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# Cognition and the temporal arts: Investigating audience response to dance using PDAs that record continuous data during live performance

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**Abstract**

If artists and art explore organization of the brain [Zeki, S., Lamb, M., 1994. The neurology of kinetic art. Brain 117, 607–636], then investigation of response to artistic performance holds promise as a window to perceptual and cognitive processes. A new instrument for recording real-time audience response – the portable Audience Response Facility (pARF) – is described. Twenty, hand-held, Personal Digital Assistants (PDAs) collect responses on customizable skin interfaces. The pARF server transmits the customizable options, synchronizes devices and collects data for export. We report two studies using the pARF that demonstrate respondent agreement of perceived emotion during particular sections of two dance works. Greater agreement was evident in continuous ratings of arousal than valence; arousal appears to be related to surface features of the dance work. Future applications of the pARF to studies of multi-modal perception and cognition are discussed.


*Keywords:* Continuous response measurement; Portable response instrument; Live performance; Emotional response; WiFi; IEEE Wireless LAN 802.11; Pocket PC; HP iPAQ

The performing arts – music, dance, theatre – provide a rich and relatively untapped domain for the investigation of psychological processes. Beholding a work of art involves attention, multimodal perception, memory and may elicit emotional responses (e.g., Camurri et al., 2003; Hanna, 1979; Sloboda, 1991). These temporally unfolding arts challenge those researchers interested in rapid and hidden processes to develop methods that: (i) are portable so as to be used in situ in a gallery, theatre or auditorium; (ii) are flexible, modifiable and non-intrusive; and (iii) capture responses as a live, multimodal performance unfolds in time. In this spirit, and in the context of recording continuous psychological responses from audience members, we have developed the portable Audience Response Facility or pARF (as in singer Edith Piaf). The pARF is a set of hand-held computers commonly known as personal data assistants (PDAs) that have been programmed to record and synchronize one- or two-dimensional ratings from up to 20 audience members as a live or recorded dance, music, theatre, multimedia performance or installation takes place.

Audience response in the present study is investigated in the context of performances of two dance works. In contemporary dance, the major medium is movement, deliberately and systematically cultivated for its own sake with the aim of achieving a work of art. Dance is relevant to psychology because it is a form of behaviour that, since antiquity, has been found in all cultures. It is a sophisticated means of expression (Hanna, 1979), and communication through dance is tantalizingly non-verbal,

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multi-modal, and multi-dimensional (McCarthy et al. 2006; Stevens et al., 2003). Within the dance studio, dancers and choreographers often communicate with each other by showing complex phrases of movement rather than by using words (Grove, 2005). In performance, ideas are expressed through movement and stillness, rhythms, and sculpted patterns in space and time (Glass, 2006; Hanna, 2001; Stevens et al., 2003). The creation and performance of dance involves a complex interaction between procedural and declarative memory (Stevens and McKechnie, 2005a).

## 1. Why measure audience response?

During the past 20 years, there has been intense research interest in the perception and cognition of music (e.g., Deutsch, 1999; Dowling and Harwood, 1986; Sloboda, 2005) and, more recently, dance (Brown et al., 2006; Calvo-Merino et al., 2005; McCarthy et al., 2006). Most often, perception, cognition and emotional responses have been recorded in a laboratory setting, with individual participants responding to pre-recorded music or dance stimuli. While this approach ensures rigor, it is achieved at the expense of capturing reactions to live performance of a multimodal (i.e., auditory, visual, kinesthetic) artform in the presence of other perceivers or audience members. Now, hand-held computers and wireless technology enable the recording of audience reactions to live performance in naturalistic, group settings. Such techniques provide the means to investigate the validity of results from earlier laboratory-based, unimodal studies where participants were tested individually.

A fundamental question regarding audience response concerns the extent to which, for a single performance, audience reactions diverge and converge. As in other perceptual domains, it is of psychological relevance to quantify agreement among respondents, identify the underlying mechanisms, and eventually investigate factors that influence agreement such as observer expertise and stimulus familiarity. With the evolution of practice-led research and research-led practice among performing artists (see Barrett and Bolt, 2007; Haseman, 2006; McKechnie and Stevens, 2009) it is also beneficial for artists to have the means available, when desired, to compare artistic intention and audience reception (e.g., Weale, 2006). Organizations that support the arts recognize the connection between methods that shed light on audience understanding and interpretation and new ways to develop audiences through workshops and education programs (e.g., James, 2000; Walker-Kuhne, 2005). Such programs can be tailored to the needs of new and more expert audiences as revealed by quantitative audience response data and analyses.

A final reason for measuring audience reactions is motivated by long-standing discussions of art, perception, and aesthetics. According to Zeki and Lamb (1994), artists in their explorations are unknowingly exploring the organization of the visual brain. In a similar vein, Ramachandran and Hirstein (1999) search for artistic universals and propose eight laws of artistic experience – a set of heuristics that artists are said to consciously or unconsciously use to optimally titillate the visual areas of the brain. Such assumptions about production and perception of art, especially those art forms that unfold in time, require methods that can accommodate both change in the stimulus and cumulative responses through time.

Continuous data collection tools (e.g., Ariely, 1998; McAdams et al., 2004; Madsen and Frederickson, 1993; Schubert, 1999; West and Biocca, 1996) may supplement more qualitative questionnaire or survey methods that simply summarize responses and ratings across an entire work. While such pen and paper survey and open-ended methods are easy to administer and yield much information, they are retrospective, rely on observer memory, and do not allow an understanding of moment to moment fluctuations in response that may occur as a performance unfolds. Continuous data can be compared directly with other time series such as an accompanying musical score or soundscape, structural analysis of an artwork, or motion data captured from a dancer (e.g., Stevens et al., 2008, 2009a). In the present paper, we outline a method for measurement of continuous response and report two settings where audience data are compared with an analysis of the dance work and, in the latter study, used to identify periods of audience agreement.

## 2. Continuous response measurement and the portable Audience Response Facility (pARF)

To capture reactions from audience members as a performance unfolds and to avoid the unwieldiness of a desktop PC-based system such as EMuJoy (Nagel et al., 2007), the PDA-based pARF has been designed to record one- or two-dimensional data sampled twice per second. PDAs were selected as the data collection device because they are small, programmable, readily available and affordable. We had considered a laptop computer being located under each audience member's seat but opted for a system that was more portable, less conspicuous, and where the data could be collated and time-stamped for synchronization purposes. The participant uses a hand held pen-like stylus as input to the PDA but other devices can be connected in an effort to match the input medium to the variable being measured (e.g., a device with some graded, haptic resistance to measure tension, or the use of a joystick where the return to a central reference position is useful).

One-dimensional continuous response measures that can be recorded individually using the pARF include engagement, tension (Krumhansl, 1996; Vines et al., 2006), aesthetic quality (e.g., Madsen, 1998), pleasingness and complexity (Stevens and Latimer, 1991). In the measurement of emotional response, Nagel et al. (2007) make a compelling case for the two-dimensional arousal-valence descriptions of both felt and perceived emotion and this has been implemented in their EMuJoy system. The popular two-dimensional description, dating back to Wundt (1874/1905), is the basis of a dimensional model of emotion discussed by many researchers (e.g., Cowie et al., 2000; Russell 1980, 2003; Schubert, 2001). The 2D emotion space ('2DES' Schubert, 1999), for example, represents emotion labels in a two-dimensional, four-quadrant space constructed from the dimensions arousal/activity (low to high) and valence (negative to positive). A two-dimensional representation of emotion space based on Cowie et al. (2000) is shown in Fig. 1. Emotion is defined as a "relatively brief episode of synchronized response of all or most organismic subsystems in response to the evaluation of an external or internal event as being of major significance" (Scherer, 2003, p. 243).

### 2.1. Technical description of the pARF

#### 2.1.1. System architecture

The system comprises four modules: (i) database server; (ii) web questionnaire server; (iii) control/server application; and (iv) client application. Client devices are connected to the database server, web server, and server application by 802.11 WiFi network. The system may be used to collect either post-performance questionnaire or continuous response data. Fig. 2 illustrates the system diagram. The database server, using Microsoft's SQL Server Desktop Engine, stores information defining questionnaires and experiments, as well as user response data such as continuous ratings and questionnaire responses. The web server generates web forms using questionnaire items defined in the database and stores user responses to these items in the database. This component was developed as an ASP.NET site, using C# (V1.1), to be run on a web server running Microsoft Internet Information Server (IIS).

The control server application controls the timing of post-performance questionnaires, synchronizes collection of continuous response data, and manages the questionnaires and experiments defined in the database. The application also includes facilities for the visualisation of continuous response data in real time via the User Datagram Protocol (UDP) and access to questionnaire responses as soon as they are submitted to the database. Data from each client device may also be downloaded using the Transmission Control Protocol (TCP). This module was developed as a windows application, targeting the .NET platform, using C# (V1.1). Fig. 3 shows the architecture of the control server application.

A client application is used on the client PDA devices to record continuous responses and present questionnaire web forms (generated and deployed by the web server). This was developed using C# (V1.1), for the .NET Compact Framework platform, and uses Socket communication to receive commands from the control server application over the wireless network connection. The continuous response display of the client application is illustrated in Fig. 4. Technical specifications for collecting post-performance questionnaire data and synchronizing continuous response data are detailed in Appendix A.

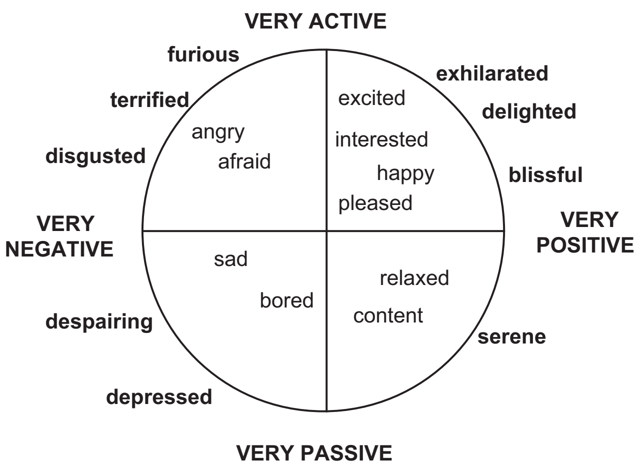


Fig. 1. Interface for *FeelTrace* software for continuous measurement of 2D emotional response (Cowie et al., 2000).

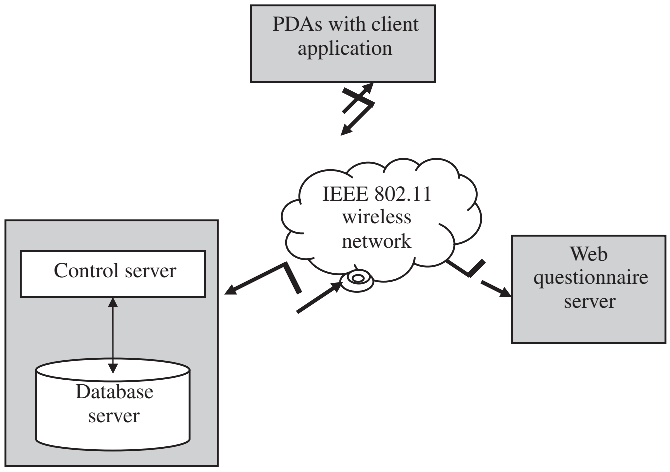


Fig. 2. pARF system diagram.

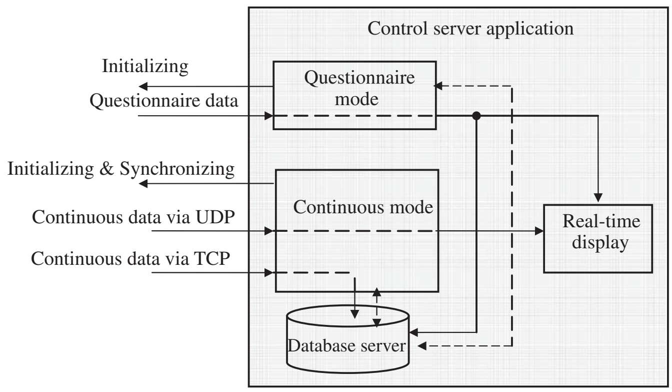


Fig. 3. Architecture of the pARF control server application/database server.

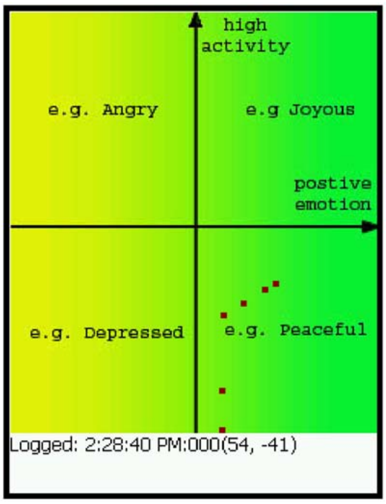


Fig. 4. An example of a continuous response on the pARF client device. The dots show the present position of the stylus and a decaying trace of prior locations of the stylus. The trace consists of up to 10 samples and remains on the display even if the stylus is removed.

## 3. Study 1 – recording perceived emotion during live performance of "Fine Line Terrain"

The aim of Study 1 was to collect responses from a small number of audience members during live performance of a dance work to investigate audience perception of structures and expression in dance. Time-series data would then be compared directly with the choreographer's description of the work.

### 3.1. Method

#### 3.1.1. Participants

Three adult participants took part in the study and were members of an audience of some 200 people in The Studio at the Sydney Opera House. The participants were recruited prior to the performance and none had expertise in contemporary dance.

#### 3.1.2. Stimuli

Continuous responses were measured throughout the 60-minute contemporary dance piece *Fine Line Terrain* choreographed by Sue Healey. *Fine Line Terrain* is an emotionally charged dance, set within a world of fragile spaces and fine lines. The five dancers navigate through a design of many white lines dissecting black, infinite space. This dynamic architecture is the terrain where relationships connect, entangle and tear apart. The music, produced by Darrin Verhagen, is eclectic, ranging from abstract electronica to intense rhythmic grooves with hints of trance and Middle Eastern vocals woven into the mix.

#### 3.1.3. Equipment

The audience responses were collected on the pARF. The system of PDAs was configured to record two dimensions of expressed emotion as the performance took place. The configuration is based on the continuous emotional response measurement system described by Schubert (1999). Participants rate the performance by using the pen-like stylus to draw on a two-dimensional space, 200 by 200 pixels, and are sampled at a rate of 2 Hz (Fig. 4). The *x*-axis represented the valence (positive-negative) scale of emotion and the *y*-axis the arousal (aroused-sleepy) scale of emotion (Russell et al., 1989). The axes crossed at the mid-point (100, 100). If the stylus is removed from the PDA the rating stays where the last samples was collected until the stylus is returned to the display. The trace of the stylus location remains on the display for 10 samples even if the stylus is removed (see Fig. 4).

The control application/web server/database server can be separated and deployed in two different machines to avoid heavy network traffic. However, we used one laptop to perform all tasks and subsequently selected a relatively small number of participants, although the system can now comfortably handle 20 users per server. The server (Acer TravelMate 8000) was equipped with a 1.8 GHz Pentium® M processor with 1GB of memory, running Microsoft Windows Server 2003. The server application (including control application, web application and database application) was installed on the server. The client device was a HP iPAQ Pocket PC h5500, with Intel PXA255 processor and 128 MB memory, running on Microsoft Pocket PC version 4.20.0. A digital camera (Sony HandyCam HCR-30E) was used to record the server clock as well as the live performance for documentation purposes.

#### 3.1.4. Procedure

The three participants, who were known to the researchers, were trained in the use of the pARF during a 15 min period prior to the performance. They were asked to rate the emotion that they judged was being expressed by the entire artwork, that is, by the dancers, the soundscape, and the choreographer. With 5–10 minutes of practice, users become accustomed to moving the stylus around the PDA screen while watching the performance and with little or no need to look at the PDA screen. As the house lights went down, participants were instructed to start at the neutral position.

### 3.2. Results and discussion

The median response of the three participants was calculated. Brief notes from the choreographer indicating some of the key moments and intended structural changes in the piece were mapped onto the continuous response data. This mapping is shown in Figs. 5 and 6. Digital video footage of the performance was used for reference.

There were clear peaks in median arousal response in the piece, with sustained arousal from the '2 Duets in rectangle of light' at the 38th minute, until the peak at the 43rd minute with 'Nalina string solo in right corner with quartet

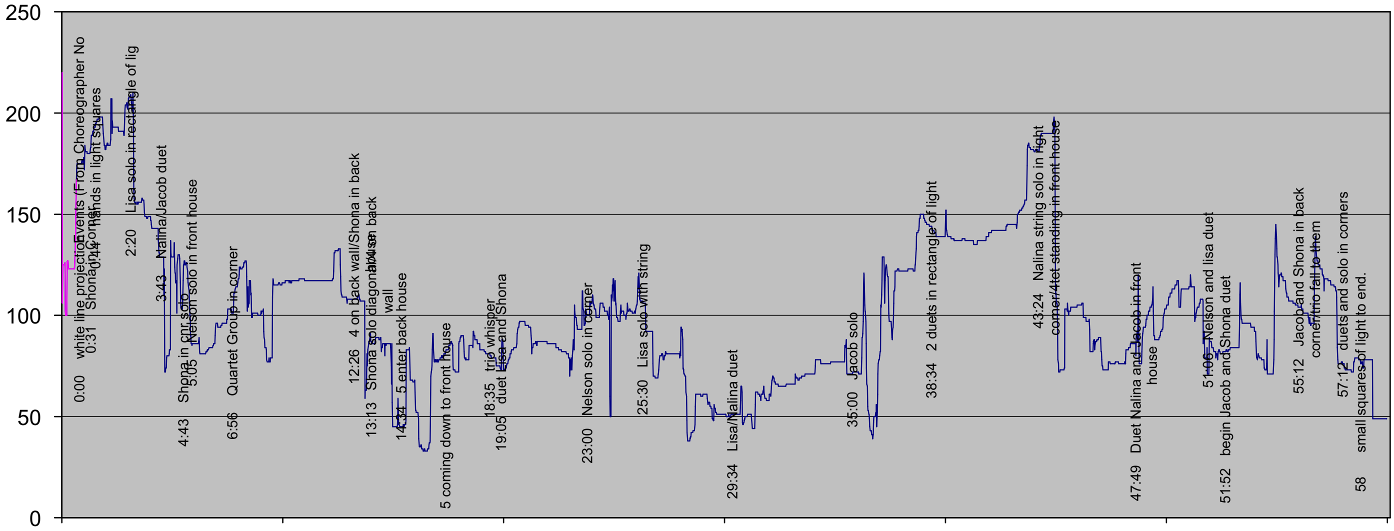


Fig. 5. Study 1. *Fine Line Terrain:* Median arousal response time series with events superimposed; the values along the horizontal axis refer to time.

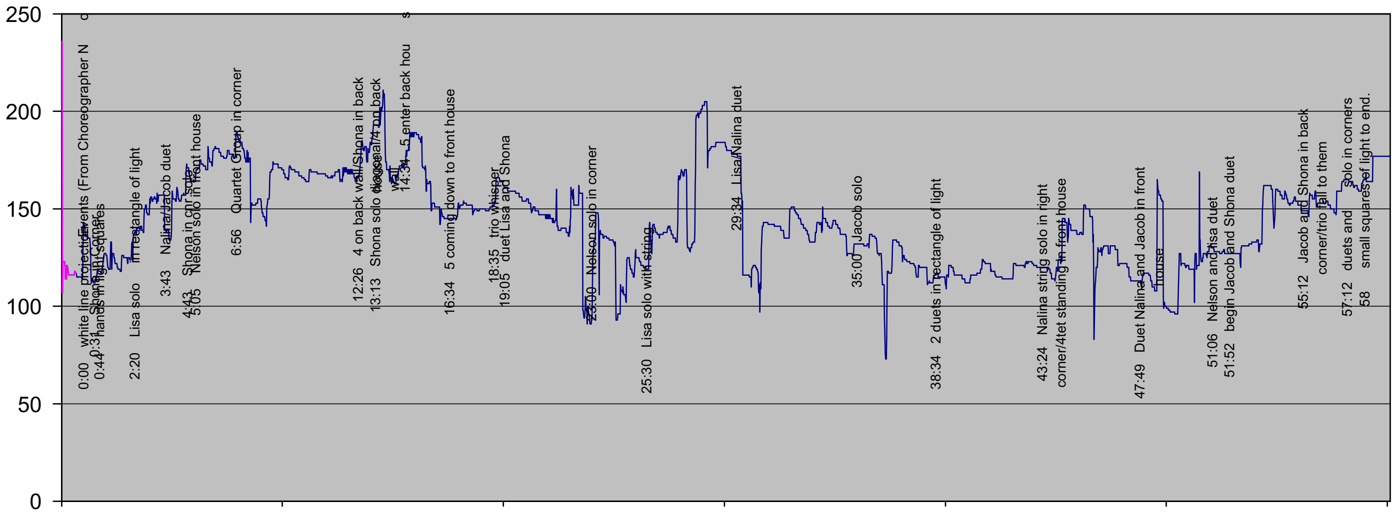


Fig. 6. Study 1. *Fine Line Terrain:* Median valence response time series with events superimposed; the values along the horizontal axis refer to time.

standing in front house'. Low arousal occurred for a short time after the 14th minute (Quintet enters back house) and from the 26th to 36th minute, which featured the 'Lisa and Nalina duet'. Valence peaked at the 13th minute with 'Shona solo and quartet on back', after Lisa's solo (28th minute). There were clear indications of a connection between audience emotional response and structural/expressive aspects of the performance based on visual inspection of the data.

Standard errors (SE) were collected at each sampling point across the three participant scores. For valence the mean SE was 17 ($SD = 8.9$) and for arousal 22 ($SD = 12$), which is less than or close to 10% of the total scale in each case, suggesting reasonable agreement between responses and providing positive indication of the reliability of this method of collecting data, comparable with Schubert (1999). Further directions that this method may take in the analysis and understanding of the dance process and its perception are being considered, some are based on the time-series analysis techniques described by Schubert and Dunsmuir (1999).

### 3.2.1. Specific 'cases'

Two particular sections of the performance, or 'segments of interest' (Vines et al., 2006) were investigated in greater detail. Each segment included a section where a strong emotional response was detected by both choreographer and audience. In one section, the audience response seemed to move in the opposite direction to that planned by the choreographer. In the other section, response and intention were congruent.

An incongruency between choreographer intention and audience response occurs over the 2nd to 5th minute of the piece. At 2:20 and 4:44 there were large dips in arousal within a general downward pattern until around the 4th minute (see Fig. 5). However, at these points the intention was part of an overall build up in arousal, reflected in the music and the use of space. These opening scenes were meant to highlight distinct spaces as the various characters were introduced. There is meant to be an overall development of tension, which one may expect to correspond with a region of high arousal. Instead, valence is increasing and arousal is decreasing. The drop in arousal is most surprising. However, a closer investigation of the three responses can explain the dissonance. Table 1 highlights the large changes in response and the corresponding change in the median response. At 4:36 there is a sudden drop in the arousal median (which can also be seen in Fig. 5). But only participant P2 is making this change. The response from P1 is relatively stable, and for P3 drops from 143 to 110 and then recovers back towards the 120 range. All three participants disagree with the direction of valence expressed in this vicinity. P2 is falling from 157 to 110 and P3 is rising from 159 to 183. Interestingly this is occurring at around the same time, while P1's response is unchanged. This suggests a problem of reliability of responses at this point. Possibilities are that there is an ambiguity in the message transmitted by the performance, or two of the respondents were making an erroneous response, or they were interpreting the arousal dimension differently. The problem could be addressed by recruiting more participants and exploring different models of emotion (e.g., Ilie and Thompson, 2006), but the intention of the current study was to examine the feasibility of the instrument with a small number of participants and, as reflected in the next section, there were numerous periods of good agreement even with a small number of participants.

As anticipated, there were numerous examples where intention and response were congruent (approximately 80%). An example of congruency between intention and audience response occurs at 28:18. At around this point we see the making of a cat's cradle from pieces of string (not labeled in Figs. 5 and 6.). It is intended as a playful, congenial section. Dancer Shona's face is quite playful and relaxed in a quiet way. This is reflected in the responses because the arousal pattern is descending and the valence is ascending (indicating serene, playful and relaxed emotions). The emotional response patterns tended to fluctuate more-or-less together in this section. Individual responses are shown in Table 2, and demonstrate agreement in direction, but also that the time at which changes in response occur can vary, sometimes by up to 5 s. For example, P2 starts to increase arousal rating at 28:39 (with a score of 46), but P3 commences a rise in arousal 4 s later (from 95 to 112). P1 produces a much slower, more gradual ascent in arousal over this time span. So, while there are individual differences in response, such as response lag and absolute position on the emotion space (P1 tends to stay low, P3 is quite high), some overall trends can be observed, even with such a small sample.

Another sample of 44 non-expert dance audience members completed a pen and paper version of the Audience Response Tool questionnaire (Glass, 2005, 2006) at the conclusion of this performance of *Fine Line Terrain.* Mean arousal rating was 29 ($SD = 5.00$) where the maximum possible score was 35, indicating high, positive arousal. This is consistent with the continuous arousal responses, which tended to be higher values for much of the piece, particularly as the dance unfolded (see Fig. 5). The relationship between continuous response

Table 1
Demonstrating potentially unreliable responses.

| Time elapsed (Min:sec) | Valence | | | | Arousal | | | |
|---|---|---|---|---|---|---|---|---|
| | P1 | P2 | P3 | Median | P1 | P2 | P3 | Median |
| 4:27 | 139 | 157 | 159 | 157 | 74 | 129 | 143 | 129 |
| 4:28 | 139 | 157 | 159 | 157 | 73 | 129 | 143 | 129 |
| 4:29 | 139 | 157 | 159 | 157 | 73 | 129 | 143 | 129 |
| 4:30 | 139 | 157 | 159 | 157 | 73 | 129 | 143 | 129 |
| 4:31 | 139 | 157 | 159 | 157 | 73 | 129 | 143 | 129 |
| 4:32 | 139 | 157 | 159 | 157 | 72 | 129 | 143 | 129 |
| 4:33 | 139 | 157 | 159 | 157 | 72 | 129 | 143 | 129 |
| 4:34 | 139 | 157 | 159 | 157 | 72 | 129 | 143 | 129 |
| 4:35 | 139 | 157 | 159 | 157 | 72 | 129 | 143 | 129 |
| 4:36 | 139 | 157 | **159** | 157 | 72 | 129 | 143 | **129** |
| 4:37 | 139 | **157** | 163 | 157 | 72 | **129** | 110 | **110** |
| 4:38 | 139 | **157** | 172 | 157 | 72 | **129** | 123 | **123** |
| 4:39 | 139 | **110** | 181 | 139 | 72 | **54** | 127 | **72** |
| 4:40 | 139 | **110** | 182 | 139 | 72 | **54** | 127 | **72** |
| 4:41 | 139 | 110 | **183** | 139 | 72 | 54 | 125 | 72 |
| 4:42 | 139 | 110 | 183 | 139 | 74 | 54 | 125 | 74 |
| 4:43 | 139 | 110 | 183 | 139 | 74 | 54 | 125 | 74 |
| (Shona in corner – solo) | | | | | | | | |
| 4:44 | 138 | 110 | 183 | 138 | 79 | 54 | 125 | 79 |
| 4:45 | 139 | 110 | 183 | 139 | 80 | 54 | 123 | 80 |
| 4:46 | 139 | 110 | 183 | 139 | 80 | 54 | 123 | 80 |
| 4:47 | 139 | 110 | 183 | 139 | 80 | 54 | 123 | 80 |
| 4:48 | 139 | 110 | 180 | 139 | 80 | 54 | 131 | 80 |

P refers to participant number.

Table 2
Demonstrating agreement in change in response over time, with some lag in responses.

| Time elapsed (Min:sec) | Valence | | | | Arousal | | | |
|---|---|---|---|---|---|---|---|---|
| | P1 | P2 | P3 | Median | P1 | P2 | P3 | Median |
| 28:36 | 114 | 133 | 170 | 133 | 15 | 43 | 96 | 43 |
| 28:37 | 114 | 133 | 170 | 133 | 15 | 43 | 96 | 43 |
| 28:38 | 114 | 133 | 170 | 133 | 15 | 43 | 96 | 43 |
| 28:39 | 115 | **138** | 169 | **138** | 14 | **46** | 94 | **46** |
| 28:40 | 115 | **162** | 169 | **162** | 14 | **55** | 94 | **55** |
| 28:41 | 115 | **190** | 169 | 169 | 15 | **61** | 94 | **61** |
| 28:42 | 115 | 196 | **198** | 196 | 15 | 61 | 97 | 61 |
| 28:43 | 113 | 198 | **201** | 198 | 15 | 61 | **95** | 61 |
| 28:44 | **111** | 198 | 205 | 198 | 16 | 61 | **101** | 61 |
| 28:45 | **113** | 198 | 208 | 198 | 16 | 61 | **106** | 61 |
| 28:46 | **121** | 199 | 210 | 199 | 17 | 61 | **112** | 61 |
| 28:47 | 121 | 199 | 210 | 199 | 17 | 61 | 112 | 61 |
| 28:48 | 120 | 197 | 210 | 197 | 19 | 61 | 112 | 61 |
| 28:49 | 120 | 197 | 210 | 197 | 19 | 61 | 112 | 61 |

P refers to participant number. See also Figs. 5 and 6.

and post-performance response has been considered elsewhere (Rozin et al., 2004).

## 4. Study 2 – recording perceived emotion during live performance of "Silent Heartbeat"

The aim of Study 2 was to: (i) test the pARF with a larger sample in a live performance environment; (ii) investigate whether participants make consistent aesthetic responses specifically identifying regions where there is high agreement; and (iii) generate hypotheses for future continuous response measurement of dance performance including features that may predict response and point to the contribution of music to affective response to dance.

Consistent with Schachter and Singer's (1962) theory of arousal primacy in emotion, we propose that arousal response will be more predictable and a function of fairly low level causal events, such as sudden changes in action, and changes in music. Valence, however, may be less predictable, although more connected with cultural norms and conditioning (Meyer, 1956). These kinds of results have been supported by continuous response measurement in music (e.g. Schubert, 2004), but have not been tested in a live, dance performance environment. For example, Schubert found that simple musical features such as tempo and loudness were good predictors of arousal response, whereas valence could not be so easily predicted by such features. Culturally learnt relationships in harmony and key (major–minor; happy–sad) are more likely to explain such effects.

### 4.1. Method

#### 4.1.1. Participants

Of the 20 PDA responses, one PDA had technical problems due to a flat battery and was eliminated from further analysis. The sample consisted of 19 participants (7 males; 12 females) ranging in age from 11 years to 65 years ($M = 37.7$ years, $SD = 18.1$). All participants were regular audience members of Quantum Leap Youth Choreographic Ensemble performances and all had seen the work at least once ($M = 1.53$ times, $SD = 0.77$). They were accustomed to attending live dance performances and reported that they enjoyed watching dance "a little" (5.3%), "moderately" (10.5%), "a lot" (36.8%), or "a great deal" (47.4%). Nine of the participants reported having had some training in dance ($M = 8.27$ years, $SD = 6.96$, range 0–20 years) and nine having had some training in music ($M = 7.44$ years, $SD = 6.80$, range 0–21 years).

#### 4.1.2. Stimuli

A full-length live dance work performed by the Quantum Leap Youth Choreographic Ensemble, "Landscape: time, place, identity", was performed at the Playhouse, Canberra, Australia on August 5, 2006. It consisted of five sections in the first act each created by different choreographers and composers, unified by the theme of "The Physical Landscape". "Earth: Silent Heartbeat" was the fourth section in Act 1. In the present report, pARF responses to one section are presented—Earth: Silent Heartbeat choreographed by Albert David, with music composed by Adam Ventoura. The programme notes for "Silent Heartbeat" read: "Towards the red heart, the dead heart and the silent heart, the volatile earth and its extremities, there are secret codes to decipher in the decaying trees, the drifting stands and dried up waterholes. Bleached skulls and bones betray their final struggle. A waterless world, trees bent, the ground sallow and traces of life and history covered under waves of sand. It is a place of birth and awakening, a place of death and hostility, a ghostly land that invites to be read and understood. Inspired by three artworks: Ramingining Artists – *The Aboriginal Memorial* 1987–88; Judy Watson – *Pool* 1998 and *Museum Piece* 1998." The analysis of audience response is made from the point where Alexa is born out of the ground, where the female character is lit and at centre stage and the young male dancers are on the floor and ends at the start of the intermission (end of Act 1), thus including the fifth section, 'Fire', choreographed by Ruth Osborne and the ensemble, music composed by Luke Tierney.

We obtained choreographic notes about the piece from Mark Gordon who commissioned the work as Artistic Director of the Australian Choreographic Centre. Gordon's notes indicated events and interpretations that he made of the piece as it unfolded in time. Having intimate knowledge of the work from early creative stages to the final piece, we were particularly interested in his interpretation of the emotion that the dance was expressing. He was free to present these data in any way he liked, and he chose to nominate emotion word adjectives that appeared to be represented at different times in the piece. We then mapped these emotions onto the continuous emotional ratings obtained from the participants. The region of analysis under investigation here is 14 min.

#### 4.1.3. Equipment

Equipment was similar to that used in Study 1 with 20 PDAs as active clients of the ARF server. One of the PDAs did not return data correctly and was eliminated form the analysis.

#### 4.1.4. Procedure

During an information and training session held one hour prior to the performance in the foyer of the theatre, participants were advised that they would be asked to rate the emotion that the dance was trying to convey. Participants read the following instructions:

> This experiment has been designed to capture your rating of the emotion expressed in a performance of contemporary dance. To do this, we use a hand-held PC that records movement of the stylus that you hold as the dance is performed. You are going to rate aspects of the

> emotion expressed by the performance in two ways. Up/down stylus movements will indicate the amount of 'activity' (e.g. excited/sleepy respectively) you think the performance is portraying. Left/right movements indicate the 'valence' (e.g. sad/happy respectively) expressed. Use the sample words to remind you of what each direction means.
>
> Remember that it is the direction of the stylus movement that is of interest. So, once you are familiar with 'up is active', 'right is positive emotion' and so on, you do not need to spend much time looking at this display. Just place the stylus on the display and move it in the direction of the emotion expressed by the performance. For example, if the performance was expressing anger then started to express calmness and serenity, you would drag the stylus from the top left (angry) area down to the bottom right area.
>
> If you make a mistake, don't worry. Just keep going. Also remember that the stylus position is an approximate, crude indication. Do not worry too much about precise positions. It usually takes a minute or two to figure out how to use the stylus and display. This will be taken into account. Please keep the stylus on the display at all times.

Participants then made their way into one row of the dress circle area of the theatre, were each given a PDA, and asked to get a feel for moving the stylus around the 2DES (Fig. 4). After the training session and before the dance programme started, participants read the program notes and completed a short questionnaire about their dance and music experience, attendance patterns, enjoyment of the arts, their age and sex.

Participants used the pARF for the duration of the programme, taking a break at intermission. We report here only the last 14 min of responses before the interval, which encapsulates responses to "Silent Heartbeat".

### 4.2. *Method of analysis*

The 19 participant responses for valence and for arousal were processed to produce three new time series (each) that would be used for further analysis: Mean, SD and Reliability (Agreement).

The core of the current analysis is based on examining time series plots and comparing them with the action of the performance, including a report of the choreographic events listed in a time sheet, and an analysis of the accompanying music. The emotions from the choreographic events were extracted and, along with musical event information, were superimposed on the time-series charts. In addition, the agreement level is indicated by darkened dots over the portions of the mean response time series that had better agreement (see Fig. 7a for Valence and b for Arousal).

The mean series therefore represents the central tendency or 'typical response' based on the 19 responses at each sample point. SD is the standard deviation, which is an indicator of the spread of the scores at each sample. It should be noted that both these measure (means and standard deviation) are rough guides of central tendency and spread of scores respectively because time series data of the nature under investigation might not necessarily conform with assumptions underlying the calculation of the mean and standard deviation required for parametric inferential statistics (Ostrom, 1990). The measures were chosen because their calculation is easily available on statistics and spreadsheet applications, and are generally understood concepts.

For analysis of the time-series responses we adopted the approach used by Schubert (2007). When the standard deviation is low, we assume that the responses are in greater agreement, and so the mean response is more reliable. However, how do we know the point at which the standard deviation is small enough to be a reflection of a reliable response? Since we do not know what kind of deviation score to expect *a priori* we calculate the second order deviation scores of the region under investigation. This means that the standard deviation reading at each sample is collected and has its standard deviation calculated, 'SD2'. We then assert that when the SD of the continuous series falls below of $0.5 \times \mathrm{SD2}$ above the mean SD, the mean response at that point in time is assumed to be reliable. The selection of $0.5 \times \mathrm{SD2}$ is arbitrary (see Schubert, 2007).

These 'significant' values are highlighted in time series plots to provide an indication of where there was a relatively good agreement in response.

### 4.3. *Results*

Choreographic and musical events were listed on a time sheet and then mapped onto time series plots for arousal and for valence.

In Fig. 7, mean valence and arousal recorded during "Silent Heartbeat" are shown. The thin line shows mean valence (Fig. 7a) and arousal (Fig. 7b), averaged across a sample of 19 audience members. Mean arousal tends to increase over the course of the opening of the piece and relates to the surface features, intensity and tempo, of the dance and music. The thick, undulating faint line shows the standard deviation or variability of response, with the SD2 threshold line (mean + $0.5 \times \mathrm{SD2}$) shown as a thicker, faint horizontal line. Sudden decreases in mean arousal ratings follow dramatic changes or reduction in the soundscape and dancer activity. The dark spotted regions of the mean response series of Fig. 7 indicate areas of agreement among observers because in those sections the deviation is relatively small, suggesting that the mean is reliable. These regions are treated here as regions of good audience agreement. The text overlaid on the figure refers to an abbreviated structural description of emotion and sounds of the dance.

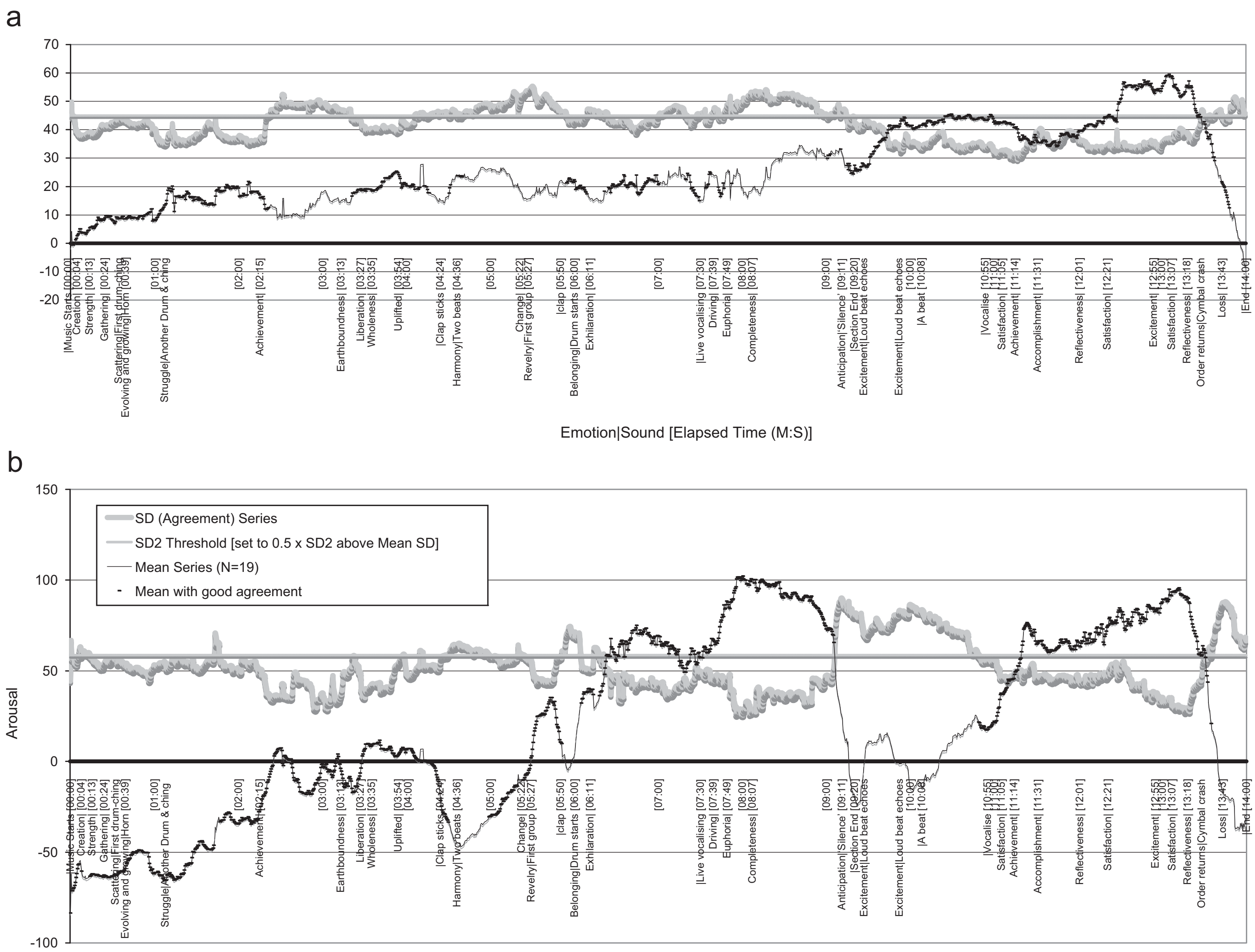


Fig. 7. Study 2. *Silent Heartbeat*: (a) Valence time-series showing mean response and standard deviation (SD) or variability; (b) Arousal time-series showing mean response and SD. Darkened dots show the portions of the mean response time-series that had better agreement. Emotion expressed and musical event information have been superimposed. Note that the scale of (a) and (b) change.

In this case, valence response starts at zero (the midpoint of the valence scale) and shows a general rising (more positive valence) trend until just before the end of the piece which is marked by 'reflectiveness' and 'loss' (Fig. 7a). It is interesting to note that there are several 'dips' in valence sections where the darker dots are absent, meaning that there is less agreement in valence ratings in those regions. There are two large 'surges' of positive valence that also have high agreement, at around the 10th minute (excitement after the 'Silence') and again at the 'Satisfaction' and 'Excitement' markers following 'Reflectiveness' at about the 12th minute. Regions of greatest agreement in valence response occur in the first two minutes, and the 9th to 13th minute, with some other shorter sections of good agreement, as shown in the darkened sections of Fig. 7a.

Arousal responses commence at the low, sleepy, end of the scale, reflected in the sporadic use of sound, and substantially noticeable silences. We also notice downward 'dips' in arousal within the overall rise, for example, around the 'struggle' section and the 'achievement' section in the region of the third minute of the work (Fig. 7b). The pattern of arousal shift follows the nature of the musical material, and also the amount of activity on the stage. For example, there are some quite acrobatic sections around the 7th minute, and around the 12th minute. And notice the sudden drop in arousal at the silence indicated at the 9th minute. There are three general regions of good agreement in the arousal response, from the 2nd to the 4th minute, 6th to the 9th minute and the 11th to just after the 13th minute (where the mean arousal line is darker). It is interesting to note, too, that the range of the scale used by the participants appears to be much greater for arousal than for valence. This may be a reflection of the level of variation expressed by the dance, or a tendency by participants to be more reserved in their valence judgments than their arousal judgments. Given the range and depth of emotions traversed according to the choreographic indications, the results suggest, again, that arousal is something that is readily controlled by surface features of dance and music (e.g. acrobatic movement and loud music both lead to increases in arousal), while changes in valence, on average, are not so easy to manipulate.

## 5. General discussion

Continuous response methodology provides a departure from more intuitive, introspective and hand waving analytic approaches used for understanding and interpreting communication through dance. For the first time choreographers, dancers and researchers can see the actual responses to dance works made in real time during a performance. With the inclusion of theoretical frameworks, specific questions can be addressed. For example, the current data set supports the notion that emotional arousal can be predicted by choreographic and musical events. Greater activity, such as acrobatics, and changes in musical material were connected with increased perception of arousal. Similarly, diminishing emotional arousal was associated with decreased activity and reduction or sudden absence of music. Hence, surface features of the dance and the music are associated with arousal perception. Although the emotions extracted from the choreographic notes matched the continuously rated emotional responses quite well for both arousal and valence (see Fig. 7a,b), no simple relationship could be found in the valence response and accompanying musical and staging parameters, despite the presence of a clear rising trend. From this result we can conclude one of two things: either the valence response was too disparate amongst participants to facilitate the emergence of a clear relationship, or the relationship is a function of factors more complex than surface features, depending on factors such as personal experience and cultural modelling.

What cognitive demand is imposed by the pARF? In a separate study with a new sample of 37 participants recorded across two sessions, we obtained PDA usability ratings (Stevens et al., 2009b). Fig. 8 shows the mean ratings, where a maximum of 5 refers to totally agreeing with questionnaire statements about: enjoying using the PDA, finding the PDA easy to use, finding the PDA was a distraction from the performance, preferring to assign pen and paper ratings after the performance than use the PDA to give ratings continuously during the performance, and the clarity of instructions for using the PDA. Of particular relevance to concerns of excessive cognitive load imposed by using the pARF during a live performance are the ratings for distraction and ease of use. A mean rating of 3.41 ($SD = 0.86$) for the former refers to a mid-range rating of the statement "I found the PDA distracted me from the performance" with a rating of 3 referring to neither disagreeing nor agreeing with the statement. Ease of use received a mean rating of 4.16 ($SD = 0.55$) suggesting that, on the whole, audience members found the pARF user-friendly.

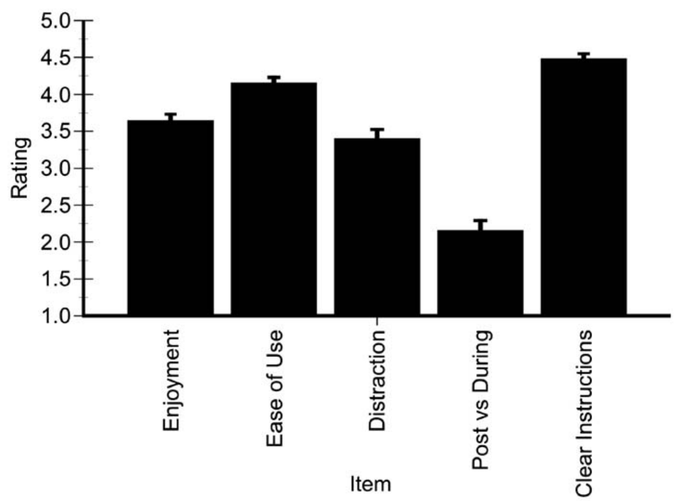


Fig. 8. Mean usability ratings for the pARF where a maximum rating of 5 refers to "totally agree", 3 to "neither disagree nor agree" and 1 to "totally disagree".

## 6. Conclusion

The pARF is a flexible instrument for collecting psychological data in real time. The pARF records post-performance rating scale and open-ended responses as well as one- or two-dimensional continuous response data. Applications include live or recorded performance of music, dance, cinema, theatre, multimedia, sport, product or political polls, market research, and experimental social and cognitive psychology tasks.

Descriptive data from Study 1 demonstrate that there is qualitative agreement between choreographer and perceiver and in Study 2 that there is some consensus among audience members and their ratings of emotional arousal. Ratings of overall arousal from an independent group of observers viewing the same live performance were reasonably positive.

The pARF is a tool capable of providing a new perspective in understanding the cognitive and behavioural processes (such as emotional responses) during a temporally dependent work of art. There is great potential for further applications, particularly in art-science collaborations and in recording immediate responses to live performance.

We are currently investigating concurrent recording of other time series to aid interpretation of audience response data such as performer motion (Stevens and McKechnie, 2005b; Stevens et al., 2008, 2009a) and music. Given the ambiguity of physiological recordings of skin conductance and heart rate, continuous data from the pARF may also be used to facilitate interpretation of physiological responses that are often synchronized with the more cognitive types of appraisals captured by the pARF. Continuous data from the pARF will also complement responses collected retrospectively using surveys and ratings scales. Also needed and using the pARF, are experimental designs that investigate the role and interplay of auditory and visual cues in audience response to live dance and music. If as Zeki and Lamb (1994) and

Ramachandran and Hirstein (1999) suggest is the case – that artists and art explore the organization of the brain – then the refinement of methods and analyses that capture the rich dynamic and cumulative effects of the temporal arts will be integral to new discoveries in vision, audition, kinesthesia, and the burgeoning field of neuroaesthetics.

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## Appendix A

### *A.1. Collecting post-performance questionnaire data*

A questionnaire is represented in the system as a set of hierarchically linked database tables. A response can take the form of a selection from a list, for example, a yes or no response, or a rating scale with values from 1 to 7, or a response can be free text, supporting open-ended questionnaire items.

The client application displays each of the sections of the questionnaire that are retrieved from the web server by an HTTP request for a URL that includes details of the current phase (questionnaire) of the experiment, the client device (participant) making the request, and the section that the user is up to in the questionnaire. The post-performance questionnaire module of the pARF uses TCP, guaranteeing data delivery and delivery of packets in the same order as they are sent. The system currently includes a questionnaire based on the Audience Response Tool (Glass, 2005, 2006). Additional post-performance questionnaires can be developed via a custom XML-based file format or by manipulating the database tables directly.

### *A.2. Collecting and synchronizing continuous response data*

The system supports collection of continuous ratings in up to two dimensions. The client application displays a two-dimensional, $200 \times 200$ pixel grid to the user (see Fig. 4), and samples the user's stylus position every 500 ms. The client device logs the data to a local file, as well as transferring it to the database server.

Data collection and upload from PDA to the pARF server is a two-step process. Continuous response data are collected for realtime visualization using the User Datagram Protocol (UDP). UDP is a faster network protocol in comparison with TCP, effective for continuous processing and for synchronizing server and client devices. Once an experiment is finished, the application uses TCP to download the continuous response data from each client device to the database server. As TCP is more reliable, data integrity is achieved.

Synchronization is a critical step to ensure that the client devices and server are running in the same time code. Once all client devices are connected to the server, the server starts sending synchronization packets to all connected client devices via UDP. The packets are sent in 2 s intervals with 10 repetitions, with the expectation that the client device receives at least one of them and synchronizes its timer with the server. Each synchronization packet contains the current time-stamp of the server as well as other necessary information, so client devices can adjust their timers. The time-stamp is in ticks (1 tick $= 10^{-7}$ s $= 100$ ns), which is the smallest time unit in C#.

Fig. 9 shows the synchronization process of five client devices (PDA 1- PDA 5). The following assumptions are made for simplifying the description. The timers (both the server and client devices) only show the last 6 digits, the other digits are denoted by either ** or ##, where ** and ## are variable lengths of digits representing the time code. Time $t'$, $t_0$, $t_1$, $t_2$ and $t_9$ are provided by a reference timer other than that of the server and client devices. They are all of a 2 s interval except that the interval between $t_2$ and $t_9$ is 14 seconds. At $t'$, each PDA runs on its own timer, e.g., **150 000 for PDA 1, and **008 060 for PDA 5. At time $t_0$, the pARF server broadcasts its first synchronization packet. It contains the current time stamp of the server (assuming it is ##000000 in this case). The packet is broadcasted in UDP, so that it reaches all client devices instantly. Fig. 9 shows that PDAs 1, 3 and 5 received the first synchronization packet, and therefore, adjust their timers to the server time, while PDAs 4 and 2 still run on their own timers until they receive the second and third synchronization packets, respectively, from the server. At time $t_9$, the time of all client devices is synchronized with that of the server (##180000).

Here we made an assumption that the synchronization packet arrives instantly to all client devices. The client devices start to adjust their timers at exactly the same time, and are therefore synchronized with the server time. However, in reality, it takes varying amounts of time for

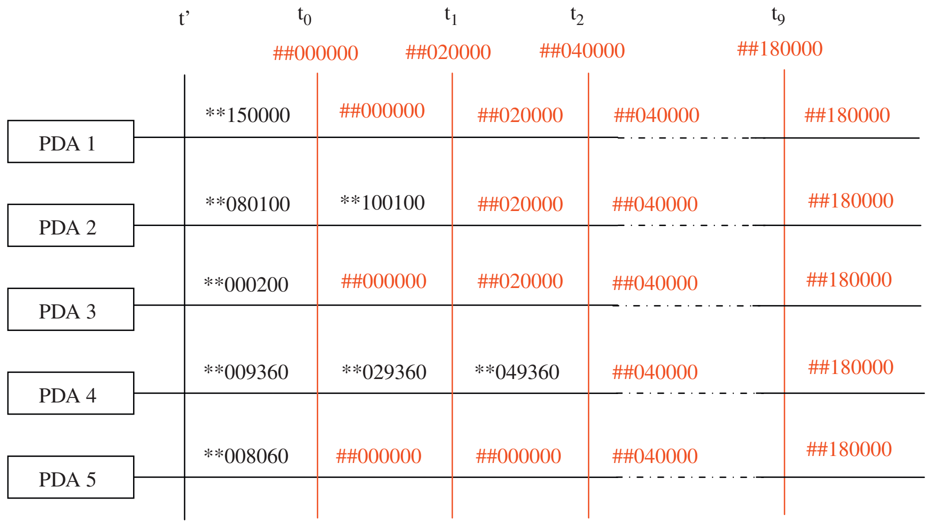


Fig. 9. An illustration of the server synchronization process for five client devices.

the synchronization packet to travel from the server to client devices. The synchronization mechanism might fail if a synchronization packet takes several seconds to arrive at one of the clients. But this is acceptable if the synchronization packet arrives at all clients within a very short time delay of around 50 ms.

TCP guarantees the delivery of the packets and in the right order. To ensure the correct order, pARF uses an acknowledgement mechanism. Once a receiver receives a packet, it acknowledges the sender. If the sender does not receive the acknowledgement in a specific time, it assumes the packet is lost (or undelivered) and it will hold all following packets, and resend the lost packet. The process repeats until the receiver finally receives the acknowledgement. This ensures data integrity, but it is too slow for continuous data transferring. On the other hand, UDP uses an available port through which it sends packets to client devices regardless of whether client devices have received the packet or not. This heavily reduces the network traffic made by acknowledgement from TCP and consequently reduces the time of sending/receiving a packet. After testing, it was confirmed that a packet took an average of 20 ms to reach a destination PDA within a radius of 25 m.

High-resolution timing is another important issue. In our implementation, an event in client devices will be called every 500 ms to handle a set of tasks, such as collecting user's input and drawing the point on the screen of the client device. On the other hand, the timer of Net Compact Framework does not provide a resolution as accurate as 10 ms. In other words, it might give a time ranging from 490 to 510 ms. Under a long run this introduces a drift in synchronization. Therefore, a more accurate timer is introduced in the application. It uses Win32 and the QueryPerformanceCounter() and QueryPerformanceFrequency() API methods. The timer uses the client device's clock counter but reads the current value of the countdown register in the timer chip to gain more accuracy; therefore, it achieves much better resolution than the "standard" ms-based timer calls. The application uses the normal .Net timer to count 460 ms, and then uses the higher performance timer to count the remaining 40 ms. This not only obtains the higher resolution but also avoids the heavy overhead of running the higher performance timer. The timer of client devices is also adjusted every minute to correct accumulated errors and minimize drift. Our tests show that the timer (both the server and client devices) can provide 500 nanosecond accuracy and the timer drift will be no more than 50 ms over a two-hour run. To synchronize the pARF with a live performance, a digital video recording of the performance is made. The time display from the pARF server should be visible at the bottom of the video recording image.

### *A.3. Control server application*

The server application is used by an experimenter to start and stop the continuous response component of the experiment sessions, including controlling the starting and stopping of individual experiment phases, each consisting of a post-performance questionnaire or continuous response data collection. Lists of connected client devices and the phases of the experiment are available to the experimenter. The server application includes facilities for exporting session data in comma-separated text format. There is also an interface that allows management of the database, including the export of old session data, import/export of questionnaires, and the creation of new experiments.

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