skin conductance data by means of nonnegative deconvolution," Psychophysiology, vol. 47, pp. 647-658, 2010.

[33] [M. Benedek and C. Kaernbach, "A continuous measure of phasic electrodermal activity," Journal of neuroscience methods, vol. 190, pp. 80-91, 2010.

[34] N. MacMillan, C. Creelman, Detection Theory: A User’s Guide. Lawrence Erlbaum Associates, 2005.

[35] A. T. Brady and M. B. Walker, "Interpersonal distance as a function of situationally induced anxiety," British Journal of Social and Clinical Psychology, vol. 17, pp. 127-133, 1978.