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Enabling Technology for Human Collaboration

Adele B. Doser, Peter B. Merkle, Curtis Johnson, Wendell Jones, David Warner, and Tim Murphy

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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Adele B. Doser, Peter B. Merkle, Curtis Johnson, Wendell Jones
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185

David Warner, Tim Murphy
MindTel,LLC
111 College Place
Syracuse, NY 13244

Abstract

This report summarizes the results of a five-month LDRD late start project which explored the potential of enabling technology to improve the performance of small groups. The purpose was to investigate and develop new methods to assist groups working in high consequence, high stress, ambiguous and time critical situations, especially those for which it is impractical to adequately train or prepare. A testbed was constructed for exploratory analysis of a small group engaged in tasks with high cognitive and communication performance requirements. The system consisted of five computer stations, four with special devices equipped to collect physiologic, somatic, audio and video data. Test subjects were recruited and engaged in a cooperative video game. Each team member was provided with a sensor array for physiologic and somatic data collection while playing the video game. We explored the potential for real-time signal analysis to provide information that enables emergent and desirable group behavior and improved task performance.

The data collected in this study included audio, video, game scores, physiological, somatic, keystroke, and mouse movement data. The use of self-organizing maps (SOMs) was explored to search for emergent trends in the physiological data as it correlated with the video, audio and game scores. This exploration resulted in the development of two approaches for analysis, to be used concurrently, an individual SOM and a group SOM. The individual SOM was trained using the unique data of each person, and was used to monitor the effectiveness and stress level of each member of the group. The group SOM was trained using the data of the entire group, and was used to monitor the group effectiveness and dynamics. Results suggested that both types of SOMs were required to adequately track evolutions and shifts in group effectiveness.

Four subjects were used in the data collection and development of these tools. This report documents a proof of concept study, and its observations are preliminary. Its main purpose is to demonstrate the potential for the tools developed here to improve the effectiveness of groups, and to suggest possible hypotheses for future exploration.

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Motivation

Many small group tasks are vital to national security within and outside Sandia. Military tactical operation centers and counter-terrorism intelligence analysis teams may operate in fast-paced, data-rich, information-poor settings where task performance error can have catastrophic consequences. Emergency operations centers like the Sandia EOC or any future national Infrastructure Operations Center can face similar challenges of time, data overload, interpersonal obstacles, and mission criticality.

By 2010, a convergence of information and communications technology is foreseen that will allow design and operation of a completely novel human-machine system. This system will enable and support those human functions best performed by humans, while more fully exploiting machine capabilities. In a possible future, people will have dedicated appliances or "PALs", which continuously integrate information about the human into an adaptive group system architecture we call "MENTOR". Physiologic, personality, attention, and interpersonal factors are among the kinds of data we believe might serve as bases for algorithms enabling higher group performance. Humans and computers are thus not separate systems, but a single complex adaptive system with both autonomous explicit self-models and goals in the context of the human group's mission.

Any group of people with reasonable freedom to act comprises a complex adaptive system. Traditional approaches to information system design do not leverage the qualities of complex adaptive systems nor do they plan for the adaptability and evolution of such systems. Designs are more or less static and assume that the system can be constrained to certain tasks, means, and structures, without unintended consequences. These approaches fail to leverage human strengths and are not robust in rapidly changing environments or for unanticipated circumstances.

The introduction to a human group of technologies (even simple ones) with broad utility is known often to result in emergent properties and dramatic changes in performance and how work is done. Use of commercial office software, cell phones, pagers, e-mail, chatrooms, on-line games, on-line shopping, product barcoding, videoconferencing, and group collaboration software are all examples of technologies that have changed the way people think and work. In each case, many of these changes were unanticipated and resulted in new behavior and results.

The use of physiologic data and other monitoring (audio, video) creates opportunities for machine customization and adaptation to the individual based on attributes such as attentiveness, current focus of attention, emotional state, stress level, learning and social styles, and current level of knowledge or expertise. The analysis of this data can also be fed back to individuals or groups to improve knowledge management, and increase self- and group awareness. This awareness can increase learning and adaptation.

The full realization of this vision is dependent upon continuing growth of technologies in diverse fields, including high-bandwidth wireless personal communications, unobtrusive and non-invasive physiologic sensors, neuroscience, several social sciences, and real-time integration of small group dynamic models with cybernetic monitoring and assessment.

1. Introduction

This report summarizes the results of a five-month LDRD project, which explored the potential of enabling technology to improve the performance of small groups. The first phase of this project consisted of the development and construction of a testbed for exploratory analysis of small groups working in high cognitive load tasks. The system consisted of four computers to be used in the function of PALs (a dedicated personal appliance), and a fifth machine to serve as MENTOR (a group system architecture). Each of the PALs was equipped with an array of devices to collect physiologic and somatic data from a group of test subjects as they collaborated on a high stress, high cognitive load task. The task selected for the subjects was a "first person shooter" collaborative video game. Audio, video, and game scores were recorded as well. Further information on the testbed can be found in Appendix B.

Phase two of the project was executed in the final month of the LDRD. Phase two involved the collection and analysis of subject data. Four subjects participated in ten game playing sessions over a period of 3 ½ weeks. The first session was a self-paced training session, after which the subjects participated in a collaborative group environment to win the video game. They were encouraged to collaborate with each other, talk, and plan. Over the course of time, the settings were changed on the video game to make it more difficult for the subjects to win. Throughout the exercise, the subjects were connected to a variety of physiologic and somatic sensors. Analysis of the data was performed concurrently and subsequently to the scheduled sessions.

The data analysis proceeded in the following manner. Videotapes were examined and events of special interest were noted. The video and physiological data were synchronized and video data were compared with heart rate data to see if any correlation existed with the events of special interest. The study culminated with the development of two unique self-organized map approaches to analyze the data: one to work on PAL, one to work on MENTOR.

This study was an exploratory project, to demonstrate the proof of concept to improve the effectiveness of groups by incorporating the human as part of the system. This report suggests possible ways to improve the performance of groups using physiological data, and makes several recommendations for future work.

2. Project Architecture and Experimental Specifics

MENTOR/PAL© Testbed

A testbed was constructed for exploratory analysis of a small group engaged in tasks with high cognitive and communication performance requirements. The system was built for Sandia by MindTel, incorporated. An instrumented collaboration station was constructed, equipped with networked computers and interface systems for tracking four users simultaneously during directed collaborative activities. The system has the capability to simultaneously track and record multiple data streams from four individuals in a group collaborative. Each of the four participants has his own computer (PAL), suitable for taking part in specified group activities. The user interface consists of an array of physiological-sensors, electro-mechanical sensors, microphone, face camera, mouse, and keyboard. This allows for the capture of physiological, somatic, audio, video, mouse click and keyboard data.

The system incorporates a fifth machine (MENTOR), which allows an observer to monitor data. The capability exists to analyze the data streams generated in near real time. A detailed description of the testbed and its capabilities is found in Appendix B.

Physiological Data Collected

The physiological data collected from the subjects included electrocardiogram (EKG), electromyelograph (EMG), galvanic skin response, respirometer (breathing), and pulse oximeter. All sensors except the respirometer and pulse oximeter (blood pulse volume, BPV) were attached using skin electrodes equipped with adhesive. The respirometer measurement apparatus was a Velcro fitted chest strap. The BPV was a clip that fit on the ear just above the lobe. Two EMG sensors were used, one on the arm to capture wrist and hand movements, the other on the upper cheek to acquire facial expressions such as grimaces. The EKG sensor was attached to the chest directly over the sternum.

Three accelerometers were used to record body movement. Two were placed on the back of the hands. These sensors were attached using standard first aid tape. The remaining accelerometer was taped directly to the earphone headset to record head movement, eliminating the risk to the subject of hair loss from tape removal..

The system was also equipped to record electroencephalogram (EEG) data, which provides information on brain activity. However, EEG data was not collected in this study.

Data collection (mechanics)

Data containing information on electrocardiogram, electromyelograph, and galvanic skin response were stored on the MENTOR machine. Accelerometers, respirometer, and pulse oximeter information were gathered using the MindTel TNG devices and stored on the individual PAL machines. (For more detailed information on collection architecture, please see Appendix B). There was some sample jitter present in the physiological data. For example, the data stored on the PAL machines had an average sampling rate of 22.6/s, or 44.2ms between samples. But at times the machine recorded duplicate time stamps (two samples with different values occurring at the same moment), and at other times samples may have been 100ms or more apart. However, for this application the data was oversampled, and the jitter was negligible. Below is an example of typical sampling jitter. At 22.6 samples/sec, the figure represents approximately one second of data. Ideally, the jagged line should be straight, indicating a smooth and even sampling interval. But as one can see, it resembles a staircase, indicating duplicate time stamps are recorded in the data. In general, the data values recorded for duplicate time stamps were different, which means they were actually recorded at different times. This implies that the device was recording time stamps incorrectly. However, there is not enough evidence for one to that the device is taking evenly spaced samples. This uncertainty in sampling interval must be taken into account when analyzing the data.

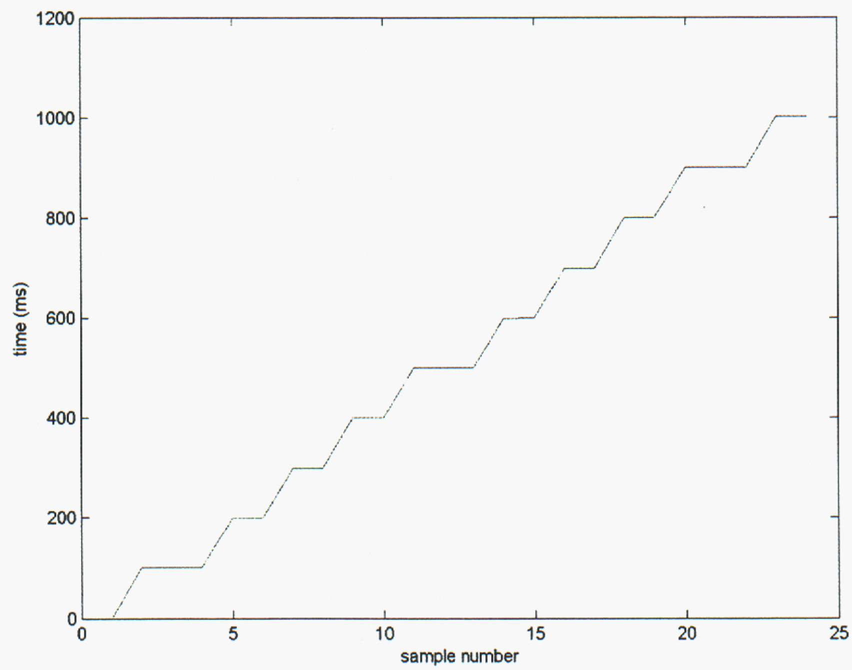

Figure 1: Variability in sampling rate of BPV over approximately one second. The y-axis represents the time, in ms, that the device records that it has taken a sample.

Due to the uncertainty involved in locating the data to a precise point in time, a time window method of signal analysis was adopted (see below). If this type of analysis was used, the error was acceptable, provided the cumulative error over a 45 minute session was one second or less.

The running game scores were recorded on VHS via a video feed from MENTOR, which was logged into the game as an observer. The start and end of each session was captured as well. Video data of subject faces and speech was displayed and collected on VHS using a quad splitting device. Thus, all four subject faces would appear on a split screen at the same moment, allowing for analysis of subject speech and facial expressions. The video was not time synchronized to the physiological data. Therefore, once each session, the subjects were asked to make a precise movement at the count of three, allowing that moment in the data to be pinpointed on the video. The time sychronization can also be double checked by noting the amount of elapsed time between the start of the data recording session, and the start of the first game (both events are recorded on the MENTOR video).

Subject selection

In July, five test subjects were recruited from the population of Sandia employees and contractors. The recruitment was conducted by placing an advertisement in the Sandia Daily News, and by emailing. A higher percentage of men volunteered for the experiment than women. For the scope of this work, it was desired to recruit subjects who had never played the game used before, nor many such games in general. Ten sessions were conducted over the course of 3 ½ weeks, each lasting approximately one hour. The subjects were required to volunteer their own time, as no monetary compensation was available. The potential recruits were each shown the test setup and equipment and allowed to review a consent form explaining the risks of the experiment before giving their agreement to participate.

The final subject group was all male. This was not the intent of the authors, and several women did volunteer for the study. However, the final selection was dictated by the schedules of the subjects. An additional unplanned outcome of the subject selection was that all five subjects knew each other before the study began. They were requested not to discuss the game or to play it outside of sessions.

As per agreement with the Sandia Human Studies Board, subjects are recorded here not by name, but rather by four digit numbers assigned at random via computer. The ID numbers of the five test subjects are: 4564, 4859, 6068, 7621, and 8913.

Group Activity (video game)

It was desired to have a group activity for this experiment that would be interesting, engaging, cooperative with individual and group outcomes, and would elevate the stress level of the subjects without requiring them to share personal information. It was decided a first person shooter video game used in the multiplayer mode would possess all these qualities. Rainbow Six 3: Raven Shield (R6)™ was selected for this study. This is a commercially available first person shooter game, with multiplayer capability. The game can be configured many different ways. The subjects can be teammates, or adversaries. It was desired to have the subjects serve as teammates, and work together to free hostages. The mission required the players to kill computer-generated terrorist characters and protect hostages, all with little or no team losses. The terrorists would shoot at the players, and they would also shoot a hostage if the cyber terrorists "detected" the close presence of the team. There were no safeguards in place to prohibit friendly fire.

There were two ways to lose the game. The first was that the entire team could be killed. It was also possible to lose the game if someone killed a hostage. Most likely it was the terrorists who killed the hostage, but it was also possible for team members to shoot a hostage accidentally. There was only one way to win the game: to kill all the terrorists.

The first meeting was a training session. The subjects worked through a set of pre-programmed training exercises at their own pace. They did not interact with other subjects during the training phase. At session 2, the subjects began to play the game interactively in multiplayer mode, working together to achieve an objective. As the subjects learned the game and became accustomed to working together, the game settings were adjusted to become gradually more difficult. An outline of the difficulty level for the 10 sessions is included below.

Session 1: All subjects were trained, at their own pace.
Sessions 2-6: "Peaks" Scenario (outdoor, daylight)
Session 2: Recruit level, 5 terrorists
Session 3: Recruit level, 15 terrorists
Session 4: Veteran level, 10 terrorists
Session 5: Veteran level, 15 terrorists
Session 6: Elite Level, 10 terrorists

Sessions 7-10: "Warehouse" Scenario (indoor, night)
Session 7: Veteran level, 10 terrorists
Session 8: Veteran level, 15 terrorists
Session 9: Elite Level, 10 terrorists

Session 10: Elite level, 10 terrorists

Multiple runs of the game were played in each session of nominally 45 minutes duration. However, if the running session time was greater than 43 minutes, another round of the game was not played. In addition, if play ran over 45 minutes, the subjects were allowed to finish playing their current game. The game was set to reload after every team win or loss. The players had between 30 and 45 seconds (depending on the session) between games to change their weapon selection. In a typical 45 minute session, the subjects would run through the game approximately nine times. Some sessions had fewer runs of the game, some had as many as eleven. Variables determining game time were ability and difficulty level of the game.

Once a team member was "killed" in the game, he would not be allowed to speak to other members until that round of the game was over. However, a dead subject could "ghost" around the scene, moving to various points as a spectator to observe the action that was still continuing.

In order to observe changes in the group dynamics, it was desired to substitute team members at pre-selected intervals. The plan was for the first four team members to be selected at random from the five volunteers. The emerging group dynamics of the data would be analyzed, and a based on observations a team member would be substituted out after session 6. The fifth team member would be substituted in and allowed to play sessions 7-10. Subsequent to session 9, one of the original team members would be rotated out, and the team member who sat out sessions 7-9 would be substituted back in for the final session. However, a schedule conflict emerged after the start of the study, which caused one subject to be unable to attend sessions for an entire week. Since there were less than four weeks to complete all ten sessions, there was no room available in the calendar for rescheduling three entire sessions. Thus, this subject was allowed to be the one to sit out sessions 7-9.

The attendance of the five subjects is listed below:

Subject 4564 was present for sessions 1, 7-10.
Subject 4859 was present for sessions 1-9.
Subject 6068 was present for sessions 1-6, 10.
Subjects 7621 and 8913 were present for all sessions.

3. Initial Data analysis

The initial examination procedure for the data included a four approaches. First, discrete observations were made of the group by the PI, who was present in the room at all times during sessions. Second, a quantitative analysis of individual and group performance was executed using the recorded game scores. Next, each session's face videotape was analyzed to identify examples of cooperation, conflict, leadership, and other critical events. Finally, the physiological data was analyzed and correlated with the other observations.

It must be emphasized that a sample set of five is too small to draw sweeping conclusions regarding the use of physiological data in the analysis of cognitive group effectiveness. However, our hypothesis was that the data could be examined for emerging trends as a proof of concept experiment.

Due to the stringent time constraints on this project, the extent of data analyses performed were very limited . All data collected in this study is stored for future study according to Human Studies Board agreement..

Social Observations

While the primary focus of this study was physiological data, it was necessary to observe the social interactions of the group to put the physiological data into perspective. As such, this section is not a detailed scientific social analysis, but rather a series of discrete observations regarding group dynamic trends.

The group at the first cooperative session (session 2) consisted of four men with a variety of different skills and prior experience with video games. By the end of this session, a leader began to emerge, subject 8913. In session 3, the other subjects began following the leadership of 8913 and asking him for advice. Interestingly enough, subject 8913 was usually the first team member to be killed in these early sessions. He was not an unskilled player (see the scoring section below). He was taking more chances than the other players and thus placing himself at greater risk. During the periods when his character was dead, he was searching around the scene (as a ghost) and looking for the vulnerabilities in the game. By session 4, 8913 was devising and executing elaborate cooperative battle plans with the assistance of the other subjects, and continued to do so throughout the remainder of the sessions.

However, another player also served as a leader and was less vocal, subject 7621. This subject admitted to having prior experience with first person shooting games. By session 5, subject 7621 was planning tactics with 8913 and coming into occasional conflict with him. By the beginning of session 6, a metamorphosis was occurring. The group was no longer one team, but two. Subjects 8913 and 7621 were each in charge of one of the other players (which player varied from session to session), and began calling themselves the alpha and bravo teams. Subject 8913 still had control of the group, but 7621 would function rather autonomously with his own two-person team in a different part of the playing field. He was typically after an important, but different, objective. In addition, if one of the less experienced players had a question on how to use equipment, etc., it was generally 7621 who took the time to calmly explain and instruct.

Subjects 6068 and 4859 generally assumed following roles, but as the sessions progressed they made more suggestions as they became more comfortable with the game. Neither one issued many commands. When subject 4564 replaced subject 6068, it appeared as if the group dynamics might change. From his introduction, 4564 made many strategic suggestions, took risks, and seemed to be trying to act as a full contributing member of the team. Perhaps he would have emerged into a leadership role had he been introduced to the game earlier. By session 7, the other players were quite versatile in the game logistics (moving, throwing grenades, etc.), while 4564 was still trying to learn. This put him at a disadvantage. However, it was observed that in the few cases in sessions 7-10 when both 8913 and 7621 died early in the game, 4564 assumed the leadership role over the remaining player.

An additional activity that would provide evidence for these observations as well as insight into the physiological data would be a leadership index survey (for example, http://www.pearsonreidlondonhouse.com/tests/cli.htm). This test was not conducted in the study as it was not approved by the Human Studies Board for use in this research.

Game Performance

A complete log of subject scores and game outcomes appears in Appendix A. There were several variables involved in the analysis of the game performance. As mentioned before, the sessions were designed so that R6 became progressively more difficult. In addition, a new player was added and old players were rotated in and out. In session 1, a training exercise was executed, and no scores were taken. Scores were recorded beginning with the first collaborative exercise, session 2.

There are two performance parameters of interest that can be measured quantitatively from scores alone: group performance and individual performance. Group performance is measured as the number of wins/losses per session. Individual performance is measured here in two ways: number of kills, total time alive per session. Group performance will be discussed first.

In a typical 45 minute session, the subjects would be able run through the game nine times. One session had 11 games, two sessions had only 6. During session 2, the subjects were doing well, winning 9 of 11 games on the easiest game setting. As the sessions went on, more terrorists were added, and the difficulty level increased. The subjects began to falter, then recover. Their best performance was achieved in session 5, winning 9 of 10 games. Session 5 was Veteran (mid-level), with 15 terrorists. In session 6, the elite level was applied, and the subjects won only one game. In session 7, a new, arguably more difficult map (location) was applied. The subjects won only one game in the last four sessions. Sessions 7-10 included the introduction of a new player and the rotation in and out of two veteran players. One cannot say with certainty that the group performance diminished due to group dynamics, or due to the increased difficulty level of the game. However, some subjects did comment that they felt the setting of the game was too difficult for their skill levels in the later sessions.

The best shooters in the game were subjects 8913 and 7621. Although subject 4564 had the worst shooting performance, he was only present for four sessions and did not have the opportunity to learn shooting at the game recruit level. The tables below demonstrate average individual results.

Table 1: Individual Results: Average number of kills/session

Subject	Average number of kills/session
4564	4
4859	6.8
6068	7.2
7621	22.6
8913	28.8

It is interesting to compare the results above with the total live time (the amount of time a subject's character is alive in a session vs. the total game time in that session). For this measurement, the interval time between games is discounted.

Table 2: Individual Results: Average total live time

Subject	**Average total live time % (live time per session/game time per session)**
4564	87.0%
4859	88.2%
6068	85.8%
7621	82.2%
8913	85.4%

Note that the subjects with the greatest average number of kills achieved them in the least average amount of time. Subjects 8913 and 7621 were the members of the group most often taking leadership roles. As such, they put their characters in more danger than the other subjects. This allowed them the most target opportunities, but also more chances for their characters to be killed.

In summary, the group seemed to adapt and perform well in spite of the increasing difficulty levels of the game in the first half of the study. In the second half of the study, the group's performance took a major downturn. It is unknown if this reduction in performance was due solely to the difficulty level of the game, or also to the change of players in the last half of the sessions. In individual results, it was noted that the players with the greatest average number of kills were also generally the first ones to have their characters killed in the game. Complete game scores and summaries can be found in Appendix A.

It is most interesting to combine the game results with the video and physiological data. This is done in a subsequent session.

Video Analysis

Each session was videotaped, using a quad-splitter device. This allowed all four subject's faces to be displayed, simultaneously, on one screen. The audio quality of the recordings was quite poor, but in general it was possible to understand the speech of a subject. The video of each session was analyzed to identify examples of cooperation, conflict, leadership, and other critical events. Examples of statements demonstrating items such as cooperation and conflict were noted from the video, and logged manually according to type and time.

Due to Human Studies Board regulations, no one outside the development team was allowed to view the videotapes. This eliminated the possibility for an independent, outside observation to confirm categories of statements. An independent observer could also have been helpful as a second ear to interpret many nearly inaudible statements.

For the purposes of this study, statements of interest were grouped into the following categories [2]. Since many statements were inaudible, it was not felt that a running count per session by person would not be very accurate. Thus, statements of interest were noted solely to provide correlation to the physiological data.

Types of statements noted:

Leadership (L): For example, "Stay behind me."
Following (F): An example would be, "Where do you want me to go?"
Cooperative (CO): For example, "I've got your back."
Conflict (C): For example, "I don't think that's a good idea."
Reporting (R): For example, "This area is secure."
Inaudible (I):

Primarily, events surrounding L, F, CO, and C statements were examined. Reporting statements, while they convey information, were not generally associated with any observable change in the physiological data.

There is some ambiguity surrounding statement classification. The same statement could be classified different ways, depending upon the context. For example, the statement, "I'm approaching the house," would generally be considered to be a reporting statement. However, if it follows another statement such as, "They're shooting at me in front of the house!" then, "I'm approaching the house," would be classified as cooperative- since one subject was running to the aid of another.

Once statements of interest were located in the video data, they were compared to the same interval of time in the physiological data, to see if the subjects exhibited any noticeable reaction. This approach is described in subsequent sections.

Correlation of vocal data with physiological data

As mentioned in the previous section, statements of interest were located in the video data in order to correlate these events with the physiological data. The point being to see, for instance, if a subject makes a statement such as "Follow me," if it results in any reaction in physiological data among the subjects, and to see if that reaction changes over the course of the sessions. However, if there is a reaction in the data, is it due to the vocal cue, or something else? For example, suppose one subject says to another, "follow me," and the second subject's heart rate spikes to a higher level. Did his heart rate spike because he was given a command, or was it perhaps because he was taking hostile fire at the same moment? Without a camera recording what each subject sees on the screen, it is difficult to tell exactly what a subject is experiencing in the game at any given time. Even if the study had been equipped with such a capability, and we could tell he was being fired upon, we still cannot answer the question with complete confidence. We could only be certain he was reacting to "follow me" if we could confirm he was experiencing nothing else of consequence in the game at the time.

That said, we can attach a confidence level to each incidence of vocal data that is potentially associated with a physiological reaction. For the purposes of this study, these levels are called high, reasonable, and low confidence.

High confidence events:
One's death: just as one's body would have a stress reaction if someone pointed a gun at him in real life, most people tend to react strongly when their video personality is killed. It is fair to assume that if a reaction in the physiological data occurs that can be associated with a person's death in the game, that he is reacting because he got killed.
Death of comrades after one's death: After one is killed in R6, he becomes a ghost. He is no longer being fired upon. He is no longer shooting. He may become disengaged and start daydreaming. But if one of the group dies after him, and we see a reaction in his data, we assume that reaction is due to the death of his comrade.
Conflict with eye contact: If two players come into conflict and have a discussion over an issue, and they are looking at each other for an extended period of time (not the computer), we assume that any reaction in the data is due to the conflict. Similarly, we can draw the same conclusion if two players are looking at each other and *cooperating* to plan an attack.

Reasonable confidence events:
A physiological reaction in the speaker of most L, F, or CO statements: The reaction in a bearer of a statement can be said to be more reliable than in the recipient of a statement. Why should this be the case? The reaction of the speaker that is observed is generally not a reaction at all, but a precursor. Often, a reaction in the data can be seen just *before* the statement is made. The subject is assessing whether to make the statement, because it

may involve a risk. For example, it was witnessed several times over the course of the sessions that one subject would say, "I need some help down here!" This statement would be followed by a pause of 5-10 seconds, then another subject would say, "I'm on my way." In many cases, the second statement would be preceded by a spike in the heart rate and respiration of its speaker. If such an association occurs, we can be *reasonably* confident of its source, provided another event does not occur within close proximity of the precursor.

Low confidence events:
A physiological reaction in the recipient of most L or CO statements: As explained previously, it is very difficult to determine if a recipient is reacting due to the statement, or some other event in the game.
Death of a comrade while one is still alive: Often, a subject is also sustaining heavy fire when his partner is killed. In addition, he may be so busy he does not even realize his buddy has been killed for several seconds. Drawing a connection in this case is difficult. The exception is if the survivor is the last one left standing. Many subjects do exhibit a strong reaction when they find they are all alone on the mission, as will be shown later.

4. Heart rate analysis

Analysis of heart rate variations can illuminate much about a person's activity and stress levels. In this study, heart rate and heart rate variation could be gleaned from two separate sensor systems: the blood pulse volume sensor (ear clip), and the EKG chest electrode sensor suite. In this section, analysis using the BPV sensor will be discussed.

Background

Data from the BPV sensor ear clip could be used to track variations in a subject's heart rate. The device that drove the BPV sensor in this experiment had a sampling rate that averaged 22.6/sec, although as mentioned earlier in this report, there may have been some timing jitter that affected the true sampling rate at any given moment. If it is assumed the true sampling rate is 22.6Hz, according to the Nyquist sampling theorum [6], in an ideal case, frequencies up to 13.3Hz can be captured without aliasing. Under normal circumstances, if a person is sitting, it is reasonable to assume his heart rate will not vary much outside the interval of 1-2Hz (60-120 beats/minute). Thus, the sampling rate is more than adequate, and the jitter should not present a significant problem if frequency analysis techniques are used.

To examine the change in heart rate in the BPV data, a time/frequency technique was used. A sliding window Fourier transform (STFT) was applied. An STFT works by taking Fourier transforms of data over short periods of time using a window, sliding the window, and repeating. Thus creating chunks of Fourier transforms. If these Fourier transforms are attached on the time axis, one can start to get a feeling of what the frequency content of a signal looks like at different periods of time.

Unfortunately, there is a trade off between time and frequency resolution. It is mathematically impossible to simultaneously achieve both great time and frequency resolution. Wavelet transforms can be useful, as they allow one to sacrifice resolution in some parts of the spectrum and save it in others. In the BPV data, the area of concern is only a small part of the spectrum, where both time and frequency resolution are desired. This makes a conventional wavelet impractical. While a custom made transform could be designed to meet these needs, the time available in the project was insufficient for its development. Thus, a compromise was made. Since, for short periods of time, there was uncertainty in the time stamps of the data, a decision was made to allow the time resolution to be 5.68 sec, with a 50% overlap between windows. Thus, a frequency contribution at 5.68 sec would represent time between 2.84 sec and 8.52 sec, a frequency component at 8.52sec would represent time between 5.68 sec and 11.36 sec, etc.. In other words, although the entire time period would be represented, it would be impossible to pinpoint any moment in the spectrum except to say that it happened sometime in a 5.68sec interval. Since heart rate cannot change instantaneously, the resolution seemed adequate. In addition, statements made by subjects may last several seconds. The corresponding frequency resolution was 0.09Hz (thus, there would be approximately 11 frequency bins covering the space of interest between 1 and 2 Hz). In other words, a change in one vertical frequency bin represents a heart rate change of approximately 5.4 beats/minute.

Often, a burst-like phenomena will appear in the STFT, where a signature appears to be smeared all over the entire frequency (vertical) axis. This artifact can be explained. When a subject reaction is accompanied by a sudden change in intensity, it sometimes is recorded as a DC shift in the data. Essentially, it is a step function (positive or negative) added into the time domain data. It is a fact of Fourier analysis that a discontinuity in a time signal has a component over the entire frequency plane. Although the largest component is at DC (0 Hz), influence can be witnessed at other frequencies.

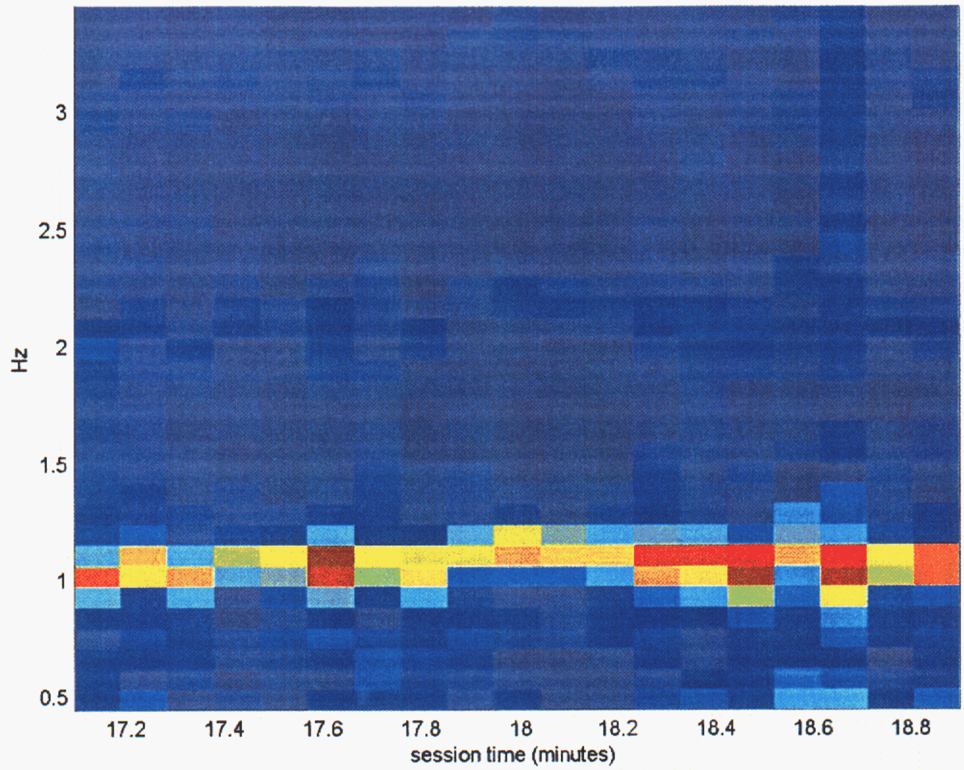

Figure 2: A typical BPV signal from a subject, processed by STFT. The x-axis is time in minutes from the start of the session, the y-axis is heart rate in Hz. Colors indicate intensity of the Fourier transform. Blue=low, Red/Brown=high.

The figure above displays the STFT of a typical BPV series for a subject during the game. Note the strong horizontal signal at approximately 1Hz. This is the subject's heart rate, which seems to be varying in intensity with the events of the game, but there is not much frequency variation in this interval. One can observe much weaker signals at 2Hz, and 3Hz (light blue). These are harmonics of the heart rate signal at 1Hz. Harmonics are an artifact of the Fourier transform, and do not represent error. Other lightly shaded pixels in the figure are the result of noise sources.

Correlation of heart rate and voice data

As mentioned previously, videos were viewed and statements logged for the purpose of seeing if any correlation existed between the voice and physiological data. This section is a qualitative one, and will provide supporting evidence for a subsequent section on self-organizing maps.

Cyber death:

The examination will begin with the high confidence events, starting with the death of one's own character. Below is an example of a typical response observed in the BPV data when a subject's character dies in the game. In general, a reaction is not observed until 2-5 seconds later, that is, the next time bin.

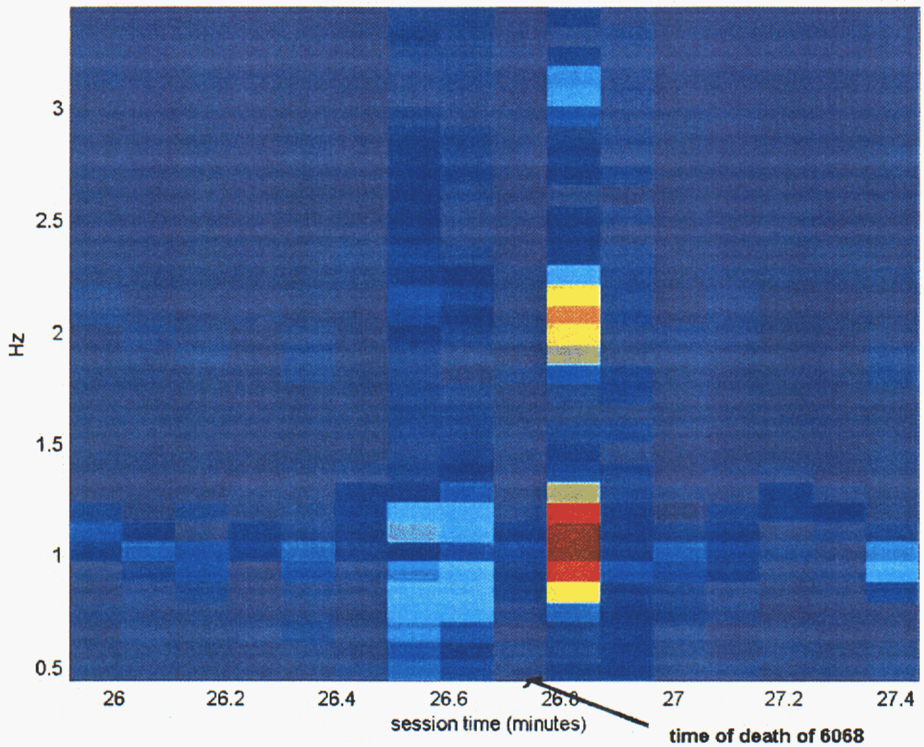

Figure 3: Reaction of a subject's BPV signal after his character's death in the game.

Note the strong reaction in heart rate intensity after the subject realizes his character is dead, as noted by the dark red pixels just before 27 minutes. The artifact can be observed in the harmonics as well. Some subjects reacted to their character's deaths with changes in heart rate intensity, an elevated heart rate, or both. It was interesting to observe that one subject, 7621, seldom produced a change in heart rate or intensity when his character was killed. However, it was noted from the videos that this subject usually did throw his head back when he was killed in the game. Thus, when his heart rate data was combined with accelerometer data (see the SOM section below), some reaction could be observed.

Death of others:

Another high confidence event to examine is the reaction of a subject to his comrade's death, after the subject has died himself. At the beginning of the sessions, the typical observation is that after one's death, one would have no reaction upon the death of a comrade. Below is one such example.

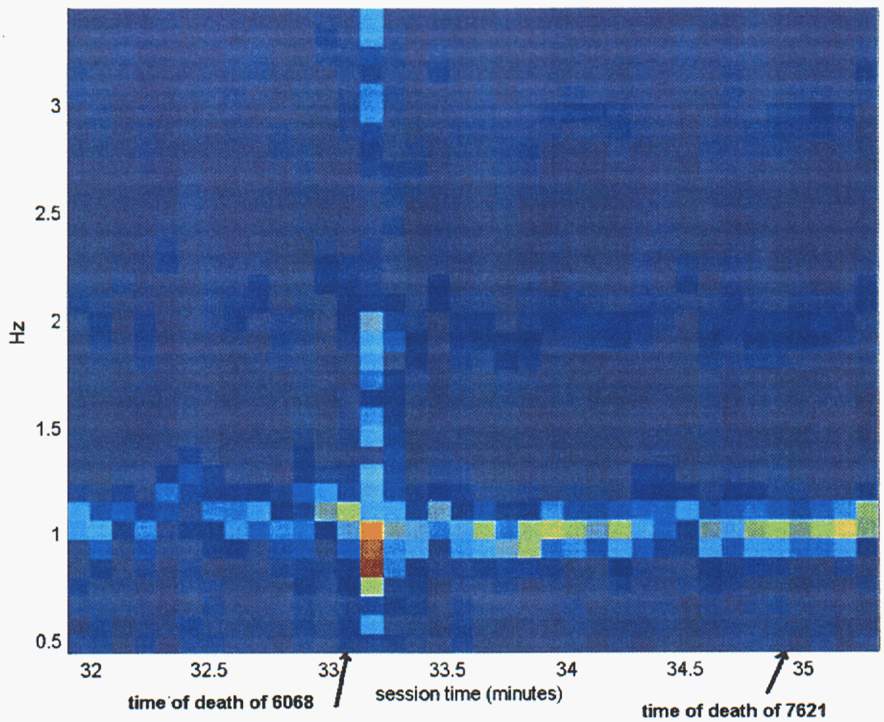

Figure 4: Subject 6068 reacts after his own death, but not the death of subject 7621.

When the data from the early sessions was first examined, it was determined that, in general, subject 8913 did not react to a comrade's death in the way illustrated above. Below is an example of subject 8913's data. Subject 8913 continued to react to events in the game after his character was dead. He experienced heart rate changes after the deaths of his teammates.

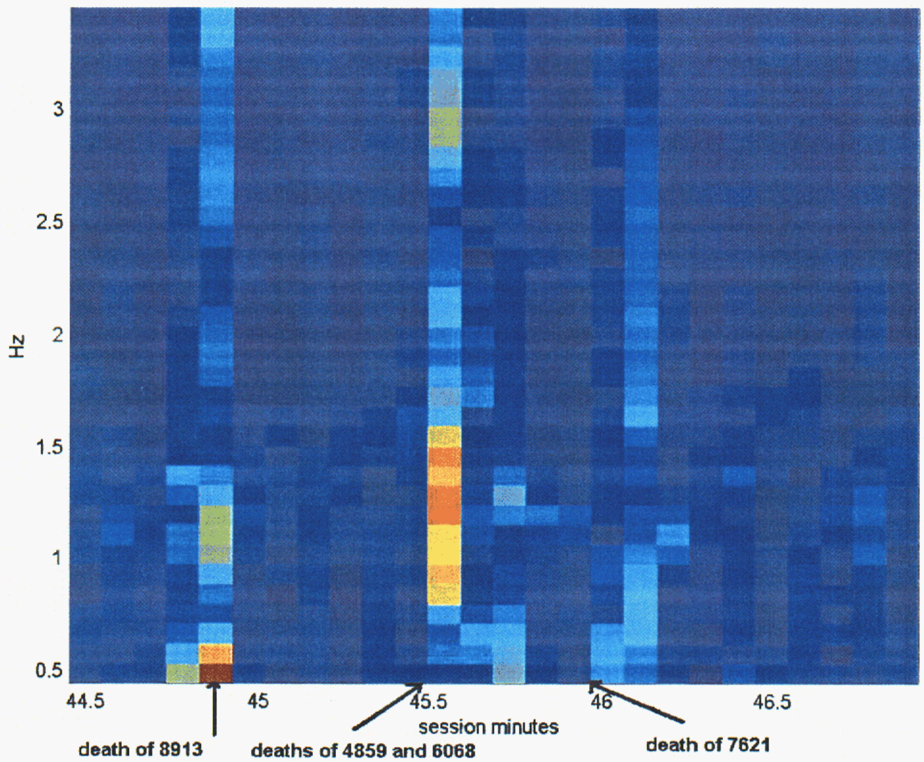

Figure 5: Subject 8913 reacts to the deaths of 4859, 6068, and 7621. BPV displayed.

Since subject 8913 emerged as the leader of the group, does that imply that reacting to the experiences of others is a characteristic of a leader? Further studies are required. However, consider the following observation. As the sessions progressed, on occasion other subjects began reacting to comrade's deaths in the same way as 8913. One conclusion is that the subjects are beginning to act cooperatively, and to behave like a team. Other possible conclusions are discussed later in this report.

Conflict and Cooperation:

As was noted previously, we can have a high confidence level that a reaction in the physiological data is associated with a conflict or cooperation only if the players involved are looking not at the computer screen, but at each other. The video data was scanned for examples of such events. Below is an example where 7621 was having a conflict with 8913. Both subjects were looking at each other. Subject 8913 displays a similar, though not as dramatic reaction.

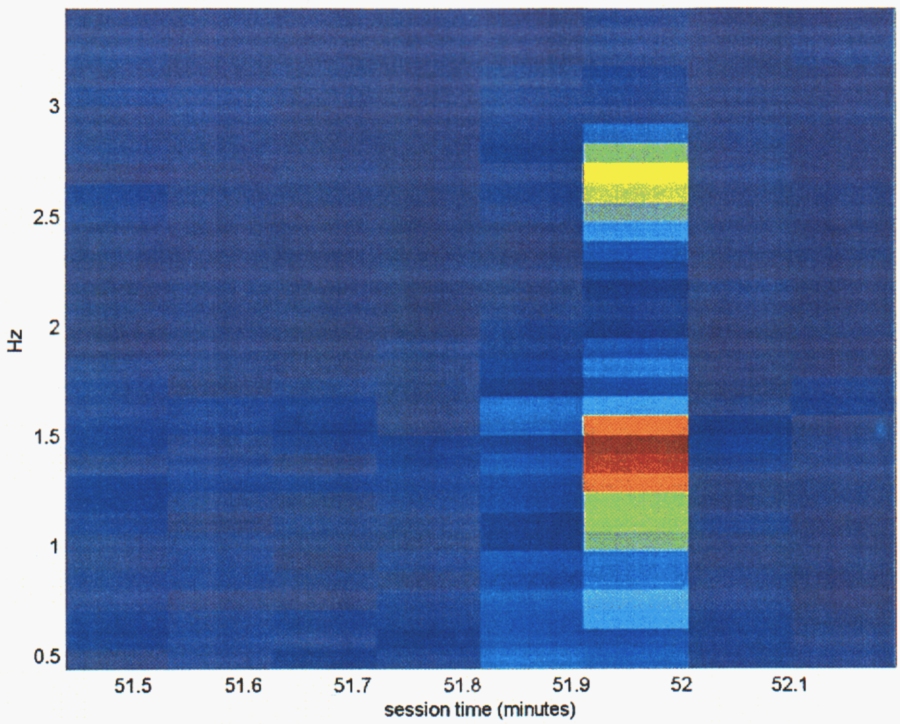

Figure 6: BPV data for 7612. He is having a conflicting discussion with 8913 at 51.9 session minutes.

Other conflicts and cooperative events were studied in the data. They do not always invoke a reaction in the data. Different subjects reacted differently. Subject 8913 reacted very little to conflict events. Subject 7621 reacted more strongly to conflict events than he did to his own death events. Subject 4859 reacted more strongly to cooperative events. Subjects reacted differently at different times, most likely due to the seriousness of the event.

Last one left standing:

It was hoped from this study that physiological data could be used to identify signatures of group learning and cooperation. But how do subjects function due to lack of cooperation? There was a multitude of data available from the study that included cases where one subject was the surviving member of the team, and often carried on for several minutes on his own. As nothing was said during these intervals (subjects were not allowed to talk after their character's deaths), it could be assumed that any reaction from the survivors was due to the events in the game. It was decided to examine heart rate data for signs that a subject may be experiencing agitation due to the lack of cooperation from his comrades.

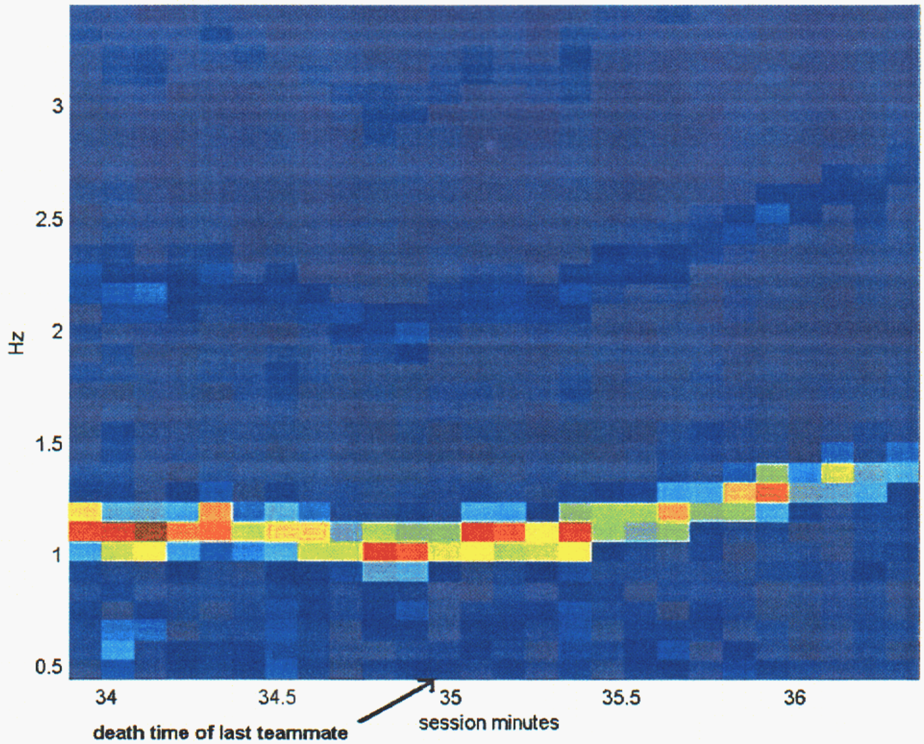

Figure 7: BPV of subject 4859, as he acts alone after the death of his last remaining teammate at minute 35, until he wins the game at 36:25.

Above can be seen the heart rate of subject 4859, as he works alone in the game for approximately 90 seconds. He wins the game at the end of this frame. Note the steady rise in his heart rate after the death of his teammate. The rise is even more apparent if one examines the first harmonic at 2Hz.

By far, subject 4859 spent the most time as the survivor. Of the others, it was almost never the case that they were left standing alone for more than five seconds. Of those games when another survivor was left standing 30 seconds or more, similar gradual heart rate elevations were witnessed in his data.

An interesting phenomena was noted in session 8. 7621 was alone in the game for 42 seconds. Not only did his heart rate rise, but the heart rates of the other subjects, who were dead, rose steadily as well. For the specific period of time, 7621's data and the data of one other subject are plotted below. It seems too, that this artifact may be an indication that later in the study the group was functioning more as a team.

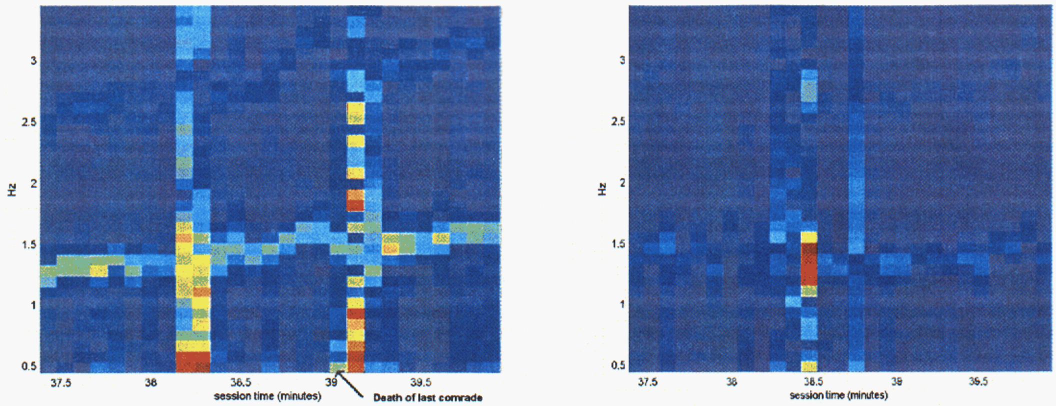

Figure 8: BPV of 7621 as the last surviving member (left) and one of his dead comrades, 4564 (right). Note the elevation of both heart rates after minute 39.

Conclusions

This section was an exercise to determine if correlations existed between what was said in the video data and reactions that were observed in the physiological data. In many cases, no reaction was observed in the physiological data. But in the events discussed here, if there was a reaction observed, it was reasonable to believe it was due to the event in question.

Additionally, the following trends were observed. In early sessions, subjects would become detached after their characters were killed, and only the leader, 8913 would remain engaged in the game. This was illustrated by the fact that the subsequent death of a comrade would result in a spike of 8913's heart rate. As the sessions progressed, this artifact was sometimes noted in the other subjects as well. It is especially true of subject 7621 (see the section on SOMs below). This behavior could indicate a possible signal of emerging group cooperation, or perhaps the subjects are beginning to emulate the reactions of the group leader.

When a subject is the last survivor in the game, it was noted that his heart rate began to gradually climb. Such was the observation in all subjects who managed to live 30 seconds or longer as the last survivor. In early sessions of the game, only the survivor's heart rate would climb. However, as the sessions progressed, it was noted in one case the dead character's heart rate would climb along with the survivor's. This could also indicate a cooperative trait.

When responding to various statements in a variety of situations, the subjects reacted very differently. Subject 8913 reacted very little to conflict events. Subject 7621 reacted more strongly to conflict events than he did to his own death events. Subject 4859 reacted more strongly to cooperative events. It was observed that subject 6068 reacted more to the start of a new game than anything else. Subjects reacted differently at different times, most likely due to the seriousness of the event. The conclusion is that all subjects are different, have different motivations, and there is no single metric that can be used to describe their individual data. While a discussion of heart rate analysis can be demonstrative, a more concise approach is required. Such an approach is discussed in the section on self-organizing maps.

5. Data Analysis Using Self-Organizing Maps

Introduction to Self-Organizing Maps

A self-organizing map (SOM) can be helpful to spot correlations in a set of data. SOMs were developed by Teuvo Kohonen, in the early 1980's. SOMs are similar to neural networks, in that they are used in pattern recognition and classification. Unlike neural networks, SOMs are based on the principle of *competitive learning*. Over the course of training, by means of positive and negative lateral interactions, one cell becomes sensitized to a region of input signal values, and suppresses the sensitivity of the cells around it to the same input. [5]. Thus, each cell in the network is activated by a different constellation of sensor input values. The *Self* in Self Organizing Maps refers to the fact that the network trains itself, without any preconceived ideas of what the final outcome should be (unlike many neural networks).

Much of the SOM's power lies in its ability to reduce the dimensionality of an input vector space, while still retaining the distance relationships within that space. For instance, it is possible to reduce a 50 dimensional space down to two dimensions, and still be able to classify the data using a SOM. For this reason, SOMs generally do not provide a 1-1 mapping, with the result that more than one combination of inputs will activate the same output cell. However, if one wants to use a SOM for classification or to identify trends in data, this does not present a problem. In a classification application, one generally wants to have many inputs be represented as a single, or at most a small cluster, of outputs. A SOM must be presented a great deal of data in the training phase to achieve satisfactory results, not a problem in this study. The computational costs of a SOM is incurred in the training phase, with very little computation required to classify new data as it becomes available. As such, SOMs are suitable for near real time applications.

In the following sections, SOMs are trained, both for individuals, and for the unit as a whole. This task was taken to fit in with the concept of what roles PAL and MENTOR might play in the future, and to demonstrate that each approach has its own merit and applicability. Ideally, the methods should be used concurrently.

Self-Organizing Maps (An Individual Approach)

In keeping with the concept of PAL, the decision was made to train a SOM for each subject. As was shown in the previous section, every subject reacted differently under varying situations. Success has been demonstrated in the past by using an individual SOM to categorize individual data [3]. Due to the uncertainty surrounding the true sampling interval in the TNG data, and the fact the EKG, EMG, and GSR data were sampled at a different rate, only the data collected by the TNG machines on the PALs (respiration, BPV, and accelerometer, were used to train each SOM. Since additional data other than BPV was used, an event that created a low stress level when only BPV data was analyzed would not necessarily map to a low stress level in the SOM.

A free version of a MATLAB SOM toolbox, developed by the students of the SOM inventor, was available to download without licensing restrictions at Helsinki University of Technology www.cis.hut.fi/projects/somtoolbox. The Helsinki SOM toolbox was found to be adequate for the scope of this project and was incorporated into the algorithms developed here.

The SOM training data

In the previous section, the use of STFT time/frequency techniques seemed to unearth some characteristics of the physiological data and make them visible to the human eye, the STFT was used to populate each SOM, as well. The vertical elements of the STFT were important in this endeavor. Each data file, when processed through the STFT in the manner described above, contained approximately 500 time bins and 129 frequency bins. Duplicate this number for each parameter (BPV, respiration, etc.). Each training vector to the SOM consisted of 17 parameters. Values 1-13 consisted of a subset of BPV STFT information. Frequency bins 11-23 were used, which represented values of approximately 0.9Hz-2Hz (54-120 beats per minute). Only magnitudes of the Fourier transform were included, the phase data was disregarded. For the respiration data, only the value and location of the highest magnitude frequency bin were included. For example, suppose the highest value for a given time bin occurred at 0.7Hz and had a value of 0.3. The parameter entries would then be 0.7 and 0.3. The question remained of what to do with the accelerometer data. It was observed that while playing the game, contact with the mouse and keyboard required a subject's hands to be quite stationary. However, it was observed that head movements were quite common, mostly side-to-side. Therefore, x-axis accelerometer input was used in training the SOMs. Similar to the respiration data, the location and magnitude of the largest component for each time bin were included in the data vector. Thus, each training vector included 17 elements: 13 from BPV, 2 from respiration, and 2 from x-axis head accelerometer. A typical 45 minute session would provide approximately 500 training vectors.

One session of data was used to train the SOM for each of the five subjects. In order to observe trends developing over the course of the study, it was desirable to select a session which was somewhere near the halfway point. But in order to have the SOM experience the full range of data, it was necessary to select a session where the subject cooperated in several battle plans, experienced conflict, demonstrated leadership and following roles, and was killed multiple times. For subjects 4859, 6068, and 8913- session 6 was used. For subject 7621, session 4 was chosen. Since subject 4564 was present for only 4 sessions, the data used for his training set was from session 7. Once the SOM for each individual was trained, data from other sessions could be fed to the map, in order to search for evolutionary trends in the data.

The dimension of each SOM was selected by the algorithm based on the eigen values of the data. As such, the SOM for each individual was a different size.

Individual SOM results

Subject 4859:

A SOM was trained for each subject, based on the data from one session. Events of interest from the video were located in the data and mapped on the SOM. Below is an example of a trained SOM for subject 4859. What is displayed is the Uniform Distance Matrix, or U-Matrix. The U-Matrix represents the distances between data elements in the input vectors. Blue areas represent where the data is close together in feature space, red colors represent data that is far apart. Generally speaking, a vector that maps to the red area would indicate a period of time where the subject was under high stress (high heart rate, high respiration, head movement). Consequently, in this case, a vector that mapped to the lower left corner (blue region) would indicate that the subject was quite calm.

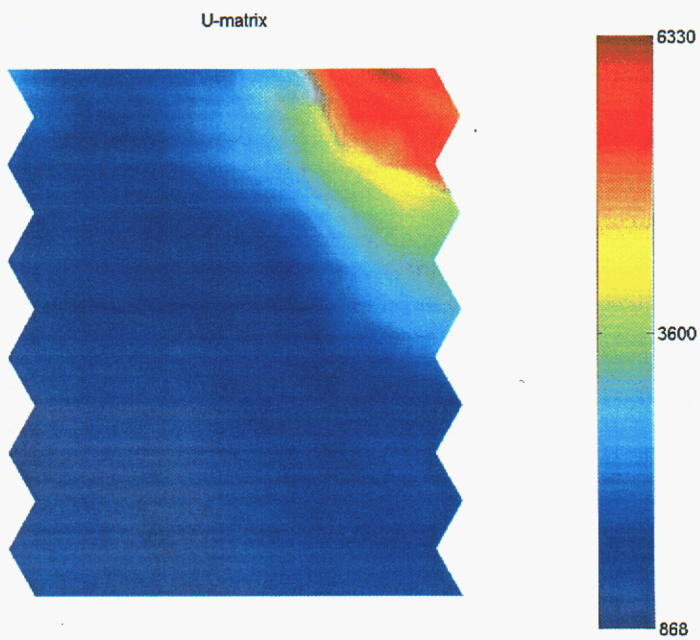

Figure 9: The U-matrix for subject 4859's SOM. Red areas indicate areas of high stress. The units on the colors are dimensionless. The SOM was trained using data from session 6.

Next, events of importance from the video were located to a certain point in time on the data and sent through the mapping process. For the training data, the results are displayed below. First of all, it should be noted that a SOM does not provide a 1-1 mapping, meaning that several data vectors may map to the same location. Even though there were five occasions where comrades were killed after subject 4859, they map to only three points in the data (red). Note how, in session 6, the subject seems to be very stressed by his character's death events (black). He is not very concerned with the deaths of others (red). By this session, he is quite comfortable with the execution of battle plans of others (green). New game starts (pink) were included in this set, as some subjects display much stress at the start of each new game. However, as can be seen here, 4859 is not one of those subjects. On the other hand, events where he comes to the aid of others or has conflict with them (blue and yellow), give him moderate stress. In session 6, one would have to say that the events that bother 4859 are his character's death, conflict, and coming to the aid of another (cooperation).

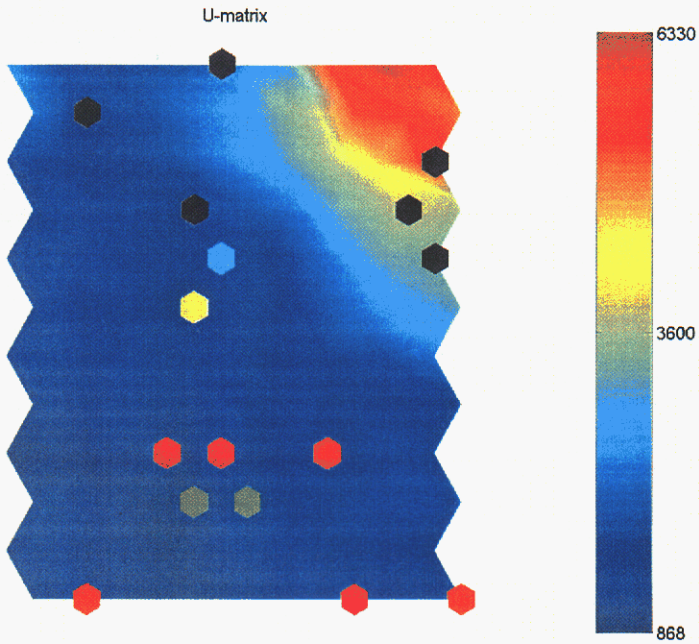

Figure 10: Events of interest for subject 4859 from session 6, plotted on the SOM trained from the same data. The color key is: subject's own death (black), comrade's death after his own (red), cooperation to aid others (light blue), conflict (yellow), cooperation with others to execute plan (green), start of new game (pink).

What, then, of the large red section in the upper right corner that represents the highest stress level, yet has virtually no points located there? Which events cause so much stress as to be mapped to this region? In an off-line exercise, the generating data was plotted point by point to see which points in time were "red points", and compared with the video and game data. This region was found to correspond to a point of time in the session where no words were spoken between subjects, and shots were being fired.

What of the important events from other sessions? Syncing events from the video to the physiological data can be a painstaking process. Time permitted the analysis of three sessions only for most subjects, including the session where the SOM was trained (ideally one of the middle sessions). The other two sessions were one selected near the beginning of the study, and the last session where the subject participated.

Below is an example of the subject data from session 3, plotted on his mapped trained from the session 6 data. This way, one can make a direct comparison between the two sessions. Unfortunately, MATLAB only provides seven colors for plotting points on a map, not enough to capture all events of interest. In the figure below, instead of representing a plan execution, green represents uttering a following statement (such as "Which way do you want me to go?").

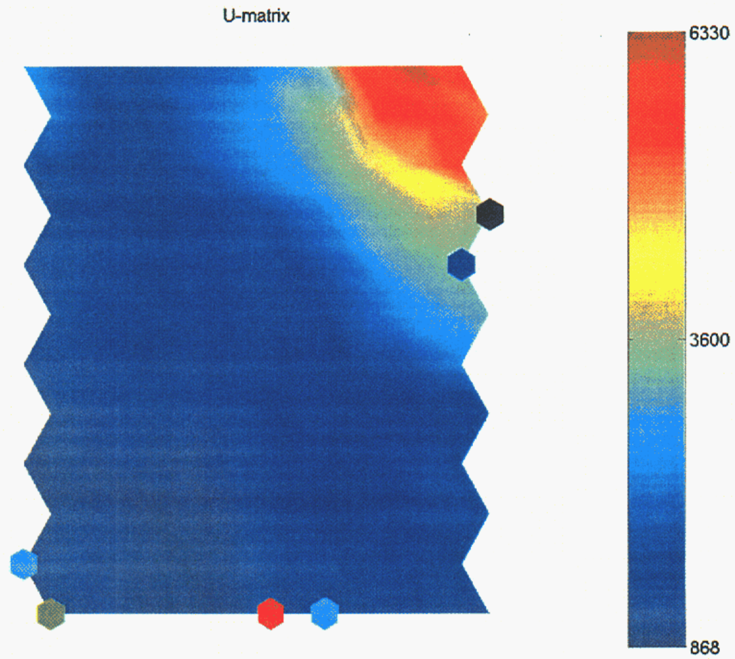

Figure 11: Events for subject 4859 from session 3, plotted on the SOM trained from session 6 data. Color key: subject's own death (black), cooperation to aid others (light blue), making commands (dark blue), following moments (green), start of new game (pink).

Much of the events from session 6 were present here, but there are some additional events, and some missing. In session 3, the subject was killed only once, and there were no occasions where a comrade was killed after 4859's death. There were no cases where 4859 was in conflict with anyone. However, he did issue commands or leadership statements (dark blue), and statements indicating he was in a follower position (green). Recall, this data is three sessions earlier than session 6. Note how uncomfortable the subject seems to be with issuing commands (dark blue), yet how comfortable the subject is with being a follower (green). At this point in the sessions, although a leader (8913) was emerging, the hierarchy of the group had not yet been established. In this session, 4859 spent much time as the lone survivor (see figure below), and occasionally won the game in that position. Thus, by the end of the session, he began to feel confident of his skills and started to issue commands to the others in the group. Interestingly enough, 4859 was not observed to issue another command until session 8, after the introduction of a new test subject.

In session 3, 4859 was the lone survivor on two separate occasions, for a total of nearly three minutes. It is interesting to note, that under such circumstances, 4859 exhibited high levels of stress (see the figure below).

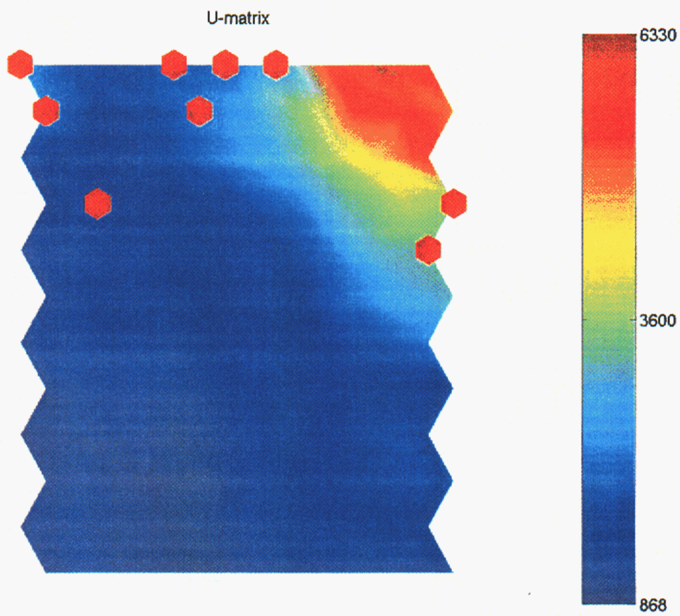

Figure 12; Periods of time during session 3 where 4859 was the lone survivor (red).

The participation of this test subject did not extend to the end of the study. Therefore, the final session where his data was examined was session 8. The results of displaying the session 8 data on the session 6 SOM are shown below.

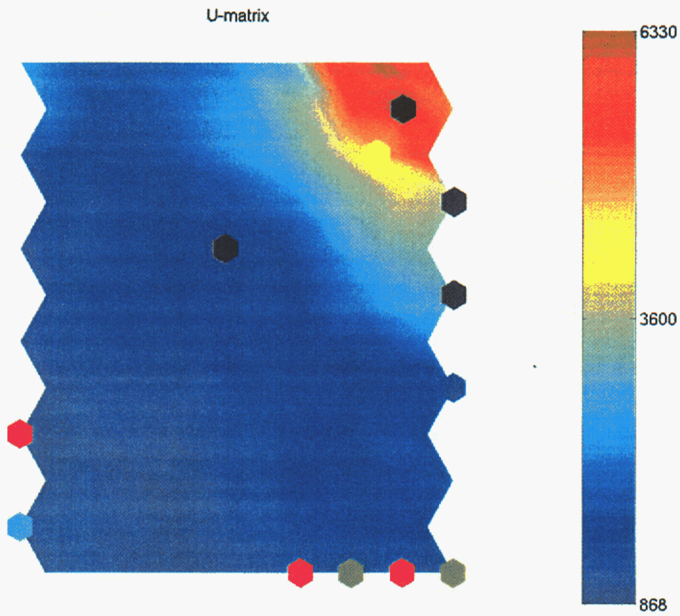

Figure 13: Events for subject 4859 from session 8, plotted on the SOM trained from session 6 data. Color key: subject's own death (black), cooperation to aid others (light blue), making commands (dark blue), following moments (green), start of new game (pink), executing a plan (yellow).

As one can see, the subject still feels quite comfortable with being a follower (green), and not as comfortable with issuing commands (dark blue). There were no occasions in session 8 where a comrade was killed after 4859 in the game.

Although a thorough examination of all the sessions might provide further revelations, the examination of the data presented here for 4859 would seem to indicate that very little change in the subject's reaction was noted throughout the course of the study. This was not the case for every subject. However, a careful review of the data here seem to indicate that the responses noted by 4859 are consistent with those of a follower.

Subject 8913:

Subject 8913 emerged as the leader of the group. His data from session 6 were used to train a SOM. That SOM was later used to chart 8913's data from session 3 and session 10. Through the entire course of the study, subject 8913 was not observed to make a single statement consistent with a follower. However, it is not impossible that there may have been such a statement imbedded in the video data which was inaudible to the observer.

Subject 8913 was very vocal, and generated many statements of interest. Because of this, it is necessary to show his data over many different plots, as some data would plot to the same points as others and would eclipse them. Below is the SOM generated by subject 8913's data from session 6. Some points of interest are plotted in each figure. Note how the SOM is a different size from the SOM of subject 4859. The size of each SOM is based on the eigen values of the data set. Different individuals have different sized SOMs.

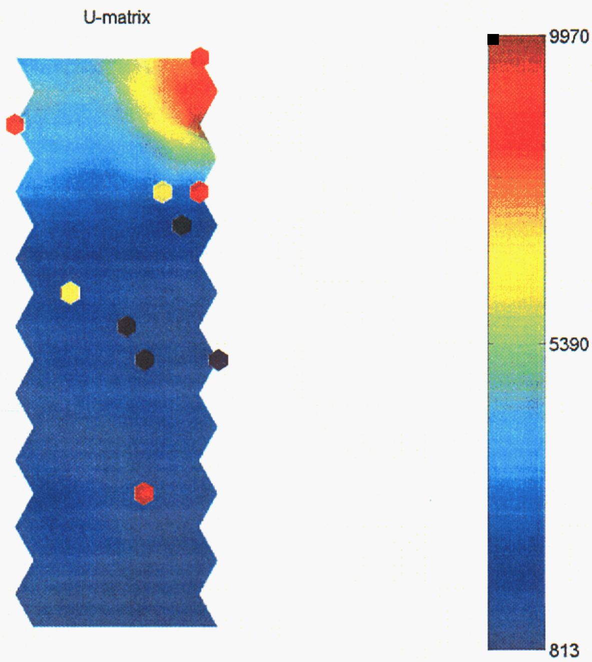

Figure 14: Trained SOM and subset of events of interest for subject 8913 from session 6. The color key is: subject's own death (black), comrade's death after his own (red), conflict (yellow).

As noted in a previous section, subject 8913 takes note of the deaths of his comrades (red), exhibiting maximum stress in one case. In session 6, in general, he shows more stress to the reaction of a comrade's death than he does from his own (black). In addition, 8913 seems to be very concerned about conflicts he has with others in the group (yellow).

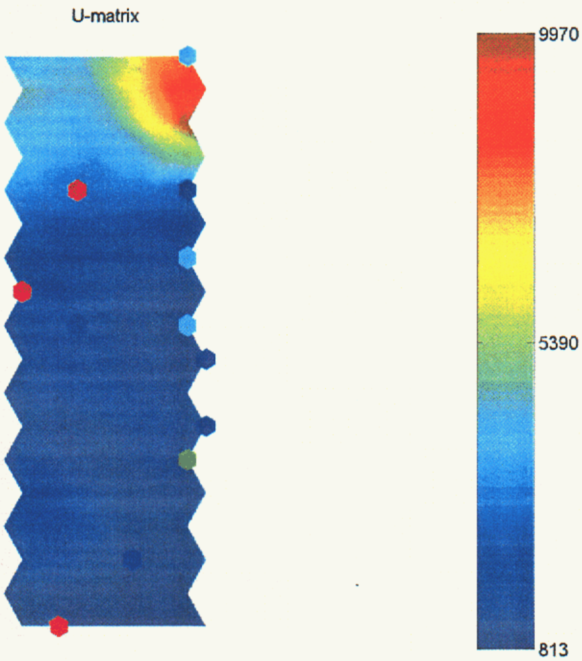

Figure 15: Trained SOM and subset of events of interest for subject 8913 from session 6. The color key is: cooperation to aid others (light blue), commands (dark blue), cooperation with others to execute plan (green), start of new game (pink).

Subject 8913 exhibits a wide range of reactions to the same stimuli. However, in general he seems to be more comfortable with issuing commands (dark blue) than with coming to the aid of others (light blue). At times the anticipation of the start of a new game can cause him stress (pink). Some of this game anticipation stress may be caused by the subjects' frantic rush between games to select new weapons. Game anticipation stress did not seem to effect everyone, as can be seen by comparison with the previous subject.

Next, subject 8913's data from session 3 were mapped using his SOM generated with the data from session 6. The results are displayed in the following two figures.

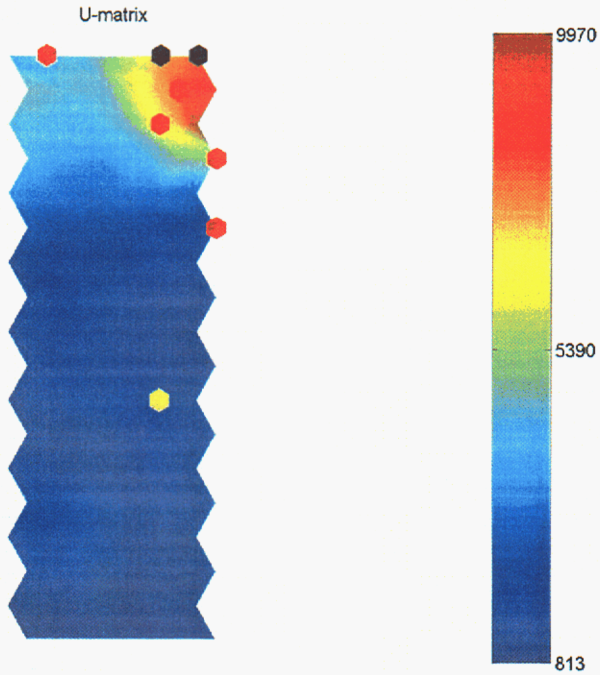

Figure 16: Trained SOM from session 6 and subset of events of interest for subject 8913 from session 3. The color key is: subject's own death (black), comrade's death after his own (red), conflict (yellow).

In session 3, it seems that subject 8913 was greatly concerned about his character's death in the game (black). He was also very disturbed by the deaths of his comrades (red). He was not as concerned in session 3 about conflicts he had with the other players (yellow). Compare these results with session 6. As the sessions progress, 8913 seems to be less concerned with his own character's death, yet continues to be concerned about the deaths of others on his team.

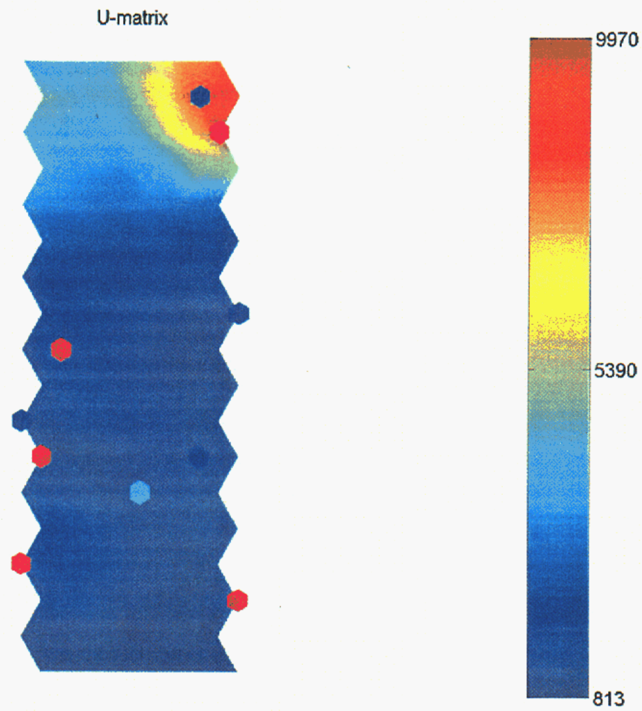

Figure 17: Trained SOM from session 6, and subset of events of interest for subject 8913 from session 3. The color key is: cooperation to aid others (light blue), commands (dark blue), start of new game (pink).

No elaborate plans were devised and executed by the team during session 3, rather, basic commands were issued. A comparison of the figure above with that from session 6 seems to yield little differences in the data. The subject exhibits a wide range of reactions to issuing commands. Only one cooperative event was noted by 8913 in session 3. It should also be noted that during session 3, subject 8913's character was alive for only 30:56 out of the 40:24 session game time. This allowed him less opportunity than the other subjects to come to the aid of others.

Finally, the data for subject 8913 from session 10 was processed through his SOM generated from session 6. The results are shown in the two figures below.

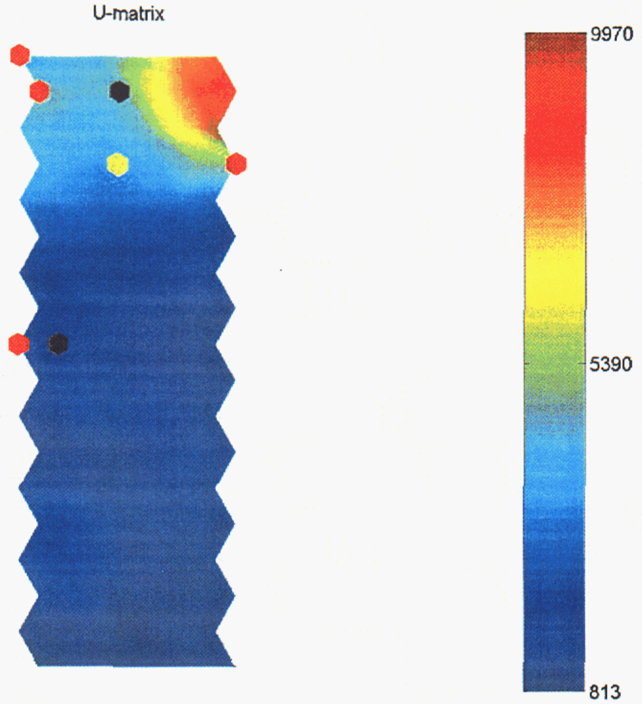

Figure 18: Trained SOM from session 6 and subset of events of interest for subject 8913 from session 10. The color key is: subject's own death (black), comrade's death after his own (red), conflict (yellow). Point of information- the yellow conflict point superimposes a red point.

In the figure above, the subject seems to be greatly concerned about the death of others, although he is less disturbed about his own character's death than he was in session 3. He is still concerned with conflicts among the group. The yellow conflict point above represents two separate conflicts that occurred during the session. In addition, it also superimposes a red point representing the death of a comrade. Again, this outcome often happens with a SOM, since its mapping is not 1-1.

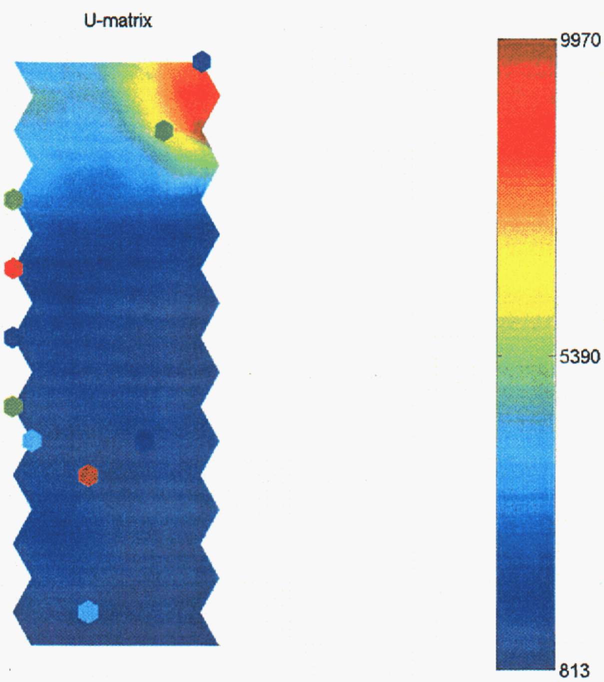

Figure 19: Trained SOM from session 6 and subset of events of interest for subject 8913 from session 10. The color key is: cooperation to aid others (light blue), commands (dark blue), cooperation with others to execute plan (green), start of new game (pink).

The figure above shows the remaining events of interest for 8913 during session 10. At this point in the study, the subjects were conceiving and executing elaborate battle plans under the leadership of 8913 (and others, in cases where 8913's character was dead). These events are plotted in green. 8913 still has a wide range of reactions to issuing commands, likely due to each particular case. However, he does seem to be more comfortable with coming to the aid of others (light blue) than in session 6.

By the end of session 3, 8913 had emerged as the leader of the group. As time went on, he became more concerned about conflicts he had with other group members. He may have been reacting to concern about his position as leader, but we do not make this determination from the data available. At times, 8913 exhibited stress at the beginning of games. As the battle plans he devised (along with other players) became more elaborate, he seemed to exhibit more stress upon their execution. He reacted very differently to executing commands, based on the situation. This continued to be the case throughout the study. As the sessions progressed, he seemed to be more comfortable with coming to the aid of others. From the beginning, he seemed to be very concerned about the deaths of other players and continued to be so throughout the study, even though he began to exhibit less stress about his own character's death. Is this a trait that is exhibited by a leader? It would be an interesting hypothesis to explore in future studies of the same nature.

Subject 6068:

Subject 6068's data from session 6 were used to train a SOM. That SOM was later used to chart his data from session 3 and session 10. It is important to note that subject 6068 was not present for sessions 7-9, and was reintroduced to the group at session 10. Therefore, one may expect him to exhibit a higher level of stress during session 10 than other subjects who were present for the entire study.

Below are displayed subject 6068's SOM and events of interest points using the training data from session 6. In this case, there were two levels of high stress in the map (red background). More exploration is needed to determine what has caused this, but it may possibly be do to conflicting physiological parameters (i.e., one red area may be associated with high heart rate but no movement, and another area many be associated with movement and low heart rate).

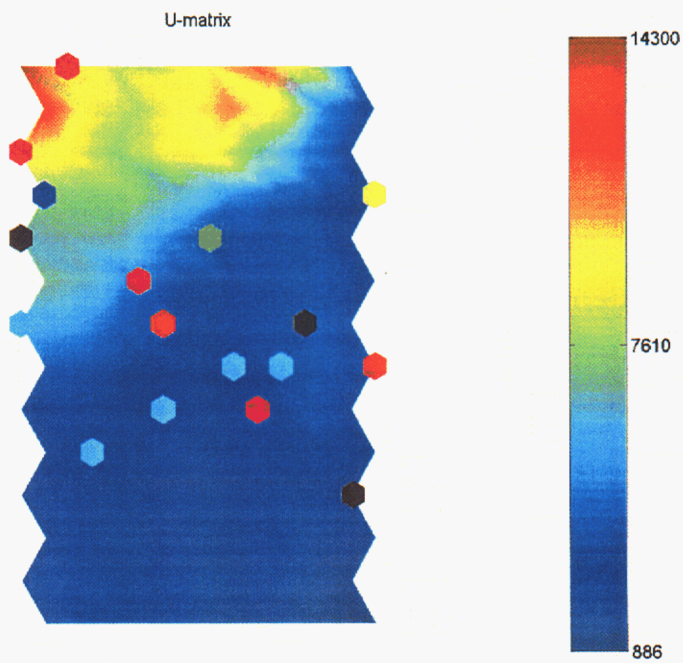

Figure 20: Events of interest for subject 6068 from session 6, plotted on the SOM trained from the same data. The color key is: subject's own death (black), comrade's death after his own (red), cooperation to aid others (light blue), conflict (yellow), cooperating with others to execute plan (green), start of a new game (pink), following moments (blue).

An examination of the figure above seems to indicate the subject reacts more strongly to the beginning of a game than anything else. Game anticipation stress seemed to be a consistent trait with this particular subject. The subject also seemed to exhibit stress when he was assuming a following role (dark blue). But he seemed more comfortable with coming to the aid of others (light blue), as well as his own character's death (black).

6068 displayed some stress over the deaths of his comrades, but not to the extent that these events erupted to the high stress level.

Next, the data from session 3 was examined, using the same SOM.

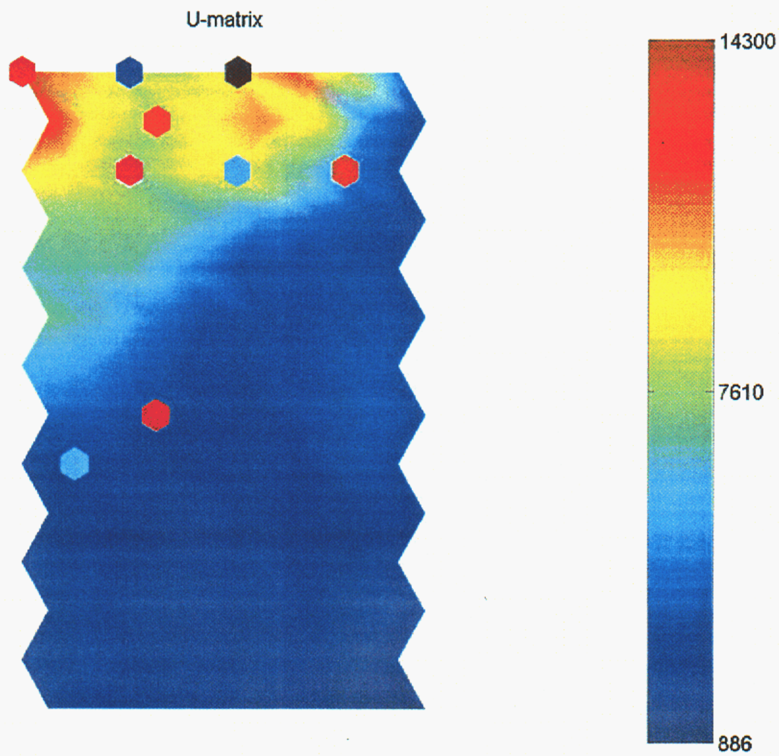

Figure 21: Events of interest for subject 6068 from session 3, plotted on the SOM trained from session 6 data. The color key is: subject's own death (black), comrade's death after his own (red), cooperation to aid others (light blue), start of new game (pink),

The figure above shows 6068's reactions in session 3. Again, he seems to exhibit high stress at the start of new games. He also exhibits high stress at his character's death (black), or when he is assuming a following role (dark blue). It is interesting to note that like 8913, he seems to be concerned over the deaths of comrades, although he does not exhibit the highest stress levels. There are two alternative reasons why this may be true. First of all, in this session, most of his comrades' deaths occurred at the end of games. In addition to exhibiting stress at the beginning of games, a jump in 6068's heart rate was observed at the end of games. Often, in this session, 6068 was observed to turn his head to look at another subject after his character had been killed in the game. This action may have led to a high stress mapping in the SOM. This hypothesis is supported by the following observation. When heart rate data was examined, it was discovered that for this session, the comrade deaths that occurred before the end of games were not accompanied by a spike in the heart rate of subject 6068.

Finally, the data from session 10 is displayed below, on the same SOM from session 6.

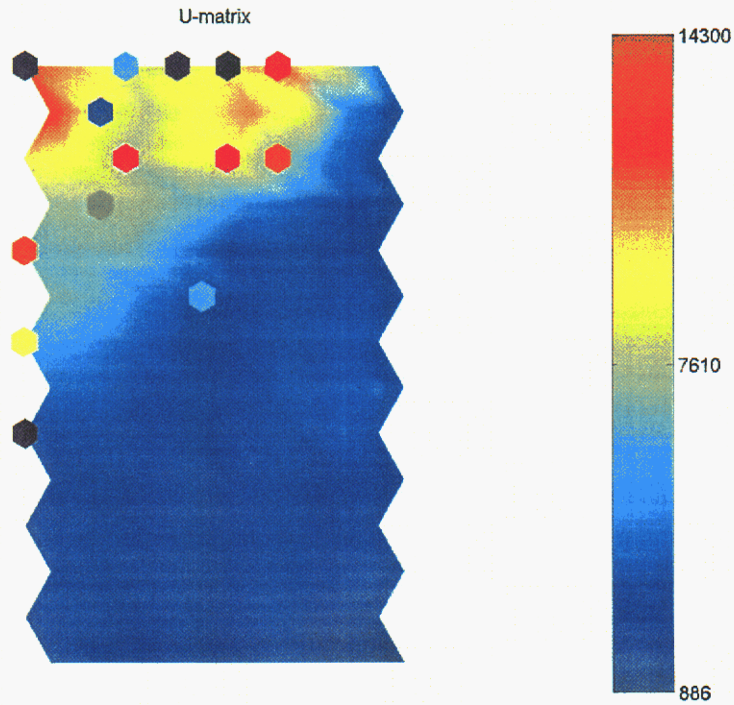

Figure 22: Events of interest for subject 6068 from session 10, plotted on the SOM trained from session 6 data. The color key is: subject's own death (black), comrade's death after his own (red), cooperation to aid others (light blue), start of new game (pink)

It seems from the figure above that the subject exhibits stress in reaction to almost all events of interest in session 10. This plot seems very similar to that of session 3. Recall that the subject was absent for sessions 7-9, and reintroduced in session 10. During his absence, his comrades had three sessions to train with a new game setting and map that he saw for the first time in session 10. He likely forgot some of the nuances of the game in the interim, as well. The result is that, although the subject seemed somewhat comfortable with the game during session 6, stress levels equivalent to the beginning of the session sequence were observed for this subject during session 10. Although 8086 exhibited more stress upon his reintroduction to the game, it seemed to have no effect on the other subjects' individual data (see 8913 above, and 7621 below).

The data examined for subject 6068 seem to indicate the following. He seemed to consistently exhibit the most stress at the beginning of a game. This was true even in session 6, when he had become accustomed to the game and became more comfortable with other events. Although he did not take a leadership role in the sessions, his data seem to indicate that he was not very comfortable in a follower role, either. His reintroduction into the game after a three session hiatus seemed to cause his stress levels to reset to their early session levels. Perhaps in the future a more lengthy study could be performed to determine if other players stress levels reset after being removed from the game.

Subject 7621

For this subject, it was decided to train his SOM using the data of session 4. His data from sessions 3 and 10 were tested through the trained network. It must be emphasized that a SOM is an *unsupervised* training method, and there is not a guarantee how the final map will look. In the case of subject 7621, the final map appears inverted from the previous subjects, with the red area of high stress located in the bottom right corner, as is shown in the figure below.

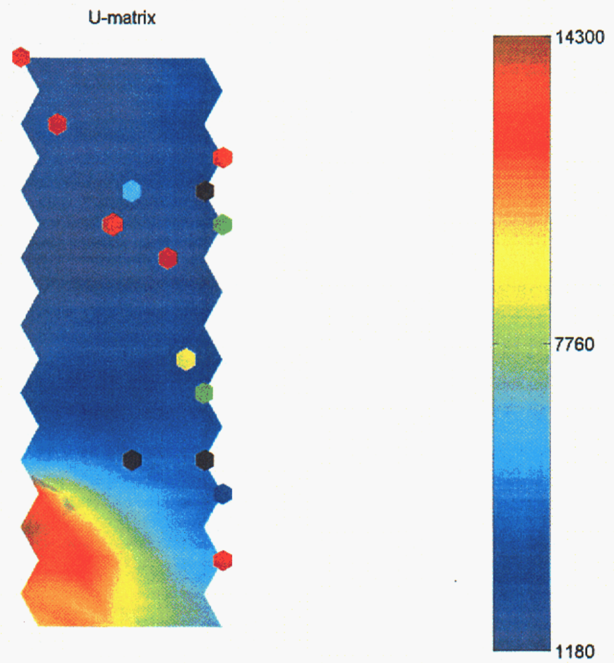

Figure 23: Events of interest for subject 7621 from session 4, plotted on the SOM trained from the same data. The color key is: subject's own death (black), comrade's death after his own (red), cooperation to aid others (light blue), conflict (dark blue), cooperation with others to execute plan (green), start of a new game (pink), issuing commands (yellow).

In addition, the convention of labeling commands as dark blue, and conflict as yellow has been inverted in this figure. Given the location of the plotted command point, it was impossible to see it in blue as it was on a blue background. From the session 4 data, the subject does not seem to be very concerned about the deaths of others. If one looks at the points that are plotted, one might say 7621 does not seem to be very stressed about anything. If this were not the training data, one might be true. However, some events in the data necessarily map to the red (stress) area. A comparison of the video and physiological data did not yield any further insights about what may have been the stressful events for subject 7621 in session 4.

Below is the data for the same subject from session 3.

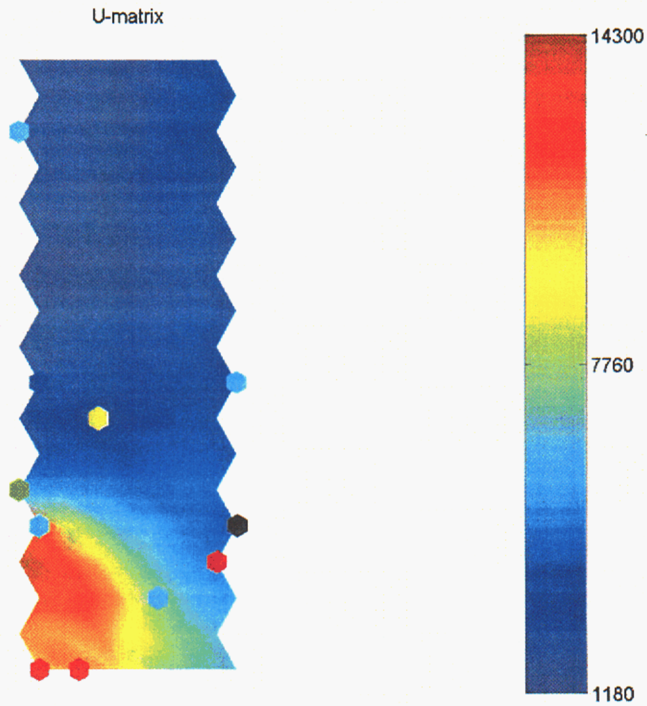

Figure 24: Events of interest for subject 7621 from session 3, plotted on the SOM trained from session 4 data. The color key is: subject's own death (black), comrade's death after his own (red), cooperation to aid others (light blue), conflict (dark blue), following commands (green), start of new game (pink), issuing commands (yellow). It is important to note the yellow point in the figure superimposes a red point.

There were no elaborate plans executed in session 3. Thus, green was used to indicate a rare following statement from subject 7621. Note how he expresses more stress at being in a following position (green) than he does at issuing a command (yellow). As noted previously in this report, later subject 7621 split off to a certain extent from subject 8913 to form his own team. In this session, the subject seems to be more concerned about lending aid to others (light blue) and the beginning of games (pink) then he does about his own character's death. The one death of a comrade experienced in the session is displayed in yellow as well, since it maps to the same point as when 7621 was issuing a command. In this case, the subject does not exhibit a great deal of stress.
Finally, the session 10 data for 7621 was mapped through the SOM. The results are displayed below. As there was more than one overlapping point, the data is split into two figures.

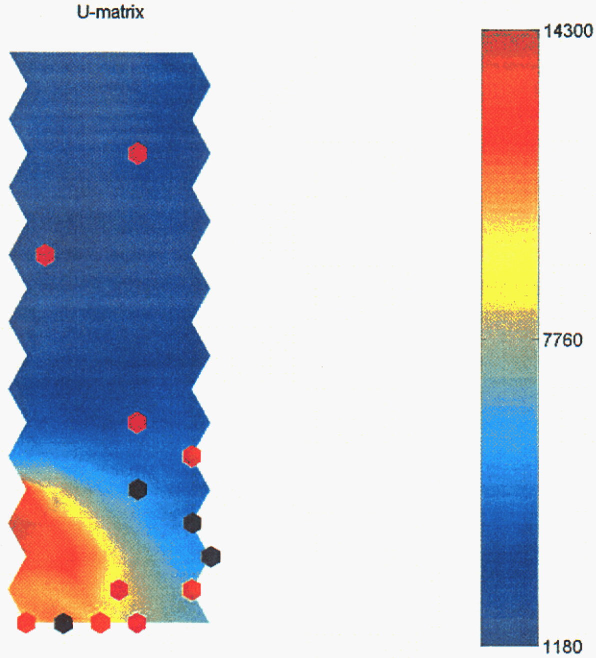

Figure 25: Events of interest for subject 7621 from session 10, plotted on the SOM trained from session 4 data. The color key is: subject's own death (black), comrade's death after his own (red), start of new game (pink).

The data seems to indicate that an interesting development occurred over the course of the study. By session 10, 7621 seems to be very concerned over the deaths of his comrades. An examination of 7621's heart rate data from session 10 supports this supposition. In fact, this comrade death data is beginning to look more like the data 8913 produced over the entire sessions. What could this mean? Recall that 7621 and 8913 split off to be in charge of their own teams. Could this be the signature of a leader? Another possibility is that it could be the signature of a team operating more as a unit. That is, the players are showing more interest in the game, are comfortable with each other, and are concerned about what happens to their comrades. Yet another option is that as time goes on, group members may tend to adopt the reactions of the team leader. We cannot conclude which, if any, of the possibilities listed above is correct.

This artifact was not displayed in the other two subjects who participated in session 10. However, one was new to the study, having only played in 3 previous sessions, and the other was returning to the game after a 3 session hiatus. It would be interesting to see if team cohesion emerges in a unit in which all subjects have been to all sessions.

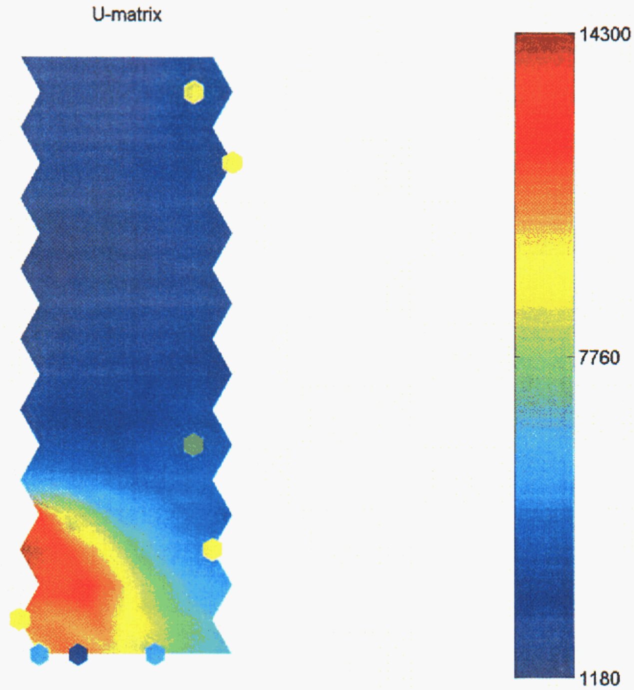

Figure 26: Events of interest for subject 7621 from session 10, plotted on the SOM trained from session 4 data. The color key is: cooperation to aid others (light blue), conflict (dark blue), cooperating with others to execute plan (green), issuing commands (yellow).

In session 10, subject 7621 exhibits the same reaction to giving commands (yellow) as was observed with subject 8913. In addition, 7621 exhibits great stress over conflicts (dark blue), and coming to the aid of others (light blue).

No firm conclusions can be drawn from the data presented here. It is very interesting to note that in session 10, the data from 7621 began to look very much like the data of the leader, 8913. Several possibilities were given for this artifact. However, it is impossible to determine given the scope of the current study, what the cause may be.

Subject 4564:

Since this subject was present for only a small part of the experiment, his data was examined in detail for one session only. Session 7, the first session in which he participated, was used. The results are presented below.

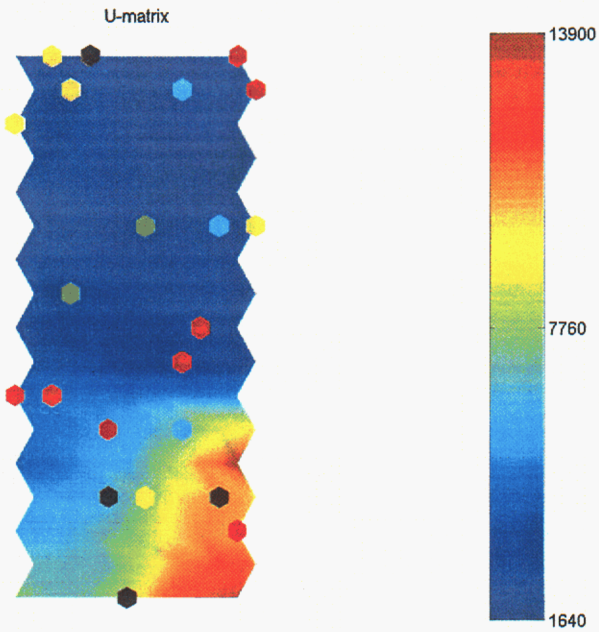

Figure 27: Events of interest for subject 4564 from session 7, plotted on the SOM trained from the same data. The color key is: subject's own death (black), comrade's death after his own (red), cooperation to aid others (light blue), following events (green), start of new game(pink), issuing commands (yellow).

No conflicts were observed between 4564 and other subjects during session 7. At first glance, the subject seems to react strongly at the beginning of most games (pink). However, a closer examination of the data revealed that the strongest responses were noted at the start of the first 2 games, after which, the subject's stressful responses to the anticipation of the game subsided. Recall that this was the first session in which this subject participated. The pattern can be attributed to him exhibiting uncertainty of the game in the beginning, then becoming more accustomed to it as the session wore on. Although this was the subject's first session, he seemed to exhibit at least moderate concern over the death of his comrades. This is similar to what was observed for subject 8913 during session 3. Of special note here is 4564's response to issuing commands (yellow). Although this was his first session, and he was breaking in to a clearly established hierarchy, he seems to be quite comfortable with issuing commands. In general, he seems more stressed by taking the following role (green), than by taking the leadership role. This is remarkable, considering the subject was a complete novice at the game and was routinely making inquiries concerning keyboard commands, etc.. It would have been interesting to observe how the group dynamics would have emerged had 4564 been present for the entire study.

Summary of study of SOMs for individuals

No general conclusions on individual or group dynamics and physiology are made here. However, based on the data collected and processed for the five test subjects who participated in the study, the following observations were noted:

1) Subject 4859 seemed to be comfortable in the role of follower.
2) Subject 8913 (the leader of the group) seemed to exhibit more stress regarding conflict and the execution of plans as the study developed and the plans became more elaborate. Whether this was an expression of concern in retaining his position as leader is undetermined and remains a question for future study.
3) Subject 8913, from the earliest sessions, reacted with concern over the deaths of his comrades, even after his own character was dead. Whether or not this is the characteristic of a leader is an interesting question.
4) Subject 6068 seemed to consistently exhibit the most stress at the beginning of each game. In session 6, he seemed more relaxed in general and less affected by the events of the game than in session 3. He was absent for sessions 7-9, and upon his return in session 10, he displayed nearly the same stress responses as in session 3. His hiatus from the game apparently caused his stress responses to, in effect, reset.
5) By session 10, subject 7621's data began to look very much like subject 8913's. Midway through the study, although 8913 retained ultimate leadership, 7621 split off to be in charge of his own team. The fact that his data by session 10 began to resemble that of the leader's (showing high concern for comrades, etc.) lends support to the idea that such responses may be traits of a leader. Alternatively, it could also be the case that over time team members will begin to emulate the responses of the leader. Another possibility is that it is a signature of a team in cooperation.
6) Subject 4564, although he was not introduced to the game until session 7 and was a complete novice, seemed very comfortable in roles that required him to demonstrate leadership. An interesting hypothetical question is: would the group dynamics have evolved differently had 4564 been present for all sessions?

Potential Impact and Opportunity

The preceding was a structured observation involving a very small group of subjects. What potential does it demonstrate for the MENTOR/PAL concept? The vision is for the final system to have feedback capability, and for the PAL to be a wireless device. It could be possible to outfit every subject with a SOM or similar network on his/her PAL. Due to the fact that the computational cost of a SOM is carried in its training, checking new data points for their meaning on the map is quite cheap in terms of complexity. As such, it would be straightforward to program the PALs to monitor the general well being of their users. Action could be taken by MENTOR if the data were outside normal ranges.

Here is one possible scenario. The MENTOR/PAL© lab equipment has the capability to install eye tracking devices. Suppose two subjects were not looking at the computer screen, and their stress levels were rising. It is reasonable to assume they were involved in a conflict. If their stress levels approach high levels, it is likely the conflict is no longer constructive. Under such a situation, the PALs could issue a signal to MENTOR, and MENTOR could respond by instructing one of the other subjects to say, "Hey, we could use some help over here." Or MENTOR could instruct the two subjects having the conflict to "Look at the computer screen."

Self-Organizing Maps (A Group Approach)

Studying the data from each individual is only half the story, the health of the team is important as well. How are they performing? Are they effective in their current configuration? What has worked in the past that can improve the situation today? In this work, a group trained self-organizing map was used as a first step to search for the answers to these questions.

The data vectors to the SOM were exactly the same as in the previous section. The only difference is that the data from all subjects were combined. Thus, the SOM would train based on the experiences of four subjects, not one. The data selected for training the group SOM was from session 3.

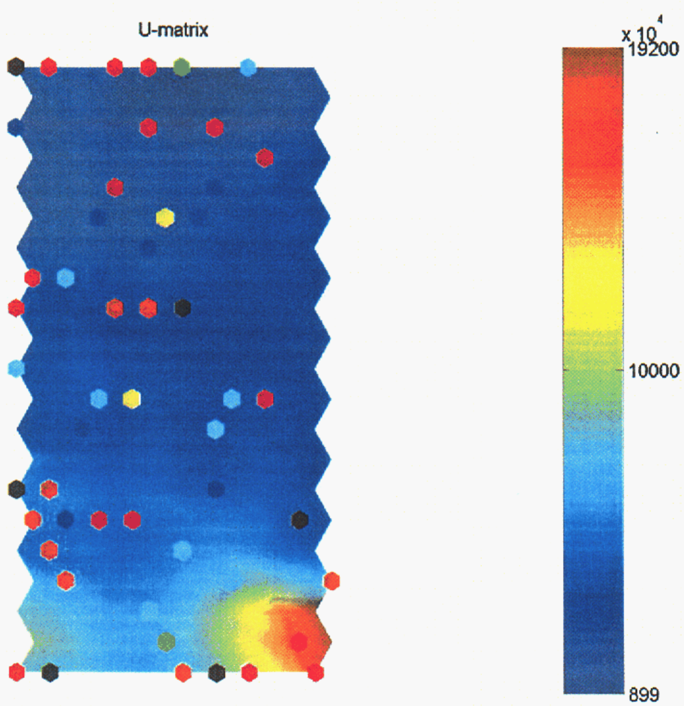

Figure 28: Events of interest for the entire group from session 3, plotted on the SOM trained from the same data. The color key is: subject's own death (black), comrade's death after his own (red), cooperation to aid others (light blue), conflict (yellow), following events (green), start of new game (pink), issuing commands or following (dark blue).

Above is plotted the group SOM data for session 3. The data used for training was also for session 3. The data plotted in this figure is a conglomeration of all the session 3 data plotted individually in the previous session.

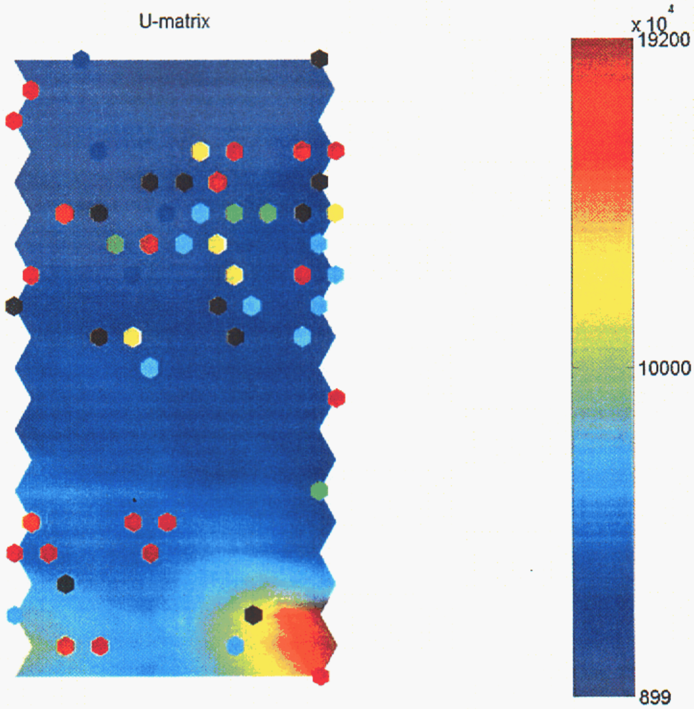

Figure 29: Events of interest for the entire group from session 6, plotted on the SOM trained from session 3 data. The color key is: subject's own death (black), comrade's death after his own (red), cooperation to aid others (light blue), conflict (yellow), following events(green), start of new game (pink), issuing commands or following (dark blue).

Above is plotted group data from session 6, using the SOM generated with session 3 data. The points plotted are a combination of all individual points of interest for session 6. What is important to note is the comparison of session 6 with session 3. In general, in session 6 there are more points clustered in the region of the figure corresponding to less stress (blue background). Note the comparison of cooperation events (light blue). Comparing sessions 3 and session 6 one will note that in session 6 the subjects seem to be much more comfortable with coming to the aid of others. This could indicate a characteristic of desirable group behavior.

Unfortunately for this phase of the study, the group changed after session 6 and the same four subjects were never together again. Thus, results can be discussed from session 10, but only the data from the 3 subjects who were in session 6 can be included. To involve the data of subject 4563 on a SOM for which it was not trained would have no expectation of reliability.

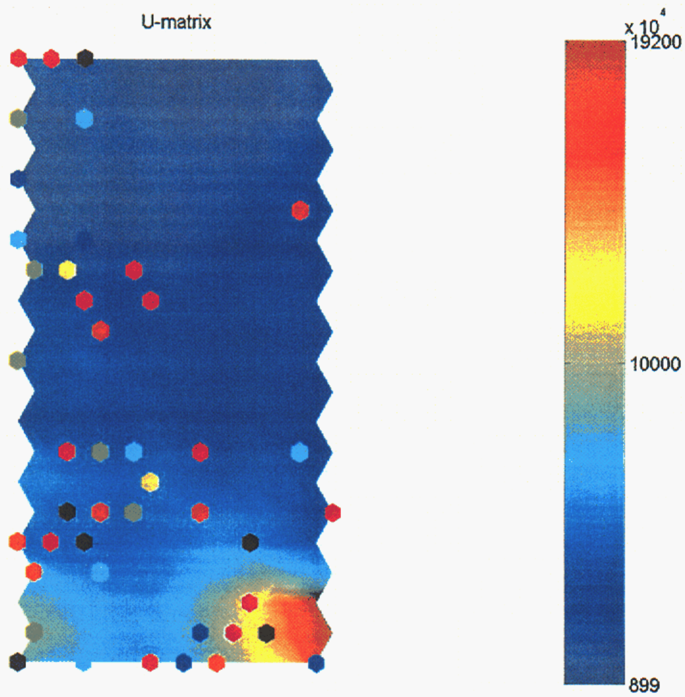

Figure 30: Events of interest for subjects 6068, 7621 and 8913 from session 10, plotted on the SOM trained from session 3 data. The color key is: subject's own death (black), comrade's death after his own (red), cooperation to aid others (light blue), conflict (yellow), following events (green), start of new game (pink), issuing commands or following (dark blue).

If one disregards that there are fewer points plotted in the figure (3 subjects instead of 4 were plotted), it seems as if there is a change in the group dynamics since session 6. Primarily, the group has moved to a higher stress level. Although the game map from session 10 was different than session 6, the settings were identical. The subjects were playing at the most difficult level. Why, then, is there a shift? Could this shift have been caused by the new player, 4564, or the reintroduction of 6068? As was demonstrated in the previous section, the stress levels of 6068 seemed to reset to high when he was reintroduced to the game. Perhaps he alone is responsible for the group shift. In order to determine if it could be true, the figure above was regenerated with subject 6068's data removed. The results of this exercise are shown below.

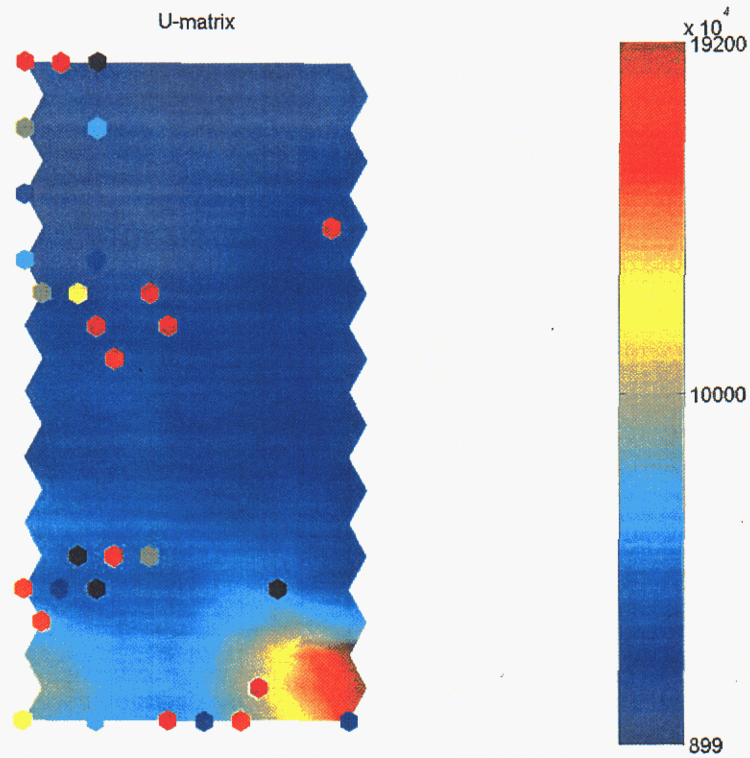

Figure 31: Events of interest for subjects 7621 and 8913 from session 10 (subject 6068's data has been removed), plotted on the SOM trained from session 3 data. The color key is: subject's own death (black), comrade's death after his own (red), cooperation to aid others (light blue), conflict (yellow), following events (green), start of new game (pink), issuing commands or following (dark blue).

Although there are fewer high stress points in the figure, the reduction seems to be proportional to the loss of 1/3 of data. From this figure, it seems that the remaining two subjects are very affected by issuing commands and conflicts within the group. Yet these findings did not surface in their individual SOMs. What could it mean? One explanation is that group dynamics and individual dynamics are different. The reintroduction of 6068, although it did not seem to influence the individual performance of a majority of subjects, affected the performance of the group as a whole. This is a hypothesis worth exploring.

Potential Impact and Opportunity

The preceding exercise yielded a number of observations and posed a number of questions. It demonstrated that it may be possible to monitor the collective group "health" using a communally trained SOM. It also suggested that as a group becomes accustomed to working together, their data on the group map tends to migrate away from the high stress region. In addition, it implied that the introduction or reintroduction of a new member of the group affects the group health. Although the change may not be witnessed on the individual SOMs, it may be possible to observe the change on the group SOM. Further research is required in this area.

What does this imply for MENTOR? The results above seem to indicate that the individual SOM is not the complete story. There is much information about the group health and effectiveness that is potentially contained in the group SOM, and may not be present in the individual SOM. MENTOR could keep track of the group dynamics and effectiveness. For instance, in this application, the desirable would be to have a majority points in the "blue" area. If MENTOR began to see the group position drift away from the desirable area, it could consult with the PALs and potentially take action. A possible action may be to have a player sit out a game, or it may be to direct all the subjects to take a few moments to decide on a game strategy.

6. Summary

In phase one of this study, a MENTOR/PAL© testbed was constructed, and found to be fully functional. In phase two, test subjects were recruited and asked to collaborate in a group video game. While the subjects played the game, the testbed equipment was used to collect various physiological and somatic data from the subjects. In addition, audio, video and game scores were recorded. A total of 10 sessions were conducted. In each session, the settings of the video game were adjusted to make the game more challenging. As an added stress, subjects were rotated in and out of the study, which forced the remaining subjects to become accustomed to a different group make up.

Analysis began by watching the subjects play the game and making observations concerning leadership and cooperation characteristics of the group. Game performance, both group and individual, was analyzed. Each session videotape was analyzed for examples of events of interest, including cooperation, conflict, leadership, and character death. These events of interest were time synchronized and compared to the heart rate data, using time/frequency techniques, to check for correlations. Correlations were found, and evidence of group cooperation was also isolated using the heart rate data.

The results of the heart rate analysis lead to the development of two different ways to approach the physiological and somatic data using self-organizing maps (SOMs). Both approaches were tested on actual subject data and found to yield interesting potential for future use. One approach was developed using separate SOMs to monitor the productivity of each individual. It was shown that a separate SOM was needed for each individual. The second approach used a conglomeration of data for the group to train a SOM to monitor the effectiveness of the group. It was shown that this SOM may be able to identify signatures of group cooperation and conflict. It was suggested that both types of SOMs be used in conjunction to improve the functionality of the group. Suggestions were given concerning how the two SOMs may be used together.

The work represented in this report constitutes the first steps in the development of research in this area at Sandia. Its purpose is to demonstrate proof of concept and pose questions that can be explored in future studies.

7. Observations

The following observations are particular to this study and are not meant to imply any conclusions outside of the study. However, they may suggest areas of future exploration using a larger subject set.

1) By the end of session 3, one subject emerged as the leader of the group. His physiological data demonstrated that he would react to concern over the mishaps of other test subjects, even after his character had been eliminated from the game.
2) By the end of session 6, a split occurred in the group, with an heir apparent branching off to be in charge of his own team. By the end of the study, his SOM data began to emulate that of the leader.
3) As the session progressed, the general trend observed in the SOM data through session 6 is that the subjects became more comfortable working together.
4) Individual SOM data suggests that some subjects seem comfortable in the role of follower.
5) Pulling a subject out of the game midway through the sessions, and reintroducing him for the last session, caused the subject's stress levels to reset to those encountered at the beginning of the sessions. It may also have an effect on the group. Although the effect on the group might not be observable in their individual SOMs, the group SOM of MENTOR seems to suggest the group was no longer as effective.
6) There was an indirect relationship in the game scores between killing effectiveness and time spent alive.

8. Suggestions for Future Work

This report has only begun to explore the potential of a MENTOR/PAL© system. Eventually, such systems could transform the way humans and computers work together, making humans a part of the system. Throughout the body of this report, suggestions were made for future study. They are included here.

1) Inclusion of EEG collection in future work may provide evidence of a correlation in what is termed in this report "low confidence events." The addition of EEG data would no doubt create a more accurate SOM.
2) Eye tracking technology could be implemented and incorporated into the SOM to make much of the classification of "high confidence events" automatic.
3) Running parallel studies using multiple subject groups on the same tasks would help to confirm or disprove the observations noted in this study.
4) The leader of the group seemed to exhibit stress at the death of others, and later, another member of the group seemed to behave the same way. Further testing

should be done to determine if this is a signature of leadership, collaboration, or coincidence.

5) Further analysis should be performed on the effect on the group of having subjects enter and exit the study at prescribed intervals.
6) The MENTOR/PAL© concept should be explored further to find if there is truly is a difference between individual and group physiological dynamics as was observed in this study.
7) More recorded data parameters could be included in the SOM training to likely produce a more complete picture of group effectiveness.
8) The Human Studies Board agreement could be amended allowing for two independent observers to view the videotapes. Such analysis could produce publishable results and supporting material for physiological data findings.
9) A specialized wavelet based transform could be designed to examine heart rate and other data with desired time/frequency resolution in spectral areas of interest.

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Appendix A: Game Scores

Summary:

Session 2

Wins: 9 Losses: 2 Total time: 35:26

Subject	Kills	Deaths	Time alive
4859	4	3	32:39
6068	7	4	28:43
7621	20	2	35:22
8913	23	3	28:01

Session 3

Wins: 4 Losses: 4 Total time: 40:24

Subject	Kills	Deaths	Time alive
4859	21	2	40:24
6068	12	3	32:11
7621	47	3	34:23
8913	45	3	30:56

Session 4

Wins: 4 Losses: 5 Total time: 34:46

Subject	Kills	Deaths	Time alive
4859	5	3	28:04
6068	6	2	33:11
7621	27	3	29:30
8913	40	2	34:41

Session 5

Wins: 9 Losses: 1 Total time: 34:12

Subject	Kills	Deaths	Time alive

4859	4	2	31:42
6068	13	3	32:36
7621	60	1	34:12
8913	69	2	33:05

Session 6

Wins: 1 Losses: 8 Total time: 34:01

Subject	Kills	Deaths	Time alive
4859	5	6	30:12
6068	3	7	24:19
7621	15	7	27:39
8913	24	7	23:04

Session 7

Wins: 1 Losses: 5 Total time: 48:10

Subject	Kills	Deaths	Time alive
4859	11	5	46:33
7621	4	6	37:58
8913	10	5	33:36
4564	8	5	41:32

Session 8

Wins: 0 Losses: 9 Total time: 35:08

Subject	Kills	Deaths	Time alive
4859	2	3	28:39
7621	14	5	25:57
8913	27	5	29:31
4564	3	5	29:21

Session 9

Wins: 0 Losses: 11 Total time: 32:47

Subject	Kills	Deaths	Time alive
4859	2	9	23:52
7621	7	8	24:08

8913	11	6	23:59
4564	2	5	28:27

Session 10

Wins: 0 Losses: 6 Total time: 47:10

Subject	Kills	Deaths	Time alive
7621	3	5	29:34
8913	10	3	36:57
4564	3	4	42:23
6068	2	4	43:12

Session 2:

Game 1- Time 4:01				Win
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
4859	0	0	33	
6068	1	0	40	
7621	2	0	66	
8913	2	0	75	
Game 2- Time 2:25				**Win**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
4859	0	0	70	
6068	0	0	70	
7621	1	0	100	
8913	4	0	41	
Game 3- Time 1:40				**Win**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
4859	0	0	50	
6068	1	0	25	
7621	4	0	83	
8913	1	1	25	Killed 0:48
Game 4- Time 10:05				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
4859	1	1	50	Killed 7:17
6068	0	1	5	Killed 6:07
7621	0	1	0	Killed 10:05
8913	3	1	20	Killed 3:51
Game 5- Time 4:20				**Win**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
4859	0	0	0	
6069	0	0	0	
7621	3	0	13	
8913	2	0	21	

Game 6- Time 1:37				Win
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
4859	0	1	0	Killed 1:32
6068	1	1	100	Killed 1:01
7621	2	0	50	
8913	2	0	100	
Game 7- Time 2:03				**Win**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
4859	1	0	66	
6068	0	0	0	
7621	2	0	66	
8913	2	0	100	
Game 8- Time 3:08				**Win**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
4859	1	0	2	
6068	1	1	33	1:16
7621	1	0	50	
8913	2	0	100	
Game 9- Time 1:29				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
4859	0	1	0	Killed 1:15
6068	0	1	0	Killed 1:12
7621	1	1	25	Killed 1:29
8913	1	1	100	Killed 1:10
Game 10- Time 2:26				**Win**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
4859	1	0	100	
6068	0	0	0	
7621	3	0	100	
8913	1	0	100	
Game 11-	Time 2:12			Win
Subject	Kills	Deaths	Shooting %	
4859	0	0	0	
6068	3	0	75	

7621	1	0	100	
8913	1	0	100	

Session 3:

Game 1-Time 7:19				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
8913	1	1	100	Killed 3:01
7621	9	1	100	Killed 2:45
4859	2	1	8	Killed 7:19
6068	0	1	0	Killed 4:05
Game 2- Time 6:20				**Win**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
8913	9	0	77	
7621	5	0	50	
4859	1	0	50	
6068	0	0	10	
Game 3- Time 2:35				**Win**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
8913	8	0	50	
7621	4	0	50	
4859	2	0	0	
6068	1	0	21	
Game 4- Time 6:15				**Win**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
8913	1	1	100	Killed 1:40
7621	9	1	83	Killed 4:48
4859	4	0	56	
6068	1	1	15	Killed 2:40
Game 5- Time 7:15				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
8913	3	0	66	
7621	4	0	62	
4859	4	0	100	
6068	4	0	83	

Game 6- Time 3:02				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
8913	4	0	54	
7621	1	0	50	
4859	2	0	66	
6068	1	0	50	
Game 7- Time 2:22				**Win**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
8913	4	1	53	Killed 1:47
7621	8	0	43	
4859	0	0	25	
6068	1	0	100	
Game 8- Time 3:20				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
8913	8	0	65	
7621	6	0	83	
4859	3	0	54	
6068	1	1	33	Killed 1:56

Session 4:

Game 1- Time 3:37				Loss
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
8913	4	0	70	
7621	3	0	83	
6068	0	0	0	
4859	0	0	0	
Game 2- Time 3:45				**Win**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
8913	8	0	47	
4859	1	0	33	
7621	1	1	100	Killed 2:56
6068	0	0	0	
Game 3- Time 2:36				Loss
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
7621	4	0	100	
4859	2	0	100	
8913	2	0	40	
6068	1	0	100	
Game 4- Time 2:30				Loss
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
8913	4	1	71	Killed 2:30
4859	1	1	25	Killed 2:25
6068	0	1	33	Killed 1:20
7621	0	1	0	Killed 0:17
Game 5- Time 5:57				Loss
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
7621	5	1	83	Killed 3:43
8913	3	1	100	Killed 5:52
6068	1	0	100	Killed 5:32
4859	0	1	0	Killed 5:57

Game 6- Time 4:03				Win
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
7621	5	0	80	
8913	4	0	80	
4859	1	0	40	
6068	0	1	100	Killed 2:34
Game 7- Time 7:05				Win
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
8913	5	0	35	
6068	4	0	71	
4621	1	0	36	
4859	0	1	0	Killed 0:28
Game 8- Time 2:49				Win
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
8913	6	0	100	
7621	4	0	66	
6068	0	0	0	
4859	0	0	0	
Game 9- Time 2:24				Loss
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
8913	4	0	100	
7621	4	0	80	
6068	0	0	50	
4859	0	0	0	

Session 5:

Game 1- Time 5:22				Loss
Subject	Kills	Deaths	Shooting %	Time killed
8913	7	1	50	Killed 2:30
6068	3	1	80	Killed 2:30
7621	2	1	25	Killed 2:30
4859	1	1	66	Killed 5:22
Game 2- Time 2:35				**Win**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
8913	8	0	75	
7621	7	0	77	
4859	0	0	0	
6068	0	0	0	
Game 3- Time 4:48				**Win**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
8913	8	0	75	
7621	7	0	77	
4859	0	0	0	
6068	0	0	0	
Game 4- Time 3:18				**Win**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
8913	8	0	71	
7621	4	0	80	
6068	3	0	60	
4859	0	1	0	0:48
Game 5- Time 3:47				**Win**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
8913	7	0	57	
7621	6	0	62	
6068	2	0	28	
4859	0	0	0	

Game 6- Time 2:05				**Win**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
8913	9	0	91	
7621	5	0	72	
6068	1	0	20	
4859	0	0	0	
Game 7- Time 2:56				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
7621	7	0	76	
8913	6	0	46	
4859	1	0	100	
6068	0	1	0	Killed 0:46
Game 8- Time 4:04				**Win**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
8913	6	0	77	
7621	5	0	77	
4859	2	0	100	
6068	2	0	80	
Game 9- Time 2:53				**Win**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
7621	9	0	92	
8913	4	1	80	Killed 1:46
6068	2	0	60	
4859	0	0	0	
Game 10- Time 2:24				**Win**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
7621	8	0	75	
8913	5	0	87	
4859	2	0	62	
6068	0	1	0	Killed 0:48

Session 6:

Game 1- Time 4:51				Loss
Subject	Kills	Deaths	Shooting %	Time killed
8913	7	0	71	
4859	2	0	37	
6068	0	1	0	Killed 0:44
7621	0	1	0	Killed 0:36
Game 2- Time 1:40				**Loss**
Subject	Kills	Deaths	Shooting %	Time killed
8913	3	1	100	Killed 1:08
6068	1	1	33	Killed 1:40
4859	0	0	100	Killed 1:08
7621	0	1	0	Killed 1:40
Game 3- Time 2:52				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
8913	2	1	66	Killed 1:33
7621	1	1	33	Killed 1:40
4859	0	1	25	Killed 2:52
6068	0	1	0	Killed 1:47
Game 4- Time 5:40				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
6068	0	1	0	Killed 5:38
7621	1	1	100	Killed 4:44
4859	0	1	0	Killed 3:01
8913	0	1	25	Killed 1:53
Game 5- Time 5:14				**Loss**
Subject	**Killed**	**Deaths**	**Shooting %**	**Time killed**
8913	4	1	62	Killed 4:10
7621	1	1	20	Killed 5:13
6068	0	1	0	Killed 4:44
4859	0	1	0	Killed 4:44

Game 6- Time 0:34				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
4859	0	1	0	0:34
6068	0	1	0	0:34
8913	0	1	0	0:14
7621	0	1	0	0:27
Game 7- Time 7:06				**Loss**
Subject	Kills	Deaths	Shooting %	Time killed
7621	6	1	87	Killed 7:06
4859	1	1	50	Killed 6:58
8913	1	1	11	Killed 3:18
6068	0	1	0	Killed 3:08
Game 8- Time 2:27				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
8913	4	1	80	Killed 2:20
7621	2	0	50	
4859	1	0	100	
6068	0	0	100	
Game 9- Time 3:37				**Win**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
8913	3	0	100	
6068	2	0	100	
4859	1	0	50	
7621	4	0	70	

Session 7:

Game 1- Time 4:30				Loss
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
4564	2	1	28	Killed 4:30
7621	1	1	25	Killed 3:35
8913	1	1	14	Killed 3:35
4859	0	1	0	Killed 3:38
Game 2- Time 6:28				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
8913	2	0	80	Killed 2:28
7621	0	1	0	Killed 2:28
4859	2	1	66	Killed 6:28
4564	0	1	3	Killed 6:28
Game 3- Time 8:53				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
4859	3	1	37	Killed 8:53
4564	1	1	11	Killed 8:45
8913	1	1	18	Killed 6:26
7621	0	1	21	Killed 6:18
Game 4- Time 8:04				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
4859	6	1	72	Killed 8:04
4564	1	1	33	Killed 5:41
8913	0	1	100	Killed 4:59
7621	0	1	0	Killed 5:08
Game 5- Time 7:02				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
7621	1	1	100	Killed 5:05
8913	1	1	100	Killed 2:55
4564	1	1	66	Killed 2:55
4859	0	1	0	Killed 7:02
Game 6- Time 13:13				**Win**

Subject	Kills	Deaths	Shooting %	Time killed
8913	5	0	44	
4564	3	0	56	
7621	2	1	65	Killed 12:28
4859	0	0	40	

Session 8:

Game 1- Time 2:50				Loss
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
8913	3	1	46	Killed 2:50
7621	1	1	100	Killed 2:41
4564	0	1	0	Killed 2:45
4859	0	1	0	Killed 2:50
Game 2- Time 5:15				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
8913	4	0	53	
7621	3	0	55	
4564	0	0	0	
4859	0	0	0	
Game 3- Time 7:07				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
8913	5	0	53	
4564	1	0	40	
7621	1	1	50	Killed 1:15
4859	0	1	0	Killed 1:20
Game 4- Time 1:57				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
7621	3	0	78	
4859	1	0	100	
4564	0	0	0	
8913	0	1	0	Killed 0:22
Game 5- Time 3:10				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
7621	3	0	63	
4564	0	1	0	Killed 1:17
8913	0	1	0	Killed 1:17
4859	0	1	0	Killed 2:28
Game 6- Time 2:38				**Loss**

Subject	Kills	Deaths	Shooting %	Time killed
8913	3	1	64	Killed 2:20
4859	0	0	0	Killed 2:38
7621	0	1	50	Killed 2:30
4564	0	1	0	Killed 1:06
Game 7- Time 4:38				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
8913	4	0	53	
4859	1	0	50	
4564	1	1	20	Killed 4:36
7621	1	1	50	Killed 1:36
Game 8- Time 4:14				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
8913	3	1	50	Killed 2:23
7621	2	1	83	Killed 4:14
4564	1	1	26	Killed 1:59
4859	0	1	100	Killed 4:14
Game 9- Time 3:19				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
8913	5	0	45	
7621	0	0	0	
4564	0	0	0	
4859	0	0	0	

Session 9:

Game 1- Time 2:54				Loss
Subject	**Kills**	**Deaths**	**Shooting %**	**Time Killed**
8913	1	0	40	
4564	0	0	0	
7621	0	1	0	Killed 0:52
4859	0	1	0	Killed 0:36
Game 2- Time 3:25				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
8913	2	0	38	
7621	1	0	40	
4859	0	0	0	
4564	0	0	0	
Game 3- Time 4:00				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
8913	1	1	50	Killed 1:15
4859	0	1	0	Killed 3:53
4564	0	1	0	Killed 4:00
7621	0	1	0	Killed 1:45
Game 4- Time 3:07				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
8913	2	0	37	
4564	0	0	100	
4859	0	1	0	Killed 1:31
7621	0	1	0	Killed 0:29
Game 5- Time 3:20				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
8913	4	0	40	
7621	1	1	69	Killed 2:21
4564	0	0	37	
4859	0	1	0	Killed 2:37
Game 6- Time 3:34				**Loss**

Subject	Kills	Deaths	Shooting %	Time killed
4564	1	0	30	
8913	1	1	80	Killed 3:19
7621	1	1	23	Killed 3:19
4859	1	1	18	Killed 3:19
Game 7- Time 0:55				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
7621	0	1	33	Killed 0:55
4859	0	1	0	Killed 0:55
8913	0	1	0	Killed 0:20
4564	0	1	0	Killed 0:20
Game 8- Time 2:21				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
4859	0	0	0	
8913	0	0	0	
7621	0	0	0	
4564	0	0	0	
Game 9- Time 1:34				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
4564	1	1	66	Killed 1:34
8913	0	1	20	Killed 0:38
7621	0	1	0	Killed 1:04
4859	0	1	0	Killed 0:56
Game 10- Time 3:25				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
7621	2	0	66	
4859	1	1	33	Killed 3:06
4564	0	1	33	Killed 3:06
8913	0	1	15	Killed 2:45
Game 11- Time 4:12				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
7621	2	1	44	Killed 4:12
4564	0	1	100	Killed 0:46
8913	0	1	0	Killed 0:35
4859	0	1	0	Killed 1:13

Session 10:

Game 1- Time 7:14				Loss
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
7621	1	0	33	
8913	1	1	100	Killed 6:01
4564	0	0	0	
6068	0	1	0	Killed 6:01
Game 2- Time 5:42				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
6068	1	0	62	
8913	0	0	0	
7621	0	1	25	Killed 1:43
4564	0	1	0	Killed 1:03
Game 3- Time 5:02				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
4564	1	1	20	Killed 5:02
8913	1	1	100	Killed 2:12
6068	0	1	0	Killed 2:42
7621	0	1	0	Killed 2:47
Game 4- Time 8:04				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
8913	2	0	50	
7621	1	1	100	Killed 5:47
4564	0	0	0	
6068	0	1	0	Killed 7:59
Game 5- Time 10:25				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
4564	2	1	11	Killed 10:25
6068	1	1	6	Killed 10:05
8913	1	1	100	Killed 1:25
7621	0	1	0	Killed 1:25
Game 6- Time 10:43				**Loss**
Subject	**Kills**	**Deaths**	**Shooting %**	**Time killed**
8913	5	0	100	

7621	1	1	10	Killed 10:38
6068	0	0	100	
4564	0	1	0	Killed 10:35

Appendix B:

Integrated Systems Design

for contract

"Enabling Technology for Human Collaboration"

issued based on RFQ 4955

submitted to

Advanced Concepts Group
Sandia National Laboratories
Albuquerque, NM 87185

by

MindTel LLC
2-212 Center for Science and Technology
111 College Place
Syracuse NY 13244-4100

Federal tax ID
EIN 16-152-7159

POC for MindTel LLC
David Warner MD, PhD
800-950-0849 voice/numeric pager
858-759-8808 office
858-759-8807 fax

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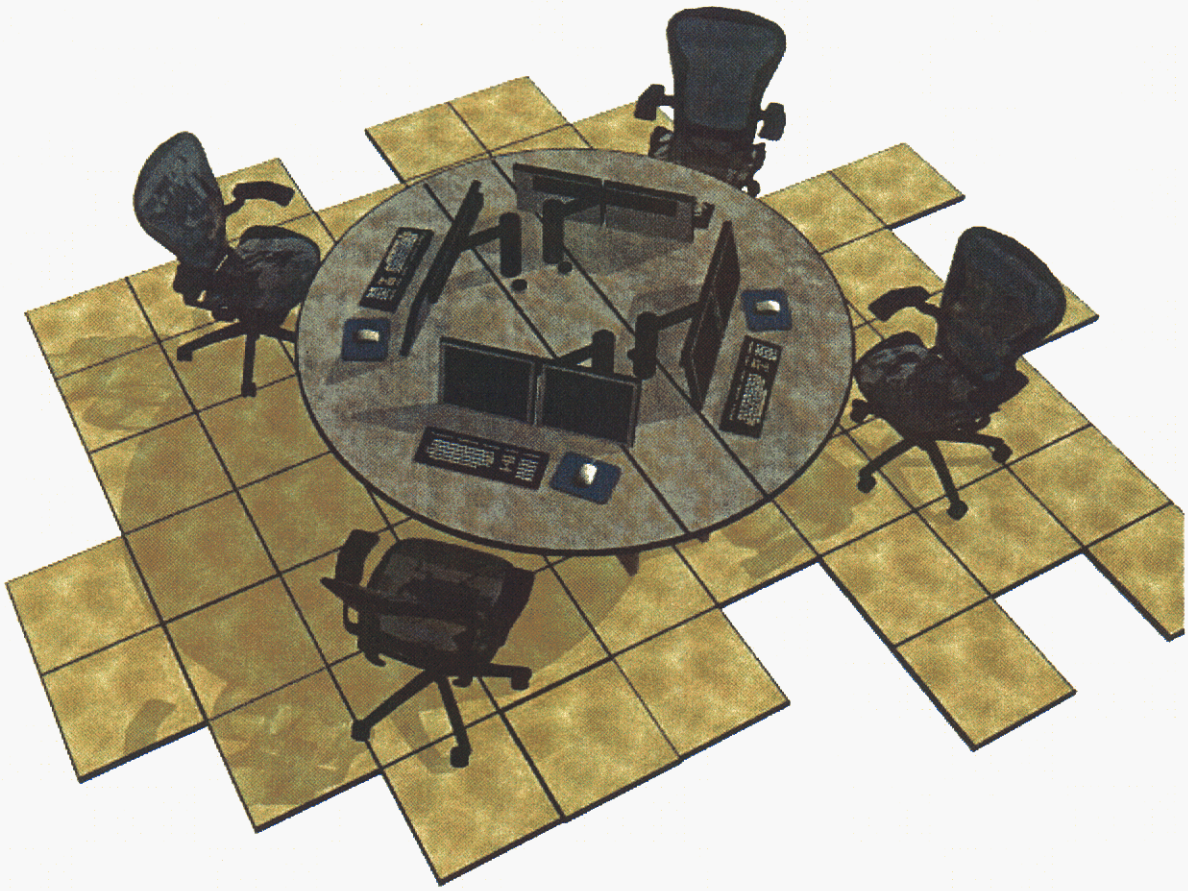
Summary

This document describes an integrated systems design, including computer network hardware, software, sensor equipment, support equipment, and utility specifications to enable a four-person prototype system to be assembled in the Sandia Advanced Concepts Group game room or equivalent facility at the Sandia National Laboratories site in New Mexico. The integrated systems design incorporates safety advisory information for Project Manager review.



Quad Pod 4-person collaborative workstation with physiological monitoring capabilities.

Introduction
A general focus of MindTel's activities has been the pioneering of new methods of physiologically based human-computer interaction, specifically for quantitative human-performance assessment. This capability promises to be a powerful tool for characterizing the complex nature of normal and impaired human performance, enabling researchers to explore new methods of interaction and analysis. Such quantitative measurement of activity during purposeful tasks allows us to quantitatively characterize individual cognitive styles.
Fusion of sensor data with user interaction parameters will allow meaningful correlations to be made across various performance modalities. To this end, we will embrace modular design for the integration of several data input devices into a single platform within a common interface protocol.

In order to refine quantitative measurement of activity during purposeful collaborative tasks, we plan to develop and integrate a set of advanced human-to-computer input devices into a single interface system and to provide an open hardware platform and modular infrastructure that will expedite the implementation of new technologies into the system. That system is designed to be scalable, extensible, interoperable, and modular at a fundamental component level. Specifically, we are developing a "reference architecture" (a formalized conceptual framework for technology development) for designing physio-informatically robust, interactive, human-computer interface systems. The reference architecture we are developing will have the necessary complexity to be able to address the physiological issues in an interactive human-computer interface system.

The experiential and experimental basis for this work comes from the researchers' extensive experience in developing interface technologies for persons with severe disabilities and from the DARPA programs for instrumenting humans for controlling distributed robotics and remote computer systems.

It is MindTel's understanding that the scope and level of effort of this project are to develop an initial operational four-person collaborative system with the following functions, features, and requirements.
Functionality
The delivered prototype system is to have the following demonstrable initial functionality:

1. real-time data acquisition from multiple simultaneous sources (biosensors and interface devices; initial set to be determined in design phase)
2. archival and timed-stamped data storage of complete data set acquired
3. real-time data analysis (to be determined in the design phase)
4. display of individual and combined sensor and data analysis simultaneously from multiple participants
5. voice-activated operation of standard Internet navigation and search operations
6. one hour of continuous operation

7. contractor's availability to assist with experimentation as needed by Sandia

Scope

To ensure agreement on scope, scale, and context of development effort, MindTel has proposed the following design of an integrated system with all hardware, software, sensors and overall functionality specified (the system):

1. Integration of all components and functionality will commence as soon as the design is accepted. After integration and testing, an operational system be delivered and demonstrated at Sandia Laboratories.
2. The initial goal is to have a fully operational system with all core components functional.
3. Fully operational implies the ability to collect and store an array of sensors monitoring each collaborators physiologic and interaction performance data during a one hour directed collaboration effort. Initial data streams include direct physiological data, data from other user-activity-monitoring devices, and data from traditional input devices. There is also the ability to stream specific data to a supervisor, observer, or session monitor for near real-time analysis.

Quad Pod

An instrumented collaboration station (Quad Pod) will be equipped with networked computers and interface systems for tracking four simultaneous users (Quad Squad) during directed collaborative activities. Some specifics of the system are as follows:

1. The system will be able to simultaneously track and record multiple data streams from four individuals in a group collaborative.
2. Each of the collaborative participants will have his or her own computer and interface system.
3. The initial system is designed for use in a fixed setting doing a specified task.
4. Four participants are seated in a common area (at a round table) engaged in a purposeful collaborative interaction (http://www.ideationsllc.com/projects/sandia2003/quadpod/quadpod-Pages/Image38.html).
5. Each person has a computer and display for collaborative interaction.
6. Each computer has a user-monitoring system consisting of an array of interface options that can be used in combination to monitor user dynamics corresponding to task-specific activities.
7. A combination of natural, spontaneous biosignals and task-specific actions will be monitored.
8. Each interface system will capture and stream data from the user. The user interface consists of the physio-sensors, electro-mechanical sensors , microphone, face camera, mouse, keyboard, and joystick.

9. The four collaborators computers will stream data to a common server for time-locked data storage, analysis and, post processing. The initial capacity of the system will be to be able to record 1 hour of directed collaborative activities.
10. The system must store a reasonably accurate record of all events from all users and the environmental monitors. A realistic range is 500–900 ms.
11. The collaboration station will have a "group" audio and video recording capability.
12. The time locked data from each of the four collaborators, along with the video of the group session will be combined to create a master session record.
13. The maintenance of record integrity is a significant issue. Such integrity is achieved through security protocols, standardized data formats, error handling, and semi-automated database archiving. The data management subsystem tasks also include linking the device data with the record and specifying sensor-specific data formats and structures.
14. The system will allow a supervisor to monitor all data, with eventual real-time access to live streams.
15. The system will be designed so that any data stream or any combination of data streams can be analyzed in near real time.
16. This collective combination of data streams contains sufficient dynamic information to provide insight into the user's state of being.

Initial Technical Choices

To ensure core functionality of the overall system we will use familiar technology.

Bioelectric signals will be acquired by ProComp Infiniti 8-channel, multi-modality encoders (http://www.thoughttechnology.com). ProComp was chosen for its core functionality, and to ensure maximum safety.

MindTel's TNG-4 serial interface will host the remaining sensors. TNG-4 is a bidirectional, 28-channel (highly expandable via SPI protocol), analog-digital interface designed to accommodate multiple sensors and controllers (http://qube1.mindtel.com/~edlipson/TNG/TNG-4/TNG4.pdf).

Both ProComp Infiniti and TNG-4 are optoelectrically isolated for safety.

In general this system addresses a multi-sensor multimodal heterogeneous data fusion problem.

Initial efforts will establish a multi-biosensor capacity with an set of direct physiological measurements (noninvasive electrophysiology) of the following signal modalities:

- Brain (electroencephalography, EEG)
- Eye (electro-oculography, EOG)
- Heart (electrocardiography, ECG)

- Breathing (respiration)
- Skin (galvanic skin response, GSR)
- Pulse (blood volume pulse, BVP)

Video of facial expression and gestures, and of eyes of each participant will be tracked for the following:

- Expressional data
- Face (video camera)
- Voice (microphone)

There will also be a set of somatic sensing devices using electromechanical motion sensors for monitoring motion, and position:

- Somatic data
- Body movement (wrist and head, using accelerometers)

Standard computer input devices will be monitored:

- Mouse
- Keyboard
- Touchpad
- Microphone (for voice commands and other sounds)

All input from all devices will be recorded.

Future Research Considerations

The current limitation to the system requires all participants in the study to be sitting in the same room, at the same table. It is the contractor's belief that further exploration into the Quad Pod system should focus on distributed systems, rather then all four participants sitting in the same table. The system has been built with the scalability enable a distributed enhancement by using network protocols to start data collection and properly time synchronize the recorded data with the other participants. Since everyone with a network connection, and proper Sandia security privilidges, would be capable of interacting with the base Quad Pod system, it is clear that the next logical progression of Quad Pod is actually a distributed Quad Pod, with the ability to reach back to the original station. This could allow either individual members with a wearable system in an outdoor area, to desktop Quad Pod interfacing stations in different buildings, to participate in the study and have physiological measurements recorded without having to be in the same geographic vicinity.

The following considerations accommodate ongoing research and refinement:

- The system is designed to be used on an ongoing basis and to support emerging collaborative research protocols.

- The modular design of the system will maximize flexibility for experimental utility.

- The system is designed to be a research tool to enable the exploration of group collaborative dynamics.

- The system is designed so that any data stream or any combination of data streams may be analyzed in near real-time.

- The system is designed so that observers can remotely monitor any activity.

- The system is designed to accommodate emerging technologies that can be added to the system when desired.

- The object-oriented nature of the software ensures maximum flexibility for including new sensors in the future

The initial hardware specification includes the following:

- 5 computers (Shuttle XPC; http://us.shuttle.com)

- 4 interface systems (ProComp Infiniti; for bioelectric sensing; http://www.thoughttechnology.com/procomp.htm)

- 8 TNG-4 serial interfaces (MindTel; for human-interface physical signals; http://qube1.mindtel.com/~edlipson/TNG/TNG-4/TNG4.pdf)

- 4 microphones (voice-command recognition and recording)

- 4 or more video cameras (face and facial gesture recognition)

- 1 AV recording setup for recording audio and video of user interaction within QuadPod.

Initial Software Specification

- Microsoft Windows 2000 Professional (operating system)
- NeatTools (human-computer interfacing, data acquisition, sensor integration, and dataflow control; www.pulsar.org/2k/neattools/)

Time Sync

- One of the difficulties of simultaneous data acquisition on four separate computers is maintaining sub-second synchronization of the data.

- Three different forms of time synchronization were developed into the system, with two approaches implemented into the final system. A client/server system, and a time synchronization windows service were implemented. The Time Sync Pattern Box was not.

- The first approach was the development of a UDP based client/server pair that allowed for multiple machines to read a continually incrementing integer from the Mentor server, and encode it within each machines data stream. This scales, allowing any number of machines from anywhere in the world to time synchronize collected data with other machines.

- The second approach involved synchronizing the system time of all machines with the U.S. Atomic Clock in Colorado. All machines have service level software installed allowing any of them to be either a time client or a time server. The time server can be one of the machines within the Pod, and not necessarily the atomic clock. This allows the system to operate on a LAN, and not need a web connection to the outside. All client machines were able to synchronize to the server to a cumulative difference of no greater than a tenth of a second. The system time is also recorded with the physiological data.

- The third developed time sync system was a Time Sync Pattern Box. This box is a rededicated command-mode TNG-4 connected via USB to one of the Quad Pod computers. Modified firmware automatically generates a pulse width modulated digital signal on each of the 4 TNG-4 digital I/O port connectors immediately after initialization on power-up. Each Pod TNG-4 could be connected to one of the four digital output ports on the Time Sync unit. The unit is battery powered to maintain the electrical isolation of the human interfaces.

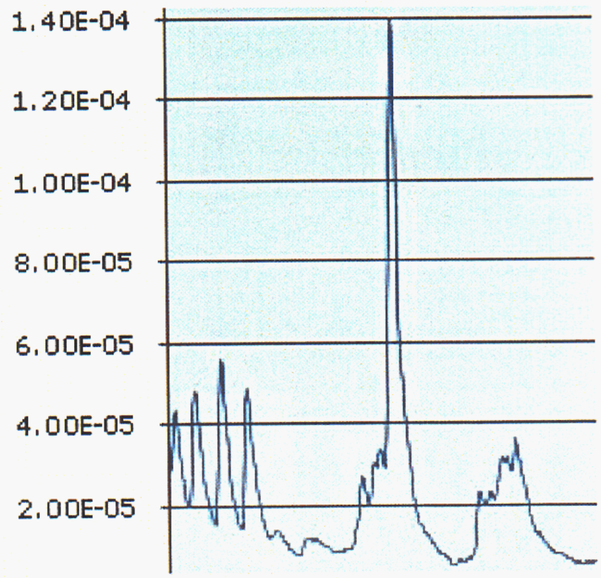
- The client/server and system time sync were both chosen. They worked complimentary, and would both scale, allowing for an indefinite amount of machines to connect to the system and synchronize. Since the systems were web based and not hardware based, they provided the best flexibility for future enhancements to connect the Pod to distributed systems in other parts of the world.

Collaborative Game

- Red Storm Entertainment series

Collected Data

Electrocardiogram of participant

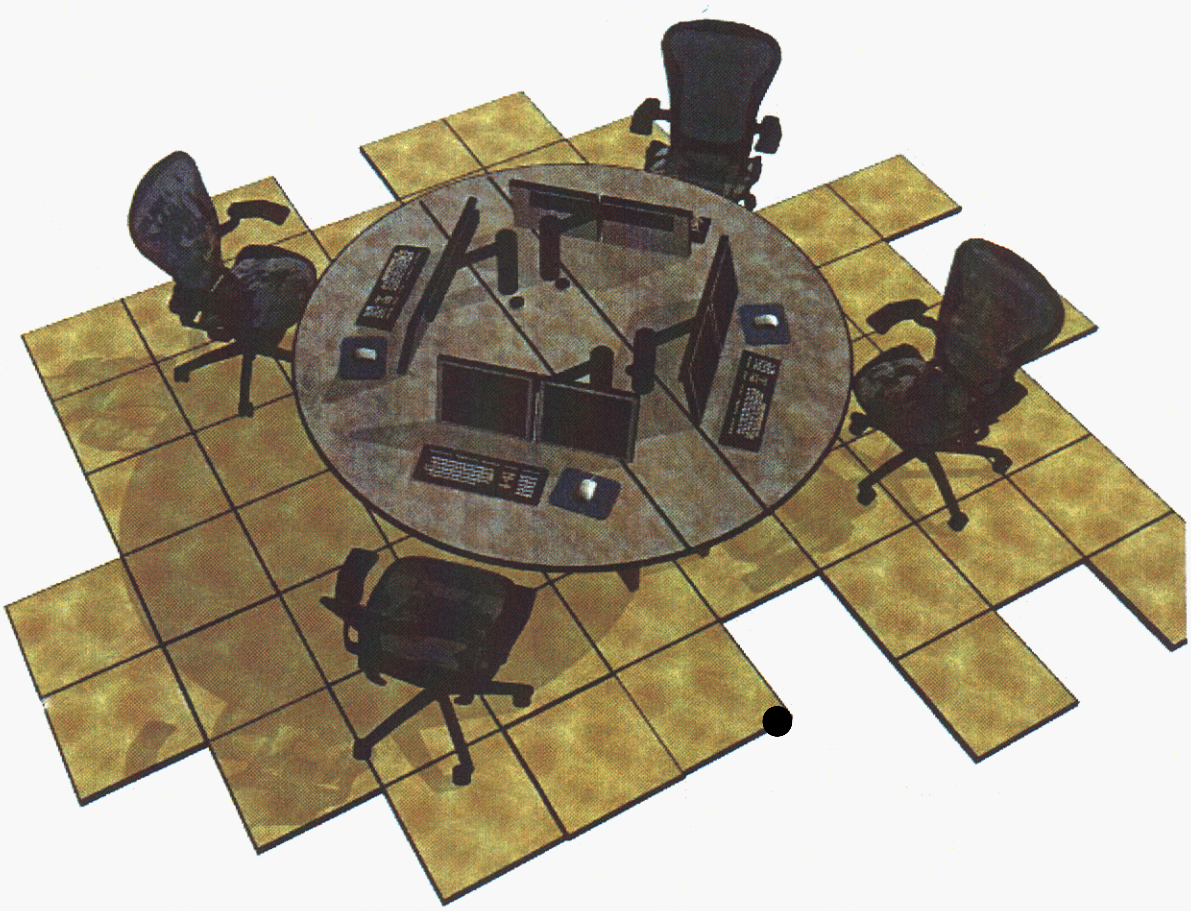


Electromyograph of participant

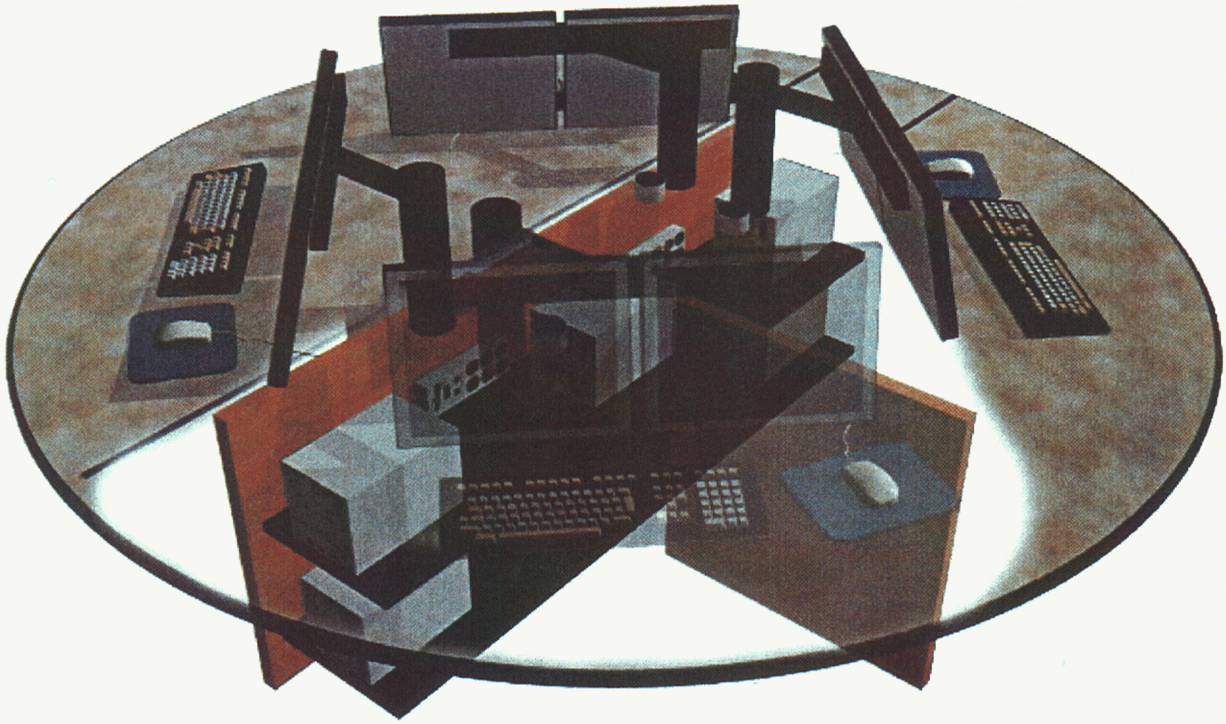
Video Capture

Distinct emotions can be derived from the recording of each participant's face. The video is also recorded at a high enough quality to allow for gesture recognition and is in sync with the recorded data. In this video capture, C4 is dead. C1 and C2 have been killed by player C3.

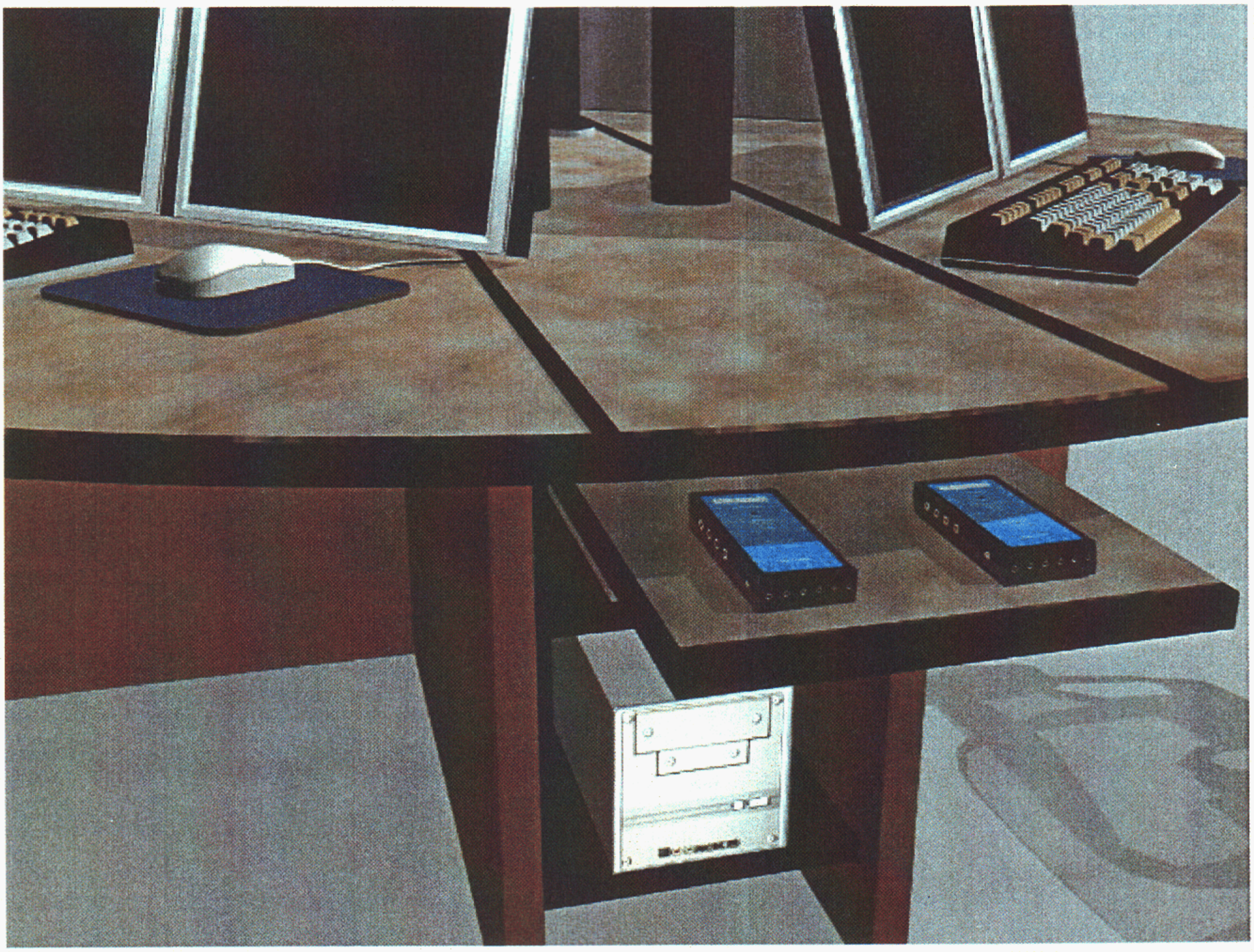
Appendix 1: Quad Pod Physical Layout



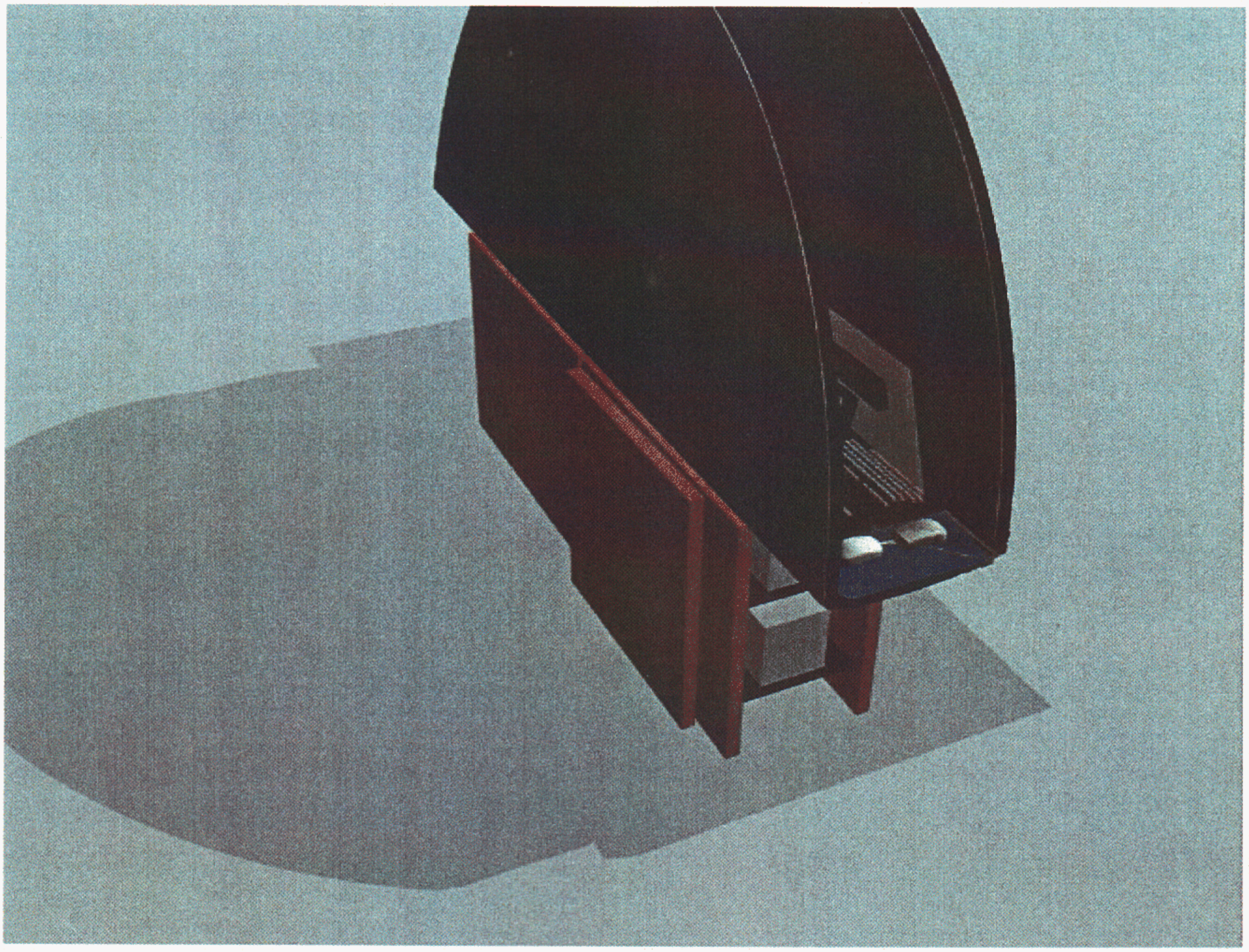
Quad Pod four-person collaborative workstation with embedded physiological monitoring system for each user.



The 7-foot Diameter round table accomodates 4 users. The 30-inch high table conceals the technology, including one server, four client PCs, power and network distribution, I/O interface boxes, and physiological monitors. The dual LCD displays as well as keyboard and mouse are on top.

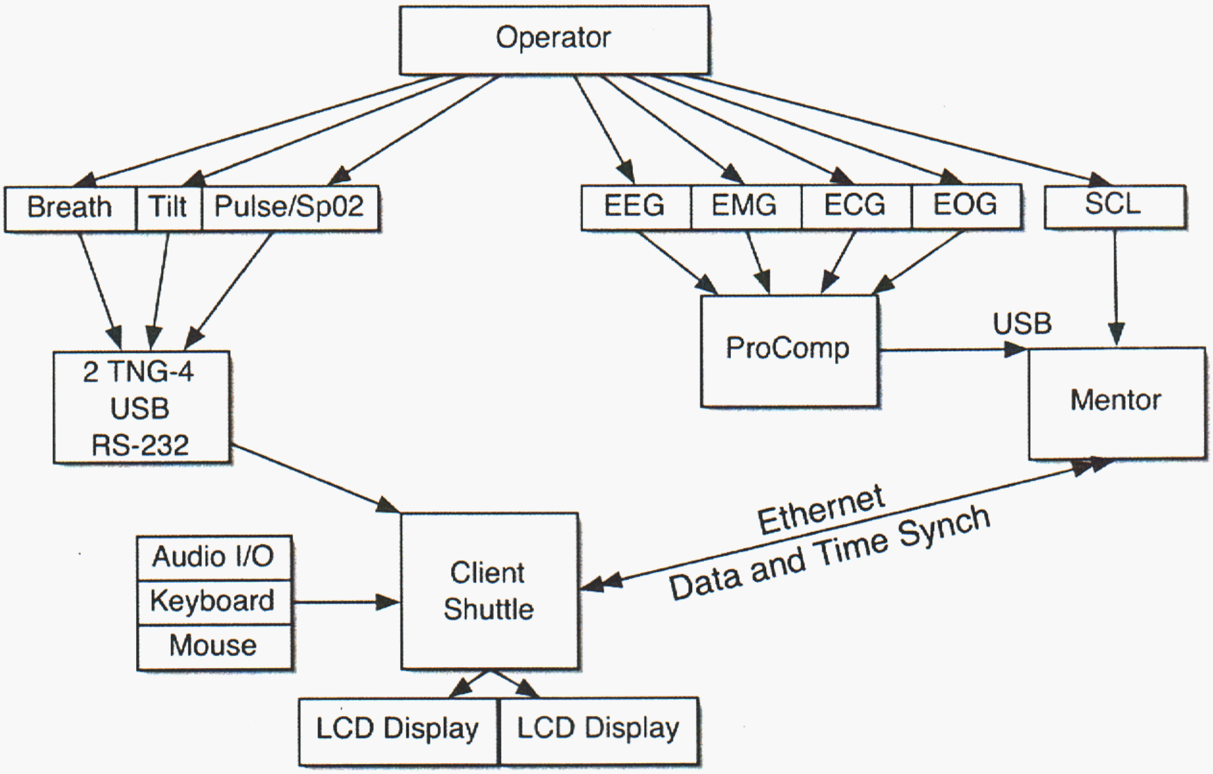


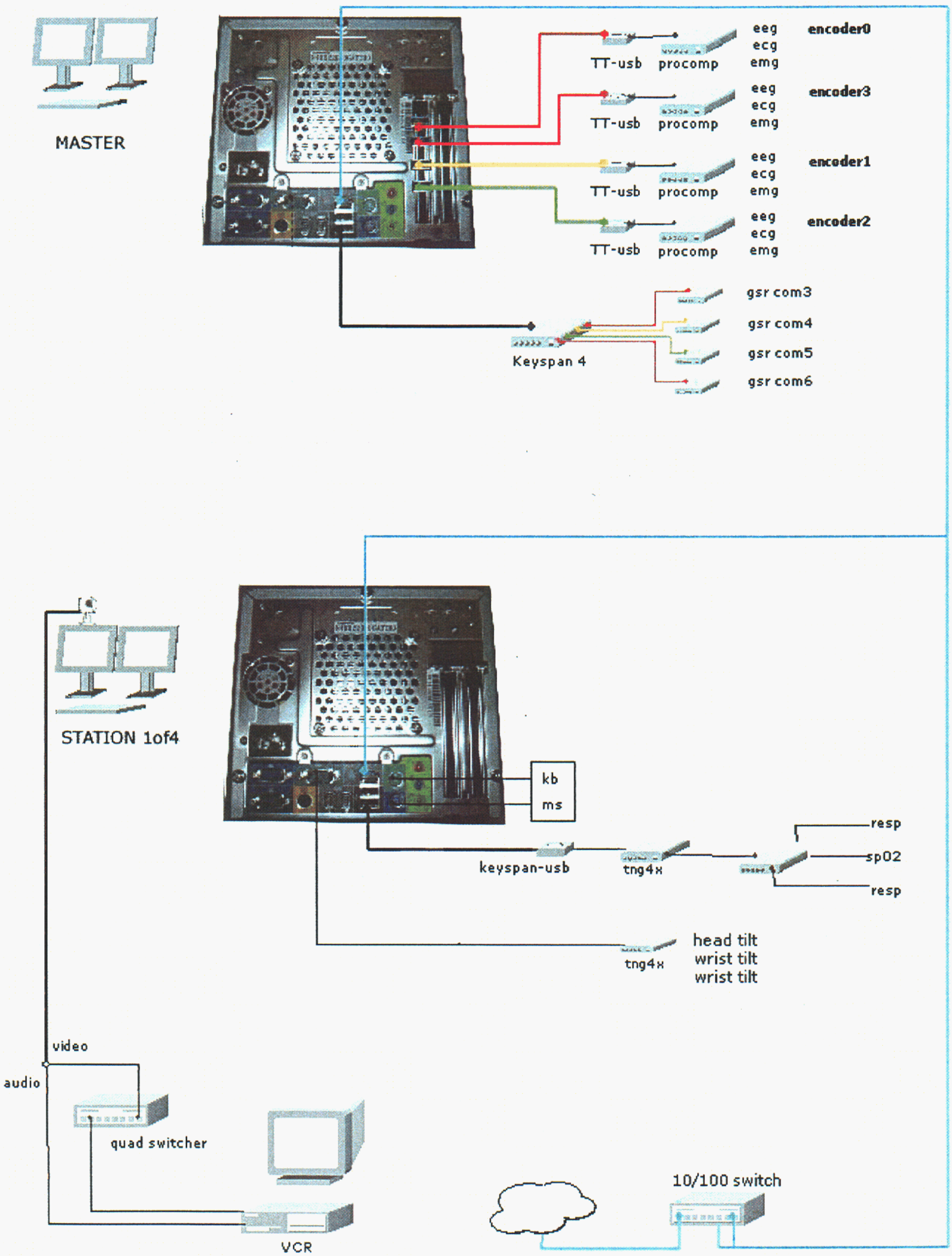
Access to frequently used interface systems is conveniently provided by sliding shelves located at opposite ends of the table. Cable management is handled at the back end of each shelf, while all cables connecting the sensors are passed through grommets at the front end of each shelf. During normal operation, the shelves conceal and protect the electronic components.



When not in use, the table can be folded up to a footprint of only 18 inches wide by 7 feet long. Keyboards and mice are moved to the center section, while the LCD display panels are pivoted towards the center of the table. The half-round wings are hinged to pivot upwards, encompassing the LCD panels, and the supporting legs are folded in towards the sides of the central structure. All electronic components are secured and well protected by the structure of the table when folded up.

Appendix 2. Quad Pod Technical Schematics

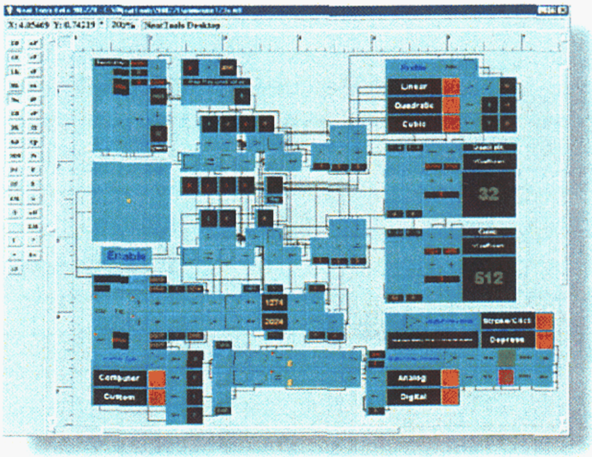




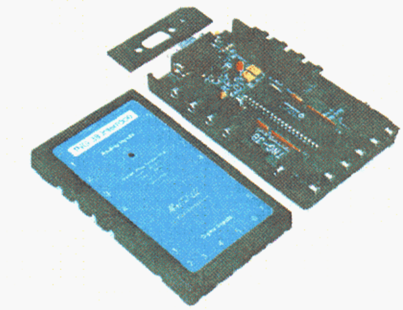
MASTER
TT-usb
procomp
eeg
ecg
emg
encoder0
encoder3
encoder1
encoder2
gsr com3
gsr com4
gsr com5
gsr com6
Keyspan 4
STATION 1of4
kb
ms
keyspan-usb
tng4x
resp
sp02
resp
tng4x
head tilt
wrist tilt
wrist tilt
video
audio
quad switcher
VCR
10/100 switch

Appendix 3. NeatTools Software and TNG Interfaces

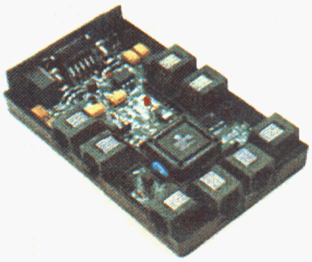
Since the mid 1990s, our team, under leadership of Dave Warner, has been developing a modular suite of hardware and software technologies for human-computer interfacing,. The flagship of this system is a sophisticated visual-programming and runtime environment known as NeatTools, available for free download from www.pulsar.org. Unlike textual programming languages, NeatTools applications are developed by dragging, dropping, and interconnecting modules (visual icons) on the NeatTools desktop. Modules typically have a number of properties that can be modified by right clicking on the module and then adjusting parameters and other fields. Because NeatTools is multithreaded, the programmer can develop and edit an application, even while it is running and displaying data in real time. NeatTools is extensible, in that new modules can be written in C++ and loaded optionally at runtime as dynamic link libraries (DLLs). A program generator to facilitate the writing of external modules is available at www.pulsar.org, as are documentation and representative application programs.



Our hardware is based on TNG serial interface boxes (palm sized) that allow signals from sensors and transducers to be interfaced to PCs, using NeatTools or other environments, such as LabView. At the heart of each TNG interface unit is a PIC microcontroller programmed in assembly language that handles most of the functions of the device; because they are flash memory devices, they can readily be reprogrammed as needed. TNG-3B accepts signals from 8 analog and 8 digital sensors, and streams the data at 19.2 kbps. NeatTools includes a TNG3 module to accept and distribute the signals. Standard sensors, mounted on cables with stereo or mono plugs, include photocells, bend and pressure sensors, rotary and slide potentiometers, and tactile switches. For use with TNG-3B or TNG-4, we also have a 2-axis MEMS accelerometer/tilt-sensor. TNG-3B has been tested to be compliant with FCC regulations.



TNG-4 is a serial interface with 8 analog inputs, 4 analog outputs, and 16 bidirectional digital lines. In addition, TNG-4 is extensible via its SPI port (Motorola's Serial Peripheral Interface that employs a synchronous serial protocol). Among the SPI extension boards developed to date are servo motor control (each board can control 8 servos and up to 8 boards can be daisy-chained); LCD display; keypad input (up to 8 × 8) and IR communication; vibrotactile control (up to 8 vibrator motors per board, which can



be used for other pulse-width-modulation applications too); AC and/or DC relay control (4 per board; mix and match); temperature sensing (thermistor or thermocouple). There is also an electromyography (EMG) board that connects to an analog input of TNG-4 and displays rms values of raw EMG signals.

There are two distinct versions of TNG-4: streaming mode (like TNG-3B, but now duplex) and command mode; they differ only in the program in the respective PIC chip. In command mode, the computer issues specific byte sequences instructing the device how to configure itself and what specific data to accept or return. By repetitive issuance of such commands, the device can be made to stream in effect. NeatTools at present has a TNG4 module for the streaming mode version of TNG-4 only; but it is easy to construct simple data flow networks to produce the required byte command sequences for specific applications. In due course, we will develop a command mode module for TNG-4. Command mode TNG-4 is well suited to work with handhelds such as Palm OS and Pocket PC devices. We already have working interface programs on both platforms. An interface program for the TI-83 graphical calculator is under development.

An extended technical description of these technologies is available at
http://qube1.mindtel.com/~edlipson/CoreTech.pdf.

For more information (and downloads) on NeatTools, visit
www.pulsar.org,
specifically
http://www.pulsar.org/2k/neattools/.

For TNG-3B, see http://www.mindtel.com/mindtel/anywear.html.

For TNG-4, see
http://qube1.mindtel.com/~edlipson/TNG/TNG-4/TNG4.pdf
and for SPI extension boards, visit
http://www.sensyr.com/manuals/.

Archival information on TNG-4 (streaming version) is at
http://www.pulsar.org/archive/ed/tng/TNG-4/
and
http://www.pulsar.org/archive/ed/tng/TNG-4/.

Appendix 4. Description of Customized Devices.
The Pod Detail diagram (Appendix 2) depicts some devices that will be customized for the Quad Pod project. This appendix serves to offer a general description of these customizations.

Turbocharged TNG-4

A standard TNG-4 data acquisition device uses a PIC16F74 processor running at 4 MHz and communicates at 19.2 kbps. By increasing the processor clock speed to 12 MHz, we can increase the communications bit rate to 57.6 kbps. By utilizing either a PIC16F874 or a PIC16C774 processor we can increase the ADC bit resolution from 8 bits to 10 and 12 bits, respectively.

The increased ADC resolution comes at the price of having to transmit more data per acquisition cycle. At 57.6 kbps, 360 data packets (samples) per second can be transmitted when using ADC resolutions in excess of 8 bits. The standard 8-bit resolution protocol would allow 480 data packets (samples) per second at 57.6 kbps.

Respiration Amplifier

The UFI Pneumotrace II respiratory band output is in the range -100 to +400 mV. The output signal can only drive input impedances in excess of 100 kΩ (> 1 MΩ preferred). The Pneumotrace output signal is also AC-coupled with a time-constant in excess of 20 seconds.

Optimally, two respiration bands should be used: one at the level of the navel and the other around the upper chest.

The Respiration Amplifier for the Quad Pod project will provide gain and filtering for up to two Pneumotrace respiratory bands and connectivity to TNG-4. The device will be powered by TNG-4. The device will have a frequency response of approximately 0.05 to 2 Hz. There is no electrical connection to the subject.

IR Plethysmograph Signal Amplifier

This device will allow use of the Nonin SpO_2 sensors with TNG-4. The device will power the sensor and all TNG-4 to capture the blood volume pulse signal with appropriate amplification and filtering. There is no direct electrical connection to the subject with this apparatus.

If SpO_2 is desired, the sensor can alternatively be attached to a standard XPOD module equipped with a serial-to-USB converter.

SCL (skin conductance level) Device

This device will continuously digitize the subject's SCL (skin conductance level) with at least 10 bits of resolution over a range of 0 to 100 micromhos (microsiemens). The device can be calibrated by commands from the host to switch in 0.1% precision resistors. Other features include a 12-bit DAC for zero suppression and a device to read ambient temperature (optional).

The data rate (not baud rate) can be controlled over a limited range from the host. The default rate is 100 samples per second.

The SCL device is powered by a 9V alkaline battery. The device power is enabled by the assertion of DTR from the host interface (just like TNG-4). The battery-powered side of the serial interface is optically isolated from the host.

To measure SCL, a constant 0.5 volt potential is applied to the subject by means of a pair of electrodes. Even so, the device presents much less of a hazard than a 9V alkaline battery.

Appendix 5. Computer Model and Overall Electrical Requirements

Computer

Shuttle SN41G2
1 Gigabyte RAM, DVD/CD-X
120 Gigabyte hard disk
Athlon XP 333 MHz FSB

http://www.shuttle.com/new/product/spec/SN41G2.pdf

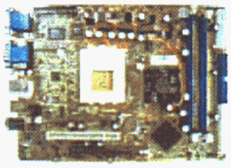
See next page for details.

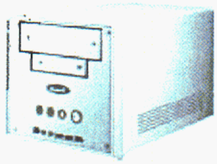
See also Appendix 7.

Electrical Requirements

Sandia needs to provide six (6) 110 volt outlets (e.g. Walker boxes in a raised floor). Each pod will require a maximum of 500 watts (< 5 amps). The Quad Pod will need a minimum of one 20-amp circuit; we recommend two. Surge protection and electrical distribution exist in the design of the Quad Pod.

XPC SN41G2





Form Factor
Shuttle Form Factor

CPU Support
AMD Athlon/XP/Duron in 462-pin package with 200/266/333MHz FSB

Chipsets
nVidia nForce2 / MCP-T

Memory
2 x 184 pin Socket support DDR266/333/400 unbuffer DDR SDRAM up to 2GB
Support Dual Channel DDR

VGA
Build in Geforce4 MX high performance 256-bit 3D engine
Support dual display

TV-Out
Support NTSC and PAL format in S-Video/Composite terminal
Support maximum input active resolution up to 1024x768

Audio
Realtek ALC 650 supports 5.1 channel audio
Support AC-3 Digital SPDIF Output

IDE interface
2 x UltraDMA/133 IDE channels

IEEE 1394a
Realtek 8801, complies with 1394 OHCI specification revision 1.0 support up to 400Mb/s data transfer rate

Ethernet
Realtek 8201BL support IEEE 802.3u 10/100Base-T
Supports Wake-On-LAN function

Expansion Slot
1 x 8x mode AGP slot
1 x PCI slot

On board connectors and Headers
3 x fan connectors   1 x ATX main power connector
1 x ATX 12V power connector
1 x Peripheral power connector
2 sets of 2x5 pin USB2.0 headers
1 set of 2x5 pin Front Panel IEEE1394a header
1 x Parallel header   1 x CD_In header
1 x Mic_In header   1 x Speaker_Out header
1 x SPDIF_Out header

Chassis
Shuttle G2 type

Dimension
300(L)x200(W)x185(H)mm, 2.85Kg (N.W.), 4.65Kg (G.W.)

Material
Aluminum

Extension Bay
2 x 3.5" bays   1 x 5.25" bay

Front Panel
2 x USB ports   1 x 1394 port
1 x SPDIF-Out   1 x Mic-In
1 x Speaker-Out   1 x Power-On button
1 x Reset button

Back Panel
1 x PCI slot   1 x AGP slot
1 x PS/2 Keyboard   1 x PS/2 Mouse
2 x VGA port2   1 x Serial Port
2 x 1394 ports   2 x USB ports
1 x RJ45 port   1 x Parallel port (optional)
1 x Front out connector   1 x Rear out connector
1 x Center/Bass port   1 x S-video/composite port

Power
Dimension: 82(W) x 43(H) x 190(D) mm (Max)
Input: 110 / 230V AC
Output: 200W(PFC)
EMI Certified: FCC, CE, BSMI
Safty Certified: UL, TUV, CB
Power Cord: Depends on specific region demand

Accessories
1 x Mainboard User manual
1 x Mainboard CD-Driver
1 x XPC Installation Guide
1 x I.C.E Technology CPU heat-pipe
1 x FDD Cable
1 x HDD Cable
1 x CD-ROM Cable
1 x 7pin Mini DIN to RCA Cable
1 x Power cord
Screws
Twin Adhesive
Friendly Front Feet

Shuttle www.shuttle.com Connecting Technologies

Appendix 6. Electrical Safety

MindTel, LLC will ensure by measurement that no exposed metal surface that a study participant is likely to come in contact with or electrode any connection will allow no more that 100 μA of leakage current (resistance to any power lead ≥ 1MΩ). The exposed, grounded, metal chassis of the computers and the power outlet strips will have to be a necessary exception. These items are tucked away under the Quad Pod table, are unlikely to be touched by a study participant while connected, and would only be a danger under the most extraordinary circumstances.

TNG-4

The TNG-4 serial interface uses two integrated circuits to optically isolate the serial (RS-232) signals and power in TNG-4: the H11L1 (http://www.fairchildsemi.com/ds/H1/H11L1-M.pdf) for the digital signals and the PVN012 (http://www.irf.com/product-info/datasheets/data/pvn012.pdf) for switching power. The H11L1 has rated voltage isolation of 7,500 volts and an insulation resistance of 10^{12} ohms at ±500 volts. The PVN012 possesses a dielectric strength of 4000 volts RMS. TNG-4 is optically isolated from the computer only when powered externally (via the TNG-4 power jack) using a medical-grade power supply (5.5-9.0V) or a battery. This is the intended mode of operation.

Additionally, none of the signals connected through TNG-4 will have an electrical contact to the study participant. All the sensors attached to TNG-4 are physically isolated from the study participant. Therefore, the optical isolation is redundant safety-wise.

SCL

The device used to measure skin conductance level (SCL) will utilize also use the same integrated circuits as TNG-4 to optically isolate the communications interface of the SCL device from the study participant. The device applies a constant, battery-derived, floating voltage of 0.5 V to the subject in order to obtain its measurement. The SCL device derives its operational power on the measurement side of the isolation barrier from a 9V alkaline or lithium battery. The worst-case failure of the battery-powered portion of the device (the portion connected to the subject participant) would be no more hazardous than applying the electrodes of a 9V battery to some location on your body.

ProComp Infiniti

The ProComp Infiniti device will be used to collect most of the low-level bio-signals involving electrodes applied to the study participant. This device is battery powered and optically isolated from the computer during signal acquisition. Optical isolation is achieved by means of a fiber-optic data cable: there is no electrical connection of the ProComp Infiniti to the computer.

The ProComp Infinti was tested by InterTek Testing Services (see below) and found to be compliant with UL 2601.1 Second Edition, Oct-24-1997 and CSA C22.2 no. 601.1-M90 (R1997).

ITS Intertek Testing Services
ETL SEMKO

AUTHORIZATION TO MARK

This authorizes the application of the Certification Marks shown below to the Product Covered (also to the multiple listee model identified on the correlation page of the Listing Report where applicable) when made in accordance with the Description and under the conditions set forth in the Certification Agreement and Listing Report:

Applicant: Thought Technology Ltd.
2180 Belgrave Avenue
Montreal, QC Canada H4A 2L8

Contact: Name: Mike Basquill Phone: (514) 489-8251

Manufacturer: Thought Technology Ltd.
8205 Montreal-Toronto Blvd., suite 223
Montreal West, QC H4X 1N1

Party Authorized To Apply Mark: (Same as Manufacturer)

Report Issuing Office: Lachine, Montreal

Report No.: 3031340

Product Covered: Models SA7500 and SA7550

Description: Biofeed back unit "Procomp Infinity" and "Flexcom Infinity"

Standard(s): UL 2601.1 Second Edition, Oct. 24, 1997 and
CSA C22.2 no. 601.1-M90 (R1997)

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c ETL us LISTED

Authorized by: William T Starr Date: 11/17/02
William T. Starr, Certification Manager

Control Number: 2001398

Intertek Testing Services NA Inc.
165 Main Street, Cortland, NY 13045-2995
Telephone 800-345-3851 or 607-753-6711 Fax 607-756-6699

Appendix 7. Quotation from Ideations LLC for Computer Equipment

See next page for quotation.

Overall, there will be five (5) Shuttle computers and eight (9) LCD monitors (preferred brand: NEC; preferred size 17”).

Computers and monitors will be purchased by Sandia for drop shipment to:

David Warner MindTel LLC 16946 Circa del Sur Rancho Santa Fe, CA 92067 858-756-1717

Appendix 8. ProComp Infiniti Product Description

Source: http://www.thoughttechnology.com/procomp.htm

ProComp Infiniti™

Product Information

The ProComp Infiniti is a new eight-channel, multi-modality encoder that has all the power and flexibility you need for real-time, computerized biofeedback and data acquisition in any clinical setting.

The first two sensor channels provide ultimate signal fidelity (2048 samples per second) for viewing RAW EEG, EMG and EKG signals. The remaining six channels (256 samples/sec) can be used with any combination of sensors, including EEG, EKG, RMS EMG, skin conductance, heart rate, blood volume pulse, respiration, goniometry, force, and voltage input.

In short, the ProComp Infiniti covers the full range of objective physiological signals used in clinical observation and biofeedback.

Housed in an ergonomically designed case and requiring only a USB port, ProComp Infiniti can be used with any IBM-compatible laptop or desktop PC. What's more, ProComp Infiniti can capture data in real time by connecting directly to the PC via fiber-optic cable, or it can store data on a Compact Flash memory card for uploading later to the PC.

ProComp Infiniti comes complete with:
- 14 bit resolution, eight-channel ProComp Infiniti encoder unit
- TT-USB interface unit
- Fiber-optic cables (1' and 15')
- Four alkaline "AA" batteries
- Sleek fabric storage and carrying case

Ordering Information

To order please call 1-800-361-3651

More information email prodlit@thoughttechnology.com

Appendix 9. Nonin Xpod Oximeter Specifications

See following four pages.

Sandia National Laboratories
Quad Pod Project
Deliverable 4

Written Recommendations for System Improvement, Utility, and Further Exploration.

The QuadPod Mentor system has enabled Sandia National Labs to physically monitor up to four individuals sitting at a table, and to look for physiological patterns between the individuals and their assigned tasks, or the group of individuals themselves.

System improvement could be considered in the area of how the electrode sensors are applied to the patient. Rather then individually placed sensors, perhaps later work could be put into human interfacing allowing the user to adhere the sensors themselves, quickly, rather then needing an additional person (in the Quad Pod system this person is a HRB approved overseer) to apply them. Individually placed sensors, however, will continue to offer the most flexibility towards patient application. New technology is emerging continually in the areas of wireless physiological sensors, which do not need to touch the patient in order to determine such signals as ECG. The system was built with future sensors like these as part of the design plan. The system is open on hardware and software layers to accommodate new sensors using both Mindtel TNG4 equipment and NeatTools.

The current limitation to the system requires all participants in the study to be sitting in the same room, at the same table. It is the contractor's belief that further exploration into the Quad Pod system should focus on distributed systems, rather then all four participants sitting in the same table. The system has been built with the scalability enable a distributed enhancement by using network protocols to start data collection and properly time synchronize the recorded data with the other participants. Since everyone with a network connection, and proper Sandia security privilidges, would be capable of interacting with the base Quad Pod system, it is clear that the next logical progression of Quad Pod is actually a distributed Quad Pod, with the ability to reach back to the original station. This could allow either individual members with a wearable system in an outdoor area, to desktop Quad Pod interfacing stations in different buildings, to participate in the study and have physiological measurements recorded without having to be in the same geographic vicinity.

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