ASSESSING USER COMPETENCE FOR MULTIATTRIBUTE DATA COGNITION

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Abstract

While computers provide access to a multitude of data, the comprehension of that data for decision making and communication purposes relies on humans. What characteristics emerge as important to the skill of data interpretation and is training possible to develop this skill? This paper assesses user competence for the perception and comprehension of graphical computer displays using a knowledge, skills and abilities framework. The basic research questions are: how do characteristics that are inherent to an individual (abilities) affect the use of moving graphical displays, how do characteristics that may be altered through training (skills) affect such use, and how does knowledge related to the task affect use? Following a model of skill acquisition, the possible characteristics of importance are presented based on an experiment conducted using an animated, graphical computer screen. Results indicate that age and domain knowledge are correlated with task performance. Younger subjects performed better, as did those subjects already familiar with the data domain of the states in the United States.

Keywords: Animation, graphics, individual differences, user competence, knowledge, skill, ability

Introduction

The Technology-to-Performance Chain (Goodhue & Thompson 1995) indicates that characteristics of individuals indirectly impact performance by interacting with task and technology characteristics. Those individual characteristics mentioned include training, computer experience and motivation. Within the realm of personnel and training, characteristics of an individual have been classified as abilities, knowledge, and skills (Koubek et al. 1999) and result in a term called user competence (Marcolin et al. 2000). This paper focuses on the characteristics of individuals that affect user competence when the task involves multiattribute data displays. The basic research questions address how inherent abilities affect the use of moving graphical displays, how characteristics that may be altered through training (skills) affect such use, and how knowledge related to the task affects use. The importance of selected characteristics is presented based on an experiment conducted using an animated, graphical computer display for comparison tasks. The results are interpreted for selection and training of personnel to use such displays in their professional duties.

Background

When graphics were first available on a computer screen, discussion centered on their effectiveness when compared to the more traditional tabular style. It became clear that the person using the technology was part of the equation for use and effectiveness. Goodhue (1992) incorporated the individual into the overall effectiveness model of technology by suggesting a task-technology fit between task, technology and individual characteristics. Once this fit is established, beliefs, social norms, habits, and facilitating conditions combine with it to describe expected utilization of the technology. The overall impact of a technology is then derived from the combination of the task-technology fit (TTF) and the utilization of the technology.

A framework of cognitive skill development was proposed by Koubek, Salvendy, Tang and Brannon (1999) which follows an approach that an individual's final problem solving skill level is constrained by the cognitive resources available to them. This framework classifies user characteristics as abilities, knowledge, and skills. The model indicates that abilities facilitate knowledge acquisition to elevate the level of problem solving skills. Since the task of perceiving and interpreting a graphical display involves cognitive skills, the framework proposed by Koubek, Salvendy, Tang and Brannon (1999) is followed in the experimental study presented here. We incorporate the Koubek and TTF framework in this research.

The abilities presented by Koubek, Salvendy, Tang and Brannon (1999) are based on the taxonomy developed by Fleishman and Quaintance (1984), which consists of 52 independent human abilities. According to the model, these abilities facilitate skill acquisition through the knowledge structure possessed by the individual. The levels of knowledge structure are specified according to the Koubek and Salvendy (1991) model as novice, expert and super-expert. As skill level develops, the underlying structure of knowledge changes from surface feature to task-specific to abstract or hierarchical knowledge. The combination of abilities, knowledge structure and training allow an individual's problem solving skills to follow Gagné's (1985) hierarchy of learning from associations to higher-order rules. The model describes that as tasks become more automatic, fewer cognitive resources are needed, less effort is required and tasks are less affected by individual variance in ability (Schneider and Shiffrin 1977).

Animation provides a means of seeing data changes over time or over another variable. The visualization technique of animation was selected as the main focus of this study, since it increases the amount of data available to the user and is currently available in commercial visualization tools (Dimension 5 2002, Platinum Technology 2002, Visual Insights 2002). Animation occurs when images are presented in rapid succession and its use multiplies the amount of information viewed in a static display by the number of frames shown.

Research Model and Propositions

Figure 1 contains the exploratory model presented in this research, which was derived from a combination of the Koubek, Salvendy, Tang and Brannon (1999) model of skill acquisition and the TTF model (Goodhue (1992). The constructs of ability, knowledge and skill were generated by Koubek, Salvendy, Tang and Brannon (1999) while personal characteristics and the technology variable of animation duration originated with Goodhue (1992) and Goodhue and Thompson (1995). The technology component of animation speed is presented as a component of the computing system impacting performance. To explore the impact of certain characteristics of individuals, three propositions were developed. One pertains to innate abilities, one to the knowledge level of the task domain and one addresses skills that humans have acquired during their lifetimes as a result of abilities and knowledge.

Proposition 1: Abilities impact performance on a comparison task using animated, graphical displays.
Proposition 2: Personal characteristics impact performance on a comparison task using animated, graphical displays.
Proposition 3: Domain knowledge impacts performance on a comparison task using animated, graphical displays.

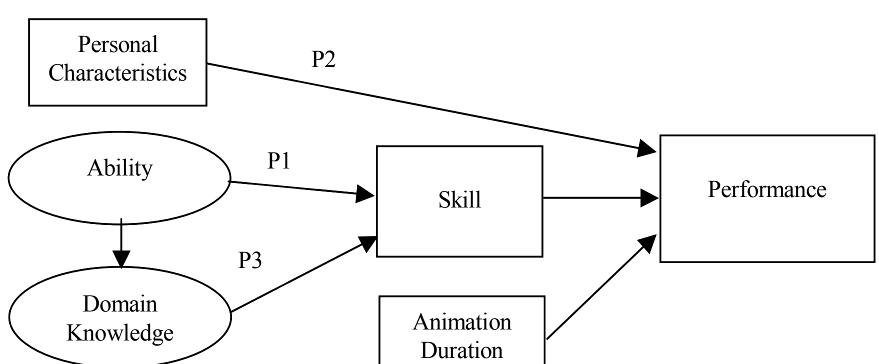

Figure 1. Proposed Research Model with Propositions Indicated

Method

To investigate the propositions, an experimental task was designed which evaluated the impact individual characteristics have on the perception of a graphical, multiattribute computer interface that is animated. Since the area of data visualization is relatively new, an experiment affords the researcher the amount of control necessary to investigate specific areas of the phenomenon. The experiment was designed to address specific issues in cognition of multiattribute, graphical data. The task that subjects performed focused on comparisons as a result of knowledge acquisition of the data displayed on the screen. That is, a subject was required to view the display and answer questions about how objects on the display changed over time. Since animation of data on a computer screen can occur at many speeds, a model for animation speed was developed and tested for the level of comprehension it produced. See Lightner (2001) for an in-depth explanation of the animation speed model development, testing and results. In summary, the model was based on the number of areas of interest on the display (which determine eye movement around the display area on the screen) and the number of frames of data included in the animated sequence. Determining what human abilities and skills affect the perception and comprehension of a multiattribute, moving display would allow the selection of more competent users for training.

Variables

This investigation consisted of determining the characteristics of individuals that may impact performance on a multiattribute cognition task. Surveys were constructed and validated tests were used to determine specifics of personal characteristics, including ability and domain knowledge. See Appendix A for the survey instrument used.

Personal Characteristics

A survey was constructed that consisted of queries concerning various personal characteristics that may affect performance on a data visualization task such as the one presented in the experiment. The personal characteristics included in the questionnaire were: corrected vision, age, sex, level of schooling achieved, major in college, grade point average and frequency of migraine headaches. Questions developed concerning personal habits focused on video arcade skill, experience using graphics, and amount of television viewing. Evidence indicates that playing certain video games, such as Tetris, enhances the ability of mental rotation and spatial visualization time (Okagaki and Frensch 1994). An 11-question questionnaire was developed to attempt to identify which of these skills and experiences affect performance on the experiment. The survey responses were self-reported.

Abilities

Abilities are defined by Fleishman and Quaintance (1984) as those characteristics that are defined for the person by nature and cannot be altered through training. Fleishman and Reilly (1992) identified 21 cognitive abilities of which two were deemed relevant to the experimental task. They are the Speed of Closure and Flexibility of Closure abilities. Tests were acquired from the Educational Testing Service and administered according to their directions (Ekstrom et al. 1976). Several physical abilities were identified as pertinent to task performance and were tested. Depth perception was measured using the RANDOT® device obtained from Stereo Optical, Inc. and red-green color impairment screening was conducted using the Pseudo-Isochromatic Color Plates created by Ishihara (1986). None of the subjects were eliminated as a result of the red-green color impairment test.

Domain Knowledge

The display selected consisted of a map of the United States (U.S.). Therefore, the domain knowledge of the location of the states was tested apriori to the experimental task. As part of the initial survey, a blank map of the U.S. was presented to the subjects with the direction of filling in the state abbreviations. A count of the number correct (full names were also accepted) was tallied for the analysis. Since the display does not have state indicators and the questions ask about specific states, a map of the U.S. with states labeled was available during the experiment. Before the display was animated, the experimenter assisted the subject in finding the appropriate states on the display if necessary.

Dependent Variable

The dependent variable of performance refers to the percent of correct answers to the experimental questions by a subject. Questions were constructed that included one, two, three, four and five states. An example of a one-state question is "How does the color of ID vary throughout the display?". Subjects were given five possible responses to each question. Response one was always "0-Can't tell". This possibility was included to allow subjects to admit their confusion when . Other responses to the one-state example are: 1-Blue->Lt. Blue->White->Lt. Red->Red, 2-Blue->Lt. Blue->Red->Lt. Red->White, 3-Blue->White->Red, 4-Random coloring and 5-Same color. An example of a three-state question is "How do the heights of ND, NY and AL relate throughout the display?". Answers presented for this question were: 0-Can't tell, 1-AL lower, 2-No relationship, 3-Change in same way, 4-Change in opposing way and 5-Same height. The experimental data was created so that subjects would know the correct response if they remembered the data on the screen. A response was considered correct if it matched the expected response. The number of correct responses was used in the data analysis.

A total of 63 subjects completed the experiment. Subjects were recruited from undergraduate courses in management related subjects of a large midwestern university and were paid at the rate of $6 per hour plus a bonus awarded for response accuracy.

Task Type

The goal of this study is to investigate basic comprehension of animated, graphical displays. To achieve this goal, domain knowledge other than the states of the U.S. was eliminated from the display and the experimental environment. For example, the height and color of the states did not have an associated meaning like revenue or gender. A definition of 'task' for the experiment was identified with that goal in mind. One elementary task definition is spatial or symbolic (Vessey 1991, Vessey and Galletta 1991). Spatial tasks involve information acquisition or comparisons. Symbolic tasks involve specific numeric values for a response. This research focuses on comparisons as a result of declarative knowledge derived from the screen. To evaluate the amount of information the subject is capable of comprehending, the questions ask about from one to five states at a time. Each state was designated in an 'area', and adjacent states were not included in any one question. A total of 30 questions were asked, six asking about one state, six asking about two, et cetera, up to six questions asking about five states at a time. States that were obscured during the animation sequence were not selected for the questions.

Display Design

The computer display was designed to contain a variety of objects with multiple dimensions spread across the screen. The display selected consists of a map of the continental U.S. floating on a black background. The display depicted 4 dimensions of information at a time for the 48 contiguous states. The definition of data dimension used is based on values at a data point. Color and shape were previously identified as separable stimulus attribute (Smid et al. 1997), and are considered one dimension each. Therefore, each data point consists of a state, color, height and an animated variable as four dimensions. The last variable is translated into 'time' for this experiment, since time is the animated variable in our naturally occurring environment. We are familiar with things moving in time, although with this display another variable could be selected for animation. See Color Plate 1 for a view of the experimental screen with the first frame displayed. The technology variable, animation duration, has three levels: Duration-1 (fast), Duration-3 (medium) and Duration-5 (slow), named for the number of areas of the screen of interest used in the suggested duration calculation. The duration levels predict good performance when the number of areas of interest on the display is that recommended by the animation duration model (Lightner 2001).

Experimental Design and Procedure

A mixed two-factor within-subjects experiment was conducted to test the validity of the proposed model for animation speed. Animation speed is a between subject factor and the number of areas of interest is a within subject factor. Subjects are nested within animation duration (21 subjects within each group). Six measurements are conducted within each cell for a total of 30 questions. The questions were administered in random order.

The same experimenter following a standard script conducted all experimental sessions individually. First, the color-impairment test was administered and then the depth perception measure was taken. Subjects then completed the ability tests for Speed of Closure and Flexibility of Closure. Finally, the survey containing personal questions and the map of the U.S. was completed. A short training session preceded the experimental questions, followed by a five minute break to allow the subject to rest their eyes. During the experiment and the training session, subjects were shown the first frame of data, the question and the possible responses. Since the states on the display are not labeled, the experimenter identified the location of the states in the question, if necessary. Once the subject was comfortable with the question and where to look on the display, they indicated to start the display. The experimenter started the animation sequence and the subject watched the display. When it finished moving, the subject wrote down their response to the question. This procedure was repeated for each of the 30 questions. Subjects were recruited from undergraduate courses in management related subjects of a large Midwestern university and were paid at the rate of $6 per hour plus a bonus awarded for response accuracy.

Results

A total of 63 subjects completed the experiment. Table 1 contains a brief description of the personal characteristics measured with the questionnaire and cognitive abilities test. A paired t-test analysis was performed to determine the validity of comparing individual characteristics in correlation analysis between the animation duration treatments. All of the characteristics of subjects were not significantly different at the $\alpha = 0.05$ level, indicating that a correlation analysis is appropriate in determining the effect of individual characteristics on performance.

Table 1. Subject Characteristics of the Experiment (N=63).

Variable – description (range of possibilities)	Mean	Standard Deviation	Low Value	High Value
Depth Perception – lower is better (20-400)	35.24	49.26	20	400
Hidden Patterns Test – higher is better (0-400)	211.79	40.47	148	306
Snowy Pictures Test – higher is better (0-24)	13.54	3.79	3	20
Age – higher is older (18+)	22.14	3.07	18	33
Level of Schooling – higher means more (1-6)	3.13	0.55	2	6
Grade point average – higher is better (1-5)	3.86	0.76	3	5
Video game skill – higher is more (1-5)	2.46	0.88	1	5
Migraine headaches – higher is more (1-5)	2.52	1.37	1	5
Graph use frequency – higher is more (1-5)	3.62	0.91	2	5
TV viewing frequency – higher is more (1-5)	3.03	1.11	1	5
Number of states identified–higher is more(0-50)	31.54	14.49	1	50
Overall percentage score–higher is better (0-100)	58.00	13.00	20	97

To determine the impact of various individual variables on results, the Pearson's correlation coefficient r is calculated between various background variables and the percentage correct responses for each subject. Table 2 shows a summary of the results based on animation duration and for each proposition.

Table 2. Summary of Propositions and Results Obtained (Dependent Variable is Response Accuracy)

Prop.	Supported? (Y/N)	Independent Variable	Individual characteristic	Overall response accuracy	Animation Duration: Duration-5	Duration-3	Duration-1
P1	N	Human Abilities test	Depth perception	-.14	-.61[b]	-.10	-.00
			Hidden Patterns	.10	-.13	.00	.27
			Snowy Pictures	.12	.47	-.27	.21
P2	Y	Individual Background Characteristics	Age	-.26[a]	-15	-.47[a]	-.26
			Gender	-.05	.07	-.39	.19
			Grade point average	.04	-.09	.07	.11
			Video game skill	.10	-.02	-06	.43[a]
			Migraine frequency	-.03	-.41	-.05	.18
			Use of Graphics	.13	-.01	.31	.06
			TV viewing	-.06	.12	-.25	-.02
P3	Y	Declarative Knowledge	Previous knowledge of states	.29[a]	.27	.06	.35

[a] indicates p-value £ 0.05, [b] indicates p-value £ 0.005

Testing of Proposition One

Proposition One states that human abilities impact response accuracy. Table 2 shows that none of the abilities tests [depth perception (r=-.14,p=.29), Hidden Patterns (r=.10,p=.42) and Snowy Pictures (r=.12,p=.33) tests] were significantly correlated with overall performance. These results suggest that a direct relationship may not exist between the abilities tested and resultant performance. However, as Table 2 indicates, the score on the RANDOT™ depth perception test was significantly inversely correlated to response accuracy (r=-.61,p=.003) when the animation treatment duration was slowest. This suggests that better depth perception resulted in higher response accuracy on the research task.

Testing of Proposition Two

Proposition Two states that background information impact performance on the experimental task. The individual characteristics data collected includes age (r=-.26,p=.04), sex (r=-.05,p=.70), grade point average (r=.04,p=.78), video game ability (r=.10,p=.42), migraine headache frequency (r=-.03,p=.79), graphics use (r=.13,p=.29) and amount of television viewing (r=-.05,p=.64). Results of the correlation analysis show that of these variables, age was significantly correlated with response accuracy, with younger subjects performing better than older subjects. These results suggest that age impacts performance on this type of task. Previous research also indicates a slowing of information processing skills past the age of twenty-five (Birren and Botwinick 1955, Botwinick and Thompson 1966, Salthouse 1985, Strayer et al 1987, Welford 1958, 1977, Welford and Birren 1965, Wickens et al 1987).

Testing of Proposition Three

Proposition Three states that domain knowledge might impact response accuracy. Correlation analysis shows that the previous knowledge subjects possessed about the states in the U.S. was significantly correlated with overall response accuracy (r=.29,p=.02). These results indicate support for domain knowledge having direct impact on performance. Knowledge of the states in the U.S. was used as a surrogate for domain knowledge, since the area of the states was recognizable as the specific state.

Impact of Animation Duration

Since three different animation speeds were used in this experiment, results based on the duration of the display also prove interesting. Analysis of the personal characteristics and ability scores indicate an equal distribution of subjects in the three animation duration levels. Performance using duration-5, which took the longest time to display, was highly correlated with depth perception. The better the depth perception of the individual, the better performance was recorded. Age was also more important to the performance using duration-3, with younger subjects outperforming older ones. In previous research, video game playing has been shown to enhance the ability of mental rotation and spatial visualization (Okagaki and Frensch 1994). This study indicates that overall performance was not enhanced by self-reported video game skill (r=.10,p=.42). One interesting find, however, is that accuracy of subjects at the fast animation duration was significantly correlated with video game skill (r=.43,p=.05). This result indicates that the skills developed through experience in a multi-dimensional, moving environment such as a video game may be transferable to the type of environment provided by this research.

Discussion

The task-technology fit paradigm suggests that the degree to which a technology assists an individual in performing a task is enhanced when the task, individual and technology characteristics complement each other. Results indicate that combinations of the technology and individual characteristics that make up user competence do indeed, affect performance in the selected task. By evaluating these combinations, suggestions for personnel selection and training guidelines may be derived.

Selecting personnel to perform tasks using a multiattribute, moving display such as the one used in this research is important to the success of such systems. Guidance in the selection of personnel is provided by this research. This study shows that age decreases the ability to comprehend the data displayed on the screen, however domain knowledge counteracts the age effect by having a significant positive effect on performance. Since domain knowledge takes time to acquire, we cannot make the recommendation to only use younger people on tasks of this nature. Good depth perception aided performance at Duration-5 (slowest duration). Ability in this sense is a naturally occurring state, which cannot be improved with practice. When the application of a multiattribute, moving display requires one that moves very fast, such as real-time displays, those skilled in video games perform better than those not skilled. This indicates that in those special environments, those accustomed to that environment will perform better. However, that skill can perhaps be enhanced through practice and proper training.

Training personnel to perform tasks using a multiattribute, moving display such as the one used in this research can improve overall display comprehension and contribute to the success of such systems. According to the Koubek, Salvendy, Tang and Brannon (1999) model, expertise level is reflected in the structure of the knowledge about the task environment. This task focused on the lowest level of knowledge structure, declarative. By measuring the number of states in the U.S. known beforehand, the amount of declarative knowledge was measured. These results indicate that the amount of declarative knowledge affects performance. Even though subjects did not need to rely on their knowledge of the states to identify where to look during the experiment, greater previous knowledge increased overall performance. This research makes it clear that appropriate knowledge of the display domain can improve performance. Knowledge structure is gained through use of the domain, whether in a training scenario or in actual use. Training programs in visualization systems should focus on advancing the knowledge of the display domain.

The conceptual framework for skill acquisition hypothesized by Koubek, Salvendy, Tang and Brannon (1999) indicates that a presence of the abilities needed to perform a task, when combined with advanced knowledge structure would produce a higher level of learning and consequently a higher level of performance on a task. None of the abilities measured in this study were found to significantly affect overall task performance. The level of knowledge was measured by identifying the number of states in the U.S. that a subject could identify on a map before the experimental task began. The skills identified as important were those that accompany a younger age. This may be based on information processing duration (relevant since the information was only visible for a period of time) or some other skill that is reduced through the aging process. When both of these characteristics are favorable, performance should increase. The subject that scored highest on the experimental task (97 percent) was age 20 and identified all 50 states. However, the second highest performer (83 percent) was age 23 and identified only 19 of the 50 states (38 percent). The lowest performance (20 percent) was recorded by a subject of age 22 and who identified 12 states (24 percent). These sample results indicate that further investigation into the effect of the constructs is warranted.

Limitations and Future Research

This research suffers from the criticism that an experimental lab does not adequately simulate real-world conditions, in that the decisions do not have significant ramifications. In addition, overlaying a real-world context might have altered the outcomes. The intention of this research was to experimentally test basic comparison ability in a data visualization environment. In the future, adding business cases and determining learning from the display might prove useful. The results from this experiment will be used to create a more robust model for testing in the future.

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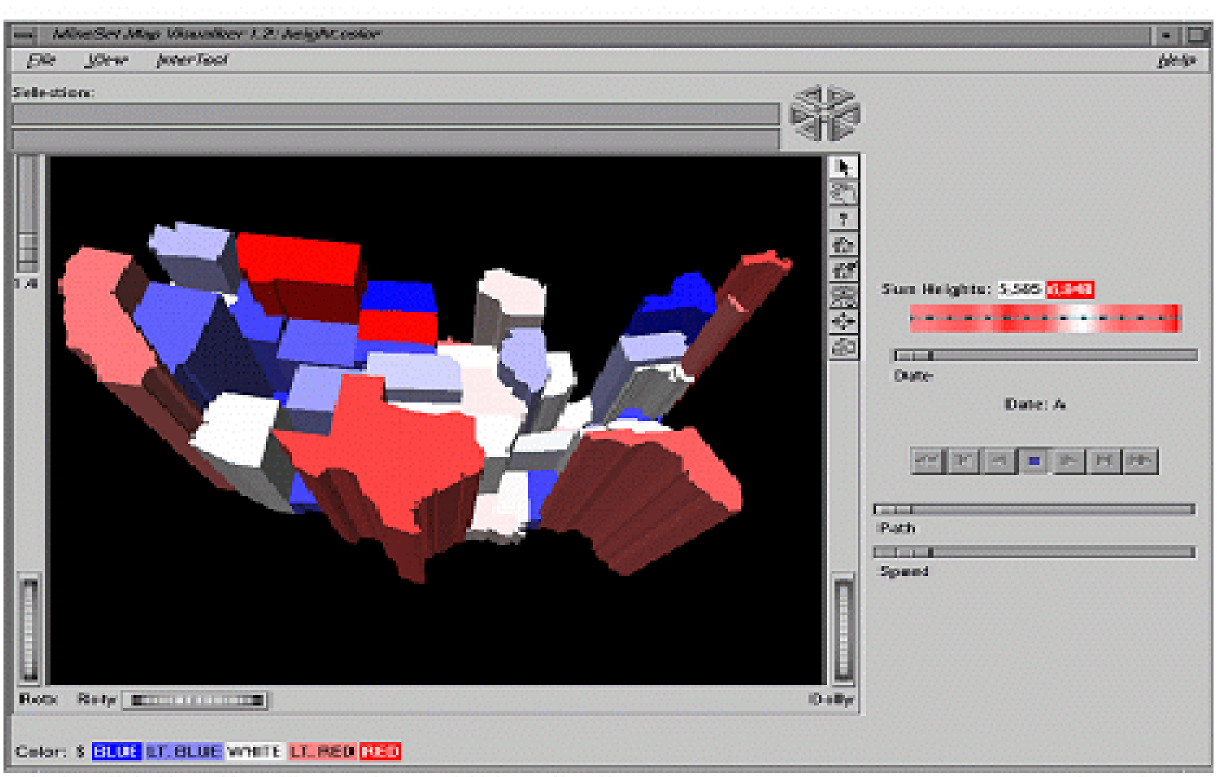

Color Plate 1: First frame of the experimental display.

Appendix A.
Background Questions for Animation Experiment

1. Is your vision close to 20/20, or corrected to close to 20/20 (circle one)? Yes No

2. What is your age? ________

3. What is your sex (circle one)? Male Female

4. What is the highest level of schooling achieved (circle one)?

   A. Grade school
   B. High school degree
   C. Some college
   D. Bachelors degree
   E. Some graduate courses
   F. Masters degree
   G. Doctoral degree

5. What is/was your major? __________________________

6. What is/was your overall G.P.A. (circle one)?

0.0 - 0.9	1.0 - 1.9	2.0 - 2.9	3.0 - 3.4	3.5 - 4.0
1	2	3	4	5

7. How would you rate your video arcade game ability (circle one)?

Never play	Occasionally play	Score high sometimes	Beat most other players	One play lasts an hour or more / I can beat the machine
1	2	3	4	5

8. How often do you experience migraine headaches (circle one)?

Never	Once a decade	Once a year	Two or three times a year	Once a month
1	2	3	4	5

9. How much experience do you have using graphics; for example, pie charts, line charts and bar charts (circle one)?

Never use graphs	Occasionally use graphs	Sometimes use graphs	Use graphs many times	Use graphs all the time
1	2	3	4	5

10. How many hours a day do you watch television (circle one)?

0	< 1 hour	1-2 hours	2-4 hours	> 4 hours
1	2	3	4	5

11. Identify as many states of the United States as you can on the following map (Write the state abbreviation in or near the state area).