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An Analysis of the Influence of Age and Ionizing Radiation on Cognitive Performance

Elizabeth L. Gerhardt

Embry-Riddle Aeronautical University - Daytona Beach

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AN ANALYSIS OF THE INFLUENCE OF AGE AND IONIZING RADIATION ON COGNITIVE PERFORMANCE

by

Elizabeth L. Gerhardt

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in Partial Fulfillment of the Requirements for the Degree of
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This thesis was prepared under the direction of the candidate's thesis committee chair, John A. Wise, Ph.D., Department of Human Factors & Systems, and has been approved by the members of his thesis committee. It was submitted to the Department of Human Factors & Systems and has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Human Factors & Systems.

THESIS COMMITTEE:

____
John A. Wise, Ph.D., Chair

____
Gerald L. Gamache, Ph.D., Member

John W Williams
John W. Williams, Ph.D., Member

____
MS HFS Program Coordinator

John W. Williams
Department Chair, Department of Human Factors & Systems

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ABSTRACT

Author: Elizabeth L. Gerhardt

Title: An Analysis of the Influence of Age and Ionizing Radiation on Cognitive Performance

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This thesis was designed to study whether age has a significant effect on cognitive test results among persons exposed to ionizing radiation. The data for this investigation came from the fourth year of a 1995-98 longitudinal study of subjects exposed to radiation from the 1986 Chernobyl, Ukraine, nuclear power plant accident. Accuracy and efficiency scores from four cognitive tests taken by 84 Ukrainian volunteers were divided into two age groups and three radiation dosage groups for analysis. The results of this study found that decrements in human performance on tasks involving spatial processing increase with age in persons who have been exposed to ionizing radiation, but only in efficiency scores. However, no significant age/radiation dose interaction was evident from the ANOVA tests.

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LIST OF ABBREVIATIONS

ANAM	Automated Neuropsychological Assessment Metrics.
Ci	Curie. A measurement unit of radioactivity; the quantity of a radioactive material that will have 37 billion transformations in one second.
CPT	Running Memory Continuous Performance Task.
DGS	Digit Set Comparison Test.
FIA	Free-in-Air. Dosage rates, not absorbed rates.
LD/50	Median lethal dose to kill 50% of subjects; 500 roentgens for penetrating external radiation to total body in 24 hours or less.
MSP	Matching to Sample Test.
Q	Quality factor for specific radiation types, multiplied by absorbed dose (rad) to determine rem (see RBE, REM below).
R	Roentgen. A measure of exposure in air to gamma and X-rays.
RAD	Radiation Absorbed Dose of any type of radiation.. One rad is the absorption of 100 ergs of energy per gram of the absorbing material.
RBE	Relative biological effectiveness. Rad x RBE = rem. The RBE of gamma radiation is 1 and of alpha radiation is 20, which means 1 rad of alpha can have approximately 20 times the effect in the body as 1 rad of gamma radiation.
REM	Roentgen Equivalent (in) Man. It relates the absorbed dose in human tissue to the effective biological damage of the radiation.
SPD	Spatial Processing Task (Simultaneous).

INTRODUCTION

One hundred and ten kilometers (km) north of Kiev, the capital of Ukraine, is a small town near the Belarus border called Chernobyl Fifteen km northwest of the town is the Chernobyl nuclear power station, and three km northwest of here is the city of Pripyat The Pripyat and Dniepr Rivers flow past the station, south to the Kiev Reservoir (AOL library, 2000) On September 28, 1977, the first reactor for the Chernobyl Nuclear Power Plant (CNPP) started operation (Gamache et al , 1999) Despite warnings of instability from engineers onsite, three more reactors were built and put into operation On Saturday, April 26, 1986, at 1 23 a m the fourth reactor exploded and caught fire, ripping off the 1000-ton concrete slab above the reactor and releasing radioactive plutonium, cesium, and uranium dioxide into the atmosphere The radioactive cloud spread over a good part of Europe, contaminating areas of Ukraine, Russia and Belarus

Three weeks later, crews were sent to the site Except for Russian radiation monitors, they were provided only with surgical masks and lead aprons, 660,000 volunteers and soldiers were involved in the cleanup operation (Chernousenko, 1991) The neighboring town of Pripyat, population 55,000, and others within a 10 km radius of the plant were not evacuated until 36 hours after the explosion Debris covered more than 5,000 square km with nearly 20 million curies of radionuclides, the contamination affected 11 regions, with a population of nearly 17 million, including 2 5 million children less than five years old. The Soviet government did not report the accident until Monday, April 28th, when the radioactivity was detected in Sweden (Holowinsky, 1993).

Reactor cooling water was flushed into the Prypyat River, a tributary of the Dniepr. Additionally, a Chernobyl sewage system break had polluted both rivers and their reservoirs, which were used to irrigate crops in the region. Some trees from the pine forests adjacent to Chernobyl were buried in pits, contributing to ground contamination. Other lesser damaged but still exposed trees 350 meters farther into the forest were recovered and sent to lumber mills for processing into products including furniture for use in homes and workplaces throughout Ukraine. Over the ensuing years, the countryside around Kiev received more contamination than the city because of smoke and soot from forest fires. Residents still grow and harvest food from contaminated soil; blackberries, mushrooms, and medicinal herbs are especially susceptible to radionuclide contamination.

The Effects of Exposure to Ionizing Radiation

Radiation emitted from microwaves, visible light, and television waves is called non-ionizing, since it does not have enough energy to pull electrons out of their orbits around atoms. Ionizing radiation does have enough energy to release tightly bound electrons, thus causing the atom to become ionized or charged (Busby, 1999a). For example, a gamma ray passing through a cell might ionize water molecules near the DNA, and the ions reacting with the DNA might cause it to break.

There are four types of ionizing radiation alpha, beta, gamma, and neutrons (The following descriptions are mainly from pamphlets published by the Atomic Energy Commission in the 1960s, including "ABC of Radiation (Brookhaven, 1964), "Living with Radiation" (Brannigan, n d), and "Handbook for Radiological Monitors" (Department of Defense, 1963))

Alpha particles are pieces of the nuclei of radioactive atoms such as radium, uranium or plutonium and contain two protons and two neutrons They are spread in such media as dust clouds, smoke from forest fires, and bird or animal droppings (Gamache et al , 1999) They can be stopped by a sheet of paper or the surface layer of the skin, but if they are breathed in or ingested, there is nothing to protect the internal body tissue and they are extremely destructive

Beta particles are high-speed electrons or positrons ejected from the nucleus of an atom They are generally short range in the air, just a few feet, and can be stopped by ¼ inch wood or 1/8 inch metal They can cause burns if concentrated on the skin for several hours and are destructive if they get into the body Neutrons are neutral particles that come from the nucleus of atoms when they are split and will pass out through any opening in the shielding from the interior of a reactor in a continuous stream Materials exposed to the neutrons inside will also become radioactive and emit beta and gamma rays Neutrons are very penetrating and destructive to human tissue, they can be slowed down by wood, plastic, graphite or water (Uranium Information Centre, 1999)

Gamma radiation is the most penetrating type, and is produced by fuel cells in nuclear power plants. It is emitted as long range, high energy electromagnetic waves rather than particles. Shielding is usually large amounts of lead or concrete. X-rays are similar to gamma rays, but come from the electrons surrounding the nucleus of the atom rather than from the nucleus itself and are produced by electron bombardment. There are several terms commonly used to measure radioactivity. These include the roentgen, which measures ionizations of the molecules in a mass of air and only applies to gamma and X-rays. A rad measures the amount of energy absorbed from any type of radiation (100 ergs of energy per gram of the absorbing material), but does not take into consideration the biological effects. The rem (an acronym for roentgen equivalent in man) relates absorbed dose to the effective biological damage and is calculated by multiplying rad by a quality factor Q unique to the type of incident radiation (Busby, 1999a) or, alternately, is equivalent to that quantity of radiation dose which produces the same biological effect as one roentgen of X-rays (Megaw, 1987).

The quality (Q) factor, which may also be expressed as RBE (relative biological effectiveness) of X-rays and beta radiation is 1, so for these types, 1 rad=1 rem=1 ber (the Russian unit of measure). The RBE of alpha radiation is 20, which means that 1 rad of alpha can have 20 times the effect on the body as 1 rad of beta. Therefore, for alpha radiation, 1 ber=1 rad=20 rem. Neutrons have an RBE of 10 (Kimball, 1999). The radiation measurement terms rad and rem are used interchangeably in this paper, since it is primarily concerned with the effects of gamma radiation, which has an RBE of 1.

Cells can repair the damage from low dosage, such as that received daily from background radiation. Brannigan (n.d.) states the permissible rate of radiation exposure to industrial employees, as set by the supplement to Bureau of Standards Handbook #59, is an average of 5 rem per year for each year after the age of 18. Up to 12 rem (not to exceed 3 rem per quarter) is allowed in any given year. Additionally, a single, "once- in-a-lifetime" 25-rem emergency exposure is permitted by the National Committee on Radiation Protection Recommendations, which are contained in Bureau of Standards Handbook #59 (Brannigan, n.d.). The World Health Organization (WHO) benchmark for lifetime exposure is 35 rems. The NATO benchmark is 70 rems. The U.S. Department of Defense (DOD) is concerned with low dose radiation, which they suggest from 1 to 70 rads (G. L. Gamache, personal communication, August 1, 2000).

Twenty-five rem of total body radiation in a short space of time would probably not have a detectable effect. At 50 rem, blood changes would show depression of white blood cell count, and at higher doses up to 100 rem more cells may die than can easily be replaced, or they may be changed permanently and produce abnormal cells at division This explains the risk of cancer from radiation exposure. At still higher doses, cells fail to function, as in radiation sickness. High whole body doses over 100 rem damage the intestinal lining which regulates food and water intake and protects the body against infection, causing nausea, diarrhea, and fatigue. The patient may experience hair loss and a general feeling of weakness.

At 200-250 rem, the first death can be expected, and over 300 rem, damage to the body's immune system will prevent it from fighting off infection and disease. At 400-500 rem, 50% of the victims will die in about four to eight weeks. This is known as LD/50, the median lethal dose it takes to kill 50% of persons exposed to penetrating external total body radiation in 24 hours or less. At 600-1000 rem, with heavily depressed white blood cell count, 80-100% of victims will die in four weeks. Over 1,000 rem destroy the blood flow to the brain and nervous tissue; and death is 100% likely (Brannigan, n.d.; Busby, 1999b; Megaw, 1987).

Soviet Radiological Committee estimates in 1988 reported that approximately 50,000 people had received 50 rads or more and 4,000 had received an average of 200 rads (Holowinsky, 1993). By 1991, it was estimated that 7,000 people had died of radiation-related illnesses (Baryahtar & Bobyleva, 1991), and more recent projected estimates may go as high as 1,000,000 or more from a population of 52,000,000 (G. L. Gamache, personal communication, March 27, 2000). By 1992, 15% of Ukraine, or 43,000 square km containing 3,200 towns and villages and four million people, excluding Kiev, had been contaminated by radionuclide waste emissions (Yakovlev, 1991). Recently the Ukrainian government stated that 4,365 of those who participated in the cleanup right after the accident have died due to the disaster ("Years later," 1999). A total of 72,838 Ukrainians are recognized as being fully disabled because of the accident, and another 323,000 adults and 1.1 million children are entitled to government aid for health problems related to the Chernobyl disaster ("Chernobyl plant," 1999). With more than

72% of the Ukraine contaminated above background radiation, the population is receiving a recontamination of between .10 rads and 4.50 rads annually from radionuclides in their food and water supplies (G. L. Gamache, personal communication, July 13, 1998).

Chernobyl-related disorders include cardiovascular, respiratory, and digestive diseases; malignant tumors, endocrine and lymphatic diseases, nervous system problems, and anemia. Children have been especially vulnerable, with increases including infectious diseases, hypothyroidism, birth defects, and thyroid and internal organ cancers (Gamache et al., 1999).

The Missing Factor

It has been fourteen years since the Chernobyl accident. Despite the leaking concrete and steel containment chamber which covers the exploded reactor, the facility with its lone operational reactor was not scheduled to be shut down until the Ukrainian government received financial aid from the West to dismantle the plant and finish construction of two new reactors at the Khmelnitsky and Rivne nuclear plants. The Chernobyl reactor number 3 was restarted in November, 1999, after five months of repairs ("Chernobyl comes alive," 1999). On June 6, 2000, President Clinton pledged $80 million in American aid to close down the plant and repair the leading sarcophagus. Two million dollars will be used for safety improvements at other Ukrainian power plants. Ukrainian President Kuchma ordered the Chernobyl plant to be closed December 15, 2000. Costs to maintain the plant for about five years until the nuclear fuel is completely unloaded are estimated at $6 million per year ("Ukraine says it will close", 2000; "Ukraine promises to close, "2000.)

Health problems related to radiation exposure are being studied, but an area which has received less attention is the effects of radiation dosage over time on neuropsychological functions. What effect has radiation had on short term and long term memory? Can survivors of high dosage maintain sufficient short term memory to complete memory tasks, rehearsing in short term memory to facilitate transfer to long term memory in order to match sequentially displayed numbers and recognize similar spatial images? Can they not only complete cognitive tests accurately but within a specified or measured time period?

These questions have been addressed in longitudinal research, but still one factor is missing. The population that was affected by the nuclear disaster at Chernobyl has aged 14 years since the accident. Cognitive exercises which test short term memory and spatial perception stray into the realm also used by aging research and open up a whole series of confounding factors which could be affecting research results heretofore attributed solely to radiation effects.

Does a subject who has trouble visualizing similar spatial images once the image has been rotated ninety degrees demonstrate organic problems from radiation dosage, or is the subject also representative of an older driver who is having increased difficulty reading maps? Is a subject who has difficulty remembering a string of numbers suffering from decreased blood flow or lack of attention because of discomfort from radiationinduced problems, or is his or her response affected by short-term memory loss related to age? In order to begin shedding some light on these questions, the independent variable of age will be added to the equation that seeks to explore the factors which affect the cognitive performance of victims of ionizing radiation.

Relevance to Human Factors Applications

Human factors studies how people perform and react to their environments, under various conditions, so that the objects and procedures they use, both at work and in their personal lives, can be designed to enhance productivity, safety, comfort and general quality of life (Sanders and McCormick, 1993). It has been difficult to perform human performance research on radiation exposed populations until the Chernobyl accident. Research on Hiroshima and Nagasaki survivors was performed from 1945 to 1952 and was concerned with medical problems, chiefly burns (G. L. Gamache, personal communication, July, 1999). Now nuclear energy is used throughout the world, and the risk of accidents is ever present.

Information on the physical and psychological effects of radiation exposure is extremely valuable to any government agency, including the Federal Emergency Management Administration (FEMA), which would be involved in the relocation and treatment of victims in the event of an accident in or near the United States. Before sending medical teams, law enforcement personnel, and cleanup details into a contaminated area, planners would need to know tolerable levels of exposure, maximum allowable length of work periods, and anticipated decrements in performance, especially in older workers.

Human performance data from populations exposed to ionizing radiation can provide important guidelines for placement of workers and design of workplace procedures, not only in industrial applications but also in occupations such as agriculture and forestry. If, for instance, short term memory is impeded, perhaps more noticeably in certain age groups, provisions can be made to schedule more rest periods, reduce complexity of tasks, and increase training to offset decrements in cognitive performance with additional practice.

Human factors research on aging has increased considerably in recent years since the proportion of seniors in the population has increased More attention is being given to products and services for older people, problems of discrimination against older workers, economics of health care and the Social Security system, and elements of everyday living, such as driving and ability to perform tasks at home (Howell, 1996). Any factor, such as age, which may be a possible confounding influence on human performance under the stress of radiation exposure, needs to be explored.

Statement of the Problem

The purpose of this study is to determine whether the available data show a relationship between age, radiation dosage, and cognitive performance. Is there a difference in the effects of radiation dosage on cognitive performance of older persons versus younger persons? Do short-term memory retention and spatial perception diminish with increases in age as well as dosage in persons exposed to ionizing radiation?

Review of the Related Literature

Effects of Ionizing Radiation on Cognitive Performance

The data for analysis by this study represent 1998 test scores from a subset of the subjects participating in a longitudinal study conducted in and near Chernobyl, Ukraine, and sponsored by the United States Defense Threat Reduction Agency (Gamache et al., 1999). Its purpose was to assess the effects of exposure to varying levels of ionizing radiation on neuropsychological and physical abilities. Volunteers resident in Ukraine at the time of, and since, the power plant accident were administered cognitive tests via a subset of the Automated Neuropsychological Assessment Metrics (ANAM) called the Automated Neuropsychological Assessment Metrics-Ukrainian (ANAMUKR) (Reeves & Gamache, 1994), which was translated into Russian. The ANAM test battery was developed at the Walter Reed Army Institute of Research, Office of Military Performance Assessment Technology (OMPAT) and is composed of computerized self-contained modules which are field-administered via laptop computer (Reeves et al., 1995)..

In the original longitudinal study, four groups (127 subjects) were tested (all dosages are reported free-in-air (FIA) and are based on the participants' medical records):

- A control group who live outside the radiation exposure area; 24 males, 7 females; mean age 33, mean dosage 0 rads.
- Eliminators, who removed nuclear debris and worked on reconstruction of

the containment chamber for the destroyed reactor; 33 males, 3 females; mean age 40, mean dosage 62.95 rads. Eliminators are also called "liquidators" and were involved in the actual clean-up at the Chernobyl site in April, 1986.

- Forestry workers who do monitoring, woodcutting, and related activities near Chernobyl; 29 males; mean age 51; mean dosage 12.61 rads.
- Agricultural workers from a rural area 150 km south of Kiev; 17 males, 14 females; mean age 36; mean dosage 8.81 rads.

Cognitive tests included the Stanford Sleep Scale to assess fatigability, administered both before and after the 45-minute cognitive testing session; Code Substitution (visual search, immediate recall, and delayed recall); Running Memory Continuous Performance Task; Digit Symbol, Matching to Sample; Spatial Processing Task (Simultaneous); Simple Reaction Time; Tapping-Right and Left Index Fingers; and Two-choice Reaction Time.

Two types of measurement were taken on the cognitive tests. The accuracy scores represent number of correct responses divided by number of incorrect responses. The efficiency scores (also referred to as throughput) reflect number of correct responses divided by time (unit of measurement depends on the test, usually milliseconds).

The 1995 tests showed that Eliminators were significantly and uniformly impaired on measures of neurocognitive performance, compared to the Control group. Forestry and Agricultural workers were impaired on certain subsets of the cognitive tests.

The 1996 retests showed the neurocognitive performance of the three exposure groups had declined, compared to both the Control group and their own 1995 test results. The 1997 tests indicated further decline in the exposure groups' neurocognitive tests. Decrements in Foresters' and Eliminators' cognitive test accuracy were more pronounced.

The 1998 tests did not show any significant declines for any groups. Some groups showed improvements from 1997 scores, but not to a significant level. Analysis of the four-year averaged test results for both accuracy and efficiency show severe neuropsychological impairment of the Eliminator and Forestry groups, including learning ability, working memory, mental flexibility, and psychomotor speed. The Agricultural group did not show meaningful impairment, and their overall scores, although lower than the control group, were comparable to it.

Probability levels were most often at .001 for all statistical analyses, showing that levels of cognitive performance for all three exposed groups are getting worse with time.

Other Radiation-Related Research

Other research specifically addressed to cognitive problems of exposed subjects is hard to find. Research involving relationships between ionizing radiation dosage, age, and cognitive performance has not so far been found in this literature search. What research has been found is chiefly concerned with checking health-related conditions and the psychophysiological responses to the stress of radiation (Collins & Bandeira-de-Carvalho, 1993).

It is difficult to separate the influence of physical health problems from decrements in cognitive performance, especially since ionizing radiation affects blood flow to the brain and nervous tissue, and the same vascular systems affecting the brain carry blood to other parts of the body that are affected by the exposure. To put it generally, cognitive test performance may be impaired if individuals don't feel well. To put it in more measurable terms, cognitive performance is affected by distractions, and both physical discomfort and mental distress are distracting influences The day-to-day strain of relocation and constant health problems experienced by severely affected Chernobyl survivors (radiophobia) could also be exacerbated by the perception that one no longer has control over ones life because radiation sickness or related disease is progressing to an inevitable termination.

Effects of Age on Cognitive Performance

Because of the increasing number of people 65 and older in the U.S population, as well as elsewhere, as "baby boomers" advance in age, a correspondingly increasing amount of research is being done on older people. Despite stereotypes of forgetful seniors wandering about without a clue as to why or where, results have been mixed from cognitive research of older persons, and other factors are emerging which are confounding the traditional view of inevitable decline in both physical and mental faculties. Three factors addressed in age comparison research and relevant to cognitive test performance described here have been storage versus processing in working memory, slower reaction time, and physical condition of the subjects Two of the cognitive tests in the ANAMUKR battery used for this study measure attention and working memory, using delayed matching of either one letter displays (the Running Memory Continuous Performance Task) or strings of 2 to 10 digits (the Digit Set Comparison) The other two cognitive tests involve spatial relationships a delayed Matching to Sample, where two matrices with one to twelve shaded cells are compared, and Spatial Processing, which displays pairs of histograms with one histogram rotated 90 degrees Both of these also use working memory, if one assumes the first stimulus is stored so the features can be compared while viewing the second

As long as simply storing small amounts of letters or numbers in working memory and recalling them is involved, research has shown age differences to be minimal or nonexistent However, if processing the information is involved, especially in a string exceeding working memory capacity of six to seven digits (Miller, 1956), older subjects have not performed as well as younger ones (Howard & Howard, 1997) Van der Linden et al (1994) found no age effect when subjects were asked to recall serially the four most recent items in strings of four, six, eight and 10 consonants In a second experiment, string lengths were increased to six, eight, 10 and 12, and subjects were asked to recall the last six items No processing was necessary for a list length of six, and performance of different aged subjects was similar Performance of older subjects decreased, however, as the list lengths increased, with the accompanying necessity of extracting longer strings from an already heavy working memory load, discarding some items and registering others for recall We might perhaps expect little influence of age on accuracy scores of the Running Memory test, since only one letter at a time must be recalled; however, although the Digit Set Comparison Successive test asked for match decisions rather than recalling portions of the digit string, one might expect slower and/or less accurate responses from older subjects for longer length strings. Seven objects may be borderline for older working memory. In a 5-by-5 matrix memory test featuring recall of seven target positions, regardless of the letters in them, results showed a decrease of .2 correct items per decade of subjects' age, which ranged from 20 to 79 years (Salthouse, Kausler, & Saults, 1988.)

With regard to age-related slowed response time, Salthouse & Babcock (1991), using same/different judgment tests of digit-symbol and digit-digit pairs, concluded that the efficiency or speed of relevant processing is reasonably a major contributing factor to age differences in working memory. While investigating the roles of slower encoding speed vs. information loss, using continuous paired-associates tasks, Salthouse found that apparently older adults are slower than young adults at encoding or activating information, but preservation of information over short intervals is relatively unaffected by increased age (Salthouse, in press-a, Salthouse, in press-c.) Factors related to slower response time include confusion about and/or rechecking of similar geometric object pairs that were different in only one dimension (Scialfa & Thomas, 1994); declaring more identical letter pairs different because of alleged internal neural noise which distorts visual features (Allen et al., 1994), and longer inspection of simultaneous matching spatial stimuli vs. quick response to delayed stimuli, at the expense of accuracy (Swearer

& Kane, 1996.) We might find more age effects lowering efficiency scores of the simultaneous Spatial Processing task, while the opposite could be true with the delayed Matching to Sample test, with corresponding poorer accuracy results.

With regard to the question of whether age effects might be similar for all four ANAMUKR tests, predictable from performance of younger subjects, or task specific because of complexity or individual subject differences, results in previous research have been mixed. Assuming "aging effects" apply mainly to certain specific age groups may even be arbitrary, since some research findings have indicated age-related slowing by age 40 (Myerson et al., 1989). In a test involving a variety of tasks with two groups of subjects, 20 to 22 years and 36 to 44 years, the age differences in response times increased with the difficulty rather than the specific nature of the task. The authors argue that age-related slowing is global and that performance (longer latencies) of middle-aged individuals may be predicted from that of young adults, no matter what the task.

On the other hand, Rabbitt (1997) in his lecture on Alan Welford's 1958 book, *Ageing and Human Skill*, points out a different approach from the generalized idea that age slows down all tasks by the same constant. Instead he concludes from results of his 1996 studies (Rabbitt, 1996a, b) that individual differences in age and intelligence affect the speed of functional processes in some tasks more than others. Welford said that individuals are genetically programmed to age at different rates and also that their aging is modified by different life experiences and accumulations of skills and information over their lifetime. Their performance on cognitive tasks is not only quantitatively different, as in the reduction of speed and accuracy, but qualitatively in that they have difficulty solving problems using abstract rules that can be logically generalized to similar situations and instead tend to look for solutions drawn from actual personal experience (Welford, 1958) This idea is similar to Horn and Cattell's later definitions of the quick problem-solving abstract rules of fluid intelligence, which declines significantly with aging, vs the learned and previously experienced procedures of crystallized intelligence more often preferred by older people to solve problems or perform unfamiliar tasks (Horn & Cattell, 1967, Horn, 1982, Sorce, 1995)

Although the impact of aging on cognitive performance may be influenced by use or nonuse of fluid intelligence, working memory capacity and processing ability, tradeoff of speed for accuracy (or vice versa), or the accumulation of life experiences, modern research is demonstrating the importance of understanding the physical and neuropsychological conditions of the subjects being studied This brings us full circle to the juncture of the effects of aging on the cognitive performance of individuals in this study, especially since many of them are over 40, with the physical effects of the ultimate life experience of debilitating radiation Just as health problems affect performance of persons exposed to ionizing radiation, certain physical conditions associated with aging also need to be recognized as possible contributing factors A selection of these which might affect cognitive testing via computer screen include reduced pupil size (adjusting to low illumination), focusing ability (presbyopia), decreased static and dynamic visual acuity, central movement in depth (reduced detection of changes in image size), specific vision loss (glaucoma, cataracts, macular degeneration); increased auditory threshold (hearing loss); blurred vision from organic heart disease; cardiac arrhythmias (fainting, dizziness); arteriosclerosis (slow reaction time, disorientation, nervousness); pain and weakness from arthritis (AARP, 1994, Salvendy, 1987).

General health factors, such as aerobic fitness, can contribute to cognitive functions. Lifelong fitness has been correlated with mental processing speed in elderly subjects, and aerobic exercise in old age can lead to improved performance on neuropsychological tests (Bashore & Goddard, 1993). Mental health, as well as physical health, is a factor in both memory and learning. Elderly persons suffering from depression often complain of memory problems, and depression symptoms can be hard to distinguish from indications of dementia (Kaszniak, 1990, Howard & Howard, 1997).

Tests of verbal memory, sensorimotor speed, and cognitive flexibility have shown aggravating effects on age-related decline of cognitive ability by diabetes, chronic bronchitis (performance speed), and age associated hearing loss (memory), although target words were presented visually. Cardiovascular problems, including hypertension, were unrelated (van-Boxtel et al., 1998). Houx (1993) did find slower performance in subjects with cardiovascular disease, including hypertension, in a study of the effects of health-related factors on age-related decline of psychomotor speed. They were concerned with "biological life events" (BLE, p. 196), biological or environmental occurrences which affect the brain. These events include neurotoxic factors such as exposure to organic solvents, repeated mild head trauma, repeated general anesthesia, and chronic diseases such as diabetes. This study is relevant, because exposure to ionizing radiation can certainly be viewed as a biological life event, and one with profound implications for its effects on the brain and the entire body. Slowed preparation responses in difficult tasks supported the idea that motor initiation (in this case, releasing a button) is a process of the central nervous system and therefore vulnerable to aging effects.

The motor initiation phase of the cognitive tests administered for the Chernobyl study consisted of pressing a key or mouse button to signify the subject's response to the stimulus on the screen. If neuromuscular changes with age influence both cognitive and motor behavior, as in slower reactions to environmental stimuli, it is not surprising to find that research explanations for slower motor responses echo those for slower cognitive reactions discussed above. These range from interference from neural noise, enhanced because of decreased neural signal levels and compensated for by allowing more time for task completion, to cautiousness, which results in trading off speed for accuracy as a part of compensating mechanisms of skill and strategies (Vercruyssen, 1997).

A final factor in the interplay of cognitive and neuromotor factors affecting the performance of the Chernobyl participants, may be motivation. Subjects in the Ukrainian study were pleased to have been selected and were highly motivated to perform as well as they could. Also they were paid $2 for participating – the Ukrainian minimum wage is $20 per month (Gamache et al., 1999). It may be, therefore, that we would find fewer performance decrements in accuracy than for efficiency, which produces reduced scores as task time intervals increase. Efficiency scores may reflect slowing effects of both radiation dosage and age on the central nervous system and possible cautionary strategies for both conditions.

Statement of the Hypothesis

There are three hypotheses. The first states that age has a significant effect on cognitive test results among persons exposed to ionizing radiation. The second states that age-related decrements in performance will affect efficiency more than accuracy scores. The third states that there will be an interaction between age and radiation dose.

METHOD

Participants

Participants for this study were a 1998 subset of Gamache et al., 1999, and consist of 84 Ukrainian volunteers (63 males, 18 females, and 3 children), ranging in age from 14 to 62, with a mean age of 41 and a standard deviation of 10.63. This includes the Control group (28 subjects), 18 Agricultural workers, 18 Foresters, and 20 Eliminators. Subjects were only selected if their data included age, gender, radiation dosage and both accuracy and efficiency scores for all four of the cognitive tests included in this study.

In Gamache et al., 1999, Eliminators were selected by the Hospital Director at the Ukrainian Center for the Radiation Protection of the Population, a special hospital in the Kiev suburbs which was established to take care of these highly exposed "at risk" patients. These individuals come into the hospital twice a year as outpatients for checkups. The tests were administered to this group at the hospital.

The Gamache et al., 1999, researchers were introduced to the forestry managers by the Ukrainian Minister of Forestry. The managers selected the forestry workers who volunteered for the study. These workers were tested in their barracks in the Ovruch forest, approximately 250 km northwest of Kiev. In addition, Dr. Peter Bidyuk went to the village of his birth in Ukraine and recruited volunteer agricultural workers for the study. These workers were tested in a farmhouse in the village of Rozumnytsia, approximately 150 km south of Kiev.

Subjects in the Control group (Gamache et al., 1999) were residents of Ternopil, population 250,000, which is approximately 450 km west of Kiev, and was selected by the researchers from a list of places not contaminated in the explosion. The researchers selected subjects to match exposed participants as closely as possible by occupation, age and gender. This group was administered the tests in High School Number 22. (Gamache et al., 1999; Gamache, G. L., Personal Communications, 1999).

Procedure

Test procedures and cognitive test descriptions are in Appendices A and B. Four cognitive tests were selected from the ANAMUKR test battery administered in the original longitudinal study and were chosen not only to provide a range of complexity, but primarily because they had already been shown to be sensitive to radiation effects (Reeves & Gamache, 1994). They also are similar to tests administered in previous research into the effects of aging on cognitive performance (Howard & Howard, 1997; Salthouse, Kausler, & Saults, 1988; Swearer & Kane, 1996). The Running Memory Continuous Performance and Digit Set Comparison Successive tasks provided a measure of attention and working memory. The Matching to Sample test measured attention, working memory, and spatial ability. The Spatial Processing Simultaneous measured spatial ability, although it could be argued that a certain amount of working memory storage and processing is involved even in simultaneous matching tasks.

Data types and Sources

Data files were received from Dr. Gerald Gamache in the form of archived email attachments he had received from Dr. Peter Bidyuk of the Kiev Polytechnic Institute in Kiev, Ukraine. Each attachment contained one subject's raw scores from the ANAMUKR subset of the Automated Neuropsychological Assessment Metrics (ANAM) test battery administered to Ukrainian test participants

The email attachment files were decompressed and input to a DOS Statview program, which had been developed by the authors of the ANAM test battery. The Statview program extracted and printed the results of each test taken by the subject.

The data selected for this study were then manually extracted from the test subject's printed summary and entered into a spreadsheet matrix for statistical analysis by the SPSS statistical processing program. Two scores were provided for each test, accuracy (number correct divided by number of errors), and efficiency or "throughput" (number of correct responses divided by the reaction time taken by the subject on the particular subtest).

Design

Since a variety of ages was represented in each of the origin groups, the subjects were split into two age groups at the median (42) for statistical purposes. The younger group of 41 subjects range from age 14 to 41; the older 43 subjects represent ages 42 to 62. This division also coincides fairly closely to research findings of age-related slowing and changes affecting visual acuity by about age 40 (Myerson et al , 1989, Cavanaugh, 1997)

There was considerable overlapping of dosage amounts between the Agricultural and Forestry workers The higher dosages were experienced by the Eliminators, although three of them had exposure of less than 25 rads, which is the maximum permissible once-in-a-lifetime total body radiation exposure defined by the National Committee on Radiation Protection Recommendations in the Bureau of Standards Handbook #59 (Brannigan, N D , p 21) This rad limit was confirmed by Dr Paul Marvin, radiation physicist at the Halifax Medical Center, Daytona Beach, Florida, who also said that 25 rads is a quoted benchmark at which there is "no detectable effect", with the next benchmark of 50 rads describing "slight temporary blood changes" (P Marvin, personal communication, March 29, 2000) When consulted on the subject, Dr Thomas Bernard, Professor at the College of Public Health, University of South Florida, stated that the Nuclear Regulatory Commission (NRC) would allow a one-time dose of 25 rads to save a life (T E Bernard, personal communication, December 8, 1999) Therefore, for statistical purposes, the subjects were logically divided, disregarding origin, into three radiation dosage groups 28 subjects with less than one rad, 39 subjects with 1 to 25 rads, and 17 subjects with 26 to 140 rads Age components of radiation dosage groups are illustrated in Figure 1 below

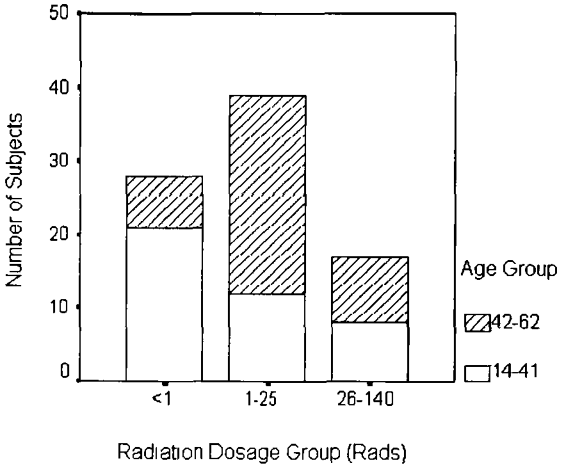

Figure 1. **Age Distribution Within Radiation Dosage Groups.**

A 14 by 84 matrix containing the data output by the Statview program was set up to contain the following information:

1. Subject origin group (Eliminator, Forester, Agricultural worker, Control).
2. Subject ID.
3. Age of the subject in 1998.
4. Radiation dose in rads.
5. Age group (14-41 or 42-62).
6. Radiation dosage group (<1, 1-25, or 26-140 rads)
7. CPT test accuracy score.
8. CPT test efficiency score.
9. DGS test accuracy score.
10. DGS test efficiency score.

11. MSP test accuracy score.
12. MSP test efficiency score.
13. SPD test accuracy score.
14. SPD test efficiency score.

Items 7-14 are dependent variables selected from those in the original study for this thesis. Although all of them will be included in analysis, concentration will be on the efficiency scores, since the time factor is more relevant as evidence of age-related slowing.

ANALYSIS

Correlations were run for age, dose, and test scores using Spearman for data not normally distributed, rather than Pearson Two-way Analyses of Variance (ANOVAs) were calculated for effects of independent variables age and radiation dosage on test scores Post hoc multiple comparisons were run for radiation dosage groups, using Least Significant Difference and the more conservative Tukey for normal distribution analysis, and Dunnett T-3 for unequal variances Since the Dunnett T-3 was the most conservative, it was selected for analysis in the text of this section Tables showing the results of all three post hoc methods for each test are in Appendix C Tables C4, C5, C9, C10, C14, C15, C19, and C20 Post hocs could not be run for age groups because there were less than three groups All effects reported as significant in this study met a criterion of $p \leq 01$

Correlations for age vs accuracy scores showed a significant negative relationship between age and performance for Running Memory ($r = - 294$, $p = 007$) and Matching to Sample ($r = - 388$, $p < 001$) tests, but were only marginally significant for the Digit Set Comparison test ($r = - 260$, $p = 017$) and not at all for Spatial Processing Correlations showed a significant negative relationship between age and efficiency scores ($p \leq 01$), but were not as high as any of the correlations for radiation dosage scores, which indicated a strong negative relationship between dosage and performance at $p < 001$ The difference in the correlations for these two variables indicated that age would not play the part that radiation dosage does in effects on cognitive test performance The correlation between age and dose was 429 and is significant at $p <$ 001 The significance of this particular correlation will be discussed with the ANOVA results Correlation results are shown in Table 1 below

Table 1. Age, Dose and Test Score Correlations (N=84)

	Age vs Test		Dose vs Test	
Test	Correlation	Significance	Correlation	Significance
Accuracy				
CPT	- 294	**.007**	- 569	**.000**
DGS	- 260	017	- 596	**.000**
MSP	- 388	**.000**	750	**.000**
SPD	- 169	125	- 453	**.000**
Efficiency				
CPT	- 319	**.003**	- 542	**.000**
DGS	- 390	**.000**	- 621	**.000**
MSP	- 535	**.000**	- 635	**.000**
SPD	- 443	**.000**	- 542	**.000**

Note Spearman correlations for data not normally distributed

Summary of ANOVA Results

As would be expected, dosage in all tests is the most significant contributor of performance because performance is most affected by dosage regardless of age Even though people are highly motivated to take these tests, the radiation interferes with the accuracy of performance Age was also a main effect in the efficiency scores of the two tests which involved spatial figures, Matching to Sample and Spatial Processing This is not surprising, considering results of previous age-related research where older subjects took more time to match geometric figures, especially ones which were different only in minor respects (Scialfa & Thomas, 1994, Swearer & Kane, 1996) ANOVA main effects and interaction for all the tests are in Tables 2 and 3 below

Table 2. ANOVA Main Effects and Interaction for Accuracy – All Tests

	CPT		DGS		MSP		SPD	
	Sig	R^2	Sig	R^2	Sig	R^2	Sig	R^2
Corrected Model	**.000**	254	**.000**	347	**.000**	500	**.001**	223
AGE	770	001	673	002	497	006	630	003
DOSE	**.000**	224	**.000**	270	**000**	473	**000**	196
AGE * DOSE	376	025	725	008	495	018	712	009
Error	--	746	--	653	--	500	--	777

Table 3. ANOVA Main Effects and Interaction for Efficiency – All Tests

	CPT		DGS		MSP		SPD	
	Sig	R^2	Sig	R^2	Sig	R^2	Sig	R^2
Corrected Model	**.000**	343	**.000**	314	**.000**	374	**.000**	369
AGE	157	026	117	031	**.004**	102	**.001**	141
DOSE	**.000**	285	**.000**	224	**.000**	227	**.000**	233
AGE * DOSE	460	020	998	000	631	012	602	013
Error	–	657	--	686	–	626	–	631

If the Corrected Model is significant, when you break out the components of age and dosage, one or both of these has to be significant As shown in the above tables, dosage is the significant variable in all the tests, joined by age in the Matching to Sample and Spatial Processing efficiency scores.

The discussion of correlation above stated that the correlation between age and dosage was significant at $p < .001$. However, the ANOVA interactions between age and dosage were not significant. The reason for this is twofold. First, the analysis of variance is a more robust statistical method for identifying significance. Secondly, the correlation is a relationship between variables that does not include error, and 50 to 78 percent of the ANOVA variance, as shown in the above tables, was caused by error because we only had two independent variables. My suspicions are that if we had more main effects, i.e., more independent variables or a larger sample assigned to more groups, the interaction effect would be significant.

Running Memory ANOVA Results

Twenty-five percent of the variation in total Running Memory accuracy scores is explained by age, dosage, and age/dosage interaction ($R^2 = .254$), but the only significant main effect was for dosage group, $F(2,78) = 11.226, p < .001$. Dosage accounted for 22 percent of the variance ($R^2 = .224$). ANOVA test results for Running Memory efficiency scores followed a pattern similar to that of the accuracy scores, although age, dosage, and age/dosage interaction accounted for a slightly higher 34 percent of score variations ($R^2 = .343$). The only significant efficiency main effect was for dosage group, $F(2, 78) = 15.547, p < .001$, which accounted for 28.5 percent of the variation in total efficiency scores, $R^2 = .285$.

The results which indicate that 66 to 75 percent of the variation in Running Memory test scores is due to error, are a reminder that we are only dealing with two main effects, age and dosage, while error assumes other factors not present in our independent variables. The absence of age as a main effect for this test is not surprising, since research has shown minimal or nonexistent age differences in tasks requiring storage of small amounts of letters or numbers (Howard & Howard, 1997). Running Memory accuracy and efficiency performances by age and radiation group are shown graphically in Figures 2 and 3. Mean scores and ANOVA test results for accuracy and efficiency scores are in Tables C1, C2, and C3 in Appendix C.

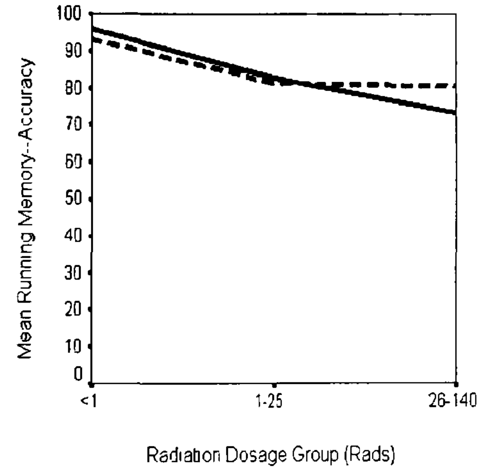

Figure 2. Performance by Age And Radiation Group: Running Memory Accuracy.

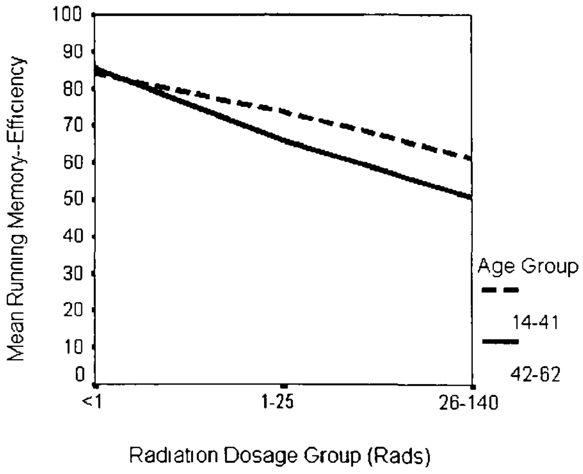

Figure 3. Performance by Age and Radiation Group: Running Memory Efficiency.

Dunnett T3 Running Memory post hoc multiple comparison tests for radiation dosage group scores found significant accuracy as well as efficiency mean differences between the <1 rad dosage group and both the 1-25 rad dosage group and the high dosage (26-140 rad) group, $p \leq$ 001 The Dunnett efficiency post hoc test also found marginal significance for the 1-25 rad vs the 26-140 rad group ($p =$ 047) In spite of age not being significant and although post hoc comparisons could not be run for age because there are only two groups, Table C1 and Figure 2 above illustrate that the overall mean difference of 29 efficiency score points between the >1 rad dose group and the high exposure 26-140 rad dose group rises to 35 points for the older age group, vs 23 points for the younger group only Results are in Tables C4 and C5 in Appendix C

Digit Set Comparison ANOVA Results

The Digit Set Comparison ANOVA accuracy test results showed a significant main effect only for radiation dosage, $F =$ 14 461, $p <$ 001, which accounted for 27 percent of score variation ($R^2 =$ 270) Age, dosage, and age/dosage interaction accounted for 35 percent of the variation in accuracy test scores ($R^2 =$ 347) For efficiency scores, radiation dosage was the significant main effect, $F =$ 11 245, $p <$ 001, and accounted for 22 percent of efficiency score variation ($R^2 =$ 224) Age, dosage, and age/dosage interaction accounted for 31 percent of efficiency score variation ($R^2 =$ 314)

As previously discussed, with such a large component of variation assigned to error (65 to 69 percent), caveats are advised In this task, some age affect might have been expected with storing and processing strings over six or seven digits in working memory (Miller, 1956) However, since the computer automatically terminated the test if the subject's performance with strings up to six digits was error free (G L Gamache, personal communication, July, 2000), we can only speculate as to what percentage of the strings processed were below a length that might strain working memory capacity. In any case, we are dealing again with small amounts of familiar objects, which may have been a factor in the absence of age as a main effect. It is interesting to note that, although not significant, the *p* level for age group effect in this test drops from .673 for accuracy scores to .117 for efficiency, where time is a part of the score measurement. It may be that, as Figures 4 and 5 below show, the very slightly better accuracy level scored by the older age group was achieved at the expense of more time, but the point spread is so small it is insignificant. Figures 4 and 5 illustrate Digit Set Comparison accuracy and efficiency performances by age and radiation group. Mean scores and ANOVA test results are in Tables C6, C7, and C8, in Appendix C.

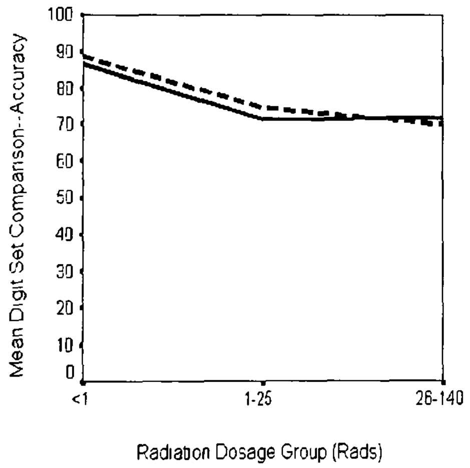

Figure 4. Performance by Age and Radiation Group: Digit Set Comparison Accuracy.

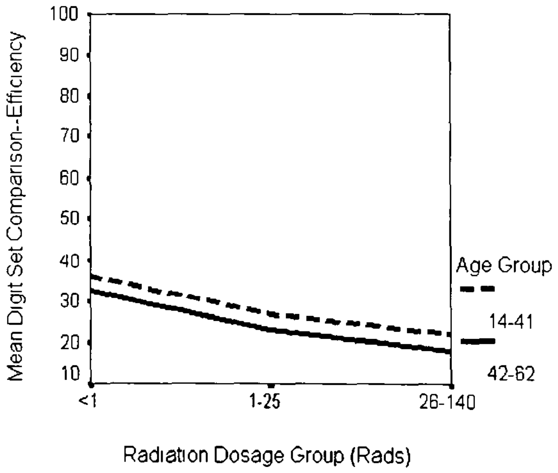

Figure 5. Performance by Age and Radiation Group: Digit Set Comparison Efficiency.

Digit Set Comparison Dunnett post hoc multiple comparison test results for radiation dosage group accuracy and efficiency scores were significant for both the <1 rad dosage group vs 1-25 rad dosage group and the <1 rad dosage group vs the high dosage 26-140 rad group, $p \leq$ 001 There was less than one point difference in the mean efficiency scores of the two age groups when comparing the <1 rad dosage group to either of the exposed groups Results are in Tables C9 and C10 in Appendix C

Matching to Sample ANOVA Results

Matching to Sample ANOVA tests showed a significant radiation dosage main effect for accuracy scores and main effects for both dosage and age group for efficiency scores One-half of the variation in accuracy test scores was accounted for by age, dosage, and age/dosage interaction ($R^2 =$ 500) Dosage group showed a significant main effect for accuracy, $F = 34\ 973$, $p <$ 001, and accounted for 47 percent of score variation ($R^2 =$ 473)

Age, dosage, and age/dosage interaction accounted for 37 percent of efficiency score variance ($R^2 =$ 374) Radiation dosage was a significant main effect for efficiency, $F = 11\ 474$, $p <$ 001, and accounted for 23 percent of score variance ($R^2 =$ 227) Age group was also a significant efficiency main effect, $F = 8\ 889$, $p =$ 004, and accounted for 10 percent of score variance ($R^2 =$ 102)

A similar statement regarding the components of error as stated above is applicable here Although lower than the accuracy error of the other three tests, fully one-half of the variance in accuracy scores was unaccounted for, and in spite of the emergence of age group as a significant main effect in the efficiency scores, the efficiency error was still 63 percent. Evidently effects of radiation, which accounted for almost all the accuracy score variance, were especially significant in limiting the ability, especially of the more highly exposed subjects, to store, process and recall the variously shaded geometric figures correctly. The significantly lower throughput scores for older subjects in a task which measures attention, working memory, and spatial ability are consistent with previous aging research in matching geometric object pairs (Scialfa & Thomas, 1994) and age-related slowing with difficult tasks (Myerson et al., 1989). Figures 6 and 7 illustrate Matching to Sample accuracy and efficiency performances by age and radiation group. Mean scores and ANOVA test results are in Tables C11, C12, and C13 in Appendix C.

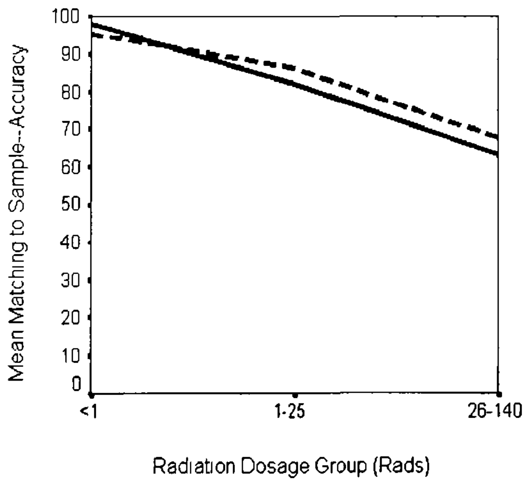

Figure 6. Performance by Age and Radiation Group: Matching to Sample Accuracy

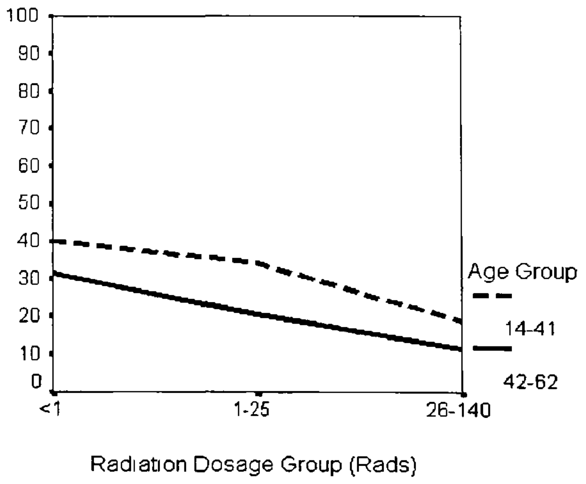

Figure 7. Performance by Age and Radiation Group: Matching to Sample Efficiency

Dunnett Matching to Sample post hoc multiple comparison test results for radiation dosage group accuracy scores showed significant mean differences between all three dosage groups, <1 rad, 1-25 rads, and 26-140 rads, $p \leq$ 001 Efficiency score mean differences between all three dosage groups were significant at $p \leq .01$ There was a 31 point spread in accuracy scores between the <1 rad and high exposure 26-140 rad groups, and a 23 point difference for the same groups in efficiency scores Results are in Tables C14 and C15 in Appendix C

Spatial Processing ANOVA Results

Spatial Processing ANOVA tests showed a significant radiation dosage main effect for accuracy scores and main effects for both dosage and age for efficiency scores For accuracy scores, age, dosage, and age/dosage interaction accounted for 22 percent of score variation ($R^2 =$ 223) Dosage group showed a significant main effect, $F = 9\ 501$, $p <$ 001, and accounted for 20 percent of score variation ($R^2 =$ 196)

Age, dosage and age/dosage interaction accounted for 37 percent of efficiency score variance ($R^2 =$ 369) Age was a significant main effect, F = 12 819, $p =$ 001, and accounted for 14 percent of score variation ($R^2 =$ 141) Radiation dosage was also a significant main effect, $F = 11\ 844$, $p <$ 001, and accounted for 23 percent of score variance ($R^2 =$ 233)

The Spatial Processing accuracy scores have the largest error factor of any of the tests, 78 percent, and dosage group, although significant, accounted for the least amount of variance Age group accounted for the greatest percent of efficiency variance of any of the tests, 14 percent, but the overall error was still 63 percent, so caveats again are recommended when viewing these results. This test involved visuospatial processing of simultaneously displayed objects, which Swearer & Kane, 1996, found involved longer inspection by older subjects, so the main age effect for lower time-related efficiency scores in this study is not surprising. Figures 8 and 9 illustrate Spatial Processing accuracy and efficiency performances by age and radiation group. Mean scores and ANOVA test results for accuracy and efficiency are in Tables C16, C17, and C18 in Appendix C.

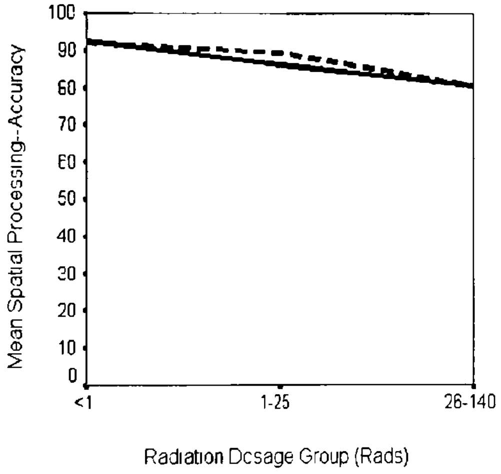

Figure 8. Performance by Age and Radiation Group: Spatial Processing Accuracy.

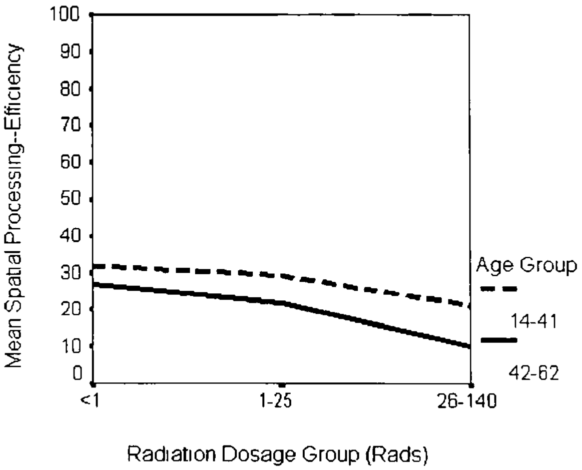

Figure 9. Performance by Age and Radiation Group: Spatial Processing Efficiency.

Dunnett Spatial Processing post hoc multiple comparison tests for accuracy scores showed significant differences between the <1 rad dosage group and both the 1-25 rad and 26-140 rad dosage groups, $p \leq .01$. The efficiency score mean differences between the <1 rad and high exposure 26-140 rad dosage groups and between the low exposure 1-25 rad and high exposure 26-140 rad dosage groups were significant at $p \leq .01$. This is the first test that did not show more than a marginally significant difference between the < 1 rad dosage group and the 1-25 rad dosage group, $p = .024$, in this case, in efficiency scores, thus illustrating that dosage was not as great a factor in performance on this test. Results are in Tables C19 and C20 in Appendix C.

CONCLUSIONS

The results of this study only partially support the hypothesis that age has a significant effect on cognitive test results among persons exposed to ionizing radiation, but only on Matching to Sample and Spatial Processing and then only on efficiency scores. The second hypothesis that age-related decrements in performance will affect efficiency more than accuracy scores was also partially supported. The specific results that supported these hypotheses occurred in the efficiency scores of the two tests which involved processing of spatial figures. Age was a significant main effect in both the Matching to Sample and Spatial Processing cognitive tests and accounted for 10 percent and 14 percent of the variance in their efficiency scores, respectively. The third hypothesis concerning the interaction effect was not supported.

Radiation dosage was a significant main effect in all eight tests, accounting for from 20 to 47 percent of variance in accuracy scores and from 22 to 29 percent of variance in efficiency scores. The evidence that increased decrements in cognitive performance are positively related to increased exposure to radiation is consistent with the results of the longitudinal research which supplied the data from which the subset used in this study was taken (Gamache et al., 1999). The questions left by these results are, first, "Why didn't the first two tests show aging effects?" Secondly, "Why were no aging effects found in the accuracy scores, which did not contain time as a measurement factor?" Finally, "Why was there no significant ANOVA interaction between the two independent variables when they were significantly correlated?"

The effects of age on spatial task performance are consistent with previous research findings that cognitive slowing was more evident in nonverbal and complex tasks than in simple or verbal processing tasks (Kirasic et al., 1996), and that difficulty in recalling target positions in a matrix, regardless of content, increased with age (Salthouse et al., 1988). The significant aging effects on efficiency scores of matching spatial objects, and the spatial processing task where two geometric objects, one rotated, were displayed simultaneously, recall the confusion of older subjects who checked and rechecked similar geometric object pairs which differed in only one dimension (Scialfa & Thomas, 1994) and the longer inspection of simultaneous matching spatial stimuli by older participants (Swearer & Kane, 1996).

Research in aging effects has shown small or nonexistent age differences in performance of tasks that required retention of small amounts of information for short periods of time, and some studies have shown no age differences in performance on digit span tasks (Howard & Howard, 1997). This may contribute some explanation to the lack of aging effects on performance on the Running Memory and Digit Span tests. Furthermore, these two tests involved working memory storage and processing of familiar objects, namely single letters and numeric digits. The spatial object tests which showed the aging effect involved unfamiliar geometric figures, which may have increased the difficulty of the tasks and the corresponding time the subjects took to solve them, in keeping with previous research where age differences in response times increased with the difficulty of the task (Myerson et al., 1989). Manipulation of unfamiliar spatial figures requires subjects to use fluid, immediate problem-solving intelligence, which declines with age, while processing familiar objects permits the subject to use accumulated systems of knowledge, the more crystallized form of intelligence which seems to be retained or even improve with age (Horn & Cattell, 1967; Horn, 1982; Sorce, 1995).

One of the difficulties in trying to separate and identify the effects of radiation exposure and aging on cognitive test results is that radiation affects individuals cognitively in different ways depending on their age. The effects of radiation are exacerbated in older people because they are already experiencing the affects of age alone on their sensory perception and on the cognitive and motor processes of their central nervous system. They will try, when performing cognitive activities, to compensate for the debilitating effects of age and radiation exposure by time-consuming cautionary procedures and the advantage of their life experiences. The subjects in this study were exceptionally highly motivated to do well, to make a good impression on the visiting researchers, and to respond with correct scores because someone was paying attention to them. However, no matter how hard they try, radiation interferes with their accuracy and efficiency of performance. Some of the research into the decline of visuospatial test performance with age has investigated age-related decline in prefrontal brain functioning, decline in right-hemisphere functioning, and disruption in executive control functions (Libon et al., 1994). The extent to which exposure to radiation has contributed to, interacted with, or even accelerated aging effects in these functional areas would be a rich and rewarding area for further research

A major reason for viewing the results of this study with caution is the lack of significant interaction between age and radiation dosage in the ANOVA results The dominant main effect in all eight test scores analyzed was the radiation dosage groups, joined by the age groups as a main effect in the two spatial processing efficiency scores However, in spite of a significant correlation between age and dosage, no significant ANOVA interaction of age and dosage appeared As was discussed in the Analysis section, correlation is more of an indication of a relationship between variables than a precise breaking out of the participation of each variable, because correlation does not include an error factor A consistent characteristic of each ANOVA test was a large error, ranging from 50 percent in the Matching to Sample accuracy score to 78 percent in the Spatial Processing accuracy score Five of the eight tests had an error over 60 percent, and two errors were over 74 percent This means that most of the variance in test scores was accounted for by unknown factors, rather than by the known variables of age group, radiation group, and age/dosage interaction

One of the reasons for the lack of interaction was that there were only two independent variables, age and radiation dosage, and there were not enough subjects to increase the number of groups or assign at least ten subjects to each age/dosage "cell" Suggested guidelines to improve the chances of finding significant age/dosage interaction in future research, and implications of this study's findings for human factors are offered in the next section

RECOMMENDATIONS

Further Research

The previously discussed absence of significant ANOVA interaction between the independent variables of age and dosage, which had been shown to be significantly correlated, was affected by the sample size, the number of independent variables, and the number of groups and subject/group assignments However, if there were more candidates for main effects, i.e , more independent variables and/or a larger sample that could be assigned to more groups, there would be a better chance for significant interaction between the independent variables There need to be at least ten subjects in each age/dosage "cell", such as age group *x*, dosage group *y*. There also need to be more than two age groups so that post hoc tests can be run for age as well as dosage. Real life radiation exposure may not fit neatly into a normal distribution, but an increased subject population together with the robust ANOVA test and adjustments such as post hoc procedures specifically designed to take score variance into consideration, such as the Dunnett test used in this study, would greatly improve the chance of identifying more of the factors and interactions than this study was able to do.

It is also recommended that the scores from the Code Substitution tests, administered as part of the ANAMUKR battery to the Ukrainian subjects during the Gamache et al., 1999, study, be added to the dependent variables to be analyzed. This task tests paired associate learning, and both short term and long term memory. It involves matching a symbol/digit pair to a coding string of symbols and digits, which is displayed during the learning trial, but hidden during subsequent immediate and delayed memory trials (Reeves et al., 1995). A learning trial, an immediate recall, and two delayed recall memory trials were administered. This test, like the others in the battery, has been shown to be sensitive to radiation dosage and would expand the range of age-related factors, since learning and long term memory were not targets for analysis in this study but have been addressed in previous age-related research (Howard & Howard, 1997).

Adult age-related performance on cognitive tasks involves other factors besides chronological age, including gender, education, current or former occupation, physical condition, mental health, especially depression, and biological life experiences. Research designs need to take these categories into consideration, plus the kinds of physical disabilities experienced because of radiation exposure, and how they affect attention span, reaction time, and ability to concentrate. Within group designs are needed to compare individual performance.

In order to further target the segments of the radiation-exposed population who need special help in schools, the workplace and the tasks of daily living, research should expand to develop laboratory tests that simulate activities older adults experience as part of day-to-day living, as well as use experimental cognitive processing of low-meaning material such as letters and number strings. Individuals with the double burden of radiation exposure and aging factors (and radiation dosage can speed the aging process) may tend even more than non-exposed subjects to rely on solutions from personal experience to solve problems (Rabbitt, 1997; Welford, 1958). Such research might determine whether radiation affects crystallized intelligence, which appears to be stable in older non-exposed individuals, and might identify other areas where human factors could be used to design tools and procedures to improve living and working conditions for the affected population. Examples of such tests used in America, which would have to be modified or newly created for Ukrainian participants, are choosing the best nutritional cereal from a list of brands with accompanying key and descriptive attributes; determining solutions to common life planning problems such as work vs. family responsibility or whether to retire early; everyday problems such as a broken refrigerator; and basic skills tests (reading labels and street maps, filling out forms) (Sorce, 1995).

Human Factors Implications

There are profound human factors implications in the finding that older people are having age-related as well as radiation-related difficulties with cognitive tasks involving spatial processing. Examples of areas affected by the findings of this study as they apply to radiation-exposed patients over 35 include interpretation of maps, including maritime maps for individuals involved in waterway navigation, charts of all kinds, shopping mall diagrams, subway maps, bus and train schedules, newspaper television schedules, and similar day-to-day objects which require cognitive spatial processing. Human factors considerations would involve making sure that design of the above items stressed simplicity in appearance and clear explanations; designing training sessions, perhaps in local schools, to help affected people do simple things such as reading street maps and bus schedules, and "training the trainers" to conduct the sessions

A typical seminar for older people would be held, perhaps, once per week for four weeks and repeated as needed and as long as teaching and location resources were available Sessions would be limited to two hours to avoid fatigue and would register no more than twenty people so that an informal atmosphere could be maintained If full funding was not available from state, community, or private sources, participant fees should be kept to an absolute minimum as far as possible Typical topics might include

- Street map reading How to orient oneself in the map, turning it as necessary to following various preset paths from a house to school, a bus station, a subway entrance, a shopping mall, a hospital, a medical clinic and a grocery store
- How to arrange a week's worth of pills in a plastic or homemade container containing one slot for each day Use small nuts or candies, which become the reward for the lesson
- Design of a bus route map from a real or simulated bus schedule, again emphasizing spatial orientation
- Road signs Bring in a representative from the local constabulary to explain and review signs Even if the students do not drive, as pedestrians they need to be familiar with common signs and icons, such as Stop, Workers ahead, Keep Out, Open Trench, etc
- Shopping mall diagram Self orientation and a "shopping trip" from a "You are here" point to various stores, using a list from the nearest shopping mall, if

available

- Arranging things in a space to accommodate shape and size Furniture in a room Pictures on a wall Food in a refrigerator Books in a bookcase Flower pots and tools in a garden shed Prescription and over-the-counter medicinal containers, tubes and bottles in a medicine cabinet Give the students a list of objects for each exercise Use a chalkboard to lay out the space and have them suggest where to put things
- Small things How to set and read a thermostat How to figure out a radio dial How to use a TV remote How to interpret a bathroom scale How to use and read a medical thermometer, an outside thermometer Any dials or controls common to the area where the students live, such as parking meters

Finally, research results can help prepare scenarios for government agencies such as FEMA for use in planning and training emergency teams in case of nuclear accident, especially if age-related differences in reaction to radiation exposure can be taken into consideration when selecting personnel for specific tasks Human factors experts who are aware of age/dosage related effects on human performance should be included in planning sessions both for generalized emergency training and on site disaster assignment of tasks and resources

For instance, if people exposed to radiation take part in the emergency efforts, assignments should include some people under 35 years of age for

- Mapping the area, including buildings, passable and impassable streets, obstacles, hydrants, ditches, debris, abandoned or destroyed vehicles.

- Rescue personnel who need architectural or engineering drawings to locate injured in buildings.
- Setting up emergency headquarters, selecting and placing furniture and electronic equipment such as telephones, computers, scanners and other peripherals.
- Setting up First Aid stations, selecting and placing furniture and basic medical equipment.
- Placing appropriate icon signage in the area for warning and directions.

These are just some suggestions. The important human factors issue to remember is that in order to provide tools and environmental conditions optimal for the comfort and safety of the people involved, the limitations associated with the combination of radiation and age need to be planned for and constantly tracked, for even the most careful research will not discover every facet of the combined effects.

REFERENCES

AARP (American Association of Retired Persons), Washington, D C (1994) *55 Alive Mature Driving Student Workbook.* Edition IV

Allen, P A , Patterson, M B , & Propper, R E (1994) Influence of Letter Size on Age Differences in Letter Matching *Journal of Gerontology, Psychological Sciences* 49(1) P24-P28

AOL (America Online) Library (2000) http://library.thinkquest.org/3426/data/introduction/location.html

Ashcraft, M H (1994) *Human Memory and Cognition.* Second Edition New York HarperCollins College Publishers p 146

Baddeley, A D (1986) *Working memory.* Oxford, England Oxford University Press As referenced in Salthouse (1994)

Baryahtar, V & Bobyleva, O (1991) "Generalized Data of the Academy of Sciences of the Ukraine and the Ministry of Health Characterizing the Consequences of the Chernobyl Disaster with Respect to the Health of the Population " *Ukranian Ecological Bulletin.* 4 As referenced in Gamache, et al , 1999

Bashore, T R , & Goddard, P H (1993) Preservative and restorative effects of aerobic fitness on the age-related slowing of mental processing speed In J Cerella, J Rybash, W Hoyer, & M L Commons (Eds), *Adult information processing: Limits on loss* (pp 205-228) San Diego, CA Academic Press As referenced in Howard & Howard, 1997

Brannigan, F L (n d) *Living with Radiation.* United States Atomic Energy Commission, Safety & Fire Protection Branch, Office of Industrial Relations, Washington, D C

Brookhaven National Laboratory (1964) *ABC of Radiation.* Upton, New York Associated Universities, Inc

Busby, B , University of Michigan (1999a) *Definitions; Radiation Related Terms* Department of Nuclear Engineering, Oregon State University **http://www.ne.orst.edu/rhp/terms.html#top**

Busby, B , University of Michigan (1999b) *Radiation and Risk* Department of Nuclear Engineering, Oregon State University **http://www.ne.orst.edu/rhp/risk.html**

Cavanaugh, J C (1997) *Adult Development and Aging.* Pacific Grove, CA Brooks/Cole Publishing Co p 88

Chernobyl plant to operate until funds come from West (1999, April 22) *The Times-Union*, Jacksonville, FL p A-15

Chernobyl comes alive (1999, November 26) *The Times-Union,* Jacksonville, FL p A-16

Chernousenko, V M (1991) *Chernobyl: Insight from the inside* Berlin Springer-Verlag As referenced in Gamache et al , 1999

Collins, D L & Bandeira-de-Carvalho, A US Air Force Office of Scientific Research, Bolling AFB, Washington, DC (1993) Chronic stress from the Goiania ^{137}Cs Radiation Accident *Behavioral Medicine* 18(4) 149-157

Department of Defense, Office of Civil Defense (1963) *Handbook for Radiological Monitors, FG-E-5.9.* U S Government Printing Office, O-680953 April 1963

Gamache, G L , Reeves, D L , Levinson, D M , & Bidyuk, P I (1999) *Neurocognitive and Physical Abilities Assessments Twelve Years after the Chernobyl Nuclear Accident: Final Report.* Defense Threat Reduction Agency, Alexandria, VA 22310-3398 Contract No DSWA01-97-C-0047

Holowinsky, I Z (1993) Chernobyl nuclear catastrophe and the high risk potential for mental retardation *Mental Retardation* 31(1) 35-40

Horn, J L (1982) The theory of fluid and crystallised intelligence in relation to concepts of cognitive psychology and aging in adulthood, in F I M Craik and S Trehub (eds), *Aging and Cognitive Processes* (Plenum, New York), 237-278 As referenced in Rabbitt, 1997

Horn, J L & Cattell, R B (1967) Age differences in fluid and crystallised intelligence *Acta Psychologica.* 26, 107-129 As referenced in Rabbitt, 1997

Houx, P J & Jolles, J (1993) Age-related decline of psychomotor speed Effects of age, brain health, sex, and education *Perceptual and Motor Skills.* 76, 195-211

Howard, J H Jr , & Howard, D V (1997) Learning and Memory In Fisk, A D , & Rogers, W A (Eds) *Handbook of Human Factors and the Older Adult* San Diego, CA Academic Press, Inc 7-26

Howell, W. C. (1997). Foreword, Perspectives, and Prospectives. In Fisk, A. D., & Rogers, W. A. (Eds.) *Handbook of Human Factors and the Older Adult.* San Diego, CA: Academic Press, Inc.1-6.

Kaszniak, A. W. (1990). Psychological assessment of the aging individual. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (3rd ed., pp 427-445). San Diego, CA: Academic Press. As referenced in Howard & Howard, 1997.

Kimball, R., University of Vermont Radiation Safety Office. (1999). *Biological Effects of Ionizing Radiation.* **http://moose.uvm.edu/~radsafe/newsletter/bioeffect.47.html.**

Kirasic, K. C., Allen, G. L., Dobson, S. H., & Binder, K. S. (1996). Aging, Cognitive Resources, and Declarative Learning. *Psychology and Aging.* 11(4), 658-670.

Libon, D. J., Glosser, G., Malamut, B. L., Kaplan, E., Goldberg, E., Swenson, R., & Sands, L. P ((1994). Age, Executive Functions, and Visuospatial Functioning in Healthy Older Adults. *Neuropsychology.* 8(1), 38-43.

Megaw, W. J. (1987). *How Safe: Three Mile Island, Chernobyl and beyond.* pp 34 & 39. Toronto, Ontario: Stoddart Publishing Co. Limited, 34 Lesmill Road.

Miller, G.A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review.* 63, 81-97. As referenced in Ashcraft (1994).

Myerson, J., Hale, S., Hirschman, R., Hansen, C., & Christiansen, B. (1989). Global increase in response latencies by early middle age: complexity effects in individual performances. *Journal of the Experimental Analysis of Behavior.* 52 (3). 353-362.

Rabbitt, P (1997). Ageing and human skill: a 40th anniversary, the Alan Welford Memorial Lecture. *Ergonomics.* 40(10). 962-981.

Rabbitt, P. M. A. (1996a). Do individual differences in speed reflect 'global' or 'local' differences in mental abilities? *Intelligence*. 22, 69-88. As referenced in Rabbitt, 1997.

Rabbitt, P M. A. (1996b). Intelligence is not just mental speed. Journal of Biosocial Science. 28, 425-449. As referenced in Rabbitt, 1997.

Reeves, D & Gamache, G (1994) *Ukrainian subset of ANAM battery: ANAMUKR.* (Report No KGAI-94-106-TR) St Augustine, FL KGA International As referenced in Gamache et al , 1999

Reeves, D , Kane, R , Winter, K , & Goldstone, A (1995) Office of Military Performance Assessment Technology (OMPAT) *Automated Neuropsychological Assessment Metrics (ANAM), ANAM V3.11, Clinical and Neurotoxicology Subsets.* NCRF SR-95-01 Special Report Series, National Cognitive Recovery Foundation, Office of Publications, 13448 Samantha Ave , San Diego, CA 92129

Salthouse, T A (in press-a) Aging associations Influence of speed on adult age differences in associative learning *Journal of Experimental Psychology: Learning, Memory, and Cognition.* As referenced in Salthouse, 1994

Salthouse, T A (in press-c) Selective influences of age and speed on associative memory *American Journal of Psychology* As referenced in Salthouse, 1994

Salthouse, T A (1994) The aging of working memory *Neuropsychology.* 8(4) 535-543

Salthouse, T A & Babcock, R L (1991) Decomposing adult age differences in working memory *Developmental Psychology.* 27 763-776 As referenced in Salthouse, 1994

Salthouse, T A , Kausler, D H , & Saults, J S (1988) Investigation of student status, background variables, and the feasibility of standard tasks in cognitive aging research *Psychology and Aging.* 3, 29-37 As referenced in Salthouse, 1994

Salvendy, Gavriel (1987) Design for Older People *Handbook of Human Factors.* New York John Wiley & Sons, Inc 496-504

Sanders, M S & McCormick, E J (1993) *Human Factors in Engineering and Design.* New York McGraw-Hill, Inc 4-5

Scialfa, C T & Thomas, D M (1994) Age Differences in Same-Different Judgments as a Function of Multidimensional Similarity *Journals of Gerontology* 49(4) 173-178

Sorce, P (1995) Cognitive Competence of Older Consumers *Psychology & Marketing.* 12(6) 467-480

Swearer, J M & Kane, K J (1996) Behavioral Slowing With Age Boundary Conditions of the Generalized Slowing Model *Journals of Gerontology-Series B, Psychological Sciences and Social Sciences.* 51B(4) 189-200

Ukraine promises to close Chernobyl (2000, June 6) *The St. Augustine Record*, St Augustine, FL p 7A

Ukraine says it will close Chernobyl (2000, June 6) *The Times-Union*, Jacksonville, FL p A-7

Uranium Information Centre Ltd, Melbourne, Australia (1999) *Nuclear Electricity (Fifth edition, January 1999).* **http://www.uic.com.au/neApl.htm.**

van Boxtel, M P J , Buntinx, F , Houx, P J , Metsemakers, J F M , Knottnerus, A , & Jolles, J (1998) The Relation Between Morbidity and Cognitive Performance in a Normal Aging Population *Journal of Gerontology: Medical Sciences.* 53A(2) M147-M154

Van der Linden, M , Bredart, S , & Beerten, A (1994) Age-related differences in updating working memory *British Journal of Psychology. (*85) 145-152

Vercruyssen, M (1997) Movement Control and Speed of Behavior In Fisk, A D , & Rogers, W A (Eds) *Handbook of Human Factors and the Older Adult.* San Diego, CA Academic Press, Inc 55-86

Welford, A T (1958) *Ageing and Human Skill.* 1st edn (Oxford University Press for the Nuffield Foundation, Oxford) As referenced in Rabbitt, 1997

Yakovlev, E A (1991) "Geological and Economical Aspects of Decommissioning the Chernobyl Nuclear Power Plant *Ukrainian Ecological Bulletin* 2 As referenced in Gamache et al , 1999

Years later, Chernobyl's messy legacy lingers (1999, April 26) *The St. Augustine Record*, St Augustine, FL. p 6A

APPENDIX A

Test Procedure

The tests were administered via IBM-compatible notebook computers. Each session required approximately 45 minutes. A table was set up at the entrance to the test site for registration, and each participant was asked to read and sign an informed consent form in Russian and English. Three testing stations were established, each containing a table, two chairs, and a laptop computer. The test subject occupied one chair, and a test administrator sat in the other to make sure the participant understood instructions and to encourage him or her to ask as many questions as necessary. The administrators also made sure participants did not discuss the tests.

At the end of the sessions, the participants were thanked and given the equivalent of two American dollars. The test scores were stored on the computer hard drives and at the end of the day were backed up twice to 3 2" floppy disks, which were labeled for the group and test year (Gamache et al., 1999).

APPENDIX B

Cognitive Test Descriptions

Four of the nine cognitive tests were selected for analysis in this study. Test descriptions are from Reeves et al., (1995).

1. CPT - Running Memory Continuous Performance Task.

   Purpose: Measure attention and working memory

   This is a continuous letter comparison task. A randomized sequence of upper-case letters, in the Cyrillic alphabet for the ANAMUKR version, are presented one at a time in the center of the screen. Subjects are asked to continuously monitor the letters and press the left mouse button if the letter on the screen matches the letter that immediately preceded it. They are requested to press the right mouse button if the letter does not match the preceding one. Sixty letters are presented.

2. DGS - Digit Set Comparison Successive

   Purpose: Measure attention and working memory

   This test is an approximation to the WAIS-R digit span-forwards test. A string of from 2 to 10 digits is presented in the center of the screen. After a specified period, the first string disappears and a second string is presented. The subject is asked to compare the two digit strings and decide whether they are the same digits and in the same order, and respond by pressing one of two specified buttons on the mouse. If the subject's responses are error free for the digit string length of 4, 5, and 6, the test is terminated automatically by the computer.

3. MSP Matching to Sample

Purpose Measure attention, working memory, spatial ability

The subject is required to respond correctly to stimuli that correspond in some way to a sample stimulus A single 4 x 4 matrix, like a checkerboard, is presented in the center of the screen as a sample stimulus For each trial, the number of cells that are shaded varies at random from 1 to 12 cells When the subject presses a response key (or after a pre-specified time), the sample is removed from the screen After another pre-specified time interval, a set of two comparison matrices are shown side by side on the screen One of them will match the "sample" matrix, while shading in the other will differ by a cell or more The subject is asked to press the appropriate response button to indicate which matrix matches the "sample"

4 SPD - Spatial Processing Simultaneous

Purpose Measure spatial ability

Pairs of four-bar histograms are presented simultaneously on the monitor One histogram is always rotated 90 degrees with respect to the other The subject is requested to determine whether they are identical and press the specified key or mouse button to indicate "same" or "different"

APPENDIX C
Tables

Table C1. Running Memory Mean Scores by Age and Dosage Group

Age Group	Radiation Dosage Grp	N	CPT Accuracy Mean	CPT Accuracy Standard Deviation	CPT Efficiency Mean	CPT Efficiency Standard Deviation
14-41	<1	21	93 02	7 38	83 96	15 34
	1-25	12	81 25	21 18	73 79	22 45
	26-140	8	80 50	14 89	60 96	20 34
	Total	41	87 13	15 06	76 49	20 21
42-62	<1	7	96 14	1 42	85 38	11 13
	1-25	7	82 76	9 61	65 84	12 85
	26-140	9	73 24	14 00	50 66	14 04
	Total	43	82 94	12 00	65 84	16 45
Total	<1	28	93 80	6 54	84 31	14 22
	1-25	39	82 29	13 91	68 29	16 51
	26-140	17	76 66	14 45	55 51	17 54
	Total	84	84 99	13 66	71 04	19 04

Table C2. ANOVA Tests of Between-Groups Effects -- Running Memory Accuracy. Independent Variables: Age Group, Radiation Dosage Group

Dependent Variable Running Memory--Accuracy

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Corrected Model	3931.188[a]	5	786.238	5.306	.000	.254
AGE	12.761	1	12.761	.086	.770	.001
DOSE	3326.648	2	1663.324	11.226	**.000**	.224
AGE * DOSE	293.448	2	146.724	.990	.376	.025
Error	11557.534	78	148.174			
Corrected Total	15488.722	83				

a. R Squared = .254 (Adjusted R Squared = .206)

Table C3. ANOVA Tests of Between-Groups Effects -- Running Memory Efficiency Independent Variables: Age Group, Radiation Dosage Group

Dependent Variable Running Memory--Efficiency

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Corrected Model	10314.028[a]	5	2062.806	8.143	.000	.343
AGE	517.744	1	517.744	2.044	.157	.026
DOSE	7876.752	2	3938.376	15.547	**.000**	.285
AGE * DOSE	397.670	2	198.835	.785	.460	.020
Error	19759.441	78	253.326			
Corrected Total	30073.470	83				

a. R Squared = .343 (Adjusted R Squared = .301)

Table C4. Post Hoc Multiple Comparisons - Running Memory Accuracy.

Dependent Variable: Running Memory--Accuracy

	(I) Radiation Dosage Group	(J) Radiation Dosage Group	Mean Difference (I-J)	Std. Error	Sig.
Tukey HSD	<1	1-25	11.5057*	3.0152	**.001**
		26-140	17.1445*	3.7427	**.000**
	1-25	<1	-11.5057*	3.0152	.001
		26-140	5.6387	3.5377	.254
	26-140	<1	-17.1445*	3.7427	.000
		1-25	-5.6387	3.5377	.254
LSD	<1	1-25	11.5057*	3.0152	**.000**
		26-140	17.1445*	3.7427	**.000**
	1-25	<1	-11.5057*	3.0152	.000
		26-140	5.6387	3.5377	.115
	26-140	<1	-17.1445*	3.7427	.000
		1-25	-5.6387	3.5377	.115
Dunnett T3	<1	1-25	11.5057*	3.0152	**.000**
		26-140	17.1445*	3.7427	**.001**
	1-25	<1	-11.5057*	3.0152	.000
		26-140	5.6387	3.5377	450
	26-140	<1	-17.1445*	3.7427	.001
		1-25	-5.6387	3.5377	.450

Based on observed means.

* The mean difference is significant at the .01 level.

Table C5. Post Hoc Multiple Comparisons - Running Memory Efficiency

Dependent Variable: Running Memory--Efficiency

	(I) Radiation Dosage Group	(J) Radiation Dosage Group	Mean Difference (I-J)	Std. Error	Sig.
Tukey HSD	**<1**	1-25	16.0263*	3.9424	**.000**
		26-140	28.8049*	4.8938	**.000**
	1-25	<1	-16.0263*	3.9424	.000
		26-140	12.7785	4.6257	.019
	26-140	<1	-28.8049*	4.8938	.000
		1-25	-12.7785	4.6257	.019
LSD	**<1**	1-25	16.0263*	3.9424	**.000**
		26-140	28.8049*	4.8938	**.000**
	1-25	<1	-16.0263*	3.9424	.000
		26-140	12.7785*	4.6257	**.007**
	26-140	<1	-28.8049*	4.8938	.000
		1-25	-12.7785*	4.6257	.007
Dunnett T3	**<1**	1-25	16.0263*	3.9424	**.000**
		26-140	28.8049*	4.8938	**.000**
	1-25	<1	-16.0263*	3.9424	.000
		26-140	12.7785	4.6257	.047
	26-140	<1	-28.8049*	4.8938	.000
		1-25	-12.7785	4.6257	.047

Based on observed means.

* The mean difference is significant at the .01 level.

Table C6. Digit Set Comparison Mean Scores by Age and Dosage Group

			DGS Accuracy		DGS Efficiency	
Age Group	Radiation Dosage Grp	N	Mean	Standard Deviation	Mean	Standard Deviation
14-41	<1	21	88.49	9.12	36.20	14.46
	1-25	12	74.65	12.24	26.93	7.85
	26-140	8	69.79	11.73	22.12	7.07
	Total	41	80.79	13.17	30.74	12.85
42-62	<1	7	86.31	6.24	32.61	5.05
	1-25	27	71.45	12.64	23.27	7.80
	26-140	9	71.76	8.78	18.16	5.01
	Total	43	73.93	12.24	23.72	8.13
Total	<1	28	87.95	8.44	35.30	12.77
	1-25	39	72.44	12.45	24.40	7.90
	26-140	17	70.83	9.99	20.02	6.21
	Total	84	77.28	13.09	27.15	11.20

Table C7. ANOVA Tests of Between-Groups Effects -- Digit Set Comparison Accuracy. Independent Variables: Age Group, Radiation Dosage Group

Dependent Variable: Digit Set Comparison--Accuracy

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Corrected Model	4934.000[a]	5	986.800	8.293	.000	.347
AGE	21.350	1	21.350	.179	.673	.002
DOSE	3441.566	2	1720.783	14.461	**.000**	.270
AGE * DOSE	76.942	2	38.471	.323	.725	.008
Error	9281.502	78	118.994			
Corrected Total	14215.502	83				

a. R Squared = .347 (Adjusted R Squared = .305)

Table C8. ANOVA Tests of Between-Groups Effects -- Digit Set Comparison Efficiency. Independent Variables: Age Group, Radiation Dosage Group

Dependent Variable: Digit Set Comparison--Efficiency

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Corrected Model	3265.880[a]	5	653.176	7.127	.000	.314
AGE	229.693	1	229.693	2.506	.117	.031
DOSE	2060.984	2	1030.492	11.245	**.000**	.224
AGE * DOSE	.350	2	.175	.002	.998	.000
Error	7148.145	78	91.643			
Corrected Total	10414.025	83				

a. R Squared = .314 (Adjusted R Squared = .270)

Table C9. Post Hoc Multiple Comparisons - Digit Set Comparison Accuracy

Dependent Variable: Digit Set Comparison--Accuracy

	(I) Radiation Dosage Group	(J) Radiation Dosage Group	Mean Difference (I-J)	Std. Error	Sig.
Tukey HSD	**<1**	1-25	15.5105*	2.7020	**.000**
		26-140	17.1135*	3.3540	**.000**
	1-25	<1	-15.5105*	2.7020	.000
		26-140	1.6030	3.1703	.869
	26-140	<1	-17.1135*	3.3540	.000
		1-25	-1.6030	3.1703	.869
LSD	**<1**	1-25	15.5105*	2.7020	**.000**
		26-140	17.1135*	3.3540	**.000**
	1-25	<1	-15.5105*	2.7020	.000
		26-140	1.6030	3.1703	.615
	26-140	<1	-17.1135*	3.3540	.000
		1-25	-1.6030	3.1703	.615
Dunnett T3	**<1**	1-25	15.5105*	2.7020	**.000**
		26-140	17.1135*	3.3540	**.000**
	1-25	<1	-15.5105*	2.7020	.000
		26-140	1.6030	3.1703	.940
	26-140	<1	-17.1135*	3.3540	.000
		1-25	-1.6030	3.1703	.940

Based on observed means.

*. The mean difference is significant at the .01 level.

Table C10. Post Hoc Multiple Comparisons - Digit Set Comparison Efficiency

Dependent Variable: Digit Set Comparison--Efficiency

	(I) Radiation Dosage Group	(J) Radiation Dosage Group	Mean Difference (I-J)	Std. Error	Sig.
Tukey HSD	**<1**	1-25	10.9079*	2.3712	**.000**
		26-140	15.2789*	2.9434	**.000**
	1-25	<1	-10.9079*	2.3712	.000
		26-140	4.3709	2.7822	.264
	26-140	<1	-15.2789*	2.9434	.000
		1-25	-4.3709	2.7822	.264
LSD	**<1**	1-25	10.9079*	2.3712	**.000**
		26-140	15.2789*	2.9434	**.000**
	1-25	<1	-10.9079*	2.3712	.000
		26-140	4.3709	2.7822	.120
	26-140	<1	-15.2789*	2.9434	.000
		1-25	-4.3709	2.7822	.120
Dunnett T3	**<1**	1-25	10.9079*	2.3712	**.001**
		26-140	15.2789*	2.9434	**.000**
	1-25	<1	-10.9079*	2.3712	.001
		26-140	4.3709	2.7822	.093
	26-140	<1	-15.2789*	2.9434	.000
		1-25	-4.3709	2.7822	.093

Based on observed means.

* The mean difference is significant at the .01 level.

Table C11. Matching to Sample Mean Scores by Age and Dosage Group

			MSP Accuracy		MSP Efficiency	
Age Group	Radiation Dosage Grp	N	Mean	Standard Deviation	Mean	Standard Deviation
14-41	<1	21	95 24	5 63	39 94	17 65
	1-25	12	86 11	13 77	34 23	13 48
	26-140	8	67 50	11 51	18 62	11 46
	Total	41	87 15	14 25	34 11	17 16
42-62	<1	7	98 10	5 04	31 59	11 25
	1-25	27	81 97	10 91	20 46	11 27
	26-140	9	62 96	20 85	11 54	7 70
	Total	43	80 62	16 70	20 40	12 07
Total	<1	28	95 95	5 54	37 86	16 50
	1-25	39	83 25	11 83	24 70	13 45
	26-140	17	65 10	16 75	14 87	10 02
	Total	84	83 81	15 81	27 09	16 22

Table C12. ANOVA Tests of Between-Groups Effects -- Matching to Sample Accuracy. Independent Variables: Age Group, Radiation Dosage Group

Dependent Variable: Matching to Sample--Accuracy

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Corrected Model	10364.303[a]	5	2072.861	15.589	.000	.500
AGE	61.848	1	61.848	.465	.497	.006
DOSE	9300.553	2	4650.276	34.973	**.000**	473
AGE * DOSE	188.640	2	94.320	.709	.495	.018
Error	10371.571	78	132.969			
Corrected Total	20735.873	83				

[a] R Squared = .500 (Adjusted R Squared = 468)

Table C13. ANOVA Tests of Between-Groups Effects -- Matching to Sample Efficiency. Independent Variables: Age Group and Radiation Dosage Group

Dependent Variable: Matching to Sample--Efficiency

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Corrected Model	8160.057[a]	5	1632.011	9.304	.000	.374
AGE	1559.137	1	1559.137	8.889	**.004**	.102
DOSE	4025.080	2	2012.540	11.474	**.000**	.227
AGE * DOSE	162.359	2	81.179	.463	.631	.012
Error	13681.328	78	175.402			
Corrected Total	21841.385	83				

[a] R Squared = .374 (Adjusted R Squared = .333)

Table C14. Post Hoc Multiple Comparisons - Matching to Sample Accuracy

Dependent Variable: Matching to Sample--Accuracy

	(I) Radiation Dosage Group	(J) Radiation Dosage Group	Mean Difference (I-J)	Std. Error	Sig.
Tukey HSD	**<1**	1-25	12.7041*	2.8563	**.000**
		26-140	30.8530*	3.5455	**.000**
	1-25	<1	-12.7041*	2.8563	**.000**
		26-140	18.1489*	3.3513	**.000**
	26-140	<1	-30.8530*	3.5455	**.000**
		1-25	-18.1489*	3.3513	**.000**
LSD	**<1**	1-25	12.7041*	2.8563	**.000**
		26-140	30.8530*	3.5455	**.000**
	1-25	<1	-12.7041*	2.8563	**.000**
		26-140	18.1489*	3.3513	**.000**
	26-140	<1	-30.8530*	3.5455	**.000**
		1-25	-18.1489*	3.3513	**.000**
Dunnett T3	**<1**	1-25	12.7041*	2.8563	**.000**
		26-140	30.8530*	3.5455	**.000**
	1-25	<1	-12.7041*	2.8563	**.000**
		26-140	18.1489*	3.3513	**.001**
	26-140	<1	-30.8530*	3.5455	**.000**
		1-25	-18.1489*	3.3513	**.001**

Based on observed means.

* The mean difference is significant at the .01 level.

Table C15. Post Hoc Multiple Comparisons - Matching to Sample Efficiency

Dependent Variable: Matching to Sample--Efficiency

	(I) Radiation Dosage Group	(J) Radiation Dosage Group	Mean Difference (I-J)	Std. Error	Sig.
Tukey HSD	**<1**	1-25	13.1599*	3.2805	**.000**
		26-140	22.9838*	4.0721	**.000**
	1-25	<1	-13.1599*	3.2805	.000
		26-140	9.8240	3.8491	.033
	26-140	<1	-22.9838*	4.0721	.000
		1-25	-9.8240	3.8491	.033
LSD	**<1**	1-25	13.1599*	3.2805	**.000**
		26-140	22.9838*	4.0721	**.000**
	1-25	<1	-13.1599*	3.2805	.000
		26-140	9.8240	3.8491	**.013**
	26-140	<1	-22.9838*	4.0721	.000
		1-25	-9.8240	3.8491	.013
Dunnett T3	**<1**	1-25	13.1599*	3.2805	**.003**
		26-140	22.9838*	4.0721	**.000**
	1-25	<1	-13.1599*	3.2805	.003
		26-140	9.8240	3.8491	**.013**
	26-140	<1	-22.9838*	4.0721	.000
		1-25	-9.8240	3.8491	.013

Based on observed means.

* The mean difference is significant at the .01 level.

Table C16. Spatial Processing Mean Scores by Age and Dosage Group

			SPD Accuracy		SPD Efficiency	
Age Group	Radiation Dosage Grp	N	Mean	Standard Deviation	Mean	Standard Deviation
14-41	<1	21	91 90	6 42	31 91	10 11
	1-25	12	89 17	5 97	29 45	9 38
	26-140	8	80 63	11 16	21 00	10 53
	Total	41	88 90	8 40	29 06	10 58
42-62	<1	7	92 14	4 88	26 85	7 80
	1-25	27	86 11	7 76	21 73	8 67
	26-140	9	80 56	12 61	10 01	4 68
	Total	43	85 93	9 15	20 11	9 52
Total	<1	28	91 96	5 98	30 65	9 71
	1-25	39	87 05	7 32	24 11	9 49
	26-140	17	80 59	11 58	15 18	9 56
	Total	84	87 38	8 87	24 48	10 96

Table C17. ANOVA Tests of Between-Groups Effects -- Spatial Processing Accuracy Independent Variables: Age Group, Radiation Dosage Group

Dependent Variable: Spatial Processing--Accuracy

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Corrected Model	1454.712[a]	5	290.942	4.477	.001	.223
AGE	15.237	1	15.237	.234	.630	.003
DOSE	1234.972	2	617.486	9.501	**.000**	.196
AGE * DOSE	44.343	2	22.171	.341	.712	.009
Error	5069.097	78	64.988			
Corrected Total	6523.810	83				

a. R Squared = .223 (Adjusted R Squared = .173)

Table C18. ANOVA Tests of Between-Groups Effects -- Spatial Processing Efficiency Independent Variables: Age Group, Radiation Dosage Group

Dependent Variable: Spatial Processing--Efficiency

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Corrected Model	3681.050[a]	5	736.210	9.137	.000	.369
AGE	1032.880	1	1032.880	12.819	**.001**	.141
DOSE	1908.584	2	954.292	11.844	**.000**	.233
AGE * DOSE	82.365	2	41.182	.511	.602	.013
Error	6284.661	78	80.573			
Corrected Total	9965.711	83				

a. R Squared = .369 (Adjusted R Squared = .329)

Table C19. Post Hoc Multiple Comparisons - Spatial Processing Accuracy

Dependent Variable: Spatial Processing--Accuracy

	(I) Radiation Dosage Group	(J) Radiation Dosage Group	Mean Difference (I-J)	Std. Error	Sig.
Tukey HSD	<1	1-25	4.9130	1.9968	.042
		26-140	11.3761*	2.4787	**.000**
	1-25	<1	-4.9130	1.9968	.042
		26-140	6.4630	2.3429	.020
	26-140	<1	-11.3761*	2.4787	.000
		1-25	-6.4630	2.3429	.020
LSD	<1	1-25	4.9130	1.9968	.016
		26-140	11.3761*	2.4787	**.000**
	1-25	<1	-4.9130	1.9968	.016
		26-140	6.4630*	2.3429	**.007**
	26-140	<1	-11.3761*	2.4787	.000
		1-25	-6.4630*	2.3429	.007
Dunnett T3	<1	1-25	4.9130	1.9968	**.011**
		26-140	11.3761*	2.4787	**.003**
	1-25	<1	-4.9130	1.9968	.011
		26-140	6.4630	2.3429	.126
	26-140	<1	-11.3761*	2.4787	.003
		1-25	-6.4630	2.3429	.126

Based on observed means.

* The mean difference is significant at the .01 level.

Table C20. Post Hoc Multiple Comparisons - Spatial Processing Efficiency

Dependent Variable: Spatial Processing--Efficiency

	(I) Radiation Dosage Group	(J) Radiation Dosage Group	Mean Difference (I-J)	Std. Error	Sig.
Tukey HSD	**<1**	1-25	6.5371	2.2234	**.012**
		26-140	15.4658*	2.7599	**.000**
	1-25	<1	-6.5371	2.2234	.012
		26-140	8.9287*	2.6087	**.003**
	26-140	<1	-15.4658*	2.7599	.000
		1-25	-8.9287*	2.6087	.003
LSD	**<1**	1-25	6.5371*	2.2234	**.004**
		26-140	15.4658*	2.7599	**.000**
	1-25	<1	-6.5371*	2.2234	.004
		26-140	8.9287*	2.6087	**.001**
	26-140	<1	-15.4658*	2.7599	.000
		1-25	-8.9287*	2.6087	.001
Dunnett T3	**<1**	1-25	6.5371	2.2234	.024
		26-140	15.4658*	2.7599	**.000**
	1-25	<1	-6.5371	2.2234	.024
		26-140	8.9287*	2.6087	**.009**
	26-140	<1	-15.4658*	2.7599	.000
		1-25	-8.9287*	2.6087	.009

Based on observed means.

*. The mean difference is significant at the .01 level.