Physiological Responses to Breaks in Presence: A Pilot Study

Mel Slater, Andrea Brogni and Anthony Steed
Department of Computer Science, University College London, UK
Email: m.slater@cs.ucl.ac.uk

1. Introduction

A participant in an Immersive Virtual Environment (VE) is subject to two streams of sensory data, the first from the real world in which the experience is taking place, and the second from the virtual world displayed by the virtual reality system. A 'break in presence' (BIP) occurs when the participant stops responding to the virtual stream and instead responds to the real sensory stream. By 'respond' we mean the total response of the participant – including involuntary changes in physiological response, changes in eye movement patterns, changes in volitional behaviour, and finally subjective verbal responses including questionnaire and interview responses. Presence in a VE, in this view, corresponds to a situation where the participant is responding and acting much the same as they would as if they were in a similar situation in reality. A BIP is signalled when their overall response switches to that appropriate to the real rather than to the virtual environment. Such BIPs were first studied by Slater and Steed (2000), where a simple stochastic model was proposed which led to a measure of presence that was positively correlated with a questionnaire measure. This BIPs model is an abstraction and does not account for all possibilities – it deliberately chooses a binary response and the switches between these, and so cannot account for mixed responses as studied by Spagnolli & Gamberini (2002).

In this paper we examine whether BIPs correspond to real changes in physiological state. We hypothesise that BIPs should be detectable in physiological time series. A sudden change in presence in everyday life is an extremely rare event for most people – only experienced as a result of breakdown – for example, due to drugs, psychotic episodes or neurological disease. If a person, however, truly became present in a VE then a BIP (a sudden switch in presence to physical reality) should be experienced as a profoundly shocking event. Of course, given today's VE systems, we do not expect such a profound sense of presence and therefore a very strong shock in response to a change in presence is unlikely. Nevertheless, it is useful to examine whether there is any support for the notion that a BIP registers as an event at the physiological level. We report on the results of an experiment where subjects reported BIPs, in the same way as in Slater & Steed (2000) and where SCR and heart rate data were recorded. We find that the evidence to date does not contradict the hypothesis that BIPs are observable as events in the SCR and heart rate time series.

2. Background

Measures of presence have been dominated by questionnaire measures. These have been argued to be unsatisfactory, when used alone, on several grounds. Freeman et al. (1999) have shown the inherent instability of subjective presence questionnaires, and have proposed behavioural measures. Slater (2003) has argued that presence questionnaires alone are unsafe on methodological grounds since it is difficult to rule out the possibility that the phenomenon to be measured is brought into being merely by asking questions about it. More generally presence questionnaires are administered after the event, and so cannot reflect the changing state of the participant during the ongoing experience. Physiological measures have been used in an attempt to overcome these problems with the traditional questionnaire approach. Dillon et al. (2001) used a questionnaire and heart rate to distinguish between stereo and mono experiences. They found that although the questionnaire clearly discriminated between these two, that the evidence was much weaker for heart rate. Meehan et al. (2002) successfully used physiological measures (in particular heart rate) as a surrogate for presence. Subjects in an experiment that depicted a precipice in a room showed a significant increase in heart rate when compared to a non-threatening training room. The argument in this case is that they would not have exhibited anxiety on seeing the pit had they not been present, and in this way presence is indirectly measured.

The problem with using physiological measures directly as a measure of presence is that it is not clear what the response should be in mundane situations. The expected physiological response to a stressful VE is one thing, but what is the expected response to being in, for example, a virtual simulation of an ordinary hotel room, just like one you've stayed in dozens of times before, where nothing out of the ordinary is happening?

An approach that we follow in this paper is not to attempt to characterise presence itself by physiological responses, but to examine whether there is a physiological signature corresponding to breaks in presence.

2. Experiment

The experiment that generated the data reported in this study was designed to examine the impact of six different kinds of VE scenes on presence. We are only interested in one aspect of this experiment for the purposes of this paper, the part that relates to BIPs. Sixty subjects were randomly and equally assigned to six different worlds, with a gender balance for every world. The VE experience was inside a 4-walled Trimension ReaCTor (Cave™-like system) with Intersense Tracking. They were asked to visit one of six urban VEs through which they were able to move around freely using a wand. There was no interaction with the objects of the virtual environment. Prior to entering the VE they were trained to report BIPs in the same way as in the Slater & Steed (2000) study. They were shown a series of Gestalt Images that could be interpreted in one of two ways, and their spontaneous switch in interpretation was used to explain the idea of 'change in place' within a VE. They were instructed to press a button on the wand device whenever they experienced a change in their sense of place, from being in the VE to being in the real world of the Cave and laboratory environment. During the virtual experience, any time the button on the wand device was pressed the relative elapsed time since the beginning of the experiment was recorded into a file.

3. Results

A ProComp+ device was used to record Skin Conductance Response (SCR - GSR) and Blood Volume Pulse (BVP) from which heart rate per minute (HR) is derived. Treating BIPs as stimuli and the SCR and HR waveforms as response, we wished to examine whether there was any correlation between the stimuli and the response.

The heart rate was normalised for each person by applying a 'de-trend' routine (MATLAB) that takes out trend and absolute value. Figure 1 shows the mean waveform within ±4 seconds of a BIP. This (the solid black curve) is found by averaging the waveform in this range over all 60 participants over all BIPs. As we can see the mean heart rate appears to increase and reach a peak approximately 1 second before a BIP is signalled. The dashed (relatively flat) curve labelled 'random BIPs' shows the mean waveform averaged over randomly placed stimuli points (500 iterations were used for the mean). I.e., pseudo-random BIP times were generated for each subject, and these were used in place of the true BIP times. The difference between this curve and the true BIP one demonstrates that the true BIP curve is not simply picking up an inherent property of the underlying time series itself, and that the behaviour of the time series in the neighbourhood of a BIP probably shows a genuine spike.

The heart rate response may be caused by the action or intention of pressing the button to signal a BIP, rather than by the BIP itself. A further 10 subjects were recruited who were placed in the Cave wearing all the same equipment as the original subjects, and who were given visual signals to carry out a number of different activities – raising an arm, looking to the left or right, and so on. One of the activities signalled was to press the wand button. These wand button press times were recorded, and used as pseudo BIPs in order to carry out the same analysis for this control group as the original group. The resulting curve is shown as the dotted line labelled 'button press control'. This shows an oscillation that is again quite different from that of the 'true BIP' curve.

Finally another 10 subjects were recruited. These also stood in the Cave and were shown a red ball projected on the Cave wall. They were asked to press the button only when the ball turned red. This

instruction was communicated forcefully, in order to produce some anxiety about the importance of pressing the button at the right time. This control group was used in order to generate some anxiety in the subjects. We were interested in the extent to which the heart rate response would be similar to a BIP in this case. Once again the time of the button presses were used as pseudo-BIPs in the analysis. The curve is labelled 'anxiety control' in Figure 1. The result is a curve that has a similar shape to the heart rate BIP curve, but seems to be shifted about 4 seconds to the right. Clearly there is a heart rate peak but the slope increases at the onset of the button press rather than before the button press.

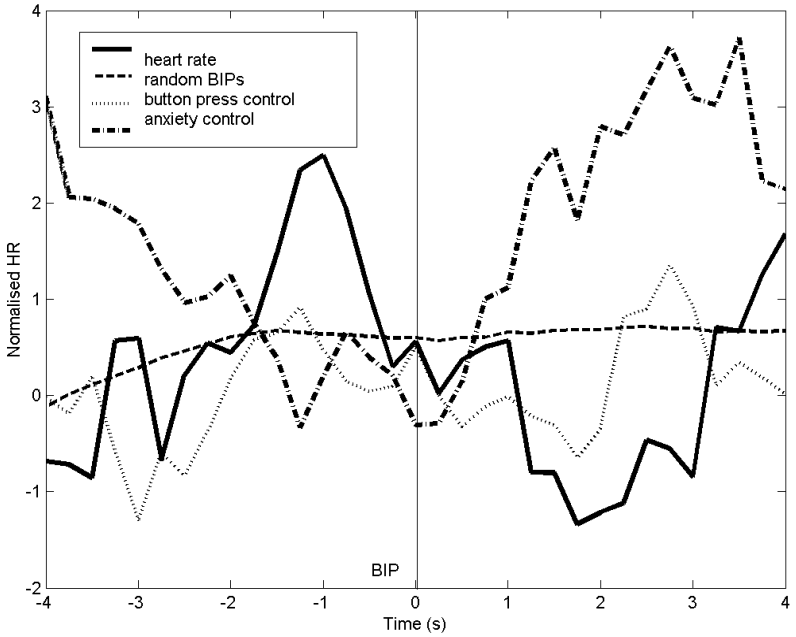

Figure 1: Mean Wave Form for Heart Rate in the Neighbourhood of a BIP

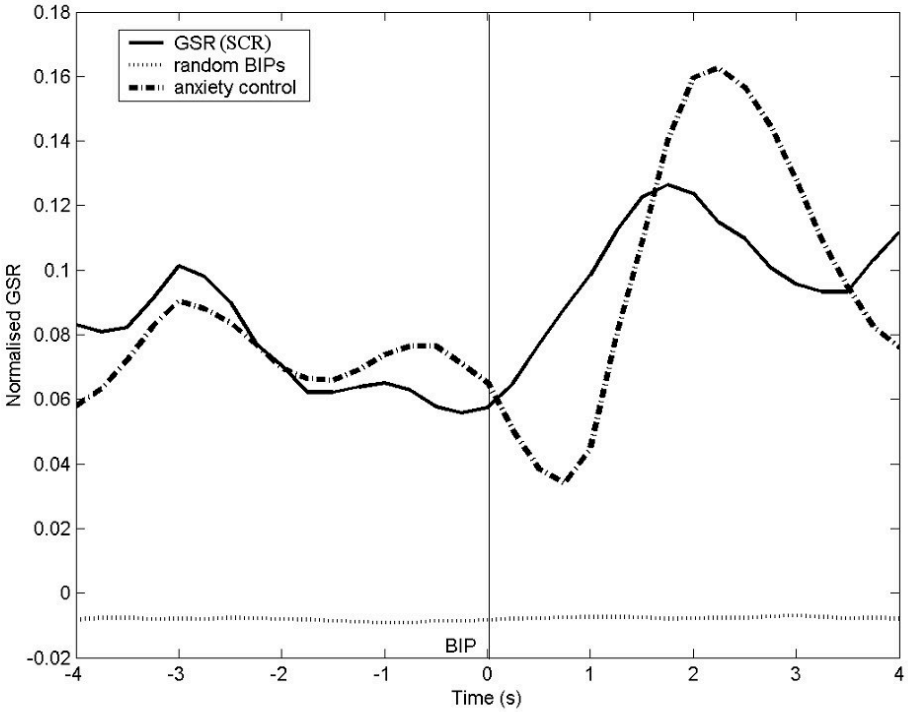

Figure 2: Mean Wave Form for SCR in the Neighbourhood of a BIP

A similar analysis was carried out for SCR, which was measured only for a subsample of 20 subjects during the original experiment. Again the SCR results were de-trended and these normalised results were averaged. The result is shown in Figure 2. Here we see that mean SCR reaches a peak approximately 1.8s after the BIP (the solid line labelled '*GSR (SCR)*'). If we compare with the 'random BIPs' curve (the dotted line), we see that the pattern around the true BIPs is quite different from what is obtained from randomly placing stimuli through the time series (again 500 iterations were used). The 10 people recruited for the anxiety inducing control also had their SCR measured. The result is shown with the dash-dot line labelled 'anxiety control'. In this case we see a similar pattern to the BIP waveform, with a rise in SCR reaching a peak after about 2.25 seconds. There was no control group for SCR where just the button pressing activity was measured.

4. Conclusions

The evidence is not inconsistent with the hypothesis that BIPs are associated with observable physiological responses. These responses are probably not associated with the simple act of pressing the button to signal a BIP – as evidenced by the heart rate data. The SCR response is especially interesting because this indicates a similar type of arousal as caused by an induced anxiety in the control group. This is not inconsistent with our hypothesis that the experience of a BIP is likely to be a stress-inducing event (since loss of presence in everyday life is something rarely experienced).

There are several criticisms that we would like to make of our results. First, we cannot rule out the possibility that it is the pure anxiety of pressing the wand button at the right moment that itself is responsible for the physiological signature also in the case of BIPs. In other words it might not be signalling a switch in presence but purely the stress caused by having to press the button at the right time. Second, the heart rate data was based on blood-volume pulse samples. This was somewhat inaccurate, leading to occasional unrealistic heart rate estimates. Heart rates were therefore truncated to values of up to 120 bpm. In future we will be measuring heart rates with EKG rather than blood volume pulse. Finally, using this methodology we can never rule out the possibility that it is the act of signalling the BIP itself that is responsible for the spikes in physiological recordings. In our ongoing work we are using a different methodology that eliminates this and other problems.

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