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Abstract

An evaluation of skills and abilities that could conflict with each other during multi-task performance of driving and mobile telephone usage was performed using Fleishman's taxonomy of human performance with data collected using the job assessment software system computer-based survey tool. A literature review of mobile phone use during driving and dual task performance was first conducted to assess current thinking about the topic. Taxonomic-based data were collected from 27 survey respondents for the tasks of driving on city streets, driving on long distance highways, dialing a mobile telephone, and talking on a mobile telephone. Data were analyzed, and each of the driving tasks was compared against each mobile phone task using a compatibility index based around the taxonomy. Conclusions are reached that generally suggest some of the reasons, from a human factors viewpoint, why overall performance can be reduced during simultaneous driving and use of a mobile telephone.

ACKNOWLEDGMENTS

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CONTENTS

AN EVALUATION OF SKILLS AND ABILITIES REQUIRED IN THE SIMULTANEOUS PERFORMANCE OF USING A MOBILE TELEPHONE AND DRIVING AN AUTOMOBILE

INTRODUCTION

In today's technology-based society, new machines and systems that would have been undreamed of only a few short years ago have rapidly proliferated and become a way of life. Developments and advances, especially in the areas of digital electronics and micro-circuitry, have spawned subsequent technology-based improvements in transportation, communications, entertainment, automation, and many other areas, which would not have been possible otherwise. This rapid "explosion" of new capabilities and ways of performing tasks has been partially motivated by the philosophy that if it is possible to make something better or work faster or be more cost effective or operate over greater distances, then it must be inherently good for the people who will use and benefit from the new products, services, systems, and machines produced as a result.

The formal concept of human-system interface design has only emerged this century as a recognized academic discipline; however, the practice of developing ideas and concepts for new products for which the human is the primary user and benefactor has been in existence since man started experiencing cognitive thought.

One example of a human-system interface technology for communication and dissemination of information that has evolved over centuries of trial and error development is the book. It is no accident that the form and shape of today's book of are as they are. The book's optimal configuration was determined by centuries of trial and error until it has become readily usable. This slow evolution was mirrored by a rate of technological evolution that allowed new technological advances to be experimented with as part of the overall use requirement and need for the existence of the printed word and some way to contain it.

Today, however, technology is advancing at such a rapid rate that evolutionary use requirements have no chance to develop alongside the fast-paced technological advances. One result of this recognition is the establishment of disciplines such as human factors engineering, which have stated purposes and goals of systematic determination of good and bad human-system interface designs. However, other results of this phenomenon are systems that are developed and placed into public use simply because new technology allowed them to be made. This development can proceed without a full appreciation of how the system might be used and, perhaps even more significantly, without regard to the impact that the use of this new system might have on the person(s) using it. The U.S. Army has a term for this type of activity: "stove-piped development." The implication of this term is that a system is developed in isolation where the developers are only looking "up" and not "around" and where they are thus concerned only with how this system may work or be used for its own singular purposes and not how it might be used in the larger community of existing systems and interfaces or, even more importantly, in the larger community of other new systems in concurrent development.

Some of the impacts for the Army are communication systems that work exactly as designed but are unable to interface with other communications systems in other domains for battlefield-wide communications capabilities. Having communications systems that cannot communicate with each other is one problem, but when developments in one industry produce products that humans use or attempt to use with products from totally separate developments or industries, the Army's concept of product development resulting from stove-piped design visions can have significant implication on the use and operation of each system and the human operator attempting to use them.

Many examples would illustrate this concept; however, two that are explored here are the automobile and the mobile telephone. Each system is the product of a long (for our generation) development process that has proceeded without any thought or consideration of the other until recently. The automobile's existence is in response to human desires for travel and mobility, which technology, over the course of the past century, has been able to address through ever more advanced mechanization. The entire previous development of transportation of the human race before the development of the automobile and "cousins" such as the railroad, depended on animal-borne locomotion and power. Whether the power came from beasts of burden such as mules or directly from the human's own efforts, it was biology-based power with all of its inherent capabilities and limitations.

Technology-based mechanization has changed all of that and has occurred very quickly when compared to the evolutionary scale that preceded it. Motorized conveyances are the norm across the planet, with the possible exception of a few native tribes still residing deep in the Amazon rain forests or those who choose to not embrace modern technology such as the Amish religious sect found in Pennsylvania. The resulting cataclysmic change of life style that is considered normal by today's society has produced a mind set for the population at large, which is characterized by such concepts as a highly mobile daily routine, freedom of movement to proceed at will over great distances, and individual preference generally not constrained by a need to congregate simply to move over land (as in massing for public conveyances).

Many of the same types of thought processes could be applied to the development of the telephone where technology now allows the spoken word to travel farther than the broadcast voice power of the speaker. Initial developments carried the voice over electrically stimulated wire, but concurrent developments in radio technology and the digital computer now allow the telephone to operate as a truly mobile instrument, allowing the human user to have voice communications with literally anyone on the planet while operating anywhere on the planet. It is only natural that now, with the small size and portability of the mobile telephone, that it should be carried into and used within the confines of the automobile. This was a convergence of use patterns and technologies that was probably not considered in previous designs and application areas for either system. If a passenger in a car uses the phone as a singular act while someone else is driving the car, it is really not much different from using the phone from any other location or in any other situation. However, if the driver of the automobile attempts to use a mobile telephone concurrently while driving, then activities that were designed into each system for independent human interaction could cause simultaneous demands to be placed on the human operator that cannot be met simultaneously. When this occurs, some modification of behavior of the operator toward one system or the other or both can happen. Exact reaction performances are highly dependent on the specifics of the situation (driving conditions, importance of the phone call) and the individual nature of the operator (experience driving, experience with mobile phone, preferences, performance desires, etc.). Techniques exist to examine these potential conflicts, which can generate unexpected and unpleasant consequences such as a car crash that occurred while the driver's attention was distracted by the mobile phone.

This report explores these potential conflicts by evaluating individual normative cognitive and motor skills and abilities required for the operation of each system. By looking at skills and abilities required for each system and then assessing when the same skill and ability could be demanded from the operator by the different systems at the same time, an evaluation will be performed to determine, from a human performance point of view, whether the concurrent act of driving an automobile and using a mobile telephone is a desired combination of activity. Data to support these analyses and conclusions will be empirically collected from individuals with identified experience with both systems. Demographic correlations of the data for age and gender groupings will be performed to identify tendencies in either area. Other demographic data for experience level and operator preferences will be used to determine if either of these factors plays a role on the demand requirements placed on the operator by each system. Finally, recommendations based on the conclusions reached will be presented for system improvements and possible recommended modifications of operator habits.

APPLICATION OF A TAXONOMY OF HUMAN PERFORMANCE

With work first published in 1954, Edwin Fleishman (1975) began what would become a lifetime of effort focused on the development of a taxonomic descriptor of work performance. The resulting taxonomy (Fleishman & Quaintance, 1984) presents a set of skills and abilities that can be used to describe human performance characteristics in any general work situation. Fleishman stated (1975, 1978) that some kind of taxonomy of human performance is required, which provides an integrative framework and common language applicable to a variety of basic and applied areas. He further stated that predictions and generalizations about human performance appear to be enhanced by some linkage of task classification systems based on human abilities and task characteristics. In 1988, Fleishman quoted 1947 work by others with the observation that apparatus tests of perceptual motor abilities had been found to have considerable validity for predicting the success of pilots and bombardiers in completing training during World War II. Comments by others point out that Fleishman's work tends to be neglected in the mainstream of human information processing research, perhaps because the skills and abilities in the taxonomy are only based on factor analyses and are void of any process description. However, the tests used by Fleishman to develop the taxonomy belong to the same type of performance tests that are studied in Wickens' more accepted dual task experiments and therefore deserve closer scrutiny (Sanders, 1997). There have been many attempts in the human factors community to develop similar descriptions of human performance, and while this taxonomy may not be generally accepted by all for every attempt at evaluations of human performance, it does provide a set of skill and ability descriptors that are heavily weighted to cognitive performance.

Previous work at the U.S. Army Research Laboratory (ARL) (Knapp, 1996, 1997; Kanpp et al., 1997a through 1997c; Schipani et al., 1998) and the U.S. Army Research Institute (ARI) (Seven, Akman, Muckler, Knapp, & Burnstein, 1991) identified a job skill and ability taxonomy (Fleishman, 1984; Fleishman & Quaintance, 1984), which showed promise to provide the basis for workload scaling in Army battalion level C2 modeling efforts. This taxonomy consists of 52 skills and abilities that include mental processing, sensory perception and fine and gross motor skills. The selection of this taxonomy was influenced by its detailed decomposition of mental abilities and the existence of behaviorally anchored rating scales (Knapp et al., 1997b). Subsequently, 50 of the 52 skills and abilities from the taxonomy were adopted to support work that was performed for the U.S. Army Intelligence Center at Fort Huachuca, Arizona. This work sought to determine basic soldier training requirements needed to provide requisite skills and abilities for various military occupational specialties (MOSs) at the Intelligence Center's basic soldier training units. As shown in Figure 1, the taxonomy was grouped into eight demand categories (reasoning, speed loaded, conceptual, communications, visual, auditory, psychomotor, and gross motor). From Knapp (1997b), "Each skill and ability has an associated behaviorally anchored rating scale that ranges from '1' for a very low level demand, to '7' for the highest demand. Definitions for all 50 skills and abilities, along with their behaviorally anchored scales, are documented in Seven et al. (1991)." The original use of the taxonomy was supported by a manual data collection instrument called the job comparison and analysis tool (JCAT) as documented by Seven. Knapp used this in 1996 to investigate skill and ability requirements for the 96B MOS for the Army and for nurses' requirements in hospital emergency rooms. As more experience was gained with the taxonomy, it was decided to automate it into a computer-based tool (Knapp & Tillman, 1998). This new tool was named the job assessment software system (JASS) and capitalizes on computer technology by implementing logic decision tree structures to determine which skill and ability would be queried to the survey respondent, based on initial task-based question responses.

Cognitive Skill and Experience Clusters

Communication
1. Oral Comprehension
2. Written Comprehension
3. Oral Expression
4. Written Expression

Conceptual (1.20)
5. Memorization
6. Problem Sensitivity
7. Originality
8. Fluency of Ideas
9. Flexibility of Closure
10. Selective Attention
11. Spatial Orientation
12. Visualization

Reasoning (1.25)
13. Inductive Reasoning
14. Category Flexibility
15. Deductive Reasoning
16. Information Ordering
17. Mathematical Reasoning
18. Number Facility

Speed-loaded (1.22)
19. Time Sharing
20. Speed of Closure
21. Perceptual Speed and Accuracy
22. Reaction Time
23. Choice Reaction Time

Cognitive skills weighted in the model

Perceptual-Motor Ability Clusters

Vision
24. Near Vision
25. Far Vision
26. Night Vision
27. Visual Color Discrimination
28. Peripheral Vision
29. Depth Perception
30. Glare Sensitivity

Audition
31. General Hearing
32. Auditory Attention
33. Sound Localization

Psychomotor
34. Control Precision
35. Rate Control
36. Wrist-Finger Speed
37. Finger Dexterity
38. Manual Dexterity
39. Arm-hand Steadiness
40. Multi-Limb Coordination

Gross Motor
41. Extent Flexibility
42. Dynamic Flexibility
43. Speed of Limb Movement
44. Gross Body Equilibrium
45. Gross Body Coordination
46. Static Strength
47. Explosive Strength
48. Dynamic Strength
49. Trunk Strength
50. Stamina

Fleishman, E. A. and Quaintance, M. K. (1984) Taxonomies of Human Performance: The Description of Human Tasks. Orlando: Academic Press.

Figure 1. Skills and abilities taxonomy.

JASS DATA COLLECTION INSTRUMENT

JASS runs on IBM-compatible PC computer systems with Pentium® processors running Microsoft Windows™ 95 or later. JASS allows multiple tasks to be queried for each skill and ability and has built-in capabilities to reduce the raw data collected from a survey pool to mean values with indicated standard deviations, thus making them ready for immediate analytical use after data collection is finished. The JASS data are stored in Microsoft Access™ database format that includes data tables containing the job assignments, questions, behaviorally anchored scales, raw scores, and reduced results. If desired, other questions can be added to the question and scales tables to collect data to either augment the skill and ability data or to gather additional information such as magnitude estimation opinion responses from the respondent for other analytical purposes.

Each question and answer sequence in JASS begins with exploratory questions that determine if that category of skills and abilities applies to the task being evaluated. Once it has been determined that the task being evaluated is applicable to the skill category being evaluated (e.g., ORAL COMPREHENSION), then questions are presented that query for a magnitude of application responses from the survey respondent. Figure 2 shows a data collection screen from JASS, which results from using the computer mouse to click on the "yes" response to the exploratory question. These data collection screens are all supported by individual anchors for each question that solicits data for each skill and ability of the taxonomy.

The survey respondent enters data by first clicking on the check box next to the question with the computer mouse and then using the mouse to move the vertical slider on the scale labeled from 1 (low) to 7 (high) to indicate the desired choice of 1 to 7. As the slider moves up and down on the anchor scale, the number in the box to the left of the check box automatically registers a number of 1 to 7, depending on how far up the scale the slider is moved. The anchors are proportionally placed on the scale. In the Figure 2 example, the bottom "Watch street signs..." anchor represents a scale value example of 3.0. Work by Knapp, Seven, Tillman, and others, working from Fleishman's original documentation, verified the anchors and anchor placement on the 7-point scale in the performance of earlier projects.

As shown in Figure 2, the JASS database configured to support this driving versus phone use study has four task-oriented questions related to driving and mobile phone use.

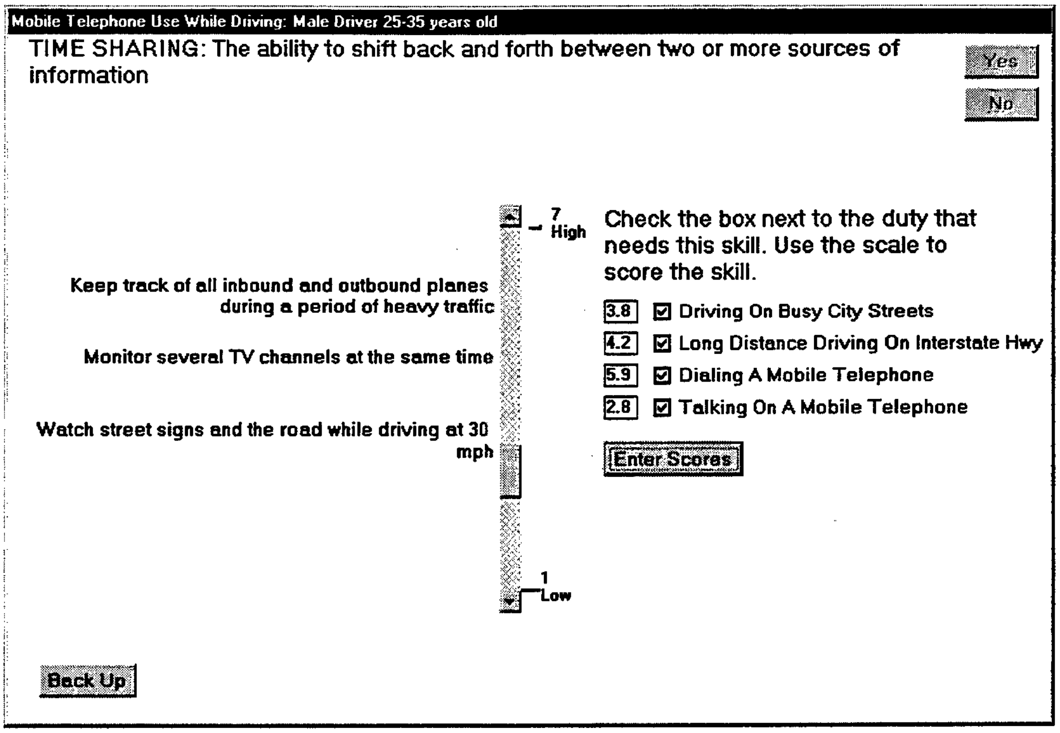

Figure 2. JASS data collection screen.

The four job tasks are

1. Driving on busy city streets,
2. Long distance driving on interstate highways,
3. Dialing a mobile telephone, and
4. Talking on a mobile telephone.

The two driving cases are intended to provide situations of stressful versus relaxed driving conditions. Although highway driving may be stressful for selected drivers, it is anticipated that this is a more relaxed case where automatic speed controls are employed and the main driver function is to keep the car steered in the center of the roadway. The two telephone job tasks are intended to represent the two main operator interface modes with the mobile phone. The dialing task represents all cognitive and motor activities that are involved when the phone controls are being manipulated for any reason. The talking task is intended to represent no other activity than a conversation once the connection has been established. Analysis of the data will correlate the skills and abilities from each driving condition to each phone use condition.

Preliminary questions in the JASS survey determine the driver's age band and gender. The following age bands were selected to see if the data presented any discriminations between the generally younger and the generally older driving population:

18 to 45 years old

45 to 65 years old.

Skill and Ability Compatibility Assessment

In 1998, Tillman and Knapp used the JASS instrument in an Army study to investigate skill and ability requirements for the MOSs 96U, 96B, and 96D. They looked at 16 job tasks related to work requirements for each of the MOSs and began preliminary work to identify which of the 50 skills and abilities from the taxonomy could conflict with each other when task demands require simultaneous attention to multiple skills and abilities. They developed a 5-index compatibility rating scale for each skill and ability against each of the other 49 skills and abilities that went from –2 to +2, with "0" as a valid index point. Tillman (1997) described this scale as follows:

> We wanted to use the JASS data to generate a number that would rate the compatibility of two tasks. Here is the idea we were working with: Simultaneous use of some skill pairs can cause conflict and degrade task performance. Other skills may actually enhance each other.
>
> We created a 50-skill by 50-skill matrix and scored each cell according to conflict or compatibility. Enhancing skill pairs got a score of +2, and conflicting pairs got a score of -2. Other skill pairs may not affect each other at all, and got a score of 0. For example, night vision is incompatible with glare sensitivity. The matrix score is therefore -2. On the other hand, idea fluency and originality are very compatible and have a score of +2. Other skills with limited interaction get scores of -1 and +1.
>
> After we get the JASS data, we can multiply the score for a skill in task A times the score for another skill in task B. We can then multiply that product by the conflict or compatibility score. For example, suppose task A has a score of 6 for night vision and task B has a score of 5 for glare sensitivity. The total score would be 6x5x(-2) or -30. If we do this for all the skill combination cells and then total the cell scores, we will have a single "task compatibility" index.
>
> I have put the skill matrix scores into a database so that we can compute this compatibility index for any task pair (once we have the JASS scores). The idea is to be able to quickly check task compatibility. We can use this information to distribute tasks among a crew; each person should have tasks with high compatibility scores. Or, if one person has two incompatible tasks, we can look at the JASS data and try to determine ways to reduce this incompatibility.

Tillman stated that this work was preliminary as it had not undergone rigorous evaluation; however, it provided a technique for comparative analysis of the large 50- by 50-skill and ability arrays for each job task by direct manipulation of the JASS skill and ability information already in the data set. To date, the work is still developmental, but the approach is considered to represent a systematic application of the Fleishman taxonomic data into an application matrix for examining competing skills and abilities while unrelated tasks are performed. In Appendix A, Table A-1 shows a sample of the data produced by the JASS program; Table A-2 contains the compatibility matrix for the 50- by 50-skill and ability taxonomy; Table A-3 shows a sample of the compatibility calculation that combines the matrix with the JASS data; and Table A-4 shows compatibility scores for the entire survey population normalized from –100 to +100 for the four data points that result from comparing each of the two driving conditions to each of the two mobile phone conditions. This process is repeated four times for the two gender and two age groupings, and the results are presented next.

Analysis of Data

Using the compatibility process just described, we reviewed the data for the total survey population to identify competing skill demands in the various combinations of performance tasks. These task combinations were

City driving versus dialing a mobile phone,
City driving versus talking on a mobile phone,
Highway driving versus dialing a mobile phone, and
Highway driving versus talking on a mobile phone.

In addition, each performance task was compared against itself to determine competing and complementing skills required for that task. Figure 3 shows the results of the compatibility assessments for each task against itself to provide a representative benchmark for the complexity of the task itself as represented by performance of the skills and abilities in the taxonomy.

The driving tasks show strong demands on written comprehension skill and somewhat lesser demands on the vision and gross motor skill clusters. Significant is the fact that the dialing task also places demands on the vision and gross motor skill clusters as well as some demands on written comprehension. Figure 4 shows the taxonomic skill demands during the multi-task performance of each driving task compared against each mobile phone task.

From Figures 3 and 4, it is apparent that the multi-task case presents even more demands in areas where the performance levels were already high, such as in the vision skill cluster, especially the written comprehension skill. A problem with reaction times in city driving was indicated, which supports comments from literature. Also, significant indications show competing requirements in audition tasks, which is, of course, a primary function of the mobile phone.

City Driving vs. City Driving:

- Strong competing demands:
  + WRITTEN COMPREHENSION.
  + ARM HAND STEADINESS.
  + MULTI LIMB COORDINATION.
- Good complementing influences to
  + PROBLEM SENSITIVITY.
  + FLEXIBILITY OF CLOSURE.
  + TIME SHARING.
  + CHOICE REACTION TIME.
- General competition between components of VISION Cluster.
- General competition between components of GROSS MOTOR Cluster.

a

Highway Driving vs. Highway Driving:

- Strong competing demands to WRITTEN COMPREHENSION.
- Good complementing influences to
  + PROBLEM SENSITIVITY.
  + FLEXIBILITY OF CLOSURE.
  + SPEED OF CLOSURE.
  + PERCEPTUAL SPEED AND ACCURACY.
  + TIME SHARING.
  + CHOICE REACTION TIME.
- General competition between components of VISION Cluster.
- General competition between components of GROSS MOTOR Cluster.

b

Dialing a Mobile Phone vs. Dialing a Mobile Phone:

- Mild competing demands to
  + WRITTEN COMPREHENSION.
  + GLARE SENSITIVITY.
- Mild complementing influences to
  + MEMORIZATION.
  + PROBLEM SENSITIVITY.
  + FLEXIBILITY OF CLOSURE.
  + SELECTIVE ATTENTION.
- Some competition between components of VISION Cluster.
- Some competition between components of GROSS MOTOR Cluster.

c

Talking on a Mobile Phone vs. Talking on a Mobile Phone:

- Mild competing demands to
  + TIME SHARING.
  + GENERAL HEARING.
- Mild complementing influences to
  + SELECTIVE ATTENTION.
  + GENERAL HEARING.
  + AUDITORY ATTENTION.

d

Figure 3. Compatibility assessment results.

City Driving vs. Dialing a Mobile Phone:

- Strong competing demands:
  + Entire VISION Cluster.
- Mild competing demands:
  + ARM HAND STEADINESS.
  + MULTI LIMB COORDINATION.
  + SPEED OF LIMB MOVEMENT.
- Good complementing influences to
  + Most of PSYCHOMOTOR Cluster.
  + SPEED LOADED Tasks.
- General competition between components of VISION Cluster.
- General complementing between components of AUDITION Cluster.

a

City Driving vs. Talking on a Mobile Phone:

- Strong competing demands:
  + WRITTEN COMPREHENSION.
- Mild competing demands:
  + TIME SHARING.
  + PERCEPTUAL SPEED AND ACCURACY.
  + CHOICE REACTION TIME.
- Mild complementing influences to:
  + Most of CONCEPTUAL Cluster.
  + AUDITION Tasks.

b

Highway Driving vs. Dialing a Mobile Phone:

- Strong competing demands:
  + WRITTEN COMPREHENSION.
  + VISION Tasks.
- Mild competing demands:
  + MEMORIZATION.
- Mild complementing influences to
  + Some CONCEPTUAL Tasks.
  + Some PSYCHOMOTOR Tasks.
- General competition between components of VISION Cluster.
- General complementing between components of AUDITION Cluster.

c

Highway Driving vs. Talking on a Mobile Phone:

- Strong competing demands:
  + WRITTEN COMPREHENSION.
- Mild competing demands:
  + Some SPEED LOADED Tasks.
  + PERCEPTUAL SPEED AND ACCURACY.
  + CHOICE REACTION TIME.
- Mild complementing influences to AUDITION Tasks.

d

Figure 4. Taxonomic skill demands for each multi-task grouping.

To draw the analysis to a climax, the compatibility numbers for each of the four combinations of multi-task performance for three variations of the survey population were calculated. In addition to the total population, the survey group was first segregated into age groupings and then into gender groupings with the four compatibility numbers calculated for each grouping. The results are shown in Figure 5.

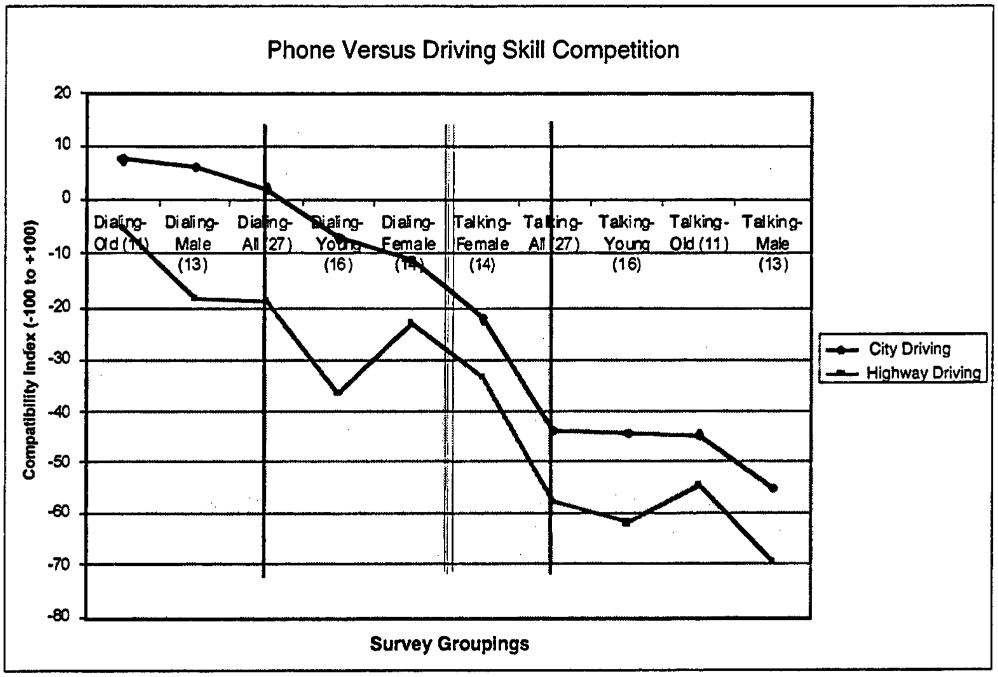

Figure 5. Results of phone versus driving skill competition.

The double vertical bar separates the dialing and talking phone tasks, and the single vertical lines indicate the data points for the total population, with lines drawn for the city driving and highway driving cases. In all cases, the highway driving versus talking task combination indicated the most severe competition of human performance skills. Concerning gender significance, the talking task indicated a much stronger task demand for males than for females, with the dialing task being slightly more demanding on the females than on the males. Age discrimination was mixed, with the dialing task indicating more difficulty for younger drivers and the talking task showing clear indications against older drivers. A point noted without comment is that young females tend to show the least effect of this multi-task performance requirement, while old males clearly show the most effect.

DISCUSSION

Surveys of the literature reveal that a significant interest is being placed on the topic of combined-cell-phone-use-while-driving activity. Some of the literature surveyed by this study addressed such issues as age, demographics, legal issues, human physiology, safety, dual task performance, performance taxonomies, and some technology-based observations. As stated before, the act of driving has become a common-place activity in modern society. It is observed that phone conversation is the most prominent of many activities that motorists engage in while driving. However, police observations of potentially distracting driver activities also include such things as eating ice cream, typing on a laptop computer, brushing their teeth, flossing, changing clothes, balancing a pet on their lap, and switching positions in the front seat, among other things (Ahrens, 1999). This study only focuses on the immediate problem and leaves attempted review of these other activities to others.

Significance of Age

The first complete cellular telephone systems became operational in 1984. While a cellular telephone conversation is no more distracting than a conversation of the same intensity with a passenger, all users of cellular phones should be advised not to engage in intense phone conversations while driving a vehicle. Specifically, this study has shown that all forms of cellular phone usage lead to significant decreases in abilities to respond to highway traffic situations and an increased time to respond. Further, complex intense conversations are shown to cause the greatest increase in the likelihood of the driver overlooking significant highway traffic conditions and his or her resulting response time. Age plays a significant role since the distracting effect of cellular phones among drivers over 50 is two to three times as great as that for younger drivers (McKnight & McKnight, 1993). Does ability increase with age, decrease with age, or remain constant? Recent work in the area of relating the aging process to ability would indicate that the answer to this question is "yes." To which part the "yes" applies depends on a number of factors. Cross-sectional studies have shown a clear decrease in tested general intelligence with increased age (Fleishman & Bartlett, 1969). From a human physiology standpoint, divided attention, or the ability to attend to both auditory and visual stimuli simultaneously, declines with age, particularly between 40 and 50 (Boff & Lincoln, 1988a). Overall, there seems to be general agreement that age negatively correlates with driver simulator performance. In driving simulator tests with professional taxi drivers, age was the most constant predictor of performance—the greater the age, the poorer the performance in the driving simulator (Edwards, Hahn, & Fleishman, 1977).

Physiology Considerations

Considering basic human capabilities, dividing attention between concurrent visual search demands generates compensatory performance; as performance of one task improves, the performance of the other task declines (Boff & Lincoln, 1988c). Also, dividing attention among several spatial locations produces a deleterious effect whereby performance drops significantly as the number of possible locations increases (Boff & Lincoln, 1988b). In the specific case of driving and simultaneous telephone use, when the interference between these concurrently performed tasks was investigated, it was concluded that perception and decision making could be critically impaired by switching between visual and auditory inputs (Brown, Tickner, & Simmonds, 1969).

Dual Task Performance

Here, the literature becomes prolific. Considering the dual activities of driving and mobile telephoning, in tests measuring the ability of drivers to follow a lead vehicle and remain close to that car in actual traffic, subjects showed a considerable delay in reaction time as a consequence of the additional task of using a mobile telephone (Brookhuis, DeWaard, & Mulder, 1994; Nilsson, 1993). Jacoby (1977) points out that information overload refers to the fact that there are limits to the ability of human beings to assimilate and process information during any given unit of time. Once these limits are surpassed, the system is said to be "overloaded" and human performance becomes confused, less accurate, and less effective. Whether the concurrent use of cell phones while driving can cause an information overload state can be debated, but data presented later in this study indicate cognitive competition between driving performance and focused conversations on the mobile phone.

In studies of the effects of driving performance while a driver uses a hands-free mobile telephone, it was concluded that an "easy conversation" (2 minutes or less about general topics) did not impair driving and could, in some cases, be considered facilitative. However, a difficult conversation (2 to 5 minutes about subjects that invoked a test of working memory span) could impair driving performance significantly, and prolonged manipulation of the mobile telephone controls contributes to driver performance impairment, especially when the tasks place significant demands on driver attention and skill. While simply conversing over the telephone had the least effect on observed behavior during this test, manipulation of the equipment while driving affected driver performance the most. This study concludes that the driver is well advised to park the car before attempting a mobile telephone call, especially during difficult driving conditions (Briem & Hedman, 1995).

Another study of the effects of mobile phone usage on driving ability showed that telephoning use had a significant effect on the ability of the driver to operate the vehicle. Observed effects from concurrent mobile phone use and driving include less checking of the rear-view mirror, increased reaction time to braking, increased speed variation, and decreased average speed. The conclusion reached was that empirical evidence supported a statement that operating a mobile telephone while driving may decrease traffic safety (Brookhuis, De Vries, & De Waard, 1991). Studies of the effects of rest and secondary task performance in truck-driving simulations showed that performance with perceived fatigue was significantly reduced when secondary tasks involving voice communications were added to the basic driving tasks (Drory, 1985). Simulator-based tests of truck driving performance found that complex secondary tasks requiring text reading and interpretation resulted in the greatest impact on the primary task of driver performance (Kantowitz, Hanowski, & Tijerina, 1996).

The need to develop driving simulators that provide a controlled environment for observing driver behaviors is the same as for any other human-machine system. These simulators allow direct observation of such driver physiology factors as vision, audition, proprioception, and vestibular motion sensation, as well as task demand and general workload level (Allen & Jex, 1980). We need to know if drivers are able to conduct car phone conversations as they would if using a fixed system and still maintain the safety margin in the driving task. Driving is a primary task that has an inherent high risk associated with it. Drivers express awareness that holding car phone conversations involves increased workload and some amount of stress, and studies point to significant increases in response times when drivers are engaged in car phone conversations (Parks, 1993). Manual cellular phone dialing sometimes is as demanding as manually tuning a radio, which is a conventional task that has been associated with crashes (Tijerina, Kiger, Rockwell, & Tornow, 1995). One study investigated the extent to which personality and ability measures predicted the transfer effects of associative interference when the subject shifted to a second task and then shifted back to the original task. Results indicated that ability measures predicted performance level during all original and reversed tasks, but personality measures did not (Fleishman & Ellison, 1969).

Abilities-oriented job analysis is concerned with identifying human attributes necessary to perform the job. The abilities required to perform a job are of paramount importance because they are the link between the potential worker and specific tasks that he or she may be asked to perform (Wilson & Zalewski, 1994). The ability requirements approach describes a task in terms of the human abilities required to perform it, so that an entire task can be described in terms of a profile of basic abilities, which accounts for performance of the task. This ability requirements approach has been shown to be useful for a variety of purposes, including predicting and assessing performance (Mallamad, Levine, & Fleishman, 1980). Studies of the ability to predict total task performance, based on the amount of prior practice exercised singularly and collectively on the tasks involved, indicated that the most important factor was simultaneous practice of the tasks involved (Fleishman, 1965). Attempting to quantify what is happening, Sanders (1997) theorizes that it is evident that the main trend in present-day focusing on dual tasks and divided attention is moving away from the concept of limited capacity. One reason for this conclusion is that problems related to multiple resources are identified as "separate abilities" without coherence (Sanders, 1997).

The fact of the matter is, however, that driving an automobile requires the full range of human capabilities, including perception, decision making, and motor skills. These capabilities must be performed in a highly coordinated fashion, often during stressful conditions. The intrusion of the mobile telephone into this human performance envelope can significantly detract from the primary driving task (Sanders & McCormick, 1993). Amazingly, some research test observation has actually used cellular telephones to collect opinion-based data from drivers while in motion, concerning the amount of stress they were experiencing while driving. Although the test apparatus was configured to allow hands-free operation for the driver, the cognitive task-intrusive nature of communicating with another individual outside the vehicle environment was apparently ignored, although such task trait behaviors such as "listening to radio traffic" was examined. Even though the study acknowledged that other research had shown that distractibility and the ability to divide attention deteriorate with the age of individual drivers, it was recommended that this was a viable way to collect data in situ to observe driver performance while being nonintrusive of the driver communications (Hennessy & Wiesenthal, 1997)! This may be true, but it ignores the implication of observational data contamination because of secondary task performance of conducting the mobile phone conversation.

Safety Concerns

The mobile telephone industry is rapidly expanding, and proponents have cited numerous safety benefits resulting from the availability and use of mobile telephones. These phone advocates claim that using a mobile phone within the confines of an automobile constitutes no more of a safety hazard or distraction to drivers than the use of automobile radios. However, driver performance measured in vehicle simulators showed a notable deterioration when drivers were required to manually dial a 10-digit number using a console-mounted phone. Safety concerns were centered primarily about the issue of driver distraction from the primary driving task. The risk of injury from phones striking passengers during automobile crashes was deemed relatively insignificant (Department of California Highway Patrol, 1987). Safety concerns about the use of mobile telephones while driving are compared to similar concerns expressed circa 1929 about the placement of radio receivers in automobiles. It was predicted then that they would never be allowed in cars and that laws would be passed to enforce that restriction. This study indicated that while manually dialing a mobile phone placed considerable distractive demands on the driver, there was little to indicate that mobile telephones in general represent a significant traffic hazard. In fact, it was noted that voice-activated dialing and memory dialing were considered less hazardous than tuning a radio.

From a different viewpoint, many express the view that the use of the mobile phone in emergency situations represented a significant safety benefit (Billheimer, Lave, Stein, Parsehgian, & Allen, 1986). However, analysis of 1989 and 1992 accident databases indicates that cellular phone usage accidents are becoming more prevalent. The conclusion is that any new design item introduced inside the automobile, which requires vision from the driver while the vehicle is moving, can be expected to increase accident rates (Wierwille & Tjerina, 1996). Attempting to quantify some direct results of this type of activity, one study showed results that talking more than 50 minutes per month on cellular phones in a vehicle was associated with a 5.59-fold increase in risk of traffic accidents (Violanti & Marshall, 1996).

Technological Developments

A major role of new technology should be to make tasks simpler. However, in the wildly competitive telephone market of today, there are fierce desires to market products with mass-market appeal, which are distinctive and different. As a result, the market demands speed and novelty that are often achieved at the expense of functionality and forethought (Norman, 1988). In a multi-year study focused on investigating human factors relationships between driving and driver information systems, one system evaluated in particular was car phones. In regard to mobile phone usage, people who had them were reported as loving them. Those who did not have them were concerned about their use while driving. Almost no one indicated that they typically stopped to make a car phone call (Green, Williams, Serafin, & Paelke, 1991). The benefits of information technological advances for such systems as driver information displays and route guidance services could benefit drivers both collectively and individually, as well as society as a whole.

As a result of this philosophy in Europe, the transport ministers from the nations that belong to the European Conference of Ministers of Transport (ECMT) are pushing for communication standards and international public development of route guidance and driver information systems. Although it is recognized that poorly designed vehicular information systems can adversely affect driver behavior, the identification of a good design has not been specified. However, general guidance for in-vehicle information systems (IVIS) and cellular telephones includes such recommendations as the use of a hands-free unit, refraining from dialing while driving, becoming proficient in the use of communications systems without having to look at them, and never attempting to make written notes while driving (ECMT, 1995).

The telephone industry is actively involved in human factors research designed to better interface the human operator with the telephone, especially the mobile phone. Essential user operations for mobile phones are defined as call initiation, call termination, clearing the called number storage register, and hands-free transfer. Recommendations for improved performance designs are being developed, and many features such as "send" and "end" buttons already exist on currently used phones (Hanson & Bronell, 1979). A Bell Laboratories' study compares the effects of dialing a mobile telephone to tuning a car radio. This effort could find no significant advantage of one design over another, although test subjects expressed concern about any task that would interfere with the driving task. Driver preference indicated that any design that forces the redirection of visual attention from the road should be avoided (Kames, 1978).

The truth is that drivers of motor vehicles have anthropometric, sensory, perceptual, motor, judgmental, and other attributes that need to be addressed by vehicle designers in order to construct vehicles compatible with human physiology (Mortimer, 1972).

Legal Implications and the Driving Population

Bell Laboratories' surveys of driver populations indicated that most mobile customers were business users who were competent drivers. Also, most mobile telephone activities were perceived to be in the same category as common automotive tasks such as tuning a radio (Smith, 1978). In the years since this study, cellular telephone networks have seen huge expansions, but the predominance of business use today cannot be substantiated. However, it is presumed that a large business-oriented user population still exists, and many businesses are not providing insurance liability that covers the use of mobile phones while their employees drive. This philosophy is based on conclusions by the American Automobile Association Foundation for Traffic Safety, which found that car phone use significantly increases driver reaction time, increases driver tendency to overlook significant traffic conditions, and increases the tendency for distraction with age (Jarvis, 1994).

CONCLUSIONS AND SUMMARY

The literature contains several recurring themes concerning the act of using a cell phone while driving. Some of these themes are substantiated by this study that attempts to answer, from a human factors viewpoint, why some of these concepts are significant. The first recurring theme is age, with study after study presenting evidence that reaction times and multi-task performance reaches discernible levels of decline, especially in drivers over 50. The most severe competition of skills identified here occurs during highway driving while conducting a cognitive conversation which can distract the driver from the primary task of highway focus at high speed. Significant results from this competition are increased reaction times and decreased average speed, both of which can contribute to accidents. Gender distinctions are not well supported in the literature, but this study shows a tendency for male drivers to be more affected than females.

In closing, the literature contains references that state that it is advisable to pull off to the side of the road and stop before attempting to use a mobile phone while driving. The increasing realization among the driving public is that this advice is both prudent and wise. Some of the reasons from a cognitive and physiological point of view that substantiate this assessment have been presented here.

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APPENDIX A

TABLES

TABLES

1. Sample of JASS Raw Data
2. Skill and Ability Compatibility Matrix
    a. Skills 1 through 25
    b. Skills 26 through 50
3. Sample of Compatibility Matrix Calculation
4. Compatibility Scores for Total Survey Population

Table A-1

Sample of JASS Raw Data

DutyName	Scale Number	ScaleName	N	AvgScore	StdDev
Dialing A Mobile Telephone	0010	ORAL COMPREHENSION	27	0.49	1.27
Dialing A Mobile Telephone	0020	WRITTEN COMPREHENSION	27	1.11	1.25
Dialing A Mobile Telephone	0030	ORAL EXPRESSION	27	0.22	0.79
Dialing A Mobile Telephone	0040	WRITTEN EXPRESSION	27	0.04	0.19
Dialing A Mobile Telephone	0050	MEMORIZATION	27	2.79	1.94
Dialing A Mobile Telephone	0060	PROBLEM SENSITIVITY	27	2.57	1.70
Dialing A Mobile Telephone	0070	ORIGINALITY	27	0.74	1.39
Dialing A Mobile Telephone	0080	FLUENCY OF IDEAS	27	0.77	1.33
Dialing A Mobile Telephone	0090	FLEXIBILITY OF CLOSURE	27	2.42	1.73
Dialing A Mobile Telephone	0100	SELECTIVE ATTENTION	27	3.09	2.21
Dialing A Mobile Telephone	0110	SPATIAL ORIENTATION	27	2.14	1.97
Dialing A Mobile Telephone	0120	VISUALIZATION	27	1.33	1.88
Dialing A Mobile Telephone	0130	INDUCTIVE REASONING	27	1.23	1.60
Dialing A Mobile Telephone	0140	CATEGORY FLEXIBILITY	27	0.42	1.05
Dialing A Mobile Telephone	0150	DEDUCTIVE REASONING	27	1.54	1.79
Dialing A Mobile Telephone	0160	INFORMATION ORDERING	27	1.58	1.53
Dialing A Mobile Telephone	0170	MATHEMATICAL REASONING	27	0.59	1.24
Dialing A Mobile Telephone	0180	NUMBER FACILITY	27	0.19	0.53
Dialing A Mobile Telephone	0190	TIME SHARING	27	3.18	2.30
Dialing A Mobile Telephone	0200	SPEED OF CLOSURE	27	1.42	1.77
Dialing A Mobile Telephone	0210	PERCEPTUAL SPEED AND ACCURACY	27	2.51	1.95
Dialing A Mobile Telephone	0220	REACTION TIME	27	0.63	1.25
Dialing A Mobile Telephone	0230	CHOICE REACTION TIME	27	1.79	1.75
Dialing A Mobile Telephone	0240	NEAR VISION	27	3.12	2.28
Dialing A Mobile Telephone	0250	FAR VISION	27	0.96	1.72

Table A-2a

Skill and Ability Compatibility Matrix
Fleishman's Taxonomy of Human Performance

	Compatibility Matrix	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	Part 1																									
1	Oral Comprehension	2	-1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	0	-1	0	-1	0	0
2	Written Comprehension	-1	2	0	0	0	-1	0	0	-2	0	0	-1	0	0	0	0	0	-2	-2	0	-1	0	-1	0	0
3	Oral Expression	0	0	2	-1	0	0	0	0	0	0	0	0	0	0	0	0	-2	-1	0	0	0	-1	-1	0	0
4	Written Expression	-1	0	-1	2	0	-1	0	0	-2	0	0	0	0	0	0	0	0	-2	-1	0	-1	0	-1	2	-2
5	Memorization	0	0	0	0	2	-1	-1	-2	-1	2	0	0	0	0	0	0	-1	-1	-2	-1	0	0	0	0	0
6	Problem Sensitivity	0	-1	0	-1	-1	2	0	0	2	0	0	2	2	1	2	2	0	0	2	2	2	2	2	0	0
7	Originality	0	0	0	0	-1	0	2	2	0	0	0	1	2	2	0	0	0	0	0	1	0	0	0	0	0
8	Fluency Of Ideas	0	0	0	0	-2	0	2	2	0	0	0	1	2	2	0	0	0	0	0	1	0	0	0	0	0
9	Flexibility Of Closure	0	-2	0	-2	-1	2	0	0	2	1	1	1	2	2	0	1	2	0	0	2	2	0	0	0	0
10	Selective Attention	0	0	0	0	2	0	0	0	1	2	0	0	0	0	0	1	0	1	1	0	1	0	0	0	0
11	Spatial Orientation	0	0	0	0	0	0	0	0	1	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Visualization	0	-1	0	0	0	2	1	1	1	0	1	2	1	0	0	1	0	0	0	0	0	0	0	0	0
13	Inductive Reasoning	0	0	0	0	0	2	2	2	2	0	0	1	2	2	0	2	1	0	0	2	0	0	0	0	0
14	Category Flexibility	0	0	0	0	0	1	2	2	2	0	0	0	2	2	0	0	2	0	0	2	0	0	0	0	0
15	Deductive Reasoning	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0
16	Information Ordering	0	0	0	0	0	2	0	0	1	1	0	1	2	0	2	2	2	1	0	0	0	0	0	0	0
17	Mathematical Reasoning	0	0	-2	0	-1	0	0	0	2	0	0	0	1	2	2	2	2	0	0	1	0	0	0	0	0
18	Number Facility	-1	-2	-1	-2	-1	0	0	0	0	1	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0
19	Time Sharing	-1	-2	0	-1	-2	2	0	0	0	1	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0
20	Speed Of Closure	0	0	0	0	-1	2	1	1	2	0	0	0	2	2	0	0	1	0	1	2	2	0	2	0	0
21	Perceptual Speed And Accuracy	-1	-1	0	-1	0	2	0	0	2	1	0	0	0	0	0	0	0	0	0	2	2	0	2	0	0
22	Reaction Time	0	0	-1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0
23	Choice Reaction Time	-1	-1	-1	-1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	0	0
24	Near Vision	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	-1
25	Far Vision	0	0	0	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	2
26	Night Vision	0	-2	0	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	2
27	Visual Color Discrimination	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
28	Peripheral Vision	0	-2	0	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	2
29	Depth Perception	0	-1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	1
30	Glare Sensitivity	0	-2	0	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	-2
31	General Hearing	-2	0	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	Auditory Attention	0	0	-1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	Sound Localization	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0
34	Control Precision	0	-1	-1	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0
35	Rate Control	0	-2	-1	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	2	0	0
36	Wrist-Finger Speed	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	Finger Dexterity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	Manual Dexterity	0	0	0	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	Arm-Hand Steadiness	0	0	-1	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	Multi-Limb Coordination	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	Extent Flexibility	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	Dynamic Flexibility	-1	-1	-1	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	Speed Of Limb Movement	0	-2	0	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0
44	Gross Body Equilibrium	0	0	0	-2	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-1	0
45	Gross Body Coordination	0	-1	-1	-2	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	Static Strength	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	Explosive Strength	-1	-2	-2	-2	0	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	-1
48	Dynamic Strength	-1	-1	-1	-2	0	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1
49	Trunk Strength	0	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	Stamina	-1	-2	-1	-2	0	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A-2b

Skill and Ability Compatibility Matrix
Fleishman's Taxonomy of Human Performance

Compatibility Matrix		26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
	Part 2																									
1	Oral Comprehension	0	0	0	0	0	-2	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	-1	-1	0	-1
2	Written Comprehension	-2	0	-2	-1	-2	0	0	0	-1	-2	0	0	0	0	0	0	-1	-2	0	-1	0	-2	-1	-1	-2
3	Oral Expression	0	0	0	0	0	-2	-1	-1	-1	-1	0	0	0	-1	0	0	-1	0	0	-1	0	-2	-1	-1	-1
4	Written Expression	-2	0	-2	-1	-2	0	0	0	-2	-2	0	0	-2	-2	-1	-1	-2	-2	-2	-2	-1	-2	-2	-1	-2
5	Memorization	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	Problem Sensitivity	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	-1	-1	0	-2	-2	0	-2
7	Originality	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	Fluency Of Ideas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	Flexibility Of Closure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	Selective Attention	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	Spatial Orientation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Visualization	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	Inductive Reasoning	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	Category Flexibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	Deductive Reasoning	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	Information Ordering	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	Mathematical Reasoning	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	Number Facility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	Time Sharing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	Speed Of Closure	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	Perceptual Speed And Accuracy	0	1	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	Reaction Time	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
23	Choice Reaction Time	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	Near Vision	-2	0	-1	-1	-2	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	0	0	-2	-1	0	0
25	Far Vision	2	0	2	1	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	0	0
26	Night Vision	2	-2	2	-2	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	0	-1
27	Visual Color Discrimination	-2	2	-2	1	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	Peripheral Vision	2	-2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	0	0
29	Depth Perception	-2	1	0	2	-2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	Glare Sensitivity	-2	-2	0	-2	2	0	0	-1	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0
31	General Hearing	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	0	0
32	Auditory Attention	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	Sound Localization	0	0	0	1	-1	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	Control Precision	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	-2	-2	-2	-2	-2	-2	-1
35	Rate Control	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	-2	-2	-2	-2	-2	-2	-1
36	Wrist-Finger Speed	0	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0
37	Finger Dexterity	0	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0
38	Manual Dexterity	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	0	1	-1	-1	-1	-1	-1
39	Arm-Hand Steadiness	0	0	0	0	0	0	0	0	0	0	0	0	2	2	-2	-2	-2	-2	-2	-2	-1	-2	-2	-1	-1
40	Multi-Limb Coordination	0	0	0	0	0	0	0	0	0	0	0	0	2	-2	2	1	1	1	1	2	0	1	1	0	0
41	Extent Flexibility	0	0	0	0	0	0	0	0	0	0	0	0	2	-2	1	2	1	0	1	1	0	2	2	1	0
42	Dynamic Flexibility	0	0	0	0	0	0	0	0	0	0	0	0	2	-2	1	1	2	2	2	1	0	2	2	1	0
43	Speed Of Limb Movement	0	0	0	0	0	0	0	0	0	0	0	0	2	-2	1	0	2	2	1	1	0	0	2	0	0
44	Gross Body Equilibrium	0	0	0	0	-1	0	0	0	-2	-2	0	0	0	-2	1	1	2	1	2	1	-1	0	0	-1	0
45	Gross Body Coordination	0	0	0	0	0	0	0	0	-2	-2	0	0	1	-2	2	1	1	1	1	2	0	2	2	0	0
46	Static Strength	0	0	0	0	0	0	0	0	-2	-2	0	0	-1	-1	0	0	0	0	-1	0	2	-2	-2	0	-2
47	Explosive Strength	-1	0	-1	0	0	-1	0	0	-2	-2	0	0	-1	-2	1	2	2	0	0	2	-2	2	-2	-2	-2
48	Dynamic Strength	-1	0	-1	0	0	-1	0	0	-2	-2	0	0	-1	-2	1	2	2	2	0	2	-2	-2	2	-2	-2
49	Trunk Strength	0	0	0	0	0	0	0	0	-2	-2	0	0	-1	-1	0	1	1	0	-1	0	0	-2	-2	2	-2
50	Stamina	-1	0	0	0	0	0	0	0	-1	-1	0	0	-1	-1	0	0	0	0	0	0	-2	-2	-2	-2	2

Table A-3

Sample of Compatibility Matrix Calculation

Compatibility Matrix Calculations																						
Duty 1 Scores:		Talking On A Mobile Telephone	3.39	0.56	2.80	0.00	1.00	1.05	0.90	1.33	1.12	2.75	0.94	0.83	1.20	0.55	1.48	0.93	0.78	0.49	3.01	1.15
Duty2 Scores: Long Distance Driving On Interstate Hwy	Sum = 531		0010	0020	0030	0040	0050	0060	0070	0080	0090	0100	0110	0120	0130	0140	0150	0160	0170	0180	0190	0200
			ORAL	WRIT	ORAL	WRIT	MEMC	PROB	ORIGI	FLUE	FLEXI	SELE	SPATI	VISUA	INDUC	CATE	DEDU	INFOR	MATH	NUMB	TIME	SPEE
0.49	0010	ORAL COMPREHENSION	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0
1.93	0020	WRITTEN COMPREHENSION	-7	2	0	0	0	-2	0	0	-4	0	0	-2	0	0	0	0	0	-2	[illegible]	0
0.44	0030	ORAL EXPRESSION	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0
0.00	0040	WRITTEN EXPRESSION	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.18	0050	MEMORIZATION	0	0	0	0	4	-2	-2	-6	-2	12	0	0	0	0	0	0	-2	-1	[illegible]	-3
3.06	0060	PROBLEM SENSITIVITY	0	-2	0	0	-3	6	0	0	7	0	0	5	7	2	9	6	0	0	18	7
1.35	0070	ORIGINALITY	0	0	0	0	-1	0	2	4	0	0	0	1	3	1	0	0	0	0	0	2
0.90	0080	FLUENCY OF IDEAS	0	0	0	0	-2	0	2	2	0	0	0	1	2	1	0	0	0	0	0	1
3.06	0090	FLEXIBILITY OF CLOSURE	0	-3	0	0	-3	6	0	0	7	8	3	3	7	3	0	3	5	0	0	7
3.67	0100	SELECTIVE ATTENTION	0	0	0	0	7	0	0	0	4	20	0	0	0	0	0	3	0	2	11	0
4.00	0110	SPATIAL ORIENTATION	0	0	0	0	0	0	0	0	4	0	7	3	0	0	0	0	0	0	0	0
1.61	0120	VISUALIZATION	0	-1	0	0	0	3	1	2	2	0	2	3	2	0	0	2	0	0	0	0
1.68	0130	INDUCTIVE REASONING	0	0	0	0	0	4	3	4	4	0	0	1	4	2	0	3	1	0	0	4
0.71	0140	CATEGORY FLEXIBILITY	0	0	0	0	0	1	1	2	2	0	0	0	2	1	0	0	1	0	0	2
2.45	0150	DEDUCTIVE REASONING	0	0	0	0	0	5	0	0	0	0	0	0	0	0	7	5	4	0	0	0
1.99	0160	INFORMATION ORDERING	0	0	0	0	0	4	0	0	2	5	0	2	5	0	6	4	3	1	0	0
1.17	0170	MATHEMATICAL REASONING	0	0	-7	0	-1	0	0	0	3	0	0	0	1	1	3	2	2	0	0	1
1.07	0180	NUMBER FACILITY	-4	-1	-3	0	-1	0	0	0	0	3	0	0	0	0	0	1	0	1	0	0
3.60	0190	TIME SHARING	[illegible]	-4	0	0	-7	8	0	0	0	10	0	0	0	0	0	0	0	0	22	4
2.12	0200	SPEED OF CLOSURE	0	0	0	0	-2	4	2	3	5	0	0	0	5	2	0	0	2	0	6	5
3.20	0210	PERCEPTUAL SPEED AND ACCURACY	[illegible]	-2	0	0	0	7	0	0	7	9	0	0	0	0	0	0	0	0	0	7
1.47	0220	REACTION TIME	0	0	-4	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.39	0230	CHOICE REACTION TIME	[illegible]	-2	[illegible]	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	8
3.14	0240	NEAR VISION	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.33	0250	FAR VISION	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A-4

Compatibility Scores For Skill Demands of Driving Versus Mobile Telephone Use–Total Survey Population

Compatibility Scores for Driving an Automobile and Using a Mobile Telephone

		Driving On Busy City Streets	Long Distance Driving On Interstate Hwy	Dialing A Mobile Telephone	Talking On A Mobile Telephone
1	Driving On Busy City Streets	1425			
2	Long Distance Driving On Interstate Hwy	n/a	1075		
3	Dialing A Mobile Telephone	869	752	616	
4	Talking On A Mobile Telephone	612	531	n/a	290

Normalized (range = 1425 to 290 = 1134)

(-100 to +100)

		Driving On Busy City Streets	Long Distance Driving On Interstate Hwy	Dialing A Mobile Telephone	Talking On A Mobile Telephone
1	Driving On Busy City Streets	100			
2	Long Distance Driving On Interstate Hwy	n/a	38		
3	Dialing A Mobile Telephone	2	-19	-43	
4	Talking On A Mobile Telephone	-43	-58	n/a	-100

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An evaluation of skills and abilities that could conflict with each other during multi-task performance of driving and mobile telephone usage was performed using Fleishman's taxonomy of human performance with data collected using the job assessment software system computer-based survey tool. A literature review of mobile phone use during driving and dual task performance was first conducted to assess current thinking about the topic. Taxonomic-based data were collected from 27 survey respondents for the tasks of driving on city streets, driving on long distance highways, dialing a mobile telephone, and talking on a mobile telephone. Data were analyzed, and each of the driving tasks was compared against each mobile phone task using a compatibility index based around the taxonomy. Conclusions are reached that generally suggest some of the reasons, from a human factors viewpoint, why overall performance can be reduced during simultaneous driving and use of a mobile telephone.

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