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PERFORMANCE AND THE RELATION TO TESTS OF
BASIC FUNCTIONAL CAPACITIES.

The Ohio State University, Ph.D., 1974
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AN INVESTIGATION OF AGE-RELATED CHANGES IN
DRIVERS' VISUAL SEARCH PATTERNS AND DRIVING PERFORMANCE
AND THE RELATION TO TESTS OF BASIC FUNCTIONAL CAPACITIES

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By

Nick Joseph Rackoff, B.I.E., M.S.

* * * * *

The Ohio State University

1974

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CHAPTER I
INTRODUCTION AND REVIEW OF THE LITERATURE

Introduction

Over the past few years there has been an increasing interest in the aged driver's ability to drive an automobile in today's traffic system. This interest has been stimulated by a number of factors, including: informally observed decrements in aged driver's performance, older age of drivers ordered in to license exam stations to be reexamined, observed self-imposed driving restrictions by elderly drivers, and perhaps a general feeling that older people who are approaching or in retirement are just not as capable as they used to be when they were younger. Census statistics and accident statistics also contribute to this increased interest in studying the aged driver. Census figures show that a significant portion of the driving population is composed of aged drivers. Some 22% of the licensed drivers are 55 or older and some 9% are 65 or older. Furthermore, this percent is expected to increase in the future (Planek, 1972). Accident statistics, when adjusted for the driving exposure (older drivers drive fewer miles), show older drivers have a poorer accident record than middle-aged drivers. Thus, older drivers constitute a significant portion of the driving population and they do appear to have less ability to drive.

Questions of considerable practical importance (particularly to licensing officials) appear to be, "At what age should the aged driver

be singled out for specialized treatment?" "What abilities or characteristics should be tested?" And, "What treatments are appropriate?"

In terms of treatment, drivers' licenses can be totally revoked, licenses can be restricted; drivers can be given special training; some conditions can be corrected; and in some cases, more information of the condition of the driver may be adequate. The question of what age, however, is quite complicated. The research to date indicates that chronological age is a totally inadequate indicator of ability. Sensory, mental, and physical characteristics vary widely within groups of individuals of the same age. Some older drivers seem to be in as good condition as many young drivers. We are left then with the problem of determining a driver's functional driving age, that is, the state of the driver's performance, which at some critical level remedial action seems warranted.

Interestingly enough, the above concept carries a very strong assumption that aging, or functional aging, is a dynamic process which inevitably moves forward toward a lessened ability with the passage of time. This may not be so, though worse accident records and decrements in other abilities with age do seem to indicate that for people as a group, the trend is downward with age. However, when the task permits it, drivers can make changes in their pattern of behavior, and maintain high levels or adequate levels of task performance by compensating for deficiencies.

For elderly drivers evidence of compensation exists in their self-imposed restrictions of avoiding certain types of driving exposure

(e.g., night, freeways), reducing the amount of exposure, and by their often noted reduced speeds.

Aside from pointing to the higher accident rates of older drivers, further analysis of accident statistics indicates the type of involvement of older drivers. Older people have higher rates of involvement due to failure to yield right of way when changing lanes or passing, improper turning, ignoring stop signs and red lights, and improper starting. On the other hand, aged drivers are little involved in accidents related to excessive speed, fatigue, or alcohol intoxication (Planek, 1969, 1972; McFarland, 1964). It would appear that older drivers have their greatest difficulty when interacting with other traffic or signing, while they can maintain guidance control of their vehicle.

The above statements establish that aged drivers, as a group, do appear to have more difficulty in driving than younger drivers. Answers to why this should be so are offered from two major sources. For one, older people do show deficiencies in sensory-central-motor capabilities due to normal aging processes which may contribute to lessened driving ability. The other major source is the presence of a number of disablements due to diseases and injury which can contribute to lessened ability. With respect to medical conditions, Waller (1967) believes that drivers with epilepsy, cardiovascular disease, diabetes, and mental illness have a higher accident rate than those without these conditions. These results permit only general statements and more research on the mechanisms of the impairment to driving caused by the disease deserves more attention.

The main focus of this paper is on the former source, the effect on driving of the normal deterioration in sensory-central-motor capabilities. Numerous laboratory studies, a few accident statistics studies, and a few on-the-road studies shed some light on the decline in these functions (sensory-central-motor) and the relation to driving.

Dissertation Organization

The following section in this chapter is a review of the literature on age-related changes in psychomotor performance. The review is followed by a conceptualization of the basic elements comprising psychomotor performance. The conceptualization provides a theoretical foundation based upon the review of research in aging, for the experimental studies in this dissertation. This chapter concludes with a section on specific objectives and hypotheses under investigation. The remaining chapters report the methodology, results, and conclusions of the dissertation.

Literature Review

Introduction

The number of articles and books on aging in general is quite impressive. Naturally, much of the work relates to topics not of direct interest to the present paper, but of interest to those involved in the aged problem in general (i.e., care of the aged, housing, etc.). Even with this omission, there are still many reports which require some organization for discussion.

The basic approaches have been twofold: 1) to measure age-related changes in psychomotor performance, and 2) to study age-related changes in basic abilities (i.e., vision) which may account for changes in performance. Many researchers appear to have studied one basic ability and tried to establish the significance of changes in that ability to aged performance. To organize the discussion of these studies, it is useful to identify the basic performance phenomena studies, including:

1. Slowing of response
2. Peripheral Factors in Slowing
 - a. Peripheral Nerve Conduction
 - b. Vision Apparatus
 - c. Motor Apparatus
3. Central Factors
 - a. Reaction Time
 - b. Perception
 - c. Degree of choice (information processing rate)
 - d. Motor Control
 - e. Central Translation

- f. Short Term Memory
- g. Visual Search and use of Information
- 4. Task Conditions
 - a. Pacing
 - b. Divided Attention
 - c. Learning
- 5. Driver Performance and Age

Slowing

The most universally observed change in performance with age is a slowing of time to complete a psychomotor task. A typical result is illustrated by results of Suci, et al. (1960) in which the stimulus information was also varied (see Figure 1). Older people are slower and show more pronounced effects with the more complex situations. Surwillo (1968) emphasized, "The adverse effect of age on speed of response is a commonplace observation and is probably one of the least disputed propositions in psychology."

Much of the research on aging has centered on searching for a deficiency in a single elemental operation (e.g., peripheral nerve conduction, peripheral motor apparatus, sensory acuity, etc.) which once identified could explain most of the universally observed phenomena of slowing. Though no single operation has been found (many of the reasons for this were discussed in an earlier section of this paper), some trends in the relative importance of the various operations which have been demonstrated are discussed below.

Reaction time as a function of stimulus information and age. Young Ss, 12 males, median age 18.5 years; old Ss, 12 males, median age 63.0 years.

Figure 1.--Slowing and Age (from Suci, 1960)

Peripheral Factors in Slowing

Peripheral Nerve Conduction

In his review, Surwillo (1968), assessed the evidence for the effects of several peripheral factors in slowing. He concluded (and as it is generally agreed), although there is some age-related deficiency in each factor, the changes found were not a major contribution to the slowing of performance. Peripheral nerve conduction accounted for only 4% of the change in reactions and synaptics and neuromuscular delay accounted for only 2% of the slowing.

Vision

The efficiency of the sense organs, another peripheral factor, has also been shown to decrease with age. Among the more well known changes are:

1. uncorrected visual acuity declines with age (see Figure 2) (Connolly, 1967),
2. lateral visual field decreases with age (Burg, 1968),
3. ability to accomodate drops rapidly to age 50 where it almost ceases to accomodate (Weiss, 1959),
4. mean pupil diameter decreases with age (Weiss, 1959),
5. resistance to glare under levels of low illumination decreases with age (Marsh, 1960),
6. when the eye is fully dark adapted, the minimum light threshold rises with age (Birren, 1964),
7. though the rate of dark adaptation does not change with age, the light threshold is at any given time on the curve highly age related (Birren, 1964), (Weale, 1965) and
8. low contrast visual discrimination decreases with age (Forbes, 1973).

Acuity Level	Per Cent Distribution by Age							
	Total, 18-79 Years	18-24 Years	25-34 Years	35-44 Years	45-54 Years	55-64 Years	65-74 Years	75-79 Years
20/10 or Better	1.1	1.8	2.1	1.5	0.7	-	-	-
20/15	29.2	48.3	48.0	42.3	17.5	4.2	0.9	-
20/20	23.6	24.7	27.2	32.9	26.4	16.8	4.8	1.5
20/30	15.4	10.4	9.6	10.9	23.7	21.8	19.3	13.1
20/40	6.5	3.6	2.5	3.1	7.8	11.8	13.3	17.6
20/50	4.6	1.9	1.5	1.9	6.3	8.3	9.9	12.3
20/70	3.5	1.0	1.6	1.5	3.8	7.1	6.9	13.5
20/100	9.6	3.6	2.8	2.8	8.5	20.2	28.9	28.0
20/200	4.1	3.0	2.4	1.9	3.8	7.7	9.2	6.0
Less than 20/200	2.4	1.7	2.3	1.2	1.5	2.1	6.8	8.0

Figure 2.--Distribution of Acuity by Age (from Connolly, 1967)

Though decrements in visual capabilities are well known, of great concern is the contribution of these vision changes to changes in performance. With respect to the driving task, much of the suspected relationships have been developed entirely through logical arguments (as opposed to controlled experimentation), which seem particularly convincing for night driving (this will be discussed later in the paper in more detail). A statistical correlation approach was taken by Burg (1968) in which he found small but positive correlations of vision capabilities with driving record (i.e., accidents and violations, not driving control performance). In an experiment by Wallace (1956), subjects were shown only small portions of various figures (the experiment is described in more detail in the next section, "Perception"). Older subjects performed much poorer than younger subjects in identifying the pictures. When shown the entire picture, subjects were able to easily identify the pictures and all subjects used had no vision difficulties. The large differences in performance were not attributable to differences in visual sensory function, but the ability to utilize the information in the cues of partial pictures (i.e., perceptual abilities). More evidence is derived from an experiment by Weston (discussed in Welford 1958) who matched his younger and older subjects on standard visual acuity tests. Subjects were required to cancel the break in Landolt rings, but only those in a specified orientation and in a specified time limit. The performance of older subjects which was markedly worse than younger was attributed to factors other than visual acuity which does not take account of speed of performance.

A classic work on the relation between sensory acuteness and reaction time was undertaken by Koga and Morant (1923). They tested hundreds of subjects ranging in age from childhood to old age. The measure of hearing acuity was the highest audible pitch and the measure of visual acuity was the number of inches at which the unaided eye could read diamond type. Acuity in both senses declined with age, while reaction times reached a minimum in the 20's and rose about 10% in the 70's. The correlation between visual acuity and visual reaction time was .11 while the hearing reaction time correlated with hearing acuity at .09. The correlation between the two reaction times was much higher at .45. The association of the reaction times between the two senses was much greater than the association between sensory acuteness and reaction time. The authors interpreted this as evidence that reaction times are mainly a function of central effectiveness rather than sensory effectiveness.

Motor Apparatus

The evidence also seems clear that limits imposed by the motor apparatus are not likely to be a contributing factor (except in cases where extreme muscular exertion is required). A clear example is provided by the work of Szafran (1951 in Welford, 1959) in a simple test of reacting to lights. While overall time to respond to the lights increased with age, the actual time to move from the center position to the button did not change with age.

Conclusion

A. T. Welford (1969) sums up the research by stating:

"Experimental studies have made it clear that this (slowing) has little to do with the falling of sensory acuity, muscular power, or maximum speed of action which have been traditional scapegoats to account for slowness in older people. The loss of speed is mainly in the central mechanisms of the brain. . ."

The evidence for the contribution of the central mechanisms is discussed in the next sections. Before departing, we should draw some caution about the apparently relatively small importance of sensory capabilities. It is possible that some tasks may rely heavily on the sense organs and their importance to optimal performance in that task may be much greater than has been shown in these studies. Later in the paper this point will be explored relative to the driving task, particularly night driving.

Central Factors and Aging

Reaction Time

In the simplest of tasks, a subject is presented with a stimulus which the subject must respond to by pressing a button. The period between the appearance of the signal and the initiation of the responding movement is commonly referred to as the reaction time and is interpreted as a measure of the time taken by the central processes. As discussed earlier, the major components of this time are the perception of the stimulus, translation from perception to action, and shaping and initiation of the responding movements. As Welford (1959) shows, this time usually increases with age by about 10 or 20 percent.

Of course, the experiments by Koga and Morant (1923) which showed a higher correlation between reaction times of different senses than

the correlation of RT's and sensory acuity also provides evidence of the importance of central factors in determining speed of performance.

Perception with Age

As concluded above, the mere receptive capability of the peripheral sensory apparatus is not likely to be a major factor in task performance (except for some special tasks; e.g., night driving). However, in any psychomotor skill, the stimulus is received by the receptors and then sent to the brain where further processing must take place. At the simplest levels, detection, comparison, and recognition are involved; while at higher levels, the human must process the information contained in the stimuli not just the physical magnitude of the stimuli (e.g., pattern recognition) (Fitts, 1967).

As shown in the previous section, the ability of the visual system to resolve fine detail decreases with age especially if time constraints are imposed on the task. (This result is presented again merely to point out that often it is difficult to draw a line between strictly sensory function which typically only considers accuracy and brain function which incorporates accuracy and time.) Another of the simplest perception skills is simple detection of the presence or absence of a faint stimulus. Craik (1969) applied the concepts of signal detection theory to the analysis of this task. The technique enables determination of sensory efficiency and of caution-riskiness in the task. In one task, older subjects were more cautious, while in the other task no differences were found.

Welford (1958) discusses the results of discrimination experiments by others which show that older subjects require larger changes in

stimulus intensity to detect minimum perceptual changes in stimulus intensity. Older subjects also required longer times to discriminate between two lines of different lengths (reported in Welford, 1958). Using signal detection theory to analyze a visual inspection task experiment by Bebin and Shimmin (reported by Craik, 1969) older subjects were found to be poorer discriminators and more cautious. When re-trained, however, these older subjects were able to eliminate both effects. This last point is important in that it shows the potential influence of instruction and training on the performance of subjects.

The above experiments describe simple tasks that essentially take place at or near threshold. More realistic perceptual tasks are more complex and usually above threshold. In reviewing several experiments by others, Welford (1958) concluded that older people are slower than younger at discrimination tasks. Verille and Cameron (reported by Braun, 1959) found older subjects took longer to recognize or identify an incomplete picture of common objects. Crook (also reported by Braun, 1959) found little effect of age in the identification of imbedded figures with optimal viewing conditions. But as exposure time, luminance, and contrast were reduced, or visual noise increased, age difference became more pronounced. Other researchers have also found poorer performance in locating concealed figures (reported in Braun, 1959). The experiments by Wallace (1956 in Welford, 1958) are particularly revealing of the magnitude of decrement in perceptual ability with age. Wallace presented his subjects with a moving window slit of complete objects behind the screen. The slit size was varied and moved vertically at a constant speed across four types of figures;

1. geometrical figures,
2. complex block figures,
3. representational silhouettes, and
4. pictorial line drawings.

The results shown in Figure 3 reveal the greatest age decrement for the pictorial line drawings. Further experiments with the line drawings revealed that two factors were important in viewing the figures:

1. the amount of display seen at one time, and
2. the total viewing time with a series of experiments where the entire display was seen at one time with a tachistoscope.

Older subjects when allowed sufficient time could correctly identify pictures as well as younger subjects. However, older subjects needed to see the display some twenty times as long as younger subjects to do this (with tachistoscope).

The researchers have noted in the response patterns of their older subjects a tendency for rigidity of perception. The tendency of an older subject is to be greatly influenced by his previous response on the current. Guesses of the nature of the current picture tended to be in the same category as the previous picture identified. Botwinick (reported by Birren, 1964) found that older subjects persisted in their first impressions of an ambiguous figure and could not "see" the other figure. In conclusion, older subjects

1. require longer times to make perceptual judgments,
2. more information to make the same accuracy as younger,
3. if conditions of time and space permit, older subjects can be as accurate as younger subjects,
4. older subjects appear rigid in their maintenance of a perception and require more time to change to a new perception.

Figure 3.--Age Decrement in Perception (from Welford, 1958)

Degree of Choice

Hick's information theory approach was considered by Welford (1959) in his discussion of several experiments where some degree of choice was required by the subject. In one experiment (by Goldfarb), the complex reactions were longer than simple reactions for younger and older, but the effect was constant for both age groups. In another experiment by Crossman and Szafran (1956, also in Welford 1959) subjects sorted cards based on different degrees of discriminability and choice. In this case no differences with age were found in the no-choice condition, while age differences were constant for various degrees of choice and discrimination. Though older people took longer to respond in the more complex conditions, the differences could not be described as difference in the slope or intercept of Hick's formulation. Suci (1960) found that the age differences were greater, the greater the stimulus uncertainty, while Carpenter (1968) found just the opposite, that age differences were the greatest in the least complex condition. It must be concluded that the results on information processing capacity which reflects degree of choice, are not clear and depend very much on the task being studied.

Central Control of Movement

Welford (1958, 1959) discusses a series of experiments by others in which it was possible to separately measure reaction time and movement times. Szafran (1951 in Welford, 1959) required subjects to respond to a console of lights by moving from a center position to the indicated light. He found (see Figure 4) that actual movement time changed little with age while the reaction time accounted for most of the changes in performance.

REACTION TIMES AND MOVEMENT TIMES IN AN AIMING TASK
(In Seconds)

	AGE GROUP			
	Twenties	Thirties	Forties	Fifties
Time from appearance of signal to beginning of responding movement.....	0.86	0.99	1.29	1.37
Duration of responding movement.....	1.18	1.20	1.14	1.22

Figure 4.--Movement time and central reaction time (from Welford, 1959)

In an experiment by Leonard (1952, in Welford, 1959) upon presentation of one of five lights, subjects moved a stylus from a center disk to one of five disks below the corresponding stimulus light and quickly back again to the center disk which immediately lit the next stimulus. Movement time was not affected by age, but almost the entirety of the extra time was spent stationary on the five disks and center disk. In two more experiments by Singleton (1954, 1955 in Welford, 1959) similar to Leonard's, the time spent stationary rose greatly in the sixties while the actual movement times rose only moderately. Welford (1958) summarizes these experiments by stating "the main locus of slowing with age in sensori-motor performance lies not in the speed of movement but in the time taken by central processes initiating, shaping, and monitoring movement."

Singleton (1955 in Welford, 1959) conducted another experiment to determine the contribution to limiting speed of performance of the processes involved in controlling movement for both young and older subjects. In one task, the repetition movement was in a guided slot which required no aiming, while the other task required the subject to guide his repetitive movement to one inch disks across the same distance (18 inches). Both younger and older subjects took twice as long in the unguided task while the age changes were most pronounced in the unguided task but of less magnitude than the difference between tasks. Thus, the central processes which control movement and limit speed in older persons, similarly limit younger persons.

Another question of interest discussed by Welford is whether this slowing can be conceived as a lowering in the rate of information

transfer. The formulations by Hick which represents the information transfer when a degree of choice is afforded the subject is not appropriate. The central mechanisms which control movements are different and the formulation by Fitts can be used to quantify the relation between time and movement. *N. Welford (in Welford, 1958) required subjects to dot between two targets. As shown in Figure 5 the rate of information transfer was almost half for the aged subjects (sixties). Thus, it would seem reasonable to view the slowing with age as an actual decrease in capacity by the central mechanisms to control movements.

In a series of tracking experiments, Welford (1958) found little differences between young and old subjects in their performance at low speeds. At higher speeds, however, older subjects moved the pointer much less than younger, and the phase lag (degrees) was greater for older subjects. The performance of all subjects improved with a preview of the track, but even at the longest preview (3 sec.), the performance of the older subjects did not approach the performance of the younger subjects. The results of these experiments were interpreted by Welford as a lessening of capacity of older people to deal with data in a given amount of time.

The experiments on central control of movement may be summarized by stating that a) the slowness observed was due to a limitation by the central mechanisms which initiate, shape, and monitor movements, and b) this limitation can be viewed as a lowering of capacity of older subjects to transmit information into movement.

$$*T_{me} = K \left(\log \frac{2A}{W} \right)$$

T_{me} = time, A = amplitude of movement, W = target width, K = constant.

SPEED OF "DOTTING" BETWEEN TWO TARGETS AS A FUNCTION
OF TARGET SIZE AND DISTANCE
(In Seconds)

AGE GROUP	1-FOOT MOVEMENTS		2-FOOT MOVEMENTS	
	2-Inch Targets	1-Inch Targets	2-Inch Targets	1-Inch Targets
Mean Time per Movement, Including Time Spent on Target				
Twenties.....	0.293	0.370	0.401	0.491
Thirties.....	.355	.435	.443	.547
Forties.....	.455	.544	.568	.656
Sixties.....	0.558	0.661	0.716	0.798
Rate of Information Transfer in Bits per Second				
Twenties.....	12.2	12.4	11.4	11.4
Thirties.....	10.1	10.5	10.3	10.2
Forties.....	7.9	8.4	8.1	8.5
Sixties.....	6.4	6.9	6.4	7.0

Figure 5.--Information transmission in central capacity
to control movement (from Welford, 1959)

Central Translation

In a task, it is possible to introduce complications in the relation between the stimulus and response and require more translation of the stimulus information into a response. The more indirect or complex the relation, the greater the decrement in performance for aged subjects. For example, in one experiment, (Ruch, 1939 in Welford, 1959), older subjects performed very poorly on a pursuit-rotor task when using a mirror. Other tasks requiring mirror or image-reversals (discussed by Welford, 1959), showed similar reduction of aged performance when the additional translation was inserted in the task. Szafran (1953 in Welford, 1959) found older and younger subjects had similar accuracy when making "blind" hand movements. Young subjects improved their accuracy when given knowledge of their results, while older subjects could not make use of the information in translating the visual display of their error to corrections in kinesthetic movement. Kay (1955 in Welford, 1959) required subjects to respond to a panel of lights, a) with the response keys directly below the light, and b) with the response keys rotated 180° to the stimulus lights. Little differences were found in time to respond in condition a, but in condition b older subjects took almost twice as long to respond (accuracy was about the same). Again, we see that insertions of additional translations from stimulus to response greatly reduces performance of aged subjects.

Short Term Memory

Another central factor which has received much attention is the reduction of performance in short term memory with age. In the

simplest situation, subjects must correctly report a stimulus set of several (usually words, digits, or nonsense syllables). Talland (1968) reports that this memory span (no. of items correctly recalled) drops little with age. In this task, there is no interference from other task demands in the interval between the presentation of the stimuli and the recall. Where other activities must be carried on in this intervening interval, drops in performance with age are noted. In two experiments, (Kay, 1953 and Kircher in Welford, 1958) subjects were required to serially respond to one of twelve lights. To introduce a memory task, on some trials subjects were required to respond not to the light currently on, but to the one just previously presented. On other trials the responses had to be made to lights two-back, and three-back. Thus, subjects had to retain their response in memory while perceiving current signals. In this task (see Figure 6), older subjects were unable to perform the most extreme condition of three-back, and only performed at 38% of the level of the younger subject in the two track condition. In a tracking experiment by Griew (1958 in Welford, 1958) preview of the track was given, but the track was obscured for a fraction of a second directly before the pen. Subjects thus had to store information for this brief period before responding but also while maintaining this store had to respond to previous signals. In this test, older subjects performed much more poorly than younger. The results of the tracking experiment and the delayed response experiments show that short term memory is greatly affected by intervening activity.

TABLE 9.9. *Results of an experiment on serial short-term retention by
Kirchner. Percentage responses correct*

	Number of items back in the series subjects were required to work			
	0	1	2	3
<i>Younger subjects aged 18-25</i>				
Students	100	99	93	73
Naval ratings	100	99	81	51
<i>Older subjects aged 64-78</i>	99	80	33	Not attempted
Older as proportion of younger	0.99	0.81	0.38	

Figure 6.--Short term memory and age (from Welford, 1958)

Visual Search and Use of Information

A few studies have examined the ability of older subjects to search for visual information and the ability to utilize information contained in visual cues. In one experiment by Talland (1966), subjects had to search a rapidly changing patterned display of digits on 9 Nixie tubes for the appearance of the digit 4. At the fast presentation rate (about two displays per second with one in five containing the digit four) errors of omission increased with age but incorrect responses showed no changes. Talland attributed the affect to a slowing down of the scanning and decision processes which match the incoming message with a mental model.

In an experiment by Rabbitt (1965), subjects had to sort packs of cards into two piles. One pile consisted of cards containing the letter "A" and another pile of cards containing the letter "B". The letters "A" and "B" were termed "relevant" cues while other letters contained on the cards were termed "irrelevant" letters. The number of irrelevant letters was varied from none to eight. The other experimental condition consisted of sorting cards into eight piles, corresponding to the eight "relevant" letters. In both conditions older subjects took longer to discriminate between the relevant and irrelevant letters. Though no record of eye movements were taken, Rabbitt suggests that older people process fewer letters in a glance than younger subjects and thus require more time to perform the task.

More evidence on the differential use of vision by older subjects was noted by Szafran (1955). In his experiments and those by Leonard (in Szafran, 1955) in the lab and in a factory setting, older

subjects tended to give direct visual attention to motor actions while younger subjects carried on the task without looking. Szafran also related similar observations by two other researchers (Sheldon, Miles). In an experiment by Szafran (discussed in Welford, 1958) subjects were required to throw small metal hoops onto a target eight feet away. In one condition subjects threw directly into the target boxes; in another subjects could see the target area but had to throw over a screen; in the third condition a screen obscured direct view of targets, but the target area could be seen in a mirror. Though the performance (time and accuracy) did not differ in the first two conditions, some age trends were noted in the third condition. More striking, however, Szafran noticed a difference in the use of vision employed by the subjects. In the first two conditions, all subjects tended to look away from the target to pick up the next hoop to throw. However, with the screen obscuring the target, younger subjects tended to keep their eyes focused on the mirror image of the target and pick up the hoops by the "feel". On the other hand, older subjects continued to look at the hoops to pick them up. Szafran (in Welford, 1958) confirmed this result in another experiment; namely, that older subjects tended to foveally monitor their motor action.

Not only do older subjects utilize their vision more than younger subjects, but they also apparently make less efficient use of information contained in stimuli. In one experiment (Rabbitt, in Rabbitt, 1968) subjects were required to respond to sets of stimuli containing either letters or digits. Prior to presentation of each stimuli, a warning foresignal was presented which gave the subject advance

information about (1) the time the stimuli would appear, and (2) the type (letter or digit) of stimuli that would appear. The advance information in the foresignal improved the response times of the younger subjects, but did not improve the response times of the older subjects. Furthermore, on a few trials where false information was deliberately introduced, the reaction times of the older were more significantly slowed than younger. Rabbitt concluded that older people were not helped by information from foresignals and in fact were hindered more by false information. In discussing other evidence of inefficient use of information, Rabbitt concluded older subjects ignore redundancy or misleading attributes of complex stimuli, and that older subjects fail to abstract economical rules for classifying patterns.

In conclusion, some evidence exists which indicates: older people are less efficient at visual search, they pay more foveal attention to their actions, and they are less efficient at utilizing relevant information, and less able to ignore irrelevant information contained in cues.

Conclusion

In conclusion, there is convincing evidence that a number of central factors outlined above account for much of the slowing of behavior that has been observed in elderly persons. The next section discusses several task conditions which are particularly relevant to older persons. This is followed by a discussion of the effects of decrements in the basic mechanisms on driving performance.

Task Conditions and Performance

Many studies have centered on studying not so much the contribution of the basic mechanisms to performance, but the effect of various task conditions on performance. Among these are task pacing, dividing attention between two simultaneous tasks, and learning across trials, which appear to differentially affect older and younger subjects. The research addressing these various conditions are discussed briefly below.

Pacing

Clearly, the most significant (from a practical point of view) task condition with respect to aging is task pacing. In an experiment by Brown (in Welford, 1958), subjects were required to plot a point on graph paper to match a point indicated on another graph display. In the unpaced condition, a red light shone once the position had been plotted correctly and the next point was then indicated. In the paced condition, a new point was indicated every eight seconds whether the plot had been successfully completed or not (eight seconds was comfortable for younger subjects). The number of successful plots was the measure of performance for the ten minute task. Both younger and older performed more poorly in the paced condition, and performance in both conditions dropped with age. However, the drop in performance in the unpaced condition occurred in the sixties, while the drop in performance in the paced condition occurred in subjects in their fifties. Davies (1968), Canestrari (1968), and Talland (1966) concluded that older subjects perform worse under paced than unpaced conditions

compared to younger subjects. However, they noted that the poorer performance was marked by an increase in errors of omission (no response) rather than overt errors. Further, they attributed this effect to a failure to mobilize responses rather than a failure to perceive the stimuli.

Dividing Attention Between Two Simultaneous Tasks

There is evidence from several experiments that the ability of older subjects to perform two tasks simultaneously declines markedly when one of the tasks is a memory task. In Kay's experiment (1953 in Welford, 1958) described earlier, older subjects performed much more poorly than younger when required to perceive the current stimulus while responding to an earlier stimulus in memory. Broadbent (1962) required subjects to cross out digits in a moving display where the digit to be crossed changed from time to time. An auditory distraction task was also presented where different letters of the alphabet were repeated in series of ten and one letter in the series was repeated twice. The subject had to report the repeated letter while performing the main task of crossing the digits. Young subjects did well on both tests but the performance of older subjects was maintained on only one of the two tasks while the performance on the other dropped drastically. Thus, interference between the tasks was noted for older subjects when both tasks involved some form of memory. Speakman (in Welford, 1958) found similar results with subjects counting cards as the numbers while listening for spoken numbers.

Beyond these experiments, to this reviewer's knowledge, there are no experiments, save one, which address the question of dual tasks

and age effects. In this experiment by Griew (1958), subjects were required to respond to a buzzer every few seconds (secondary task) while simultaneously performing a tracking task (main task). The baseline for these tests were scores achieved on either test performed individually. When the tests were performed simultaneously, the reaction time increased and the tracking performance decreased. However, there was no differential affect for the age groups. This study differs from the previous in that no memory function was required by either task. We must conclude, then that dual tasks may not impose undue difficulties if no memory functions are required of the tasks, but that marked differences are to be expected if memory is required.

Learning

There is a legitimate concern that many of the age-related differences in performance observed in many lab tests are not due to age differences in the ability to perform the task, but instead to differences in ability to learn the novel task. Several experiments reported by Jerome (1959; i.e., Botwinck, Korchin and Basowitz) on card sorting and paired-associates tests show that on the first trial there is a large difference in performances. Aside from this, young and old subjects continue to improve performance at similar rates, but the initial difference in performance remains across trials. Of course, if learning were defined as the number of trials or time to achieve a specified criterion of performance, then older subjects would appear worse (McFarland, 1959). Other studies also show that (discussed by McFarland, 1959, and Jerome, 1959) the same deficiencies that

limit performance also may limit the ability to learn. If the learning situation is rapidly paced or requires much of short-term memory, then learning is expected to be impaired also.

Of course, real life tasks or jobs present the opportunity for more than a few trials. In fact, even thousands of "trials" to learn the task may be available, and there is some question as to what effect this much practice would have on the final level of performance attained.

Welford (1958) points out that with additional training, the difference between young and old grew smaller (in Brown's experiment), though it was not certain whether this difference would altogether be eliminated. Furthermore, should task performance not appear to decrease with age, the elderly person may be compensating by changing the method in which the task is performed. This compensation may or may not have consequences to the performance of additional subsidiary tasks (e.g., novel or emergency situation).

Controlled Experimental Studies of Driver Performance and Age

As mentioned earlier, accident statistics indicate that older drivers perform poorly and do in fact have a greater accident rate and different type of accident involvement than younger drivers. Further indications of age-related changes in driving behavior have been examined in controlled experiments on actual roadways, where driver performance was measured and quantified, and specifically related to age of the subjects.

scores were derived from tests in a sign tester simulator, a driving simulator, laboratory test of judgment of impending traffic hazards in partial pictures, and an instrumented vehicle on the road. (The researchers also obtained background information on driving habits, vision test scores, and accident and violation records.) In the sign tester, measures of motor coordination were derived from the number of "cars run over" and measures of judgment capability were derived from whether the subjects were "in the proper lane" as indicated by the signs and instructions. Results from the sign tester showed that older drivers could perform as well as younger drivers but to do this, the speed of the simulator had to be slower. This task demonstrated the effects of too rapid pacing on older individuals and is in agreement with laboratory work on pacing which shows that older subjects perceive the stimulus properly but cannot respond due to rapid pacing.

In the laboratory test of impending hazards, subjects removed pieces of a large photograph (at an experimenter controlled constant rate) until a correct judgment of the hazard was indicated. The authors interpreted the data as yielding separate measures of manual dexterity (ability to remove pieces) and judgment scores (time to correctly assess the hazard). Results showed that the differences (time to completion) between groups were attributable to manual dexterity rather than judgmental ability.

The six-mile test routes with the instrumented vehicle were driven by seven older subjects (age 53 to 71) and twelve younger (average age 31). Measures were: 1) length of travel, 2) time,

3) average speed, 4) speed change rate, 5) brake application rate, 6) brake duration, 7) steering reversal rate, 8) lane changes, 9) heart rate (some trials), and 10) GSR (sometimes). The following differences were statistically significant: older persons drove about two mph slower where the mean was about 20 mph; older persons made fewer accelerator pedal reversals; and older persons brake more often and depress the brake longer. It should be noted, however, that these differences were small and that in all the other measures no differences were found, indicating remarkably similar performance between age groups.

A correlational analysis was conducted between the sign tester scores and the vision test scores of static and dynamic acuity. Of course, the trend of decreasing acuity with age was found, but only one correlation between manual dexterity performance and visual acuity was noted while no other scores correlated. Also, the effect of age on this relation was not partialled out which (based on the high inter-correlations between these scores) probably would have reduced the correlation. However, the finding of lack of correspondence between visual acuity and performance is consistent with the laboratory research discussed earlier in the paper.

In the final test battery, 29 older subjects and 21 younger "drove" the car in the UCLA simulator. The film is a condensed version of many traffic events and all subjects "drove" identical routes. Most of the measures available in the instrumented vehicle are obtained in the simulator. The results, largely in agreement with the on-the-road tests, included: an analysis of ten selected events showed that

older drivers reacted more often but did not differ significantly in proportion of failures to events, and drove slower during the events; statistics for the entire length of the "drive" showed that older drivers drove slower, had higher accelerator reversal rates, pressed the brake more often, and had lower steering reversal rates. Most of the differences were of a larger magnitude than those found in the on-the-road tests, and the comparability of the simulation data to the road tests is not known.

The authors (Case, et al.) summarized the results of their study as evidence that older drivers do experience decrements in motor capabilities, but maintain judgmental capabilities. They also concluded that older drivers reduce the pace of the driving task by driving at slower speeds.

One study by Tsongos and Schwab (1970) examined the gap acceptance behavior of driver at intersections as influenced by different vehicular lighting systems. Ten young drivers in their early twenties and ten aged drivers, average age of 57, performed in the controlled studies. The subject driver was instructed to pull out and cross the intersection at the "last possible moment" with a test car coming from the through-road. The main objective of the study was to determine the effect of headlamp glare from a third vehicle across the intersection facing the subject driver. Both age groups had a similar pattern of gap-acceptance values for the various headlamp beam systems. The aged group, however, had slightly longer gap acceptance values than the young, and the aged group had a greater intersubject variability than the young. Discomfort glare was rated

as slightly less bothersome for the aged than the young. Disability glare was not measured, though it may have likely explained the differences. Differences in performance may also be attributed to different risk acceptance behavior and to capacity to perform the task.

The most recent study of driving behavior of aged drivers was conducted by Roush (1971) in which gross visual search behavior was recorded while subjects drove an instrumented vehicle. Ten college age students (5 male, 5 female; age 20 to 23) and 5 elderly subjects (age 51 to 67) drove in several driving tasks including open-road driving, freeway ramps, lane changing, passing, and through an intersection. Eye locations were classed into several codes including glances to the speedometer, scenery ahead, rear view mirrors, side windows, and blinks. The main measures of performance were glance frequencies, while some analyses were conducted on glance durations. The results showed that college males and older males were most alike, while college females differed from either of these in many measures. Older subjects tended to have slightly less percentage of glances straight ahead and slightly more to the mirrors. During the lane change maneuver, older subjects tended to have shorter glance durations to the scenery ahead, and to start using mirrors later than younger subjects. In most of the analyses, however, age differences were not significant and individual differences tended to be very large compared to group differences. The lack of greater differences between groups may have been masked by the small sample size. Also percent glance frequency is a very gross measure and may not reflect differences in visual search behavior that may be found in more refined recording

and analysis techniques. Furthermore, of the five older subjects only three were 59 or older, the other two being 51 and 54. The past research discussed earlier indicates that much of the age-related changes in various tests are not exhibited in the 50's, but in the 60's. The author did not discuss the individual performances of the older subjects to assess the differences between the two younger (50's) and older (60's) drivers within the aged group.

In conclusion, these road studies provide evidence that there are some measurable differences in performances between age groups in control behavior and gross search behavior. Many of the differences have been slight, but these findings indicate possibilities for future research. The object of future research must not only be investigation with more refined measures and the changes that occur with age, but an exploration of the possible causes associated with changes that are found. This is particularly important if remedial corrective or selective actions are to be most effective.

Conceptualization of Psychomotor Performance

The review of the literature inspired a conceptualization of the basic functional component comprising psychomotor performance, as shown in Figure 7. The figure illustrates that these basic mechanisms operate somewhat serially in a chain.

Where there is spatial uncertainty as to where the stimulus information will occur, the person must search and scan the environment or display. When the stimulus information cannot be acted upon immediately, it must be stored for a short time in short term memory. This view of

Figure 7.--Conceptualization of the basic functional mechanisms comprising psychomotor performance.

psychomotor task performance suggests that if all the mechanisms are operating at their maximum efficiency, task performance will be maximum. Should one or more of the mechanisms be operating at less than maximum efficiency, the overall task performance may suffer.

Many researchers have observed and studied changes in overall task performance of younger and older persons. In an effort to understand the locus of these changes, researchers have designed special tasks to measure the efficiency of the basic mechanisms and to interpret the possible relation of changes in these tasks to changes in overall task performance.

It is important to take note of several theoretical problems of the research approaches taken with specific lab tests and consequent errors in generalizing interpretation to all types of tasks. For one, not all tasks require maximum efficiency of the five basic components for maximum overall task performance. If a non-critical mechanism is found to deteriorate with age, but task performance does not, we could conclude this mechanism is not essential to psychomotor performance. This generalization to all types of psychomotor performance is not justified, for in other tasks, this mechanism may be critical. Should a critical mechanism show decrements which relate to task performance decrement, we might conclude that all psychomotor tasks would likewise suffer. This too may be misleading, since another task may not require maximum efficiency of this mechanism. Finally, drops in overall task performance may result from drops in efficiency of all the mechanisms in the chain.

These notes of caution or interpretation of research studies seem necessary, for it appears that many researchers have set out to identify that one mechanism, which once identified, would explain all age-related changes in performance. In fact, age-related changes in the various mechanisms have been found, some more pronounced than others in various tasks. The finding that a unique deficiency in a single mechanism as the major factor in all psychomotor performance has not been forthcoming. The tests studies have different requirements of the efficiency of the basic mechanisms. In terms of extending research results to other psychomotor tasks, the requirements of these new tasks from the mechanisms must be considered before overall performance decrement can be explained.

The conceptualization, though simple, seems to be very useful in organizing and interpreting most of the past research on aging and performance. This conceptualization then was viewed as a reasonable theoretical foundation for the current studies of driving performance and age. That is, performance on the road can be measured and tested for differences with age, and these differences can be examined for relation to tests of the basic functional mechanisms.

Relation of Driving Performance and the Basic Mechanisms

To date little experimentation has been done relating to the age-related changes in driving performance, though some statistical analysis of driving record (e.g., violations and accidents) and age have been accomplished. Several researchers have sought to relate changes in the basic mechanisms to changes in driving behavior through

the method of logical reasoning (e.g., "this particular ability is known to decline with age and it ought to affect driving behavior in the following way. . ."). Though this method is far from rigorous (and sometimes highly speculative), it does suggest areas where controlled experimentation research would be potentially beneficial. It, therefore, seems worthwhile to consider some of the more significant points made by others (particularly, McFarland, 1954, 1959, 1964; Marsh, 1960; Allen, 1967; Richards, 1967; Connolly, 1967; Birren, 1964; Welford, 1958, 1959; and Planek, 1969, 1972) and by this researcher's analysis of the past research on the changes in the basic mechanisms as well as the research in pacing, divided attention, and use of vision.

Vision

It is generally agreed that vision is the most important, and certainly necessary, sense in driving. A number of visual functions are known to decrease with age and the potential effect in driving performance has been discussed by McFarland, Allen, Richards, and Marsh. In view of the laboratory research which indicates that changes in visual function explain but little of the changes in psychomotor performance, it seems unlikely that a direct relationship will be found between visual efficiency and driving performance. Except for the small statistical correlations found by Burg (1968), there appears to be little disagreement on this point with respect to day driving.

The situation for night driving might be much different. Since much of what must be seen at night is at or near threshold values, the known decrements in visual efficiency may affect driving performance.

Furthermore, many older drivers consider night driving difficult and often limit their night driving. Thus, we might expect some relationship between visual efficiency and night driving performance.

Perceptual Capabilities

Much of the laboratory research indicates that there are large age-related changes in perceptual capabilities and that these changes do seem to account for some changes in psychomotor performance. In driving, the older driver may take longer to take in the relevant information and, therefore, longer to respond to events; this may be particularly relevant in novel or emergency situations.

Central Control of Movement

The laboratory research indicates that older people take much longer to initiate and monitor movements. In driving, responses to novel or emergency situations may take longer. Lateral and longitudinal control of the vehicle require frequent corrections through motor actions, thus, we might expect these actions to take longer to initiate, to execute, and perhaps be less precise.

Central Translation

The laboratory research indicates that the more complex the relation between the stimulus and response, the longer the time to respond. Older people seem particularly handicapped in translating visual information into kineasthetic movements. In driving, maintaining lateral control especially around curves may be difficult if this central factor is deficient.

Short Term Memory

Laboratory studies indicate that this ability is greatly influenced if other activities must simultaneously be performed. In driving once a portion of the scene has been scanned, the data must be stored for a short time while other portions of the scene are being scanned. This later scanning and also continuous control of the vehicle may erase the information that was being stored. The driver may either unnecessarily rescan the area, or perhaps forget the relevance of the information and respond inappropriately.

Pacing

Under conditions of fast pacing older people often do not respond. In driving, fast pacing may be viewed as driving at too great a speed or following another vehicle at too close a headway. The often noted slower speeds of older drivers may be an indication that the normal road speeds for some drivers induce too fast a pace on some older drivers.

Dividing Attention among Simultaneous Tasks

The literature is clear that trying to perform two simultaneous tasks is difficult for older people, when one of the tasks requires use of short term memory. Beyond this the evidence is not clear. In driving, maintaining guidance control may be considered one task, while looking for and responding to signs, signals, and other traffic may be considered the other task. The accident statistics indicate that older drivers do have difficulty in these situations.

Use of Vision and Information

The laboratory research indicates that older persons pay more direct visual attention to motor actions. In driving we may expect more time to be spent perhaps by older people actually monitoring their frequent control actions with the steering, gas, and brake, and perhaps more direct monitoring of operation of other controls (radio, lights, shift lever, etc.). All of these will take the driver's attention from the road ahead.

The lab research also indicates that older people are inefficient at visual search and unable to ignore irrelevant information. This may manifest itself in driving as more active search patterns, but perhaps longer time to detect important information.

In conclusion, it does seem reasonable that changes often noted in the laboratory in the efficiency of the basic mechanisms may be related to changes in driver performance.

Objectives

The previous research and the arguments presented suggest that there are likely to be age-related changes in driving performance and that these changes are likely to be related to changes in basic functional mechanisms. The general purpose of the present study is to quantitatively measure and describe these age-related changes in actual on-the-road driving tasks and to relate these to changes in the basic functional mechanisms as measured in laboratory tests.

Unlike many previous researchers who have concentrated on a deficit in a single basic functional mechanism, the current research

examines each basic mechanism (or at least some index of efficiency in the mechanisms) and the relationship between deficits in one or several mechanisms and driving performance. It must be kept in mind that different road tasks may make different demands on the basic mechanisms. It, therefore, was expected that the relationship between driving task performance and deficiencies in basic mechanisms may vary from task to task. In recognition of this possibility, several driving tasks, covering a wide range of driving circumstances were included in the driving tasks. Since the past research indicated little promise to the relations between the two mechanisms of vision apparatus and motor apparatus, these were not tested. The remaining five functional mechanisms all involve the central capacities of visual search, perception, central translation (information processing), short term memory, and motor control.

Like much of the past research, the current dissertation will be especially tuned to the possibility that a test of a single basic mechanism (or a simple relationship) will account for much of the changes in performance across many driving tasks. Though this may be a reasonable finding to expect since all tasks are driving tasks, the subtle differences between the tasks may not provide such a simple result. Nevertheless, the experiments are hopefully designed to uncover the nature of the relationships, however uniform or varied they may be.

As pointed out, the relation between driving performance may be so complex as to elude the research or the differences between subjects may, in fact, obscure the relation. In any case, the primary

consequent of deficiencies in some or all of the basic mechanisms has been slowing. This basic phenomenon itself is of such importance that its relation to driving performance also deserves attention. Thus, another objective of the research project is to relate changes in driving performance to changes in the basic phenomenon of slowing.

Another purpose of the dissertation is to develop a methodology for studying age-related changes in driving performance and relating these to changes in the basic mechanisms, and to identify areas of potential value for future research and the aged driver.

To limit the size of the experiment it is necessary to define two age groups, young (20's) and aged (60's). The presumption in choosing these is that the young group so defined is near some maximal level of performance, while the older group is experiencing some decline in function, but are still actively driving.

The general objectives outlined above can be restated in more specific terms:

1. Measure and identify age-related changes in drivers' basic functional mechanisms including
 - a) perceptual capabilities,
 - b) choice reaction capability--information processing rate,
 - c) central control of movements,
 - d) short term memory; and
 - e) visual search and scan ability
2. Measure and identify age-related changes in the basic phenomenon of slowing as measured by a serial choice reaction test
3. Measure and identify age-related changes in driver visual search patterns, visual occlusion behavior, velocity and headway behavior, and velocity and time estimation as reflected by a cross-sectional study of extreme age groups*

*Age groups: Young - 20's Aged - 60's

4. Establish the relationship between (1), (2), and (3) above;
5. Develop a methodology for quantifying the relation between age-related change in driving performance and basic mechanisms
6. Identify relationships (4) above of potential value for future research on the aged driver;
7. Describe the performance capabilities for two age groups--
 young - maximal performance
 aged - declining performance

Hypotheses

Below are some hypotheses and some of the more significant relationships expected.

1. In general, performance on the laboratory tests will be reduced with age.
2. It is hypothesized that older drivers will require more visual capacity when voluntarily occluding their vision while driving.
3. The literature indicates that: older persons require longer times to perceive information; they are inefficient at visual search; and they are unable to ignore irrelevant information. In driving, these effects may be manifested as increased look times and more spatially active search and scan patterns, larger percent time in view.
4. It is expected that the aged drivers will drive more slowly than the young in the various tasks and when car following will elect longer headways.
5. It is hypothesized that aged drivers will be less accurate in their estimates of speed and time.
6. It is expected that the greatest age group differences will be found in the lab tests where a premium is placed on speed. It is

also expected that the visual occlusion task, which load drivers to their limit, will also exhibit large age differences. On the other road tests, differences between the age groups will be less pronounced since task loading is not as large and does not push drivers to their limit. Where differences are noted on the road it is expected that laboratory scores of the basic mechanisms will be significantly correlated with the road measures.

CHAPTER II

METHODOLOGY

Overview of Research Approach

The general plan of the research approach is depicted in Figure 8. A group of young subjects and a group of aged subjects performed a battery of laboratory tasks and a battery of road tasks. The laboratory tasks were designed to provide measures of performance of the basic functional mechanisms of psychomotor performance (e.g., perception, short-term memory). The road tasks included tests in which drivers voluntarily occluded their vision. Drivers' eye movements as well as velocity and headway response were recorded (day and night); drivers estimated velocities and estimated time intervals (day and night). Measures of performance for the lab tests (e.g., time, accuracy, and capacity) and the road tests (e.g., fixation times and locations, speed, accuracy of velocity estimates, etc.) were developed. Performance scores for the lab tests and road tests were compared for age group differences. Finally, relationships between lab test scores and road performance scores were analyzed for the young group, for the aged group, and for both groups combined.

All ten young and thirteen aged subjects performed the lab tests, but not all subjects completed all road tests, day and night. The exact sample sizes for the various tasks are discussed in succeeding sections.

Figure 8.--General plan of the research approach

Subjects

Ten young subjects, ages 21 to 29, and thirteen aged subjects, ages 60 to 70, participated in this project. The young subjects ranged in years of driving experience from 5 to 13 years while the aged had 46 to 60 years driving experience. As reported on a questionnaire, young subjects averaged 13,000 miles last year while aged subjects averaged 14,000 miles.

Subject participation was voluntary and subjects were paid for their time at the rate of \$3.00/hour for the younger and \$5.00/hour for the aged. Subjects were solicited from several sources including: advertisements in the university newspaper, posted notices, advertisement in a local newspaper, personal acquaintances, and acquaintances of subjects. An application questionnaire was administered to subjects which was concerned with age, occupational status (current and past), and driving history and habits. The responses are summarized in Appendix B. In addition to the questions on the application form which inquired about current driving frequency and exposure, the gross ability of subjects to drive was determined by requesting subjects to drive to the research offices.

All subjects were given a physical examination by physicians of the College of Medicine which included a history, tests of heart, lungs, eyes, ears, reflexes, blood, urine, and an EKG record. Persons were excluded from driving with current or past signs of coronary disease, cerebral vascular disease, endocrine disease, high blood pressure, or lung problem. It is recognized that while these physical restrictions do yield a sample of aged persons somewhat

healthier than the entire population of aged persons, the restrictions were deemed necessary to comply with safe testing procedures for human subjects. Several of the aged subjects who did not pass the physical and who did not drive the instrumented vehicle on the road, did complete the laboratory tests of basic skills. This fact reduces the bias of the distribution of scores in the lab tests. Conversely, though the true bias effect on driving performance of the physical exam selection is not known, it is likely that the aged subject sample will perform better than the population; thus differences between the subject age groups in this study are likely to be conservative.

All subjects were given vision tests either by the College of Optometry or by trained personnel with the Titmus Vision Tester. Results of the vision exams are summarized in Appendix C. The younger subjects' far acuity ranged from 20/13 to 20/35 and the median was 20/17. The aged subjects' far acuity (uncorrected if subject drives without glasses, or corrected if he drives with glasses) ranged from 20/13 to 20/40 and the median was 20/20.

Prior to the road testing subjects were required to read, understand, and sign a consent form describing the research tests, risks, and precautions (see Appendix D).

Discussion--Subject Sample Bias

Both the present author and anyone interested in reading this research is most likely to generalize the results of the study to the driving population. In doing so, some attention should be given to the possible biases the subject samples may have on the generality of the age differences noted. Of course, both age groups have unknown biases

such as motivation effects associated with volunteer subjects, and not much can be said about this. The young subjects used in university research typically are college students. Undergraduates generally have had only a couple years of driving experience and do not tend to drive often, both of which could bias the performance of the young toward poorer skills. However, the subjects in this study were all in their twenties, usually graduate students with six or more years of driving experience, current daily driving, and a significant yearly mileage average of over 13,000 miles. Six or more years seems certainly sufficient to attain high levels of psychomotor skill in driving, and current driving levels of the young were normal of the population. Thus, it would appear that as far as representing a maximal level of skill performance this young group of subjects is not significantly biased.

The aged group were not by any means a random sample, since all drivers had to pass a strict physical. Even with all the pretest screening, half the persons solicited did not pass the physical. Thus, the driving subjects almost certainly possess a better health status than the population of 60-70 year old drivers. If health can be expected to have a bias, then it most likely is in the direction of better performance for the subject sample than the population. Furthermore, the subject sample verbally reported current driving levels as high as the young group, an interest in driving, freeway driving was no problem, and night driving no problem either. All these factors are likely to bias, if a bias is present, the subjects tested toward better performance than the population of 60-70 year olds. Finally, the 60-70 range does not include all "aged" drivers

and, if anything, 60 to 70 year olds are likely to perform better than older drivers as a group. In conclusion, the direction of bias for the aged subject group, if present, is most likely toward better performance of the subject group than the population of aged. The differences, if noted, are likely much larger for the 60-70 population and even larger for older drivers.

Laboratory Tests of Basic Skills

Five of the laboratory tests are designed to provide a quantitative measure of five of the basic functional component skills as shown in the conceptualization of psychomotor skills in Figure I-1. A sixth test was designed to provide a quantitative measure of slowing. The resulting lab tests are outlined in Figure 9. A brief description of each of these tests and the data available is given below, while a more detailed description of the tests can be found in Appendix A. Test score developments are the topic of Chapter III.

Description of Laboratory Tests

Motor Test (Test 1)

This test, used by N. Welford (in Welford, 1958) quantifies the central capacity to control motor actions. Subjects tap a stylus between two one-inch targets separated either 12" or 24". Subjects are required to move as quickly as possible but try to keep the taps within the target. There are eight trials lasting 0.30 minutes each. Data consists of time per move and the accuracy or the actual width of the target area containing the subjects' taps.

Task	Basic Functional Component Skill	Data
1. Motor Test	Motor Control	Time, Accuracy, Capacity in Bits/sec.
2. Embedded Figures Test	Perception	Time
3. Choice Reaction Time Test	Central Translation (information processing rate)	Time, Processing Rate in Bits/sec.
4. Visual Search Test	Visual Search and Scan	Time, Accuracy
5. Serial Choice Reaction with Memory Test	Short Term Memory	Time, Accuracy, Response Rate
6. Serial Choice Reaction Test	Slowing (composite of basic skills)	Time, Accuracy

Figure 9.--Summary Descriptions of Laboratory Tests

Embedded Figures Test (Test 2)

This test measures the ability of subjects to quickly locate a simple geometrical figure in a larger complex geometrical figure (perceptually disembedded). Subjects are shown the simple figure for a few seconds, then they must locate it (as verified by their tracing) within the complex form. There are 12 problems and the data consists of the time to locate the simple form.

Choice Reaction Time Test (Test 3)

A program on a PDP8 minicomputer controlled this experiment by presenting a digit on the teletype and timing the subjects' response to press the teletype key. Subjects were required to hit the teletype key containing the same digit as the stimulus. There were three levels of uncertainty presented:

<u>Level</u>	<u>Stimulus Set</u>
1 bit	5,6
2 bit	3,4,5,6,
3 bit	1,2,3,4,5,6,7,8

Each level was presented in a block of sixteen trials, the first six being practice, the last ten considered data. The data consists of response times. Information processing rate can be computed as the inverse of the slope of the regression line [time = f (bit level 1,2,3)] .

Visual Search Test (Test 4)

The subject is presented a slide containing a row of 25 circles. All but one, two, three, or four have a line bisecting them. The subject scans the row of circles (approximately 25° of visual angle across the row) and determines the number of open circles and responds.

The first twelve slides are practice for the last set of twelve slices. Response times and accuracy are the data.

Serial Choice Reaction Test (Test 6) and Serial Choice Reaction with Memory Test (Test 5)

This test is controlled by a PDP8 minicomputer which presents stimuli on the teletype, times responses, scores accuracy, and summarizes the trials. The stimulus (digits) appears in a window on the teletype and the subject responds by hitting the teletype key (with same digit). As soon as the response key is hit the next stimulus is advanced to the window. Uncertainty level was held constant at 3 bits (digits 1 through 8). A trial consists of a series of 30 responses, and subjects were given three trials. The data consists of the mean response time, standard deviation of the response times, and percent correct responses. The test as described thus far yields a reliable estimate of response (i.e., there are 30 responses) time for the slowing phenomenon. For the short-term memory test, the test was identical, except that rather than respond to the stimulus currently in the window, the subject must respond to the stimulus that appeared two places earlier. Thus, subjects must retain two previous stimuli in memory while perceiving the current stimulus and executing a response.

Procedure and Sequence of Lab Tests

The lab tests took a total of about 2 hours and all subjects performed the tests in the same order:

<u>Order</u>	<u>Task</u>
1	Motor Test
2	Embedded Figures
3	Choice Reaction Time

4	Serial Choice Reaction
5	Serial Choice Reaction with Memory
6	Visual Search

Road Tasks

The drivers performed a series of nine driving tasks, both day and night, as outlined in Figure 10. Brief descriptions of the tests are given below (see Appendix E for task instructions).

Description of Road Tests

Freeway, Light Traffic (Task A)

Drivers drove in their normal manner in the right lane. Eye movements and control movements were recorded.

Freeway, Car Following (Task B)

Subjects drove the vehicle behind another experimental vehicle traveling 50 mph. Subjects were required to follow closely at a distance as if they were about to pass and try to maintain that distance. Eye movements and control movements were recorded.

Freeway, Occlusion, Open Road (Task C)

Subjects drove the car at their normal speeds in the right lane. No traffic was within several hundred feet. Subjects were required to voluntarily close their eyes as much as possible while still maintaining control of the car. The safety man alerted the subject to cease the task when gross deviations in lane position occurred (infrequently) or when traffic was nearing. A recording of a direct view of the eye was obtained as well as control movements.

Task	Description	Measures
A	Freeway, Light Traffic	Eye Movements ^a , Velocity
B	Freeway, Car Following	Eye Movements, Velocity, and Car Spacing
C	Freeway, Occlusion - Open Road	Occlusion ^b , Velocity
D	Freeway, Occlusion - Car Following	Occlusion, Velocity, and Car Spacing
E	Freeway Sign Reading	Velocity
G	Velocity Estimation (with time est.)	Velocity Estimates and Velocity
H'	Time Estimation	Times Estimates and Time

a. Foveal eye fixation patterns as recorded by the television eye-movement recording system.

b. Times eyes open and closed.

Figure 10.--Summary descriptions of road tests

Freeway Occlusion, Car-Following (Task D)

The voluntary occlusion instructions were the same as Task C, but in this case the subject also drove behind the experimental lead car trying to maintain a constant headway as in Task B.

Freeway Sign Reading (Task E)

Subjects were asked to take a particular exit some two miles prior to the exit. Subjects drove past several signs while control movements were recorded.

Velocity Estimation and Time Estimation (Tasks G and H)

In these tasks, the speedometer was unavailable to the subject. With the use of an auxillary speedometer the experimenter directed the subject to a target speed which the subject was required to hold for a few seconds. While holding the speed, the subject was also required to estimate a short time interval, (the start and stop points of the interval were verbally signalled by the experimenter). A total of eight pairs of estimates was given. Speeds ranged from 35 mph to 80 mph. Times ranged from 7 to 14 seconds.

Road Test Procedures and Sequence of Tests

Subjects drove the vehicle from the research offices to the starting point at the freeway, about a 15 minute drive. One group of subjects was then set up with the eye-movement recording system and drove the next 1/2 hour in the appropriate tasks. The system was removed and the remainder of the tasks performed. With the other group the eye-movement system was worn in the latter portion of the

run. The drive lasted a total of about 2 hours which included times for stops, equipment calibrations, and the reading of instructions. All road tests in the day were completed in a single session, and likewise all road tests at night were completed in a single session.

Many of the subject runs on the road, day and night, were conducted as part of another research project investigating the effects of low levels of carbon monoxide on driving. The study of the aged driver (the project which this paper reports) was conducted in part as a subinvestigation of the carbon monoxide study. The data for the control condition of the co study (i.e., no carbon monoxide), was the data used for the subinvestigation of the aged driver (both young and aged subjects).

Sequence of Road Tasks

Subjects performed all road tasks in a single run (day or night), however the tests were not performed in the same sequence by all subjects. The young subjects who drove in the day followed Sequence I and all other groups of subjects followed Sequence II:

	<u>Day</u>	<u>Night</u>
Young	Sequence I	Sequence II
Aged	Sequence II	Sequence II

The sequences of tasks were:

<u>Task Sequence Number</u>	<u>Sequence I</u>	<u>Sequence II</u>
1	Vel. & Time Est.	Freeway, Light Traffic
2	Occlusion, Open Road	Sign Reading

3	Occlusion, Car Following	Car Following
4	Freeway, Light Traffic	Occlusion, Open Road
5	Car Following	Occlusion, Car Following
6	Sign Reading	Vel. & Time Est.

The sequence effect is not deemed significant since all subjects drove the car for 15 minutes prior to testing to familiarize themselves with the car, and the total test drive time was less than two hours thus minimizing fatigue effects.

Recording Instrumentation, Data Reduction and Data Processing

Subjects drove a 1970 Chrysler Newport (full size car, all power controls) which was instrumented to record driver eye movements, vehicle control movements, and vehicle response.

FM Recorder

A seven channel FM recorder provided records on magnetic tapes of steering movements, lateral acceleration, distance, and velocity. The tapes were played back in the lab on the FM recorder and the recorded voltages fed into an analog-to-digital converter. The A/D sampling was controlled by a PDP8 minicomputer which also provided summary statistics of the various measures. These statistics were punched onto computer cards for statistical analysis by computer programs on an IBM 370/165 computer.

Eye-Movement Recorder

A detailed description of the recording system can be found in Bhise and Rockwell (1972). Briefly, the television system provides a continuous recording on video tape with the following data:

1. a $40^{\circ} \times 50^{\circ}$ view of the driving scene which moves with the driver's head,
2. a 1° spot of light superimposed on the driving scene corresponding to the driver's fixation point, accurate to 1° of the true fixation point,
3. a digital clock accurate to $1/50$ of a second,
4. a digital distance meter accurate to 5 feet, and
5. a direct view of the eye for gross eye movements.

The video tape is played back in the lab using slow motion and stop action to identify changes in the fixation point. The fixation point is defined on a grid with 1° units and the origin at the focus of expansion of the driving scene (i.e., that point in the driving scene at which the lane lines of a straight road appear to intersect ahead of the driver). Times are recorded from the digital clock, and distance from the digital distance meter. The object of fixation, such as road signs, scenery ahead, etc. is also coded by the reducer.

Gross eye movements out of view to the speedometer, rear mirror or side mirror, or blinks are also coded. Data is punched onto cards and processed with a special eye-movement program on the 370/165 which provides many summary statistics. Statistical analyses of the measures are also conducted with computer programs. Measures include fixation times, travel distances, spatial distributions of fixations, etc.

Experimental Design

The layout of the experiments is not simply represented by a single matrix since not all subjects performed all tasks in all conditions. The experiments are best represented with reference to particular tasks and measures. For the sake of organization into meaningful and manageable study units, the results of this project can be organized into several distinct study groups:

1. Studies of basic functional component mechanisms in psychomotor performance.
2. Studies of drivers' voluntary visual occlusion behavior.
3. Studies of drivers' visual search patterns.
4. Studies of drivers' velocity and headway behavior.
5. Studies of drivers' psychophysics.
6. Studies of individual driver differences.

Experimental Tasks, Factors and Subject Sample Sizes for Study Groups

The layout of the lab studies is shown in top of Figure 11. Subjects completed all tasks in a single session.

The layout of the studies in visual occlusion is shown in top middle of Figure 11. The daytime condition was completed in one session and likewise the nighttime was completed in a single session. To control for the effect of order in which the sessions were driven,

Figure 11.--Layout of Tasks, Factors and Subject Sample Sizes

some subjects drove at night first, while others drove in the day first*. A similar statement concerning the effect of road session order can be made for all road test study groups.

Figure 11 also shows the layout of the experiment for the studies of drivers' visual search behavior.

The bottom of Figure 11 shows the layout for the studies of drivers' velocity behavior. Figure 11 (top middle) is also the layout for studies of drivers' psychophysical abilities (velocity and time estimation) in open road driving.

*The order in which road sessions were traversed by specific subjects for the tasks in each study group is discussed in the results section associated with each study group. The question of the effect of the number of sessions on performance is further complicated by the participation of many subjects in CO runs, the data for which is not the subject of analysis of this project. A complete discussion of the session order and coding of the session order for analyses in this project is given in Appendix H.

CHAPTER III

STUDIES OF BASIC FUNCTIONAL COMPONENT MECHANISMS IN PSYCHOMOTOR PERFORMANCE

Overview of the Laboratory Studies of Basic Skills

The objectives of the laboratory studies are threefold:

1. To investigate differences in performance between the age groups;
2. To establish a baseline of performance scores for the two subject groups against which subsets of the subject groups (in subsequent analyses) can be compared; and
3. To investigate relationships among the scores for the five basic functional mechanisms and among those scores and the sixth test of slowing.

The Experimental Layout and Subjects

Ten young and thirteen aged subjects performed the six laboratory tests.

Data Analyses Strategy for the Lab Tests

Figure 12 summarizes the analysis strategy for the laboratory tests. The raw data for each test was examined for changes across trials primarily due to initial learning effects. In some tests, task conditions were varied from one trial to the next. The effects of these conditions on performance in the specific trials were also examined. Since the main purpose of the tests was to provide a measure of capacity, those trials where learning was still evident, or where task conditions

Figure 12.--Summary of analysis strategy for laboratory tests

were causing spurious changes in performance, were eliminated from further analysis. Comparisons were also made for similar performance across trials for both age groups. Measures based on valid trials were computed and analyzed for differences in central tendency by age group, intrasubject variability by age group, and intersubject variability by age group. Individual measures or combination of measures were used to develop a single score which could be used as an index of efficiency or capacity for the basic mechanism being measured by that test. The distribution of these test scores were analyzed for differences between the age groups. Finally, relationship among the test scores were examined primarily through correlation matrices.

Embedded Figures Test

This test is a standardized test for which the scoring technique is completely specified as the mean time of all 12 trials. It was deemed desirable to use the standard score in the interest of maintaining comparability of this project's results with previous studies using this test. As such, the analysis of the raw data from the individual trials is not strictly required for the development of a test score. However, an examination of the raw data was undertaken for an analysis of possible systematic differences between the age group which might affect interpretations of the score and perhaps create the need for alternate scoring methods.

Analysis of the raw data

The main data for this test are the mean times to locate the simple figure contained within the larger complex figure. Figure 13 shows a plot of the average times across subjects to locate the figure for each trial. Since a major concern was differential performance by age group, the means are shown for each age group separately. Also, since the 12 problems presented were given in the same order to all subjects, each trial number may also be conceived of as a unique problem. The figure shows, of course, that on all trials the aged performed more slowly than the younger. Within an age group there appears to be differences among the mean times for the trials. Particularly, trials 6 and 12 are the slowest for both age groups and trials 9 and 10 are among the fastest. An analysis of variance (see Appendix L for ANOVA table) for the young group showed trials to be significant ($\alpha = .05$) and likewise an ANOVA showed trials significant for the aged group. However, Spearman Rank Correlation for the mean times by trials between the age groups was statistically significant ($r = .74, \alpha = .01$), thus indicating that the age groups did behave similarly on the individual trials. That is, the fastest trials for the young group were also the fastest for the aged, and likewise the slowest trials were similar for both age groups. Another concern was the effect of learning, or improvement of performance across trials, and a possible difference in this learning between age groups. Unfortunately, there is no data provided with the standard equipment reporting on this aspect from previous research. Since the difficulty of the problems is not homogeneous, item difficulty is

Figure 13.--Average time to locate figure by trial-embedded figure test

completely confounded with trial number. Faster times on later trials may be due to easier problems and/or more experience with the test. The only consolation we have is the high Spearman Rank Correlation between age groups which shows both age groups to vary performance together on the trials.

Analysis of measures of test performance

A summary of the measures examined is given in Table 1.

Number of looks at simple figure

Although the standard scoring does not take into consideration the number of looks at the simple figure¹ this set of data are of some interest when examining differences in performance. Young subjects rarely looked at the simple figure again after the first showing, while aged subjects did. Young subjects averaged 1.9 looks per test set (or set of 12 problems) and aged 11.0 looks per test set. One might surmise that the longer times of the aged to perform the problems were due to difficulty remembering the simple figure rather than the (intended) perceptual skill of disembedding the simple figure from within the complex figure. While this may be a portion of the problem it does not seem likely for a number of reasons, including: 1) subjects were free to request additional looks whenever they felt it necessary, 2) the time spent reexamining the simple figure is not counted in the time to solve the problem, and 3) subjects often

¹Recall subjects could look as often as they wished at the simple figure for a look consisting of ten seconds with the complex figure out of view.

Table 1
Embedded Figures Test Measures

Measure	Age Group	Value	Age Group Difference	Statistical Test
Number of looks at simple figure per test set of 12 items	Young	1.9	Yes	Mann-Whitney $\alpha < .002$
	Aged	11.0		
Standard Deviation of trial times (12 trials)	Young	0.274	Yes	Mann-Whitney $\alpha < .002$
	Aged	0.955		
Standard Deviation of subject's mean times (seconds)	Young	0.0913	Yes	F test $\alpha < .002$
	Aged	0.5595		
Mean Time to locate figure (seconds)	Young	0.215	Yes	Median Test $\alpha < .005$
	Aged	1.497		

voluntarily commented after reexamining the simple figure that they really had remembered it, but they were having difficulty finding it in the complex figure.

Intra subject variability

Subject performance varied from trial to trial and is measured by the standard deviation of trial times for each subject. Aged subjects averaged almost four times the standard deviation of young. This indicates aged are more variable in their trial to trial performance.

Inter subject variability

A classic finding in many studies of performance (e.g., see Marsh, 1960) shows the differences among aged subjects to be much greater than the differences among young. The standard deviation of mean times for subjects within an age group is a measure of intersubject variability. Young subjects' scores had a standard deviation of .0913 while the aged group had a standard deviation of .5595. Thus, the spread of scores for the aged was much greater than the young.

Central tendency in time to locate target

The principal measure, of course, is the mean time to locate the target. Table 1 shows that aged subjects took almost a minute and a half while younger took only about .2 minutes.

Score Development-Embedded Figures Test

The score development for this test is straightforward since the method is specified as the mean time to locate the simple figure.

The greater the mean time to locate the figure, the poorer the capacity (perceptual skill) to disembed a simple figure in a complex background. Table 1 shows that the aged subjects' mean time, or score was much higher than the young. This large difference between age groups is consistent with the findings of Eisner (1972) and Schwartz and Karp (1967). Furthermore, as discussed earlier, the intersubject variability among the aged group was greater than the young. For the sake of easy comparison between the age groups and to provide a standard for comparison, Figure 21 (later in the chapter) shows the score mean for each age group bounded by one standard deviation for each group, for this test as well as the other tests.

Visual Search Test

The first twelve trials were given as practice to familiarize the subjects with the test and responding methods. The data for the last twelve trials are examined here.

Analysis of the raw data

The main raw data for this test is the time to visually search the large display of twenty-five circles for the target circles, and to press the response key. Figure 14 is a plot of the average times across subjects, each age group plotted separately. Note that the aged group responds more slowly than the younger for all trials. The mean times for the first few trials appear to be somewhat faster for both age groups. Using a Mann-Whitney U test, and comparing the first four means to the last eight, each age group separately, there

Figure 14.--Average times across subjects to locate targets-visual search test

is a statistically significant difference (young $p = .08$; aged $p = .01$). That is, there is some learning or improvement in performance when comparing the first four means to the last eight.

Analyses of variance on the differences among the last eight trials (see Appendix L for ANOVA table) for the young and for the aged showed no significant differences among trials ($\alpha = .10$). The number of targets on each trial were varied but the same for all subjects on each trial (i.e., trial 5 was always the "one" target condition). For these last eight trials, the number of targets (1 to 4) condition appeared twice at each level and the order of appearance was randomly balanced. Since the ANOVA above indicated no differences among trials, it can also be concluded that the number of targets was not a significant factor in search time. Thus, both age groups performed in a similar manner on this test with respect to the last eight trials.

Analysis of Measures of Test Performance

A summary of the measures examined, based on the last eight trials, is shown in Table 2.

Table 2

Visual Search Test Measures				
Measure	Age Group	Value	Age Group Difference	Statistical Test
Response Error Rate per test (8 responses)	Young	0.30	N.S.	Mann-Whitney U test N.S. $\alpha = .05$
	Aged	0.54		
Standard Deviation of trial times (8 trials)	Young	.2905	N.S.	Mann-Whitney U test N.S. $\alpha = .05$
	Aged	.3211		
Standard Deviation of subject's mean times	Young	0.566	N.S.	F test $\alpha = .10$
	Aged	0.845		
Mean Responses Time	Young	2.277	Yes	Median test $\alpha < .005$
	Aged	3.184		

Response Errors

Response errors were very rare; most subjects did not make errors. The average error rate for the test set per subject was .30 for young and .54 for aged, not statistically significant. (The response error rate was about 4 percent and 6 percent respectively for young and aged.)

Intrasubject variability in response times

Subjects' performance varied from trial to trial and is measured by the standard deviation of trial times for each subject. Intra-subject variability was not statistically significant between age groups.

Intersubject variability

Although the standard deviation of mean times across subjects is greater for the aged group than the young group, the difference is not statistically significant. The trend of this measure is in agreement with past studies on intersubject variability.

Central tendency in response times

The principal measure is the response time. Table 2 shows that aged subjects averaged almost 50 percent longer time to respond.

Score Development-Search Test

Since the error rate was low (i.e., about 5%) the rare errors can be ignored and it can be assumed that the primary measure is response time. One concern is the potential components of this response time. Part of the time is due to the time to visually search

and scan the slide of 25 circles and part is due to choice reaction time. As will be shown in a later section the choice reaction test response times for the case with two bits uncertainty (in digit stimuli) was approximately .55 seconds for younger and .72 seconds for aged. Thus it can be said that most of the search test response time is due to the time to search. Furthermore, only a small portion of the difference between age groups in the search test response time is due to a difference in reaction times, but most of the difference can be attributed to a difference in search times. Because of this component of reaction time in the total search test response time, the search test response time cannot be directly interpreted as a visual search rate. However, if the assumption is made that the reaction time contribution is relatively small and relatively similar for both age groups, the search test time can be considered as approximately inversely proportional to the search rate. (Since the stimuli in the choice reaction test were not similar to the stimuli in the search test, it was not deemed desirable to correct the search test response times with response time from the dissimilar choice reaction time test.)

For the reasons above, the mean search test response time was taken as a score of visual search capacity which is inversely related to search capacity. The average and standard deviations of these scores are shown in Figure 21.

Choice Reaction Time Test

The method usually employed in interpreting the results of this task is to compute the information processing rate in bits per second. This rate is the inverse of the slope of the regression line, where response time is the dependent and bit level is the independent variable. Recall that three bit levels were given, where each bit level was a block of 16 trials, the first six being practice. The order of bit conditions for all subjects was 2-bit, 1-bit, 3-bit.

Analysis of the raw data

Incorrect responses on the individual trials were very rare, averaging only about 1.0% for both age groups. Thus, an analysis of incorrect responses is not warranted, and response time for incorrect responses were not included in the analysis of mean response time.

There are two ways in which the responses may manifest changes in performance due to learning: 1) a change in performance across the ten trials within a "bit" condition or 2) across the three bit conditions. The mean times across the ten trials for each bit condition and for each age group are shown in Figure 15. As in the previous lab tests, the aged appear to respond more slowly than the young on all trials. The results of the ANOVA's and contrasts between early and late trials revealed no learning across trials for either age group.

An examination of Figure 15 shows that age group behaved similarly on the ten trials for the one-bit and two-bit conditions, but differences are apparent in the three-bit conditions. To test the

Figure 15.--Average times by trials for each bit condition - choice reactions test

possibility that age groups behaved differently on the ten trials in the three-bit case, a Spearman Rank correlation was computed between the mean trial times between age groups. The value of $r_s = .88$ was significant ($p = .01$) and thus indicated both age groups behaved in a similar manner across trials. Thus, the results of these analyses indicate that neither age group exhibited consistent learning across trials, and that where differences due to trials were found, age groups behaved in a similar manner.

The second concern was learning across bit conditions. An examination of the possible effect of learning can be effected by analyzing the mean times across blocks. Figure 16 shows the mean times for each bit condition for each group. The first thing to note is that the mean times for each age group form nearly a straight line with increasing time as bit level increases (as the theory for this task suggests it should). Since no learning across trials within each block was evident in the previous analyses, it seems likely that learning across blocks would be quite small, if present at all. Following this argument further would suggest that the 1-bit and 3-bit conditions which were performed last would be least affected by learning, while the 2-bit condition, if affected by learning, would be somewhat greater than expected by the theory. As shown in Figure 16 95 percent confidence intervals (on the mean) about the mean time for the 2-bit condition for both age groups would appear to easily include any line one might construct among the points. Thus, there appears to be no evidence to suggest significant learning across bit conditions for either age group.

Figure 16.--Mean response time for each age group by bit condition

Analysis of measures of test performance

A summary of the measures examined is given in Table 3.

Choice Reaction Times

As shown in Table 3 the mean reaction times for the aged were higher than the young by about 20 percent, a result consistent with previous research (e.g., Welford, 1959).

Intrasubject variability in response times

Intrasubject variability across trials and within a bit-condition tended to be greater for the aged, however, this trend was not statistically significant for the 1-bit and 3-bit condition.

Intersubject variability in mean response times

As seen in Table 3 the variability in response times among the aged subjects was much greater than the variability in response times of the younger.

Score Development-Choice Reaction Time Test

Information processing rate per Hick's Law is the measure usually associated with this test. As Figure 16 illustrates, the data appear to be well represented by a straight line. The rate, of course, is the inverse of the slope of that line. For each subject, a linear regression line was fit to his thirty responses and the inverse of the slope constant computed. The results of these regressions are shown for the individual subjects in Appendix J. Table 3 shows the mean and standard deviation of subject scores for the young and aged, and

Table 3
Choice Reaction Time Test Measures

Measure	Age Group	Value	Sign	Age Group Difference and Statistical Test
Mean Reaction Time	Young	.462 sec	yes	$\alpha < .002$
1-bit (10 trials)	Aged	.570 sec		Mann-Whitney U test
Mean Reaction Time	Young	.553 sec	yes	$\alpha < .002$
2-bit (10 trials)	Aged	.725 sec		Mann-Whitney U test
Mean Reaction Time	Young	.653 sec	yes	$\alpha < .002$
3-bit (10 trials)	Aged	.818 sec		Mann-Whitney U test
Std. Dev. of trial time	Young	.0504 sec	N.S.	N.S. $\alpha = .10$
1-bit (10 trials)	Aged	.0946 sec		Mann-Whitney U test
Std. Dev. of trial time	Young	.0631 sec	yes	$\alpha < .05$
2-bit (10 trials)	Aged	.1419 sec		Mann-Whitney U test
Std. Dev. of trial time	Young	.0951 sec	N.S.	N.S. $\alpha = .10$
3-bit (10 trials)	Aged	.1744 sec		Mann-Whitney U test
Std. Dev. of subject	Young	.0274 sec	yes	$\alpha < .02$
Mean times 1-bit	Aged	.1145 sec		F test
Std. Dev. of subject	Young	.0381 sec	yes	$\alpha < .02$
Mean times 2-bit	Aged	.1362 sec		F test
Std. Dev. of subject	Young	.0457 sec	yes	$\alpha < .02$
Mean times 3-bit	Aged	.1762 sec		F test
Information Pro- cessing	Young	11.13 bit/sec	N.S.	$\alpha = 0.10$
Rate Mean	Aged	9.39 bit/sec		Median Test
Information Pro- cessing Std. Dev.	Young	3.45 bit/sec	N.S.	$\alpha = .2$
Subject Rates	Aged	3.56 bit/sec		F test

Figure 21 shows a plot of the age group scores. Note that there is no difference between age groups in the intersubject variability, nor is the difference in the mean information processing rate significant, though the trend is toward higher rates for the young. Thus, it must be concluded that while there are great differences in response time, these differences are not reflective of difference in the capacity to process information. A word of caution on the results and interpretation of this test is in order. First, the mean values for the rates and response times are within the ranges cited by Fitts & Posner (1967) for choice reaction tests. However, they also point out that a great range of values is found, depending on numerous task factors. As they point out, Hick's Law seems to be very powerful in explaining changes in response times across levels of uncertainty for a specific given task. It was also pointed out in Chapter I in the review of the literature on choice reaction time and aging, that results were quite mixed with respect to age differences and information processing rate. Thus, the rates found in this study should only be interpreted with respect to relative changes among subjects and between age groups for this test.

Motor test

Subjects dotted back and forth between two targets of size one inch in diameter for eight trials, the first four being practice. The last four trials consisted of two trials where the targets were displaced by 12 inches and two trials where the targets were displaced 24 inches. The trials were given in the following order - 12, 24, 12, 24.

Analysis of the raw data

The raw data for the four trials are shown in Table 4. Four ANOVAS were run, one for each group and each measure (see Appendix L for tables). Most of the analyses indicated a significant effect due to trials. Two sources can give rise to the trial effect, 1) a change in performance due to learning, and 2) differences due to the two target amplitude conditions. The second of these can be explained by Fitt's Law for motor movement, which predicts the time per move for the 24-inch amplitude targets should be greater than the 12-inch amplitude targets (assuming target width is the same for both conditions as it was for this test). A comparison (using Scheffe's method) of the mean times on trials 2 and 4 (24") trials to trials 1 and 3 (12" trials) for both the young and aged group show a significant difference in agreement with Fitt's Law. An examination of possible learning across trials can be effected by comparing trials 1 and 2 to trials 3 and 4. For both measures and both age groups, there was no statistical significance (Scheffe's method, $\alpha = .05$). Thus, both age groups appeared to behave in a similar manner with respect to learning on both measures and the effect of target displacement amplitude on the mean time.

Although the target width was the same for all subjects and all trials (one inch), subjects did vary the actual target area used (i.e. some subjects kept all taps within a small region inside the target, others had many taps around the target as well as inside). The actual target size used by each subject was measured and the averages are shown also in Table 4. No statistical differences were noted

Table 4
Motor Test Trial Times and Accuracy

Mean Time (sec)				
	<u>Trial 1 (12")</u>	<u>Trial 2 (24")</u>	<u>Trial 3 (12")</u>	<u>Trial 4 (24")</u>
Young	.354	.448	.346	.443
Aged	.531	.665	.530	.659

Mean Actual Accuracy (inches of target width)				
	<u>Trial 1 (12")</u>	<u>Trial 2 (24")</u>	<u>Trial 3 (12")</u>	<u>Trial 4 (24")</u>
Young	1.53	1.35	1.49	1.52
Aged	0.81	0.70	0.88	0.67

among any trials for the young. However, the aged did behave differently on the 12" amplitude condition compared to the 24" condition (Scheffe's Method, $p = .05$). Furthermore, a comparison of average actual accuracy, between the young and aged, revealed the aged to use a much smaller actual target area than the young (Mann-Whitney U test, $p \leq .002$). The difference between age groups is of importance in the development of a score and will be considered in a following section on score computation.

Analysis of Measures of Test Performance

A summary of the measures analyzed is given in Table 5.

Average cycle times and average actual accuracy

The average times to move from one target to the other are shown in Table 5, as well as the average actual accuracies attained by both age groups. The aged subjects were slower than the young, but they were also more accurate in the actual target width used.

Intrasubject variability

Subjects performed each target amplitude condition (12", 24") twice. The absolute difference between two trials, where amplitude was the same, for one subject is a crude index of his variability. A measure of intrasubject variability then is the average of these absolute differences for the two amplitude conditions. Table 5 shows the age group means of this average for the time and accuracy measures. Aged subjects were much more variable in their performance times across trials, but they were less variable, or more consistent, in the actual target areas used.

Table 5
Motor Test Measures

Measure	Age Group	Value	Age Difference	Statistical Test
Average cycle time 2 trials, 12"	Young	.350 sec	Yes	Mann-Whitney $\alpha < .002$
	Aged	.530 sec		
Average cycle time 2 trials, 24"	Young	.446 sec	Yes	Mann-Whitney $\alpha < .002$
	Aged	.662 sec		
Average accuracy (2 trials, 12")	Young	1.52 in.	Yes	Mann-Whitney $\alpha < .002$
	Aged	.84 in.		
Average accuracy (2 trials, 24")	Young	1.45 in.	Yes	Mann-Whitney $\alpha < .002$
	Aged	.68 in.		
Average difference in trial times $\frac{(\text{Tr1}-\text{Tr3})+(\text{Tr2}-\text{Tr4})}{2}$	Young	.0491 sec	Yes	Mann-Whitney $\alpha < .002$
	Aged	.1206 sec		
Average difference in trial accuracy $\frac{(\text{Tr1}-\text{Tr3})+(\text{Tr2}-\text{Tr4})}{2}$	Young	.5618 sec	Yes	Mann-Whitney $\alpha < .05$
	Aged	.2573 sec		
Std. Dev. of subject mean times (12")	Young	.0528 sec	Yes	F - test $\alpha < .10$
	Aged	.0934 sec		
Std. Dev. of subject mean times (24")	Young	.0564 sec	Yes	F - test $\alpha < .10$
	Aged	.1154 sec		
Std. Dev. of subject mean accuracy (12")	Young	.5237 in.	Yes	F - test $\alpha < .10$
	Aged	.2766 in.		
Std. Dev. of subject mean accuracy (24")	Young	.4377 in.	Yes	F - test $\alpha < .10$
	Aged	.2354 in.		
Motor test score, capacity in bits/sec	Young	11.65 bit/sec	Yes	Median test $\alpha < .02$
	Aged	9.51 bit/sec		
Std. Dev. of Motor test score	Young	1.08 bit/sec	N.S.	$\alpha = .10$ F - test
	Aged	1.26 bit/sec		

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Intersubject variability

The intersubject variation in mean times is greater for the young age group (both 12" and 24" target amplitudes). However, the aged group had a lower intersubject variation with respect to actual target width used.

Score Development-Motor Test

The general form for Fitt's Law for motor movement is given by:

$$t = a + b \lg_2 \left(\frac{2A}{W} \right)$$

where

t = movement time between targets

a = constant

b = slope

A = amplitude between target centers (i.e., 12" or 24")

W = target width

The inverse of the slope is taken as the measure of capacity in bits per second. The term, $\lg_2 \left(\frac{2A}{W} \right)$ is referred to as the index of difficulty. For this test, the target width was predetermined to be one inch. Thus, each subject performed the motor test at two levels (assuming the same target accuracy) of index of difficulty. However, as noted earlier, young subjects averaged a larger target area (about 15 inches) than the aged group (about 0.8 inches). Appendix K shows the computations using the actual width provided better fits to the data. The details of the computation of the motor capacity scores, based upon the preceding formula are also shown in Appendix K.

The means and standard deviations of the motor test scores are given in Table 5 and are plotted on Figure 21. The score, or motor capacity is greater for the younger than the aged. Though the inter-subject variability within the aged group tends to be somewhat larger than the young, the difference is not statistically significant. The mean score for the young group is very close to scores reported by Welford (1959) for a group of subjects also in the twenties (about 12 bits/sec). Welford's scores for the aged group were about 7.0 bits, somewhat lower than the scores for the thirteen subjects in the current study. However, Appendix K shows that when scores were not corrected for actual target width, the aged group score would be about 7.5 bits/sec, very close to Welford's data. However, for the arguments stated, this estimate is probably low since aged subjects did use smaller actual target widths and not correcting for this would underestimate the score.

Serial Choice Reaction Time Test Without Memory

Every test given in the lab is a time-pressured task and thus provides a speed measure. The serial choice reaction test, however, is ideally suited to providing a reliable estimate of average response time since a large number of responses is possible (i.e., twenty-nine in every trial) in a very few minutes with all task conditions fixed. Furthermore, the test is rapidly paced in that responses follow one after another and thus has the desirable attribute of a continuous performance task, not found in the other lab tests. In addition,

the data for this test provided a baseline condition, i.e., "no" memory, for the short term memory task to be discussed in the following section.

Analysis of the Raw Data

Subjects performed three trials of 29 responses each, the data being mean response time and standard deviation of response time. Error rates were very low, averaging only about one to two percent, or less than one error per trial of 29 responses. The mean response times for each trial and each age group are shown in Table 6. The change in times across trials was not significant (see Appendix L for ANOVA = .05) for either age group. Thus, with respect to error rates and learning across trials, age groups appeared to behave in a similar manner in the measures of mean time and standard deviation of time.

Analysis of Measures of Test Performance

As mentioned above, mean response times for the three trials was relatively constant. An examination of individual subjects' data revealed that many subjects' fastest mean times were in the third trial while for others the second trial was the fastest. The data for the fastest trial was considered the best, since it represented the fastest time subjects could respond. The measures analyzed for this trial are summarized in Table 7.

Table 6

Serial Choice Reaction Test Trial Times

Mean Response Time (29 responses)			
	<u>Trial 1</u>	<u>Trial 2</u>	<u>Trial 3</u>
Young	1.008 sec	0.997 sec	1.001 sec
Aged	1.238 sec	1.264 sec	1.223 sec

Table 7
Serial Choice Reaction Test Measures

Measure	Age Group	Values	Age Difference	Statistical Test
Std. Deviation of Response times (29th)	Young	0.1062 sec	Yes	$p = .02$ Mann-Whitney
	Aged	0.1623 sec		
Std. Deviation of Subject mean times	Young	.0586 sec	N.S.	$\alpha = .10$ F test
	Aged	.0887		
Mean Response Times	Young	0.9829	Yes	$p = .002$ Mann-Whitney
	Aged	1.1968		

Intrasubject variability

For the set of (29 scored) responses, the standard deviation of response time provides a measure of subject variability. Table 8 shows that aged subjects were more variable in their response time than young.

Intersubject variability

The intersubject variability for the aged group tended to be greater than the young, though the F test was not significant.

Central tendency in response times

The average of the mean response times for the aged was about 20 percent higher. In fact, for the subjects tested in this study, the fastest aged subject was slower than the slowest young subject. The mean response times for the young are very near the values reported by McDowell (1973) using the same test with similar subjects.

Score Development-Serial Choice Reaction Test

The score for this test, a measure of slowing, is the mean response time already shown in Table 8 and plotted in Figure 4. It should be recalled that this score is unlike the other five lab test scored which were designed to provide an index of efficiency or capacity in each of five basic functional component mechanisms of psychomotor performance. This test was designed to provide a reliable estimate of response slowing with age. Performance components in this test include some or all of the other psychomotor skill components and as such this measure does not represent a fundamental skill component.

Table 8

Serial Choice Reaction Time with Memory Test, Data by Trials

Mean Response Time (26 responses)			
	<u>Trial 1</u>	<u>Trial 2</u>	<u>Trial 3</u>
Young	1.425 sec	1.442 sec	1.447 sec
Aged	2.148 sec	2.463 sec	2.251 sec
Response Accuracy (%)			
	<u>Trial 1</u>	<u>Trial 2</u>	<u>Trial 3</u>
Young	44.2%	80.0%	75.3%
Aged	33.8%	55.1%	59.0%

However, it does provide a reliable operational measure of the phenomenon of slowing so universally observed in aging research. As such its relation to the road measures is examined along with the measures of the basic component mechanisms.

Serial Choice Reaction Time With Memory Test

This test is nearly identical to the serial choice reaction test except that subjects respond to the stimuli that appeared in the window two positions earlier and thus stimuli must be retained in memory.

Analysis of the Raw Data

Subjects performed three trials of twenty-six responses each. The data are the mean response times for all responses, and percent accuracy of responses. A summary of these measures for the three trials by age groups is given in Table 8. Statistical analysis of the effect of trials (see Appendix L for ANOVAS and contrasts) revealed no effect of trials on response time, but that the percent correct on the first trial was significantly ($p = .05$) lower than the latter two trials, while no differences were evident between the last two trials. Thus the performance seems to be stable in the last two trials for both age groups for both measures.

Analysis of Measures of Test Performance

Clearly, the data from the first trial is not representative of performance and should not be included in computation of test measures.

However, merely averaging mean times and accuracy for the last two trials for each subject was not deemed satisfactory for several reasons. For one, while mean response times seemed relatively stable over the last two trials, differences in percent correct was quite variable; both groups averaged about 13 percent difference, but some subjects had a difference in percent correct of over thirty. If the poorer trial were the second trial, subjects may have been confused or still learning the test. If the poorer trial were the last, the subject may have felt he had already done his best on the second, and simply did not try as hard on the last trial. This interpretation is reasonable in light of subjects' comments (both young and aged) during the testing, who indicated this test was very difficult. Following this line of reasoning, inclusion of the poor trial would underestimate the subjects' capacity (in a non uniform fashion for all subjects) to perform this test with memory, while the best trial would be more representative of his capacity in this test. Thus, the measures analyzed for this test are those from the best trial (based on accuracy), and are shown in Table 9.

Mean Response Time

The mean response of the aged group was almost 50 percent longer than the young. Times for both age groups are much longer than times for the serial choice reaction test with no memory. Also, shown in the table, are the mean response times for correct responses only since this data will be of interest in the discussion on score development. Those times are somewhat less than the mean times for all responses.

Table 9

Serial Choice Reaction Time with Memory Test Measures

Measure	Age Group	Values	Age Difference	Statistical Test
Mean Response time all Responses	Young	1.3568 sec	Yes	$\alpha < .002$
	Aged	2.2605 sec		Mann-Whitney
Mean Response Time Correct Responses	Young	1.2820 sec	Yes	$\alpha < .002$
	Aged	2.1046 sec		Mann-Whitney
Percent Correct Responses	Young	84.2%	Yes	$\alpha < .02$
	Aged	62.4%		Mann-Whitney
Std. Deviation of Response times (26 trials)	Young	.5676 sec	Yes	$\alpha = .002$
	Aged	1.1728 sec		Mann-Whitney
Std. Deviation of Subject mean times	Young	.2341 sec	Yes	$\alpha < .10$
	Aged	.4718 sec		F test
Average memory score units = number of alternatives per second per response	Young	2.82	Yes	$\alpha < .02$
	Aged	4.23		Mann-Whitney
Std. Deviation of Subject memory scores	Young	1.39	N.S.	$\alpha = .10$
	Aged	.84		F test

Accuracy of responses

Aged subjects had about 20 percent fewer correct responses than the young group.

Intrasubject variability

The standard deviation of response times for the aged was almost twice that of the young group indicating much greater variability in performance.

Intersubject variability

The aged group had a larger spread of mean times than the younger.

Score Development-Memory Effect

This test is very much like the serial choice reaction time test without memory except that stimuli must be held in memory before being responded to. As such, the effect of the additional task component of memory can be expected to be manifested, assuming a detrimental effect of memory in either longer response times and/or more errors than the same test without memory. As pointed out, both response times and percent response accuracy were reduced for both groups. Both age groups were essentially 100 percent accurate in their responses without memory, and thus it is appropriate to say that with memory, aged response accuracy was more detrimentally affected than the young group. However, even without memory, aged were slower to respond than the young group, and a similar statement as to the effect of memory, then is required which incorporates both the effect on time and

on percent correct, as well as compares the effect to the baseline condition with no memory. The development of a method of scoring the effect of memory is discussed in detail in Appendix M. The method adopted is as follows:

- 1) Compute the rate of information transferred per response "without" (i.e., serial task without memory) memory. R_o
- 2) Compute the rate of information transferred per response with memory. R_m
- 3) Subtract to obtain the detrimental effect of memory introduced in the task,

$$M = R_o - R_m$$

The greater the detrimental effect of memory, the larger the value of M . The mean and standard deviations of this score are shown in Table 9 and plotted in Figure 21. The effect of memory in this experimental task is greater for the aged than the young. Interestingly, the young age group had a nonsignificant larger variation in scores than the aged. The aged had uniformly higher scores, while the young had some high as well as some very low scores. The deleterious effects of introducing memory in a serial reaction task, and the differences between age groups were also found in a study by Kirchner (in Welford, 1958).

Relationships among the laboratory test measures

In the first chapter of this report a conceptualization was developed which identified basic functional component mechanisms in psychomotor performance. This conceptualization provided a theoretical foundation for the development of the five laboratory tests and their

associated scores. A principal assumption in identifying these components is that they are somewhat unique and independent. That is, some persons might possess a large capacity in one component, and yet have a low capacity in others. However, all of these components do have a common locus of central processing. Some researchers (e.g., Welford, 1958) have suggested the possibility that loss in central capacity may be accounted for by a uniform decay in the central nervous system functioning (e.g., loss of cells, increase in neural noise). This possibility suggests that the capacities in the basic component mechanisms may be highly related. If this were the case, then rather than measures of independent components, each test could be conceived of as just another measure of "general central capacity." This argument is one primary motivation for examining the relationships among the test scores.

Another concern which emphasizes the importance of examining relationships among the test scores, is a potential weakness in the operational method of measuring these components. Even if a mechanism is unique, an operational test of that mechanism requires the subject provide a response which will depend in part on other components. For example, as argued earlier, the search test does require a response movement; the embedded figures do involve some memory; etc. The intent, of course, is that the major component of the response measures be due to the mechanism of interest in that test. However, some portion of the response can be due to other mechanisms being utilized in the response. An examination of the relationships among the test scores can shed some light on the contributing components to the scores.

The next section discusses the relationships among the lab tests primarily through the method of correlations.

Intercorrelations of Laboratory Test Scores

Correlations with all subjects combined

The intercorrelations between the five laboratory test scores for all subjects (young and aged) are shown in the top of Figure 17. Many of these correlations are not statistically significant, thus to limit the discussion of these correlations to those most likely to be greater than zero, a reduced matrix is shown at the bottom of Figure 17 with the nonsignificant (critical $r = .549, \alpha = .01$) correlations set to "*". To aid in the interpretation of the correlations, a code is inserted in parentheses above the correlation indicating the nature of the relation. A "positive" indicates that a greater capacity in one test score is associated with a greater capacity in the other; the converse is true for the code, "negative." (Recall that for some scores, increasing capacity is associated with a larger numerical score, while for others it is associated with a smaller numerical value).

The most striking result in Figure 17 is that most of the tests are not significantly correlated with one another. Focusing on the significant correlations, it is clear that the embedded figures test is correlated to some degree ($r = .56$) with visual search. This is reasonable in that in disembedding the simple figure, features of the complex figure must be scanned, in addition to being perceived. Conversely, when trying to locate the simple targets in the visual search test, in addition to being scanned, the targets must also be perceived

	Embedded Figures	Visual Search	Motor Capacity	Choice Reaction
Embedded Figures				
Visual Search	.56			
Motor Capacity	-.49	-.50		
Choice Reaction	-.10	-.12	.31	
Memory Score	.60	.30	-.55	-.42

intercorrelations
all values
shown

Young and
Aged combined
(N = 23)

	EF	VS	MC	CR
EF	(positive)			
VS	.56			
MC	*	*		
CR	*	*	*	
MS	(positive) .60	*	(positive) -.55	*

intercorrelations
values less than
 $r = .55$ set to *
($\alpha = .01$)
(N = 23)

^a positive $\Rightarrow$ greater capacity in one test score associated
with greater capacity in the other

Figure 17.--Intercorrelations between laboratory
test scores - all subjects combined

by the subject. The embedded figures test is also positively associated with the memory score. This too is reasonable since the subject must retain the simple figure in memory while disembedding it from the complex figure. Thus, the main conclusion from these two correlations is that the embedded figures test score does include elements of visual search and short term memory. The correlations, however, are not so large ($r^2 \approx .30$) to give rise to challenge this score as representing a perceptual skill of disembedding the simple figure. The correlation between the memory score and the choice reaction tests, suggests that the ability to retain stimuli in memory while simultaneously responding and perceiving new stimuli is related to information processing rate. Conversely, information processing rate may be associated with memory capacity. However, as with the other correlations, this correlation is not so high as to cast doubt on the independence of these scores.

Correlations for aged subjects only

Figure 18 shows the intercorrelations of scores for the aged subjects only. None of the scores are significantly correlated with one another. Some persons believe the sixties to be a decade of great change in capacity. Subjects' ages in this project were uniformly spread from 60 to 70 and thus offer an examination of this proposition. The figure shows that none of the test scores are significantly correlated with age. However, motor capacity was almost significant, showing a tendency to declining motor capacity with greater age in this sample of subjects.

	Embedded Figures	Visual Search	Motor Capacity	Choice Reaction	Age (60 - 70)
EF					-.02
VS	.28				.08
MC	.26	-.29			-.70
CR	.33	-.08	.04		.08
MS	.47	-.13	-.34	-.05	.53

intercorrelations
all values shown
Aged only
(N = 13)

	EF	VS	MC	CR	Age
EF					*
VS	*				*
MC	*	*			*
CR	*	*	*		*
MS	*	*	*	*	*

intercorrelations
values less than
 $r = .74$ set to *
($\alpha = .01$)
(N = 13)

Figure 18.--Intercorrelations between laboratory
test scores - aged subjects only

Correlations for young subjects only

As with the aged subjects, no significant correlations among the test scores (see Figure 19) was noted for the young group alone. Furthermore, there is no previous research indicating the twenties is a decade of change in capacity. The lack of significant correlation of the test scores with age confirms this notion. Though the correlation with information processing rate is nearly significant, this is most likely a spurious result due to this particular sample of young subjects whose ages were grouped around the age of 23 with only one subject at 29.

Conclusion on intercorrelations

The results show for the most part that the test scores are relatively unrelated or independent. This finding does not support the theory of a general decline or uniform decline in central functioning with age. The few intercorrelations that were significant were reasonable in light of an interpretation of the test performance components. These correlations were not so high to justify reducing the number of test scores by elimination of redundant scores (i.e., none were redundant). Furthermore, the use of multivariate techniques, such as a factor analysis, to create a set of completely independent factors is not justifiable for several reasons:

- 1) the intercorrelations were, in fact, quite low among the scores,
- 2) the criterion of no correlation between any pair of scores is not necessarily a "best" criterion, since it is possible and reasonable that two or more mechanisms can decline

	Embedded Figures	Visual Search	Motor Capacity	Choice Reaction	Age (20 - 29)
EF					-.20
VS	.05				-.28
MC	.19	-.02			.53
CR	-.53	-.12	.44		.83
MS	.24	-.14	-.25	-.72	-.58

intercorrelations
all values shown
Young only
(N = 10)

	EF	VS	MC	CR	Age
EF					*
VS	*				*
MC	*	*			*
CR	*	*	*		*
MS	*	*	*	*	*

intercorrelations
values less than
 $r = .86$ set to *
($\alpha = .01$)
(N = 10)

Figure 19.--Intercorrelations between laboratory
test scores - young subjects only

somewhat together (i.e., moderate correlation), but it is still important to identify the capacity of each separately, in explaining overall changes in other psychomotor task performance,

- 3) there is a strong theoretical argument for a unique mechanism giving rise to the major portion of each test score.

Retaining the individual test scores also has several desirable advantages, including:

- 1) in the subsequent analyses in later chapters, it will be possible to investigate the relation of road performance to individual interpretable lab test scores. Thus significant mechanisms and their relative importance can be easily identified and interpreted.
- 2) the maintenance of these individual test scores enables easy direct comparison to past studies, and to future studies which most likely will only utilize subsets of the lab test battery.

Relationships of test of slowing to other laboratory test scores

Five of the laboratory tests were designed to test the basic component mechanisms. The sixth test, serial choice reaction time without memory test, was designed to yield a reliable estimate of overall response slowing. It was suggested that rather than test only one mechanism, some or all would be involved in yielding a

performance score on this test. Thus, the relation between the test of slowing and the other basic component scores is of interest, and is discussed below.

Figure 20 shows the correlations between the measure of slowing and the five laboratory test scores, representing the capacity of the five basic mechanisms tested. When comparing all subjects combined, the slowing measure appears to be significantly correlated with the laboratory scores as follows:

1. Slower SCRT times are associated with poorer (high) scores on the embedded figures test.
2. Slower SCRT times are associated with poorer (high) scores in the visual search test.
3. Slower SCRT times are associated with poorer (lower) scores on the motor capacity.

The measure of slowing was not significantly correlated with any test scores within each age group separately analyzed. Thus, the correlations provide some indication that the slowing across age groups is related to other basic mechanisms. However, within each age group, the SCRT score is relatively independent of the other laboratory test scores.

Discussion of General Findings and Conclusions

Age group differences in test performance

Large differences in performance on the battery of tests were noted between the aged group and the young group on most of the test measures. These differences were generally manifested as:

- 1) The aged almost always responded more slowly than the
young

Actual correlations Statistically significant, $r(\alpha = .01)$

Embedded Figures Visual Search Motor Capacity Choice Reaction Memory Test	Slowing	Young and aged (N = 23)	Slowing	$r \geq .55$
	.63		.63	
	.55		.55	
	-.64		-.64	
	-.31		*	
	.30		*	
N.S. = *				
EF	-.18	Aged only (N = 13)	*	$r \geq .74$
VS	.24		*	
MC	-.18		*	
CR	-.20		*	
MT	-.19		*	
EF	-.37	Young only (N = 10)	*	$r \geq .86$
VS	.17		*	
MC	-.25		*	
CR	-.11		*	
MT	-.29		*	

Figure 20.--Correlation of slowing test measure
with other lab test scores

- 2) Individual aged subject's performance varied more from trial to trial than the younger group's intrasubject performance variability
- 3) The intersubject variation in performance among the aged subjects was generally greater than the variation among younger subjects.

Though most of these tests utilized are not new, nor are the general findings, the results are in agreement with past studies. This agreement tends to validate the testing methods and resulting scores and additionally confirm the representativeness of the subject age groups selected.

Age Group Differences in Capacities (test scores) of the Basic Functional Component Mechanisms in Psychomotor Performance

Four of the five tests showed aged subjects had poorer scores than the young subjects, while on the fifth test the trend was also in the same direction, (see Figure 21). This can be interpreted that aged subjects as a group have lower capacities on each of the five basic component mechanisms comprising psychomotor performance. The results also showed that the aged group tended to have a larger intersubject variation in capacity scores than the young group. Briefly, the declining capacity with age was noted for the following mechanisms:

- 1) capacity to disembed a simple figure from within a complex figure
- 2) capacity to visually search a large area for simple targets
- 3) capacity to centrally control fine motor movements

Figure 21.--Summary plot of age group means and standard deviation of laboratory test scores of capacity and slowing

- 4) capacity for information processing rate
- 5) capacity to retain information in short term memory while executing other concurrent functions.

Furthermore, on the serial choice reaction test, aged subjects performed more slowly than the young (see Figure 21).

Relationship among test scores of capacity

The general findings for each individual test of capacity is not new, but again serves to substantiate the research methods and scores and representativeness of subjects selected. On the other hand, this researcher was not apprised of any studies in which tests of all five basic mechanisms were administered on the same subjects. As such, the general findings of the relationships among the various capacity scores represent a contribution to the research on aging in psychomotor performance. The independence among the scores lends support to often assumed, but not previously proven, notion that the various central capacities are, in fact, unique and tends to cast doubt as theories of a uniform decline in central capacity within an individual person. Of course, the ideal research method for examining these latter theories is to conduct a longitudinal study of a group of individuals, rather than the method of cross-sectional age groups.

CHAPTER IV
STUDIES IN DRIVERS' VOLUNTARY
VISUAL OCCLUSION BEHAVIOR

Overview of the Studies

This is the first chapter of several on the studies of driver behavior in actual on-the-road driving performance. The task of voluntary visual occlusion is significant in that it is the most demanding road task performed. Drivers were instructed to perform at their limit, to look at the road scene as little as possible, and still maintain control of the vehicle. This task was selected to tax the abilities of young and aged, and as such, with the lower capacities generally found in the aged, it was the task deemed most likely to show differences in performance between the age groups.

The objectives of these studies were twofold:

1. To investigate differences in performance in road tasks of the voluntary visual occlusion between the age group; and
2. To investigate relationships between performance in this task (i.e., a psychomotor skill) and performance scores in the basic functional mechanisms comprising psychomotor performance.

This chapter then represents the first of several to begin to build a bridge between the current knowledge of changes with age in central capacities (in the lab tests) and changes in specific "real-world" task performance.

Experimental Layout of Studies

Figure 22 shows the experimental layout of the road studies on voluntary visual occlusion. All subjects who drove in these studies also participated in the laboratory studies. An analysis of the representativeness of these subsets of subject samples compared to the laboratory study with larger samples, is presented later in this chapter. Many subjects participated in all four road studies. The potential effect of the order which subjects performed the studies was minimized by randomly balancing the order within the constraints of various studies in which subjects participated. A complete discussion of the issues involved in the order effects as well as tables of the actual order are contained in Appendix H.

The major hypothesis investigated in each study was the difference in performance between age groups. However, since many subjects did participate in more than one study, a comparison among tasks and driving conditions (e.g. day, night) was possible.

Data Analysis Strategy

In the first portion of the analyses measures of road performance (described below) were analyzed for differences between age groups and the effects of day and night as well as tasks. The second part of the analyses centered on the relationship between the measures of road performance and the laboratory test scores representing the capacity of the basic functional mechanisms. The method of analyses were primarily correlations.

Figure 22.--Experimental layout of the road studies on voluntary visual occlusion

Measures of Performance

For each study six measures were computed (based upon approximately a two-minute trial):

- 1) The mean time open in seconds
- 2) The standard deviation of (1)
- 3) The mean time closed in seconds
- 4) Standard deviation of (3)
- 5) Percent of trial time closed
- 6) A measure of perceptual uncertainty computed as

$$\frac{\text{mean time open}}{\% \text{ time closed}} \times 1000$$

Mean time open is an indication of the time per look the subject required to obtain the necessary information to maintain control of the vehicle. The mean time closed is an indication of the time which a driver is willing to go without refreshing his information. The percent time closed is an indication of drivers space visual capacity as suggested by Safford (1971). The measure of perceptual uncertainty was developed by Rockwell, et al (1974) and reflects the changes in either or both measures of mean open time and percent closed.

All of the measures reflect the information seeking behavior of subjects. The major control task is that of maintaining lateral control in the open road study. In the car-following studies the task is maintaining lateral control as well as longitudinal speed control and car spacing control. Unfortunately, no quantitative measure of lateral control was feasible. The only inclination of the level of performance is derived from the experimenters who judged the lateral

control behavior to be similar in all subjects. All subjects performed more poorly than they did in normal driving, but none lost control during the trials, though deviances in lane position within the lane were marked. Measures of longitudinal control and car spacing are analyzed in a later chapter.

Since the six measures are derived from the same data, it is of interest to comment on the correlations among the various measures. Appendix I shows the correlation matrices among the six measures for the daytime task of open road driving for all subjects combined, and for the young and aged groups separately. Though not shown, the matrices were similar for the day car-following, night open road, and night car-following tasks. The mean open time tended to be correlated with the variability of open times. Interestingly, the mean open time was not significantly correlated with mean closed times across both groups. As expected, the mean open time is negatively correlated with the percent closed (100-percent open); that is the larger mean open, the greater percent closed. The correlations of mean open with the perceptual uncertainty measure were nearly unity, reflecting the computational dependence of these measures (i.e., $p.u. = \text{mean open} / \% \text{ closed}$).

Results - Major Experimental Conditions

The data for the four studies can be combined and analyzed using a general regression approach to evaluate the following factors:

- S(A) - subjects within age group
- A - age group (young and aged)
- C - condition (day or night)
- T - task (open road and car follow)

AC	-	} interactions
AT	-	
CT	-	
ACT	-	

Additionally, the output of the regression enables a testing of the difference between the young and the aged group separately for each of the four studies. Significant interactions can be manifested as differences between young and aged in some tasks but not in others, while a significant age factor will be manifested in differences between young and aged usually in all four tasks. To simplify the discussion, the results can be organized into two groups:

1) The effects of the major experimental conditions and 2) the effects of age in the individual tasks. The latter of these are the major emphasis of the study and are reported in detail, while the former are of secondary interest and are presented in a summary form.

The major experimental conditions are:

- 1) Subjects
- 2) Age group
- 3) Condition (day or night)
- 4) Task, (open road or car following)

The experimental conditions of subjects is represented in the regression model as the S(A) term. The condition of age can be said to be significant if any one of the terms, A, AC, AT, or ACT in the regression are significant. Likewise, the experimental condition of day and night can be said to be significant if any of the terms, C, AC, CT or ACT are significant. And, also, the task condition can be said to be significant if any of the terms of T, AT, CT, or ACT are significant. Table 10 shows a summary of the statistical significance of the conditions as interpreted above. Note that in all measures the

Table 10
Summary of Statistical Significance²
of Experimental Conditions

Measure	Subjects	Condition ¹					
		Age Group		Day, Night		Openroad, carfollow	
		Main Factor	Inter-action	Main Factor	Inter-action	Main Factor	Inter-action
Mean Open Time	*	** Aged larger	**	** Night larger	**	* Carfollow larger	
Std. Dev. Open Time		** Aged Larger	**	* Night Larger	**		
Mean Closed Time	**	* Aged Larger					
Std. Dev. Closed Time	**	** Aged Larger	**		**		
% Closed	**	** Aged less	**		**	** OR larger	
Perceptual Uncertainty		** Aged Larger	**	* Night Larger	*	** CF Larger	

¹Condition

Subjects (S)
Age Group (A)
Condition, day or Night (C)
Task (T)

Regression model
factors

Main	Interactions
S(A)	
A	AC, AT, ACT
C	AC, CT, ACT
T	AT, CT, ACT

²The significance centered in the talbe is that
level of P for the model factor with the smallest

p.
** => $p \leq .05$ * => $p \leq .10$

age condition was significant. Likewise, day or night differences were significant in all but the mean closed measure. Significance of subject condition was also noted in most measures, and finally, the task condition was significant in three measures. Of the occlusion measures, mean open time and percent closed time were sensitive to all experimental conditions. A detailed analyses of these various conditions is not given here since these were not the major hypotheses of the research. These results however, serve to demonstrate the sensitivity of the measures to the experimental conditions including age.

Results-Age Group Differences

Differences in Central Tendency Measures

Differences between the age groups for the six measures of performance for each study were tested using t-tests based upon the previous regression output. The results of the t-tests for all measures are summarized in Table 11.

Mean Open Time

The results of the t-tests shown in Table 11 show that the aged group's mean open time is much larger than the young. In the day, the mean open time of the aged is over twice the mean of the younger, and at night the aged mean is also almost twice the young. These striking results are graphically portrayed in Figure 23. These results can be interpreted to indicate that aged drivers require much longer times to acquire the minimum information to maintain minimum control of the vehicle.

Table 11

Results of t-tests for Voluntary
Visual Occlusion Studies

Measure	Study	Mean		Significance ** $\Rightarrow p \leq .05$, * $\Rightarrow p \leq .10$
		Aged ²	Young	
Mean Open Time (sec)	Day CR ¹	1.58	.68	**
	Day CF	2.03	.72	**
	Nt. CR	2.53	1.41	**
	Nt. CF	3.50	1.65	**
Standard dev. of Open Time (sec)	Day CR	.90	.43	n.s.
	Day CF	1.22	.54	n.s.
	Nt. CR	2.00	1.12	*
	Nt. CF	2.58	1.25	**
Mean Closed time (sec)	Day CR	3.12	2.25	*
	Day CF	3.00	2.02	**
	Nt. CR	4.00	2.85	**
	Nt. CF	3.80	3.12	n.s.
Standard dev. of Closed Time (sec)	Day CR	1.37	.92	n.s.
	Day CF	1.12	.69	n.s.
	Nt. CR	2.62	1.26	**
	Nt. CF	2.00	1.86	n.s.
% Closed	Day CR	66.84	77.54	**
	Day CF	58.88	67.81	*
	Nt. CR	61.17	70.60	n.s.
	Nt. CF	51.24	65.13	**
Perceptual Uncertainty Index	Day CR	27.01	9.35	*
	Day CF	39.88	10.91	**
	Nt. CR	41.91	21.67	n.s.
	Nt. CF	71.57	25.32	**

¹ OR = open road
CF = car following

² Sample sizes

Study	N	
	Aged	Young
DOR	9	6
DCF	9	6
NOR	5	5
NCF	5	5

Figure 23.--Plot of mean open times and subject group standard deviations, voluntary visual occlusion

Standard Deviation of Open Time

In the night studies, the aged subjects have a greater standard deviation (i.e., greater intrasubject variability) of open times. In the day the trend is similar though not statistically significant. This result combined with the greater mean open times for aged indicate that aged drivers have a large proportion of very long open times (three to six seconds across tasks) while younger have relatively few long open times (usually less than one to three seconds across tasks).

Mean Closed Time and Standard Deviation of Closed Times

The aged drivers keep their eyes closed longer than the young, possibly indicating a greater risk acceptance than the young. This finding is contrary to the notion that aged drivers are more cautious, at least in this experimental task.

Percent Trial Time Closed

On the average, aged subjects kept their eyes closed about ten percent less time than the young, indicating a lower spare visual capacity in open road driving (Safford, 1971) of the aged.

Perceptual Uncertainty

This statistic showed significant differences between groups; however, it is composite of percent closed time and mean open time. Since no differences were noted in the percent closed, the differences in this score are largely reflective of the already noted differences in the mean open time. This measure thus probably requires no separate attention from the measure of mean open time. To further substantiate this, the correlation between these two measures averaged over .95.

Intersubject Variability in the Mean Scores

Most of the measures did not show a statistically significant difference between the age groups in intersubject variability though the trend was toward larger intersubject variability within the aged group than the younger. Some aged subjects performed at the same level as the younger, but others performed at very extreme levels compared to the young. This trend toward greater variability among aged drivers is similar to findings of performance variability in the laboratory tests.

Results-Relations of Visual Occlusion Measures To Scores of Basic Mechanisms

One concern in conducting the correlation is the representativeness of the smaller sample subjects who performed the driving tests compared to the larger sample of subjects who participated in laboratory tests. Appendix P show tables of the means and standard deviations, aged group and young separately, of each lab score for each subset of subjects in each study conducted; compared to the full sample of laboratory subjects. For both the day occlusion studies and the night occlusion studies, no significant differences were noted between the subjects in the road study and the full sample in the lab.

Correlation of Road Measures With Lab Scores

The correlation matrixes of the six measures in each study with the laboratory scores are shown in Tables 12 to 15. Correlations significant at the $\alpha = .05$ level are circled for ease of identification.

Table 12

Correlations Open, Road, Day, OCCL

Road Measures	Lab Test Measures					
	Emb Fig	Visual Search	Motor	Infor Proc. Rate	Memory	Slowing (SCRT)
Mean Open time	0.720	0.624	-0.615	0.019	0.433	0.555
Std. Dev. Open time	0.364	0.530	-0.474	-0.021	0.114	0.552
Mean Closed Time	0.387	0.293	-0.343	-0.320	0.276	0.180
Std. Dev. Closed	0.390	0.666	-0.546	-0.322	0.367	0.370
Percent Closed	0.527	-0.485	0.422	-0.166	-0.250	-0.514
Perceptual Uncertainty	0.647	0.613	-0.542	0.107	0.338	0.530

$\alpha \Rightarrow \leq .05$

N = 6 young
 + 9 aged
 15 total subjects

$\alpha = .01$
 $\alpha = .05$
 $\alpha = .10$

$r \geq .688$
 $r \geq .524$
 $r \geq .440$

Table 13

Correlations, Car Following, Day OCCL.

Lab Test Measures						
Road Measure	Emb. Figures	Visual Search	Motor	Infor. Proc. Rate	Memory	Slowing (SCRT)
Mean Open time	0.703	0.537	-0.740	-0.174	0.424	0.499
Std. Dev. Open time	0.494	0.446	-0.618	-0.297	0.280	0.283
Mean Closed time	0.334	0.443	-0.400	-0.362	0.280	0.220
Std. Dev. Closed	0.243	0.692	-0.366	-0.313	0.165	0.315
% Closed time	-0.373	-0.284	0.259	-0.248	0.091	-0.303
Perceptual Uncertainty	0.632	0.520	-0.695	-0.145	0.376	0.462

N = 6 young + 9 aged 15 total	$\alpha = .01$ $\alpha = .05$ $\alpha = .10$	$r \geq .688$ $r \geq .524$ $r \geq .440$
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Table 14

Correlations, Open Road Night OCCL.

Road Measures	Lab Test Measures					
	Emb. Fig.	Visual Search	Motor	Infor. Proc. Rate	Memory	Slowing (SCRT)
Mean Open time	0.720	0.714	-0.258	-0.212	0.600	0.343
Std. Dev. Open	0.625	0.664	-0.230	-0.148	0.440	0.163
Mean Closed Time	0.568	0.603	-0.236	-0.133	0.510	0.310
Std. Dev. Closed	0.615	0.679	-0.247	-0.178	0.514	0.287
% Closed time	0.651	-0.499	0.426	0.419	-0.401	-0.363
Perceptual Uncertainty	0.774	0.693	-0.302	-0.211	0.536	0.344

N = 5 young	$\alpha = .01$	$r \geq .858$
+ 5 age	$\alpha = .05$	$r \geq .653$
10 total	$\alpha = .10$	$r \geq .548$

Table 15

Correlations, Car Following
Night OCCL.

Lab Test Measures						
	Emb. Fig.	Visual Search	Motor	Info. Proc. Rate	Memory	Slowing (SCRT)
Mean Open Time	0.686	0.627	-0.355	-0.358	1.351	0.482
Std. Dev. Open time	0.419	0.470	-0.100	-0.540	0.222	0.666
Mean Closed Time	0.518	0.390	0.102	0.039	0.387	-0.050
Std. dev. Closed time	0.324	0.529	-0.027	-0.078	0.528	0.074
% Closed	-0.486	-0.470	0.651	0.645	-0.275	-0.761
Perceptual Uncertainty	0.572	0.652	-0.434	-0.424	0.294	0.558
<div> <div> N = 5 young + 5 aged 10 total </div> <div> $\alpha = .01 \quad r \geq .858$ $\alpha = .05 \quad r \geq .653$ $\alpha = .10 \quad r \geq .548$ </div> </div>						

An examination of the significant correlations in each study reveals a pattern of relationships. The laboratory scores of visual search and embedded figures most consistently relate to the road measures; and of the road measures, the mean time open and perceptual uncertainty correlate most consistently with the laboratory scores. Since the perceptual uncertainty measure correlates extremely highly with mean open time, as discussed earlier, the discussion of the road measures can be limited to the mean time open.

The correlation which is consistently high in all four tasks is that of mean time open with the embedded figures test score. The longer the mean time open in the road task, the longer the time to locate or disembed the simple figure from the complex figure in the lab. More broadly interpreted, if the mean time open is taken as a measure of minimum time to acquire minimum information for vehicle control, then this skill on the road is associated with a subject's ability to perform a task of perceiving visual information in the lab task.

Another correlation which appears high across the four tasks is the mean time open with the laboratory score of visual search. The longer the mean time open, the longer the time to complete the visual search test. Again broadly interpreted, the minimum time to acquire minimum information for vehicle control on the road is associated with a subject's ability to search and scan for visual information in the lab test.

In the daytime road tasks, the mean open time is also correlated with the laboratory score of motor capacity. The longer the mean

time open, the lower the motor capacity score. Once again, broadly interpreted, the minimum time to acquire information to maintain a minimum control of the vehicle, the poorer the subject's capacity to make fine motor movements in the lab. To illustrate the distribution of scores in this correlation (similar to others discussed). Figure 24 shows a plot of mean open times versus motor capacity.

Scanning the correlation tables for the patterns of correlations that hold consistently across at least two tasks reveals additional relations. The larger percent time closed (open road driving, both day and night) was associated with shorter embedded figures test times. The percent of time closed is sometimes interpreted as an index of a driver's spare visual capacity. As such, the greater the visual capacity on the road, the better (lower time) the capacity to disembed the simple figure. The standard deviation of closed times was also correlated with the visual search score (in the car-following day, and open road night tasks). The larger the standard deviation of closed times, the poorer (or greater times) the visual search score. The standard deviation of closed times may be interpreted as reflecting the variability in uncertainty about the previously obtained information in the previous open event. The correlations suggest this road behavior is associated with poorer lab scores of visual search. Finally, the percent time closed on the road is associated with the lab score for slowing (open road day, and car-following night tasks). This may be interpreted as, the greater the spare visual capacity on the road, the faster the responding time in the lab score of overall speed of response.

Figure 24.--Plot of mean open time versus motor capacity

An examination of the tables reveals a notable lack of significant correlations between the road measure and laboratory sources of information processing rate and of short-term memory. This suggests that these central capacities (as measured in the lab tests) are not associated with information seeking behavior in a voluntary visual occlusion task (for the situations studied and the road performance measures computed).

In summary, the correlations between the pairs of laboratory scores and road measures to indicate relations between the lab scores of capacity and the road performance in voluntary visual occlusion.

Interpretation of Correlations

The preceeding results lend encouragement to the original hypotheses to be examined, namely, that variation in road performance can be explained, in part, by differing levels of capacity in the basic mechanisms. The method of analysis, correlation, has several cautions associated with its use in this instance which must be discussed. For one, correlation can only provide a measure of degree of association, not causation, though the theoretical arguments for causation between the capacities and road performance have been advanced. Secondly, the two subject populations selected are greatly separated in age, and thus, probably tends to increase the magnitude of the correlations found. Lastly, both the road measures and the lab measures were found to be different between age groups, and thus, correlation between the road and lab measures is a possible statistical result across the two age groups. However, correlation between the two measures as a consequence of correlation between each separately with

age cannot be said to be spurious, since it is expected that a general trend in both measures with age does exist.

One method of examining the possible relations between the variables in the lab and road without the additional effect of age is to examine the correlations between the sets of measures separately for each group in the study. This has the added advantage of demonstrating the possible different structures in the relations between lab and road for the young and aged group. This technique was computed, however, with the small sample sizes that were affected by dividing the subjects, almost none of the correlations were high enough to attain statistical significance (i.e., .85 to .95 were required in these small samples).

Discussion and Conclusion

The results of these studies indicate that in a demanding road task, aged drivers perform more poorly than young drivers in their information acquisition behavior, primarily as evidenced by the longer mean times open to gather the minimum information to maintain minimum control of the vehicle. Aged drivers had a tendency toward greater intrasubject variability, primarily in the open times. The spread of the distribution of mean open times for the aged subjects tended to be larger than the spread for younger subjects, a finding consistent with the lab test measures. Some aged drivers performed at the same level as the young, but others were quite separated from the young.

Correlational analyses revealed lab scores to be significantly correlated with the road test measures. Ordered in terms of their

strength of association, embedded figures capacity score, visual search capacity score, and motor capacity scores were related primarily to the mean open time. Though correlations cannot imply causation, they do provide quantitative estimates of the degree of association between the lab test scores and road performance. The statistically high values of correlations, the patterns of relations across tasks, as well as the interpretations of the direction and nature of the association support the proposition that age related changes in performance on the road, a "real world" psychomotor task, are related to various central capacities comprising psychomotor performance.

CHAPTER V

STUDIES OF DRIVERS' EYE-MOVEMENT PATTERNS

Overview of the Studies

In these studies, both groups of subjects drove the car in essentially normal driving task situations, unlike the visual occlusion studies which were experimentally loaded situations. Driver eye movements were recorded and analyzed in this chapter, while an analysis of recorded control movement and vehicle response behavior is contained in a later chapter.

The objectives of these studies were twofold:

- 1) to investigate differences in eye movement patterns in normal driving situations between the two age groups,
- 2) to investigate relationships between performance in this task and performance scores in the lab of the basic functional mechanisms.

Experimental Layout of Studies

Figure 25 shows the experimental layout of the road studies on driver eye-movement patterns. All subjects who drove in these studies also participated in the lab studies. As the figure shows, many subjects participated in all four road studies. The potential effect of the order which subjects performed the studies was randomly balanced within the constraints of various studies in which subjects

Figure 25.--Experimental layout of the road studies on driver eye movement patterns

participated. A complete discussion of the issues involved in the order effects as well as table of the actual order are contained in Appendix H.

The major hypothesis investigated in each study was the difference in performance between age groups. However, since many subjects did participate in more than one study, a comparison among tasks and driving conditions (e.g., day, night) was possible.

Data Analysis Strategy

The data analysis strategy is essentially the same as in the preceeding chapter on the road studies of voluntary visual occlusion. In the first portion of the analyses, measures of road performance (described below) were analyzed for differences between age groups and the effects of day and night as well as task. The second part of the analyses centered on the relationship between the measure of road performance and the laboratory test scores representing the capacity of the basic functional mechanism. The method of analyses were correlations.

Measures of Performance

For each study, thirteen measures of fine eye movement performance in the driving scene ahead were computed based on the data reduction grid for 30-second trials. This grid has its origin at the focus of expansion and units are visual degrees. An additional set of measures were computed representing gross eye movement behavior

to the mirrors and speedometer, based on a separate reduction of 120-second trials (to provide reliable estimates of this behavior).¹ For the sake of discussion, the first 13 measures are termed "fine eye movement" measures; the last 13 are termed "large eye movement" measures. Tables 16 and 17 respectively, describe and number the various measures of fine eye movements² and large eye movements.

The 13 fine eye-movement measures were derived from various computations on the same data, thus it is of interest to comment on the correlations among the measures. Appendix I shows the correlation matrices for these 13 measures for the daytime task of open road driving for all subjects combined ($n = 14$). Generally the mean time measures are positively correlated with each other. Also the mean time measures are correlated with their standard deviations.

The mean time measures are negatively correlated with the activity. All of the measures reflect various attributes of the information seeking behavior of subjects in normal driving. The measures summarize spatial attributes of the fixations (percent time in areas, percent time on objects, travel distance), temporal attributes (mean look times), as well as combinations of these (activity). Rather

¹Daytime only. Young ($n = 6$) Y01, Y02, Y06, Y07, Y08, Y09
in light traffic Aged ($n = 7$) A01, A02, A03, A04, A05, A06, A08

²Blinks often interrupted, otherwise continuous fixations or looks. An analysis of these blinks revealed large differences between subjects and greatly differing effects on the various measures. Since blink times were relatively short compared to look times, they were not considered significant interruptions in the look event taking place. To standardize the blink effect, all blinks were removed from the data prior to computation of the measures. Blink times averaged .20 seconds, and were almost never greater than .32 seconds. The blink time removed was included in the time for the previous look event.

TABLE 16

Measures of Fine Eye-Movement Behavior

1	Mean fixation time; consecutive fixations separated by at least one visual degree
2	Std. dev. of (1)
3	Mean travel distance; between consecutive in-view travels
4	Std. dev. of (3)
5	Concentration Index: % in-view time in 3°x3° most populous area
6	Mean time per area*: all areas including OV
7	Percent trial time in area A1*, scene ahead
8	Mean time per look within A1
9	Std. dev. of 8.
10	Percent time away from A1, but in-view
11	Std. dev. of all looks away from scene ahead
12	Mean time per look away from A1, but in-view
13	Activity index: mean travel distance x travels, divided by trial time

*Area codes as follows:

TABLE 17

Measures of Large Eye-Movement Behavior

Description
- Percent trial time looking at speedometer
- Mean time per look at speedometer
- Std. dev. of (38)
- Look rate at speedometer; No. looks divided by trial time (#/min.)
- Percent trial time looking at outside mirror
- Mean time per look at outside mirror
- Std. dev. of (43)
- Look rate at outside mirror
- Percent trial time looking at inside mirror
- Mean time per look at inside mirror
- Std. dev. of (47)
- Look rate at inside mirror
- Percent time total out of view

than expand the discussion of each of these measures at this point, further interpretations will be advanced as required in the discussion of the results.

Results - Major Experimental Conditions

As with the occlusion road studies, the data for the studies can be combined and analyzed using a general regression approach. The results enable a discussion of age group differences as well as an analysis of the major conditions of 1) subjects, 2) age group, 3) day-night, 4) task type, (light traffic, and car follow). A brief discussion of these conditions is given next, followed by a detailed discussion of the age group effects.

Table 18 shows a summary of the results of the experimental conditions (See the discussion in the occlusion chapter for the relation of regression model factors to experimental conditions). Almost every measure was significantly influenced by the two tasks of light traffic and car following. The three remaining conditions were mostly significant in the measures of mean travel distance, standard deviation of travel distance, mean time per in view look away from the scene ahead, standard deviation of all look times away from the scene ahead and the activity index. A detailed analysis of these various conditions is not given here since they were not the major hypotheses of the research. These results, however, serve to demonstrate the sensitivity of the measures to the experimental conditions including age.

Table 18
Summary of Statistical Significance²
of Experimental Conditions

Measure	Subjects	Condition					
		Age Group		Day, Night		Light traffic: car follow	
		Main Factor	Inter-action	Main Factor	Inter-action	Main Factor	Inter-action
Mean Fixation Time	*		*			** CF larger	
Std. dev. of fix time	*					** CF larger	
Mean Travel Dist.	**	* Aged larger			**	** LT larger	**
Std. dev. of Tr. Dist.	*	** Aged larger	**		**	** LT larger	**
Concentration Index						** CF larger	
Mean Time Per Area			*			** CF larger	*
^(A1) 1/2 Time in Scene Ahead						** CF larger	
Mean Time per Look in A1			*			** CF larger	*
Std. dev. of looks in A1						* CF larger	
% time Away A1 in-view							
Std. dev. look away A1			**		**		**
Mean time per in-view look, Away A1	**		**		**		**
Activity Index	**		**		*	** LT larger	

¹Condition

Subjects (S)
Age Group (A)
Condition, Day, Night (C)
Task (T)

Regression Model Factors

Main	Interaction
S(A)	
A	AC, AT, ACT
C	AC, CT, ACT
T	AT, CT, ACT

²The significance entered in the table is
that level of p from the model factor with the smallest p.
** => p ≤ .05, * => p ≤ .10

Results - Age Group Differences

Differences in Central Tendency of the Measures

Differences between the age groups for the fine eye-movement measures were tested for each study using t-tests based upon the previous regression output. Also, t-tests were run for the large eye-movement measures. The results for each set of measures are shown in Tables 19 and 20.

A scan of the column labeled "significance" shows that for most of the measures, there is no difference between the age groups. This result holds for the temporal measures, spatial measures, as well as combinations of these. The few differences that are shown are discussed below.

Travel distance

In the car-following task in the day, the aged subjects have a larger mean travel distance than the young, and furthermore, the aged subjects have a greater variability in their travel distances in several tasks. Though not statistically significant, these trends are evidenced in all road tasks. Combining both measures suggests that aged have a much higher proportion of large travels than the young. This trend toward larger travels between successive fixations by the aged is also manifested in a trend toward larger values of the activity index in all tasks.

An interpretation of these findings can be advanced from several points of view. For one, if the parafoveal acuity of aged were somewhat lower than the young (as shown in a study by Wolf, 1972) then

Table 19

Results of t-tests, Fine Eye Movement Measures

Measure No. (see Table 18)	Study	Mean Value		Significance ** $\Rightarrow p \leq .05$, * $\Rightarrow p \leq .10$
		Aged	Young	
Fix Time	DLT	1.52	1.61	n.s.
	DCF	2.41	3.97	n.s.
	NLT	1.89	1.97	n.s.
	NCF	1.99	5.12	**
Std. dev. Fix time	DLT	1.44	1.50	n.s.
	DCF	2.15	3.53	*
	NLT	1.86	1.80	n.s.
	NCF	1.82	2.52	n.s.
Mean Travel Distance	DLT	4.32	4.31	n.s.
	DCF	3.63	2.32	**
	NLT	3.94	3.26	n.s.
	NCF	3.22	3.41	n.s.
Std. Dev. of Travel Distance	DLT	2.64	2.61	n.s.
	DCF	1.69	1.02	*
	NLT	2.16	1.38	*
	NCF	2.52	1.39	**
Concentration Index	DLT	74.7	70.5	n.s.
	DCF	75.9	85.8	n.s.
	NLT	65.6	69.8	n.s.
	NCF	73.0	77.5	n.s.
Mean Time per Area	DLT	1.90	1.99	n.s.
	DCF	2.14	1.52	n.s.
	NLT	2.61	2.09	n.s.
	NCF	3.08	2.50	n.s.
Time A1 . Scene Ahead	DLT	77.8	71.6	n.s.
	DCF	78.4	84.5	n.s.
	NLT	72.8	66.0	n.s.
	NCF	79.2	71.5	n.s.
Mean time A1	DLT	3.17	3.11	n.s.
	DCF	5.31	10.12	*
	NLT	4.58	3.29	n.s.
	NCF	4.21	10.22	*
Std. dev. time A1	DLT	2.88	2.58	n.s.
	DCF	5.19	3.42	n.s.
	NLT	4.24	2.46	n.s.
	NCF	4.21	4.75	n.s.
Activity Index	DLT	2.29	2.22	n.s.
	DCF	1.21	1.01	n.s.
	NLT	2.15	1.54	n.s.
	NCF	2.43	1.02	**
Std. dev. of look times away from scene ahead	DLT	0.62	1.34	**
	DCF	0.93	0.69	n.s.
	NLT	1.46	.74	*
	NCF	0.74	1.54	*
percent of In-View Away from A1	DLT	11.1	18.1	n.s.
	DCF	12.7	8.9	n.s.
	NLT	20.5	24.7	n.s.
	NCF	15.3	17.2	n.s.
Mean time Per In-View Look away from Scene Ahead	DLT	0.57	1.02	**
	DCF	1.00	0.91	n.s.
	NLT	1.15	1.15	n.s.
	NCF	0.74	1.29	**

Task

a) DLT = Day Light Traffic
 DCF = Day Car Following
 NLT = Night Light Traffic
 NCF = Night Car Following

N	
Aged	Young
8	6
8	6
5	5
5	5

Table 20
Results of t-test, Large Eye Movement Measure
Task = Daytime Light Traffic

Measure No. (see Table 18)	Mean Value		Significance * $\Rightarrow p \leq .05$; * $\Rightarrow p \leq .10$
	Aged	Young	
% time speedometer	3.41	4.50	
Mean time per look at speedometer	1.20	0.91	
Std. Dev. speedometer times	.37	.36	
Look rate at speedometer	2.0	3.0	
Percent time side mirror	1.30	3.27	*
Mean time per look at side mirror	1.27	1.03	
Std. dev. of look times at side mirror	1s	1s	
Look rate at side mirror (#/min)	0.57	1.92	**
Percent time rear mirror	0.0	1.80	*
Mean time per look at rear mirror	1s	1s	
Std dev. of time at rear mirror	1s	1s	
Look rate rear mirror	0.0	1.00	*
Percent total time CV (includes blinks)	8.00	14.95	**

1s = insufficient data

the aged would require more foveal confirmation of cues lying within several degrees of the previous fixation point. Parafoveal vision was not measured, but this line of explanation could be explored in future studies. The lab studies have shown aged drivers as a group to have lower capacities in several basic component mechanisms in psychomotor skills, particularly visual search and disembedding the simple figure. This central capacity argument then suggests that for aged drivers to obtain the same information as the young, the aged must acquire more cues. Hence, they have larger travels and more activity. This possibility is examined in later sections in this chapter relating the road measures to the lab measures.

Time away from scene ahead

In the daytime light traffic and nighttime car-following young drivers spend longer times away from the scene ahead than the aged, and additionally the variability of these times is greater for the young. These results together suggest that young drivers spend some very long times away from the scene ahead compared to the aged (See Figure 26).

The need for the information away from the scene ahead can be signalled either by the peripheral vision or initiated by a routine search. In either case, while fixating to the side, the clarity of information ahead is reduced since it is contained in the periphery (peripheral vision is poorer than central as shown by Wolf, 1972). Since drivers' major concern is the immediate scene ahead only a short time is spent away (about one second) compared to the looks lasting several seconds on the scene ahead. The actual time spent away from

Figure 26.--Plot of mean and standard deviations among subjects; mean time per in view look away from scene ahead; fine eye movements

the scene ahead can be governed by at least two phenomenon, 1) the need to return to the scene ahead and 2) the ability to quickly acquire the information in the scene ahead. The greater the clarity of the cues in the scene ahead, being processed by the periphery, the less the need to return. If it can be assumed that the peripheral acuity of the young (not measured) were better than aged, then their need to return to the scene ahead is not as great as the aged, hence the longer times away from the scene ahead for the young.

The merit of this interpretation can be somewhat tested by a closer look at the times away from the scene ahead. The above interpretation suggests that the greater the distance from the scene ahead (for the look away), the lower the clarity of the information ahead. The lower the clarity, the greater the need to return to the scene ahead. Thus, the further the fixation from the scene ahead, the shorter the fixation times. Figures 27 and 28 show that, indeed, this is the case for both age groups in the two tasks where differences between age groups were noted. Future studies where peripheral vision is mapped can explore this relation further.

When comparing the mean times away, the aged averaged almost half the time away, compared to the young. These very short times (.5 to .8 seconds) suggest that aged drivers were obtaining the information quickly and returning to the scene ahead as soon as possible. This interpretation suggests that aged drivers were searching near their capacity when away from the scene ahead. As such the individual subject mean times away for the aged group may be related to the

Figure 27.--Mean time per look away from scene ahead ($6^{\circ} \times 3^{\circ}$) as a function of degrees from scene ahead

Figure 28.--Mean time per look away from scene ahead

various capacity scores, primarily visual search and embedded figures. This potential relation is analyzed in a later section in this chapter.

Mean Fixation Time and Mean Time per Look in Scene Ahead

In the car-following task the young drivers had much longer times per look at the scene ahead than the aged drivers. An examination of the raw data revealed that the large value for the young was attributable to one young subject's data, the same subject for both day and night. Removing his data point reduced the mean to nearly the same value as the young, and thus no real differences in the mean times were noted.

Large Eye Movements

Table 20 shows that both groups used the mirrors and speedometer infrequently and total time out of view was around ten percent. Aged drivers spent less time on the mirrors and speedometer, but when they looked at these objects, aged drivers tended (not significant) to look longer than the young. These results indicate aged drivers make fewer looks to these objects not strictly essential to the immediate control task and spend more time in the driving scene. This finding can be interpreted as another manifestation of reduced capacity of the aged who need to spend more time acquiring information in the scene ahead.

Generally no differences in intersubject variability of the fine eye-movement measures were noted. The aged subjects had a larger intersubject variability in the activity measures for the night car following and the trend was similar for the other tasks. In the large

eye-movement measures, the aged group intersubject variation was larger than the young in the mean look times. In most of the measures, some of the aged subjects performed at the same level as the younger, but others performed at extreme levels compared to the young.

Results-Relations of Eye-Movement Measure to Scores of Basic Mechanisms

One concern in comparing the road to the lab is the representativeness of the smaller sample of subjects who performed the road tests. Appendix P shows that no significant differences were noted between the lab scores of subjects in the road tests compared to the lab scores of the full sample.

Only a few of the road measures showed any differences with age, and rather than display all the correlations of all the road measures with the lab, discussion will focus on the three most significant eye-movement measures, the mean travel distance activity index and the mean in-view time away from the scene ahead.

Mean travel distance

The mean travel distance in the day car-following task showed a significant difference with age. When comparing this measure in this task to the lab scores, the travel distance correlated with the embedded figures test score at $r = .718$ ($p < .01$), and not with the other scores.

The correlation can be interpreted as the larger the time to disembed the simple figure in the lab (i.e., lower capacity), the larger the mean travel distance on the road. This association between

the scores supports the arguments posed earlier that aged subjects, to obtain the same information as the younger, must search for more cues, and that the poorer the (lab) capacity to perceive information, the greater the mean travel distance.

Mean In-View Time Away for Scene Ahead

None of the correlations were greater than .39 (not significant) with all subjects combined. On the other hand, for the aged group alone, the correlation of mean time away with the visual search score was .53 ($p \approx .15$), and with the information processing rate at -.55 ($p \approx .15$) for the light traffic task in the day. For the young group alone, the correlations were not significant. These patterns of correlations indicate that longer mean times away for the aged are associated with larger times in the visual search scores (poorer capacity) and lower information processing rates. One possible explanation for these correlation patterns is that while the young were not performing at capacity when away from the scene ahead, and in no hurry to return to the scene ahead, the aged were trying to return as fast as possible to the scene ahead and were performing at capacity when away from the scene ahead.

In the night car-following task the correlation of mean time away with embedded figures was +.71 ($p \approx .15$). This correlation indicates that for the aged, longer mean times away are associated with longer times to disembed the simple figures in the lab.

Activity Index

During night car following, the activity index for the aged was significantly greater than the young. This measure correlated with the laboratory measure of slowing in the serial choice reaction test ($r = .66$, $p \leq .05$) but not with the other lab tests. Apparently, the activity is related to general slowing of response time.

Discussion and Conclusion

If all the eye-movement measures (central tendency measures) are taken as equally important then the absence of differences between age groups for most measures indicate no differences in information-seeking patterns in these tasks. This result is not particularly surprising since the tasks were normal driving tasks and as such require but little of drivers' capacities (e.g., Safford's spare visual capacity concept shows drivers have a large amount of spare visual capacity in normal driving). However, even in these relatively unloaded tasks, a few of the measures do indicate that drivers are performing near capacity. In particular, the mean travel distance was associated with the amount of cues required to obtain information. Where perceptual capacity to obtain information is low, a greater number of cues are required to obtain the same information. This interpretation was supported by a high correlation between the mean travel distance and the laboratory score in the embedded figures test (i.e., perceptual capacity to obtain information). Aged drivers, who have a lower capacity in the lab likewise have larger travel distances in the road task.

The results of another measure, the mean in-view time away from the scene ahead, showed significant differences between the age groups. The interpretation of this measure suggested that young and aged were not both performing (or needed to perform) at capacity. Young subjects did not require rapid return to the scene ahead and thus do not perform at capacity when away from the scene. On the other hand aged drivers needed to return to the scene ahead as quickly as possible, and as such performed at capacity when away from the scene ahead. This interpretation was supported by the correlations between the road eye movement measure, mean time away, and the lab scores of visual search capacity as well as the information processing rate for the aged drivers.

In summary, then, even in these relatively unloaded road tasks, there is some indication of differences with age and that the differences are associated, in part, with the differing capacities of the basic functional mechanisms in psychomotor performance.

CHAPTER VI

STUDIES IN DRIVER VELOCITY AND HEADWAY BEHAVIOR AND STUDIES OF DRIVERS PSYCHOPHYSICS PERFORMANCE

Studies of Driver Velocity and Headway Behavior

The vehicle velocity was recorded and reduced for the subjects who participated in the nighttime driving studies. In addition, car spacing or headway was also recorded and reduced for the two car-following studies at night.

The objectives of these studies were twofold:

1. To investigate differences in velocity and headway performance between the age groups.
2. To investigate relationships between performance in this task (i.e., a psychomotor measure) and laboratory performance scores in the basic functional mechanism comprising psychomotor performance.

Experimental Layout of the Studies

Figure 29 shows the experimental layout of the tasks for the velocity studies and for the headway studies. All subjects who drove in these studies also participated in the laboratory studies. Appendix P shows that the laboratory scores of this set of subjects did not differ significantly from the scores of the full sample who participated in the laboratory studies. Appendix H shows the actual order in which subjects drove the tasks; the order was randomly balanced and similar for both age groups.

	Young					Aged				
<u>Velocity Study</u>	Y01	Y02	Y03	Y04	Y05	A01	A02	A03	A04	A05
Light traffic, normal driving, (2 min.) night freeway										
Light traffic, sign reading, (3 min.) night freeway										
Car following, normal driving, (1.5 min.) night freeway										
Open Road, occlusion driving, (2 min.) night freeway										
Car following, occlusion driving, (2 min.) night freeway										
<u>Headway Study</u>										
Car following, normal driving, (2 min.) night freeway										
Car following, occlusion driving, (2 min.) night freeway										

Figure 29.--Experimental layout of the studies of velocity and headway behavior

Data Analysis Strategy

The data analysis strategy is essentially the same as for the road studies of occlusion behavior. In the first part of the analyses, measures were analyzed for differences between age groups. The second part of the analyses centered on the relationships between the road measures and lab measures. As in the previous chapters, the method of analyses were correlations.

Measures of Performance

For the velocity studies the measures were:

1. mean velocity - miles per hour
2. root mean square of the velocity

For the headway studies, the measures were:

1. mean headway - feet
2. root mean square of the headway

Results - Age Group Differences, Differences in Central Tendency of the Measures

The results of the t-tests for the velocity measures are shown in Table 21 and for the headway measures in Table 22.

Mean Velocity Age Group Difference

As Table 21 and Figure 30 show, the aged consistently miles per hour slower than the young. This result confirms findings

¹square root of sample deviations about mean; samples at about 1.5 per second for about two minutes

²square root of sample deviations about mean; samples at about 0.5 per second for about two minutes

Table 21

Results of t-tests Velocity Studies

Measure	Study	Mean Value		Significance ** $\Rightarrow p \leq .05$; * $\Rightarrow p \leq .10$
		Aged	Young	
Mean Vel mph (MV)	Light Traffic	52.8	58.3	**
Root Mean Sign (RMS)		2.89	2.74	
MV	Sign Reading	56.5	61.5	**
RMS		4.52	2.45	
MV	Car Follow Normal	55.9	59.8	**
RMS		2.23	2.05	
MV	Open Road Occlusion	50.4	58.0	**
RMS		1.84	2.71	
MV	Car Follow Occlusion	51.4	54.0	
RMS		3.04	2.07	

Table 22

Results of t-tests Headway Studies

Measure	Study	Mean Value		Significance ** $\Rightarrow p \leq .05$; * $\Rightarrow p \leq .10$
		Aged	Young	
Mean Headway	Car follow	100.7	70.9	
Root Mean Square	Normal	3.57	4.01	
Mean Headway	Car follow	99.7	123.3	
Root Mean Square	Occlusion	16.4	17.5

Figure 30.--Plot of mean velocities

of earlier studies (e.g., Case, 1970). The laboratory studies have shown aged drivers to have generally lower central capacities in several basic mechanisms, and thus they probably require more time to acquire information. Driving at slower speed is one way that aged drivers can compensate for their lower capacities by reducing the rate at which information must be obtained from the driving scene.

Root Mean Square of Velocity Age Group Differences

The root mean square (rms) of the velocity is a measure of an individual subject's (intrasubject) variability. The rms of the velocity for the aged subjects was significantly greater in the task of freeway sign reading and the trend was similar for all but one of the other tasks. Greater velocity variability is sometimes interpreted as related to higher accident rates. Thus, the larger intrasubject variability of the aged may be evidence of a larger accident liability.

Headway Measures Age Group Differences

None of the headway measures showed significant differences with age group. The mean headway was similar for both tasks, but the variability in headway, rms, was larger in the occlusion task compared to the normal car-following task.

In the occlusion car following task, both occlusion measures and headway measures were analyzed separately. It is possible to analyze both sets of measures as a dual task. As such, it might be expected that longer mean closed times would be associated with greater headway variation. The correlations, however, were not significant ($\alpha = .10$),

indicating analysis as a dual task is not warranted; the headway and occlusion measures can be analyzed and interpreted separately.

Intersubject Variability in Velocity and Headway

No significant patterns or trends were evidenced in the intersubject variances of the road measures.

Results - Relation of Velocity and Headway to Scores of Basic Mechanisms

Headway Measures and Correlation to Lab Scores

None of the headway measures correlated significantly with the lab scores. This result is not surprising since none of these measures showed differences with age.

Velocity Measures and Correlations with Lab Tests

Table 23 shows the correlations of the ten velocity measures (mean velocity and root mean square of velocity for the five tasks) with the five scores of basic mechanisms as well as the slowing measure in the serial choice reaction test. In three of the five tasks, driving speeds are correlated with slowing. This result indicates that slower driving speeds are associated with an overall measure of slowing of response time in the lab.

The table also shows that the mean velocity in the open road occlusion task is correlated with three of the other lab test scores of the basic functional mechanisms. Recall that this task was relatively loaded compared to the other normal driving tasks, and unlike the car following tasks, drivers were almost free to elect their velocity. The correlations indicate that slower mean speeds in this task are associated

Table 23
Correlation of Velocity Measures
with Lab Test Scores
(Night Driving)

	Embedded Figures	Visual Search	Motor Capacity	Infor. Proc. Rate	Memory Score	Slowing (SCRT)
Mean Velocity, Light Traffic	-0.584	0.122	0.445	0.140	-0.421	-0.411
Rms mean, LT	0.202	0.575	-0.423	-0.170	-0.157	0.177
Mean Vel., sign read	-0.802	0.122	0.577	0.583	-0.408	-0.624
Rms sign read	0.736	0.473	-0.610	-0.607	0.105	0.155
Mean Vel. Car follow normal	-0.558	-0.412	0.647	0.045	-0.101	-0.559
Rms vel. CF	0.146	0.552	-0.509	-0.142	-0.252	0.291
Mean vel., or OCCL	-0.807	-0.540	0.636	0.474	-0.689	-0.738
Rms vel., or OCCL	0.516	0.428	0.120	-0.084	-0.252	-0.250
Mean Vel., CF OCCL	-0.645	0.525	0.222	0.286	0.021	-0.317
Rms vel., CF OCCL	0.222	-0.135	-0.017	-0.145	0.164	0.471

N = 5 young
+ 5 aged

10 total

$\alpha \leq .01$ $r \geq .858$
 $\alpha \leq .05$ $r \geq .653$
 $\alpha \leq .10$ $r \geq .548$

with: 1) lower capacity to disembed the simple figure from a complex background. 2) lower capacity for motor control, and 3) lower memory capacity.

The root mean square of velocity in the sign reading task is correlated with the embedded figures test score and the motor capacity score. Apparently greater variability in velocity is associated with lower capacity to disembed the simple figure and lower capacity of motor control. One additional correlation to note is the motor capacity with mean speed in the car following task in the expected direction.

In summary, several of the road measures of velocity do appear to be associated with several of the lab scores of capacity and of slowing.

Discussion and Conclusion of Velocity and Headway Measures

The results of these studies show that aged drivers consistently drive several miles per hour slower than the young group. It was suggested that with the generally declining capacities and slowing of response, that aged drivers elect lower speeds to reduce the rate at which information must be obtained and responded to. In one task, sign reading, individual aged drivers were noted to have greater variation (intrasubject) in the driving speed. It was also suggested that this behavior may be accident related.

Significant relationships were found between the various lab measures of capacity and the velocity measures. Additionally the laboratory measure of slowing of response was associated with slower driving speeds. These relations support the earlier suggestion that slower speeds are compensating behavior for declining capacities. As cautioned in previous chapters, correlations cannot imply causation; they do,

however, provide quantitative estimates of the strength of association between the road measures and lab test scores. The values of the correlation, the pattern of relations, as well as the interpretations of these patterns, support the proposition that age related changes in performance on the road, a "real world" psychomotor task, are related to the various central capacities comprising psychomotor performance and to response slowing.

Studies of Drivers Psychophysics

Drivers estimated a series of velocities without the use of the speedometer and a series time intervals (see the Methodology chapter for more details) both day and night.

The objective of this study was to investigate differences in psychophysical performance between the age groups. Unlike previous chapters of road studies, which measured driving skills, psychophysical abilities studied are not considered psychomotor skills. The five mechanisms studied in the lab were those comprising general psychomotor performance (of which driving skills are a specific class). The psychophysical abilities are not generally conceived as psychomotor skills but rather as basic components themselves, specific to driving psychomotor skills.

Experimental Layout of the Studies

Figure 31 shows the experimental layout of the psychophysical studies. (All subjects who participated in these studies also performed

		<u>Daytime Studies</u>	<u>Nighttime Studies</u>
		Velocity Estimation Time Estimation	Velocity Estimation Time Estimation
Young	Y01		Y01
	Y02		Y02
	Y06		Y03
	Y07		Y04
	Y08		Y05
	Y09		A01
	A01		A02
	A02		A03
	A03		A04
	A04		A05
Aged	A05		
	A06		
	A07		
	A08		
	A09		

Figure 31.--Experimental layout of studies
of Drivers Psychophysics

in the lab studies). Appendix H shows the actual order in which subjects drove the tasks; the order was randomly balanced and similar for both age groups.

Data Analysis Strategy

In the first part of the analyses, the raw data were analyzed fitting linear regressions to the estimates given the requested values. The output of the regression were used to compute various measures which were analyzed for differences between the age groups, both central tendency, as well as the intersubject variability of the measures.

Results - Age Group Differences

Analysis of the raw data

In both the velocity estimation and time estimation tasks, eight estimates were requested. Inspection of the estimates revealed some subjects yielded extremely large errors in the first velocity estimate; thus the data for the last seven trials were analyzed. Similarly, inspection of the time estimates revealed large errors in the first two trials; thus the data for the last six trials were analyzed.

Naturally estimates were influenced by the requested levels; that is larger requested velocities and longer requested times yielded larger estimates (approximately 30 to 65 mph, and 7 to 14 seconds). It was assumed that estimation behavior for a given subject was homogeneous and that the data could be summarized by fitting linear regressions to each subject's estimates. The form for the regression equation is:

$$y = a + bx$$

where y is the estimate

a is the intercept

b is the slope of line

The output of the regressions includes estimates of a and b and the standard deviation of each constant. Additionally, the output yields an estimate of the standard deviation of the estimates given the regression fit.

An interpretation of each of these measures is necessary. If the coefficient, b , is equal to one and a is zero, then the subject can be said to be an accurate estimator. A subject can be considered precise (or reliable estimator) if the standard deviation of the estimates after regression is small. The concept of precision in these psychophysics tasks is general in that it is independent of the values of a and b . On the other hand, the concept of accuracy is very much dependent on the values of a and b . If a is large in absolute value and b is one, then the subject is inaccurate over the entire range of estimates. If b is other than one, at some point the two lines (estimate and perfect) will intersect and at this point the subject can be said to be accurate. Thus, it is not appropriate to use the constant ' a ' above as an estimator of accuracy, and another estimator is required. The accuracy of any estimate obviously must be interpreted relative to a single actual requested value. The actual value can be inserted into the equation

$$\hat{y}_0 = \hat{a} + \hat{b}x_0$$

where $\hat{a}$ and $\hat{b}$ are the estimates of the coefficients a and b

from the regression equation

x_0 is the actual value (velocity or time)

$\hat{y}_0$ is the predicted estimated value for x_0

The difference between the predicted estimated value and the actual value then is an estimator of the accuracy at x_0 . Rather than analyze the accuracy for all possible values of x_0 , the value of 45 mph was chosen since it represented the approximate midrange of velocity estimate behavior studied. Thus, the measure of accuracy for each subject was the difference between 45 mph and the predicted estimate for that subject (using the regression equations). Likewise the value of 9.0 seconds was used for the time estimates.

The value of b itself can be given some interpretation regardless of the value of a . The larger the value of b , the greater the sensitivity of the subject to the input values. The closer the value of b to one, the better the estimation behavior.

In summary then, the psychophysical behavior studied can be characterized by three concepts, each of which has an estimator:

<u>Behavior</u>	<u>Measure</u>
precision	std. error of y after regression
sensitivity	slope of the regression, b
accuracy	error of the prediction at a specified point (45 mph, 9.0 sec)

Regressions were run on the data and values for each of these three measures for both psychophysical tasks were computed.

Analysis of age group differences in the measures

The mean values for the measures of psychophysical performance are shown in Table 24.

Table 24

Results of t-tests for Psychophysics Measures

Measure	Study	Mean Value		Significance ** $\Rightarrow p \leq .05$; * $\Rightarrow p \leq .10$
		Aged	Young	
Velocity Estimation	Accuracy; predicted estimation error at 45 mph	Day	8.95 -3.23	**
		Night	8.60 5.42	
	Precision; std. dev. of est. after regression	Day	4.82 4.91	
		Night	3.61 4.38	
	Sensitivity; slope of regression	Day	1.06 1.24	*
		Night	1.14 .96	
Time Estimation	Accuracy; pre-dicted estimation error at 9.0 sec.	Day	-3.49 -.74	
		Night	-2.29 1.14	
	Precision; std. dev. of est. after regression	Day	1.27 1.19	
		Night	1.81 1.61	
	Sensitivity; slope of regression	Day	1.02 1.23	
		Night	1.48 .88	

Figures 32 and 33 are plots of the average regression lines for both groups of subjects, day and night. The t-tests show aged subjects perform quite differently than the young in the day with respect to the accuracy. Aged drivers greatly underestimated the true velocity of 45 mph while young slightly overestimated the speed. Even at night, the young subjects were closer to the perfect prediction line than the aged, though this trend was not significant. In the day, the young were somewhat more sensitive to input velocities as evidenced by their larger slope in the day.

None of the time estimation errors were statistically significant, however, young subjects tended to be more accurate than aged. This finding is in agreement with a study of time estimation by Bell (1972) as well as a study by LeBlanc (1966). Aged subjects tended to overestimate the interval.

Correlation of Psychophysics with Lab Tests

For the daytime psychophysical measures, the actual error was significantly correlated with several of the lab tests. The correlation indicated the greater the degree of underestimation, the longer the embedded figures test time ($r = .70$), the lower the motor capacity ($r = .73$), the greater the memory effect ($r = .72$) and the slower the overall response in the serial choice reaction test ($r = .82$).

Of the time estimation measures, only the slope was correlated with the search time ($-.56$) and slowing measure ($-.62$). None of the nighttime psychophysics measures were correlated with the lab scores.

Thus, except for the velocity error in the day, and the slope of the time estimate, the psychophysics measures were not significantly

Figure 32.--Plot of average regression lines
for velocity estimation performance

Figure 33.--Plot of average regression lines
for time estimation performance

correlated with the lab tests. This result is somewhat expected, since, as discussed earlier, psychophysics are themselves basic components of driving skills, rather than psychomotor skills. As such they should not be correlated to the lab tests of other components of psychomotor skills.

Correlation of Psychophysics with Road Tests

If the psychophysics capabilities are viewed as basic components specific to the driving skills, then the correlations of the psychophysics measures with the road measures are of some interest. In particular, one might expect the accuracy of the velocity and time estimates to be related to velocity and headway behavior; the correlations, however, were not significant ($\alpha = .05$). Correlations between these two psychophysics measures and occlusion measures revealed no significant patterns of correlations. One correlation deserves attention, the time estimation error with the mean closed time in the occlusion task ($r = -.53$, $p \approx .06$). In the occlusion studies, aged drivers had longer mean closed times than the young which was interpreted as a possible indication of greater risk taking behavior of the aged. The correlation indicates that the greater the degree of overestimation of time the greater the mean closed time. This result suggests that the longer mean closed times cannot be attributed to a problem of time concept. On the contrary, it suggests that the problem is compounded; that is, drivers who close their eyes longer also think they have closed them for even longer times than they actually have.

Discussion and Conclusion

The results of these studies indicate that aged drivers are less accurate than young in their psychophysical abilities to estimate speeds and time. Furthermore, the results of the two tests are consistent in that overestimation of time can be associated with underestimation of velocity (the correlation between these two measures of accuracy, however, were not significant). The error in estimation for the aged was very large at 45 mph, at about 8 mph. The results of the velocity studies indicated that aged drivers elected speeds several miles per hour slower than the young. Interestingly though, if the results of these two groups of studies are combined, it suggests that aged drivers may believe they are driving even slower than the actual velocities. In the studies of velocities it was suggested that aged drivers may slow the pace of driving to compensate for declining capacities. If so, it is possible that the aged driver may not be driving as slow as he would like, since his psychophysical ability to estimate speeds is inaccurate and biased toward underestimation. This interpretation suggests that the compensating behavior may be inadequate leading to a potentially hazardous situation. Future research should prove worthwhile to resolve the value of this interpretation. If verified, it would seem reasonable to provide aged drivers this information about their behavior so that they may consider altering their driving more in line with their capabilities.

CHAPTER VII
ANALYSIS OF INDIVIDUAL SUBJECT DIFFERENCES
AND SUMMARY OF RESULTS FOR LABORATORY
AND ROAD STUDIES

An Analysis of Subject Differences

The results in previous chapters have indicated differences between the age groups in a number of road and laboratory measures which suggested a general trend toward declining performance with age. The correlation between the laboratory and road measures also suggest the general nature of the association between pairs of laboratory and road measures. These analyses do not readily reveal relations among several measures simultaneously. One method of examining these relations is to look at an individual subject's set of scores in all measures. A question that can be asked, then, is to what extent are the scores of the subject whose score is high in one test, high in other tests. Within each test a subject's score can be contrasted to the other subjects' scores. An entire set of these scores and contrasts, for all measures, can be thought of as a performance profile. The construction and analysis of particular performance profiles for several subjects is discussed below.

An accounting of all test measures reveals that over two hundred measures were computed for each subject. The construction of a performance profile using all these measures, along with the consequent analyses, would be a confusing problem. To limit the size of the profile,

only measures which showed significant consistent age differences are considered. (Only a measure from a representative task is included).

The resulting profile then consists of seven measures:

1. embedded figures laboratory test;
2. visual search laboratory test;
3. motor control laboratory test;
4. mean open time, open road occlusion, day;
5. mean travel distance, car-following normal driving, day;
6. mean velocity, open road occlusion, night; and
7. velocity estimation error, day.

Rather than try to analyze a profile for every subject, to limit the discussion, only a few selected subjects are analyzed. The choice of the particular subjects can be arbitrary, but it is appealing to select aged subjects whose behavior was in some way noteworthy. The approach taken was to utilize this researcher's subjective estimates of subject driving competence, based upon impressions after spending several hours in the instrumented vehicle driving in numerous situations. Two of the aged drivers seemed superior in their driving abilities, A01 and A03, while two others, A05 and A08, seemed less competent than the other drivers. In addition to providing information on consistent patterns of performance, an analysis of the performance profiles for these subjects can provide insight into two additional questions:

1. To what extent do A01 and A03 have better performance scores than A05 and A08 on the various measures?
2. To what extent do the performance scores of A01 and A03 fall within the range of scores for the young?

Figure 34 shows plots of these four subjects' scores on each of the eleven measures. The construction of the plots requires some explanation for ease of analysis. For each measure the mean value for all young subjects who performed the test is plotted bounded by one standard deviation of their scores. Likewise the mean and standard deviation for all the aged subjects who performed the test are shown. Finally, plotted for each test are the scores attained by the four aged subjects with the points coded for ease of identification across tasks.

The first observation to make is that in two of the three laboratory tests, embedded figures, and motor (Nos. 1 and 3 in the figure), the two aged subjects who were subjectively labeled "better drivers" also had better performance scores than the two who were considered "poorer drivers." This observation is evidence in support of a consistent pattern of performance for subjects in lab tests. Interestingly, in none of these one laboratory tests did the performance of both of the "better" aged subjects fall within the range (plus or minus one standard deviation of the mean) of the scores for the younger subjects. That is, even these "better" aged subjects still generally performed more poorly than the younger in the laboratory tests.

In three of the four road measures (No. 4, 5, and 6), the two aged subjects who were subjectively rated "better drivers" had better performance scores than the two who were considered "poorer drivers." Interestingly, in measures 4 and 5, the performance scores of these "better" aged subjects were within the range of values of the younger drivers. These observations provide evidence of patterns of consistent performance throughout most of the measures. If attention is centered

Figure 34.--Plots of individual subject measures, performance profiles

on the scores for A01 alone (the filled circle), there is a clear pattern of his scores falling among the best for the aged group, and for a number of measures, among the range of the scores of the young. Conversely, the scores for A05 (the unfilled circles) fall consistently among the poorest for the aged and rarely within the range of scores for the young.

The results of these plots of individual subject scores provide evidence of a consistent pattern of performance throughout the measures. The separation of the scores for the two pairs of aged subjects seemed to be generally in agreement with the experimenter's subjective ratings of driving ability, a rather informal validation of some of the interpretations of direction of performance of the measures. And finally, some encouraging news for those concerned about the magnitude of these decrements with age were offered by the observed values of many of the scores for the "best" subjects to fall within the range of scores for younger drivers.

Analysis of individual subject scores also enables some insight into the distinction to be made between chronological age and "performance" age. Of the road measures studied, mean open time in the occlusion task yielded consistent differences in performance between young and aged and can be thought of as a measure of road performance age. In the lab the largest differences were noted in the embedded figures tests measure which can be thought of as a measure of laboratory performance age. By plotting the individual subject scores on these two measures along with the chronological age, insight into the differences between chronological age and performance age can

be affected. Figure 35 shows such a plot with lines drawn to connect subject scores on the scales. Note that though the chronological age scores are bunched at 23 and 65, performance age scores are well spread over the entire range. Thus, lines drawn from subject chronological age radiate to the "performance" age scores. On the other hand, lines drawn between the two "performance" age measures are more nearly parallel and distributed over the range of values. This graphical portrayal of the concepts demonstrates that chronological age is not highly related to "performance" age. Some aged subjects have performance scores more like young, while others are very far, indeed, from the young. The graphs also indicate that two separate measures of "performance" age are closely associated with each other.

Summary of Results and Discussions

Figure 36, shown at the end of this chapter, diagrams the major findings of the road and lab measures which showed differences with age and road and lab measures which were correlated.

Results of Laboratory Studies of Basic Mechanisms

Raw Data Results

The raw data for each of the laboratory tests consisted mainly of time and accuracy data. Large differences between the age groups were found and manifested mainly:

1. The mean time for the aged group was always slower than the young group.
2. The intrasubject variability of the aged group, as measured by performance variability from trial to trial, was generally larger than the young group. (The one notable

Figure 35.--Plots of individual subject values for performance age and chronological age

exception was the accuracy in dotting in the motor task where aged subjects were more consistent than young subjects.)

3. The intersubject variability in performance among the aged subjects was generally larger than the young subjects.

Capacity Scores of the Basic Functional Mechanisms

The five scores representing an index of capacity for each of the basic functional mechanisms all showed aged subjects to have lower capacities than the young (information processing rate was not significant, though the trend was evident). The intersubject variation among the aged subjects was generally greater for the aged subjects. The lower capacity scores were found for the following mechanisms (see Figure 21 for a summary of lab tests results):

1. capacity to disembed a simple figure from within a complex figure (a perceptual skill);
2. capacity to visually search a large area for simple targets (visual search);
3. capacity to centrally control fine, fast motor movements (motor control);
4. choice information processing rate; and
5. capacity to retain information in short term memory while executing additional concurrent functions of perceiving and responding (short term memory).

The capacity scores were generally uncorrelated lending support to the theoretical arguments of the uniqueness of each basic mechanisms.

Results of Road Studies of Drivers' Voluntary Visual Occlusion

Results Age Group Differences

The results of the voluntary occlusion studies included:

1. The aged drivers had mean "open" time, more than twice the value of the young drivers, indicating they needed much more time to acquire the information to maintain minimum control of the vehicle.
2. Intrasubject variation in the "open" times was greater for the aged, indicating some very long (several seconds) times to acquire the information.
3. The differences among the aged subjects tended to be larger than the younger group.

Results - Relation to Lab Scores

Mean open times were significantly correlated with the lab scores of embedded figures, visual search, and motor capacity.

The correlations support a strong relation between performance on the road, a "real world" psychomotor skill, and the various central capacities comprising general psychomotor performance.

Results of Studies of Driver Eye-Movement Patterns

The results were:

1. Mean travel distances and activity tended to be larger for aged subjects than young. Standard deviations of travel distances also tended to be larger for aged indicating some very large travels. This result was interpreted as an indication that aged drivers required to search more visual cues to obtain the same information as younger subjects.
2. Mean time away from the scene ahead (3° x 6°) was less for the aged subjects than the young (in the tasks of light traffic in the day and car-following at night). It was also noted that the further the distance from the scene ahead area (up to 3° away), the shorter the duration of that look away from the scene ahead. These combined results were interpreted as evidence of a difference in the need of the age groups to perform at capacity when away. Young subjects, it was suggested, did not need to return to the scene ahead as urgently as the aged and therefore did not perform at capacity. On the other hand aged subjects did try to return to the scene ahead as quickly as possible and therefore performed at capacity. The difference in need was attributed to a possible (not measured) difference

in parafoveal acuity (i.e., the clarity of information ahead is lower for aged, while looking away from the scene, as well as differences in the capacity to obtain information while looking ahead (i.e., visual occlusion times were longer)).

This eye movement result (2) is very interesting in that it is the only measure in all the studies in which aged were faster than young. However, the interpretation as well as the supporting correlations, discussed below, indicate this result is another manifestation of reduced capacity of the aged.

Results - Relations to Lab Scores

The mean travel distance was moderately correlated with several lab variables particularly the embedded figures test. This result supports the earlier interpretation of the greater need of aged to obtain more cues to acquire the same information.

With all subjects combined no relations of the lab scores to the road measure of mean time away were significant. However, for the aged group alone, the mean time away from the scene ahead was correlated with the visual search score. These correlation results provide some substantiation of the differential behavior of the young, not performing at capacity, and the aged who were, it was suggested, performing at capacity in visual search when away from the scene ahead.

Results of Studies of Driver Velocity and Headway Behavior

Age Differences

The results of these studies show that 1) aged drivers consistently drive several miles per hour slower than the young. It was suggested that with the generally declining capacities and slowing of response, that

aged drivers elect slower speeds to reduce the rate at which information must be obtained and responded to. 2) In one task sign reading intra-subject variation and standard deviation of velocity for aged subjects was larger than young. It was suggested that this behavior may be accident related.

Results - Relations to Lab Scores

The mean speeds were correlated with various capacity measures as well as the slowing measure. These results support the interpretation that aged drivers who have lower capacities, slow their speeds to reduce the rate of information exposure.

Results of Studies of Driver Velocity and Time Estimation

The results of these studies show that aged drivers greatly underestimate requested velocities, and tend to overestimate time. It was suggested that even though aged drivers may be compensating for declining abilities by driving slower, their compensation may not be as large as they would elect if their velocity estimating were more accurate.

Results of Analyses of Individual Subject Differences

The observational analyses of the performance profiles for several aged subjects indicated:

1. Subjects tend to have consistent performance scores (generally high or low) in many measures.
2. The subjective judgment by the experimenter of the aged drivers ability to drive was in harmony with and tended to validate the differences in scores on the performance profile.

3. The "better" aged drivers scores on many measures were within the range of scores for the younger drivers.
4. Chronological age was not highly related to individual "performance" age.

Figure 36.--Diagram of the major findings of road and lab measures which showed differences with age and correlations between road and lab

CHAPTER VIII

CONCLUSIONS, AND RECOMMENDATIONS

Conceptualization of Aging Driving Performance and Research Recommendations

In the introductory chapter of this dissertation a conceptualization of the basic functional mechanisms comprising general psychomotor performance was presented. This model served as a theoretical foundation for the laboratory tests which were designed to provide an index of capacity for the basic mechanisms. The results showed aged subjects exhibited lower capacities in these tests compared to young subjects. These scores were then related to the various measures of driving performance where differences between young and aged were found. The correlations generally supported the view that differences in road performance (i.e., psychomotor performance) were associated with reduced capacities in the basic functional mechanisms comprising general psychomotor performing.

The results of the driving studies, however, provide additional information upon which the earlier conceptualization of general psychomotor performance can be expanded and modified to the specific class of driving psychomotor skills. Figure 37 diagrammatically represents a conceptualization of aging and driving performance, which includes supporting results from the dissertation. As has already been mentioned, aging is seen to reduce the various central capacities.

Figure 37.--Conceptualization of aging and driving performance

Drivers can sense these reduced capacities and try to modify their behavior by compensating for these reduced capacities. If one considers that drivers require a critical perception-reaction time space to maintain safe driving, then the deficient capacities of the aged will effectively reduce this "space." The compensating behavior of the elderly drivers is to affect this "space" by increasing it toward a safe level.

Evidence of such compensating behavior was provided by the research findings that 1) aged subjects drove more slowly, 2) increased their mean open time in the occlusion task, 3) increased their visual search activity and travel distances, and 4) looked away from the scene ahead for shorter times and less percent time compared to the young subjects. By driving at slower speeds, aged drivers increase the perception-reaction space by both allowing more time for responses and by reducing the rate at which responses must be made. The larger mean open times in the occlusion task indicate that aged drivers must look for a longer period of time to obtain the same information to control the vehicle (i.e., the minimum information to maintain control of the vehicle). The increased search activity and longer travel distances of eye movements indicate that aged drivers are scanning a larger number of cues to obtain the information necessary to drive. Finally, the shorter times away from the scene ahead indicate that aged drivers want to take their eyes away from the critical information ahead as little as possible.

In spite of these results that show the compensating behavior of aged drivers, accident statistics indicate that elderly drivers

exhibit poorer accident rates than younger drivers. Assuming that the driving task requirements are the same, the model in Figure 37 suggests that the compensated behavior of the elderly drivers is not adequate to maintain the same safety margin as younger drivers.

There are several possibilities for this inadequacy of behavior. For one, the constraints of the driving task situation may not allow the aged driver the luxury of the compensating behavior he might otherwise elect. The social demand to maintain a high flow speed or a close headway are examples of this. Subjective responses of the comfortableness of the driving conditions in various tasks may offer some insight into this possibility.

The conceptualization suggests that compensating behavior can be inadequate if driver's self-concept of reduced capacities is in error. In the lab tests, aged subjects' responses in the serial choice reaction test were slowed by twenty percent compared to young drivers; in the search test, the aged subjects were almost fifty percent slower than the young; and most striking of the test results, the embedded figures test, showed aged drivers to be several hundred percent slower than the young. The combination of these reduced capacities would seemingly have a profound effect on aged drivers' perception-reaction space, and the slower speeds of only ten percent would seem to be but a minor offset to these changes in capacities. In fact, in the occlusion studies, aged drivers required twice the mean open times of the young to obtain the minimum information to control the vehicle. It would be interesting to study the subjective assessments of subjects' self-concepts of laboratory performance and the relation to actual performance.

The results of the velocity estimation studies suggest another possibility for the assumed inadequacy of aged drivers' performance, namely that drivers' self-concept of the level of compensation is in error. Aged drivers were found to greatly underestimate their velocities without the use of the speedometer. Extrapolating this psychophysical ability to normal driving suggests that aged drivers, even though they have slowed their speeds somewhat, are not driving as slowly as they would, had their velocity estimating capability been more accurate. Further research on this possibility would prove beneficial especially since corrective actions could be initiated by training and education programs for elderly drivers.

Finally, the results suggest one additional provocative possibility for the poorer accident rates of the elderly--they are accepting greater risks. In the occlusion studies, the mean closed times were longer for the aged than the young, an indication of greater risk-taking behavior by the elderly. This result is even further magnified when combined with the overestimation of time by the elderly. That is, the aged drivers may think they have kept their eyes closed for even longer periods than the already long times. Though the suggestion of greater risk taking by the elderly in driving is somewhat novel, a reflection on the lab research results indicates that greater risk taking by aged drivers is not unreasonable. The lab findings suggest that declines in some capacities are so large that aged drivers cannot really expect to completely compensate for them. Thus, even though aware of their deficient capacities, aged drivers accept greater risks than young by only moderately altering their performance compared

to young drivers. In conclusion, in view of the large differences in capacity found, the relatively small changes in driving performance and the results of the occlusion studies, further research into the concept of risk taking of elderly drivers certainly deserves some priority.

The conceptualization in Figure 37 which includes elements of declining capacity and compensating driving performance is not the only model which can be proposed to explain some of the differences found with age in driving performance. In particular, the more active eye movement patterns of aged would seem to be explained by a greater arousal, though no measure of arousal was included. The increased open times in the occlusion task as well as the tendency to longer viewing times in the scene ahead could be explained by a model which attributes this behavior to voluntary efforts to increase preview time. The slower speeds of aged drivers in a pacing model can be attributed to an attempt to reduce the rate of the "machine-paced" driving task. The need to reduce the pace is signaled not so much by the reduced mean capacity of a particular component skill as it is related to an increase in response time variability. These models need not be viewed as alternates to the capacity-compensation model, but can be considered as additional concepts which can be of some use to explain the results and the phenomenon of aging and driving. None of these additional concepts by themselves, however, would seem adequate to explain the increased accident rates of elderly drivers without some consideration of reduced capacity.

Research Extensions of the Model of Basic Components in Driving Psychomotor Skills

It seems obvious that a good deal of driving is a psychomotor skill comprised of the various capacities outlined. As such, it seems reasonable to associate lower capacities in psychomotor performance and poorer driving performance to increased accident liability (after all, accidents are the ultimate criterion). This is probably largely true, particularly once a sequence of emergency events requiring rapid accurate responses, has begun. Noteworthy, however, is that driving is often much more than a simple psychomotor skill, but a complex one involving higher cognitive and intellectual skills. For example, drivers can exercise trip planning to avoid surprise or quick decisions; they can avoid entering a situation that could tax their psychomotor skills; or they can avoid driving in certain locations or certain times that may tax them. When confronted with a developing hazardous situation, alternative actions are available to the driver and a judgement and decision must be made. Research in aging and these higher intellectual skills, judgemental skills and decision making skills is a definite need.

The conceptualization as presented does not reflect the potential effects of stress on the aged driver. The reduced capacities of drivers may be reflected by an increased frequency of critical events in driving. Once the driver is in trouble, the stress of the situation may reduce his capacities to respond appropriately and quickly even more. This feedback effect of reduced capacity and stress may compound the problems of the drivers. Research is needed to examine the

worth of this model by studying changes in driving performance and changes in capacities under stress.

In the lab tests, where the task requirements were demanding, very large differences in performance were found between the age groups. In the one set of road studies, the occlusion studies, large differences between the age groups were again found. On the other hand, in the other road tasks which were essentially normal driving, not a very task loaded situation, fewer differences were noted between the age groups. Nevertheless, the few differences found still were indicative of declining performance capability. A question of concern is the relation of these fewer differences to accident behavior (the ultimate concern in safety). A model of accidents might surmise that accidents primarily result from rare events when loss of control of the vehicle during steady state driving occur. As such the greater the degree of poorer performance in normal driving, basically the type of road behavior studied in this dissertation, the greater the potential accident liability. To the extent that this aspect of a model of accidents is true, the results suggest aged drivers have a greater liability to accidents. Another facet of an accident model would suggest that accidents are due to the inappropriateness or inadequacy of response when the driver is confronted with a hazard, or emergency situation not arising directly from the breakdown, or loss of control of his vehicle. This suggests then, that emergency response behavior is a major accident related psychomotor skill. An emergency task certainly is a highly loaded situation. It is in this type of situation that the failing capacities of the aged drivers are likely to be

greatly magnified. Thus, one area of research need is the study of aged drivers and emergency response behavior. Measurement of the basic capacities is also needed in these studies to assess the relation of the capacities to the emergency behavior.

In the introductory chapter, it was pointed out that aged drivers have high rates of accident involvement due to failure to yield the right of way, changing lanes, passing, turning, and stopping at stop signs and red lights. These situations are ones where the information demands of the tasks are high and the responses must take place within a short time interval. In addition, each of these situations involves a complex and highly time-compressed sequence of information acquisition and response behavior. The results of this dissertation indicate that aged drivers require more time to acquire information and more time to respond. In a time-compressed task aged drivers may fail to attain adequate information, or perhaps find themselves with too little time to respond. Research is required to determine the actual mechanism of behavior in these situations. An approach to the problem would require a detailed task analysis of the situation, an empirical study of the information acquisition and response patterns of drivers to determine the aged drivers' problems. The product of this research may well lead to appropriate corrective actions which could include training to acquire only the essential information, limiting response alternatives, or perhaps methods of avoiding these situations altogether.

Additional Research Extensions

Extensions of the Subject Population

Differences between the age groups in this dissertation were likely to be conservative due to the selective process for obtaining subjects. This hypothesis requires testing by an extension of tests to other less healthy aged drivers, female drivers, aged drivers who obtain less driving experience, and chronologically older subjects. These extensions will enable an assessment of the degree of decrement in performance in the entire aged population. The methodology can also be applied to the evaluation of other groups of drivers, with various handicaps, and to the evaluation of the effects of drugs on driving and the basic mechanisms.

Vision and Driving

The literature review did not offer much evidence that the capabilities of vision were much associated with psychomotor performance. However, in the interpretation of results of this study, it was suggested that parafoveal vision capabilities were likely important. This question deserves more careful theoretical and empirical research.

Basic Mechanisms and Driving

As argued, the correlations are only suggestive of relations. Controlled studies using adequate samples of drivers of the same age with various capacity levels can be conducted to further explore the nature and degree of relations. Four of the five mechanisms studied showed various correlations with road measures and should be included. Information processing rate as measured in the choice

reaction time test correlated least with the road measures. The classical interest in this test and measure is not to be taken lightly even though the current study did not point to a promising relation. A part of the difficulty with this lack of relation may well have been due to the method of procedure, the short test periods, due to practical constraints in test time. Reliable low variance estimates of the slope require extensive training and a great deal more trials, than were obtained in this study.

A basic shortcoming with the cross-age-sectional method of studying the relation between basic mechanisms and driving is that the mechanisms of how these abilities change within individuals cannot be estimated. The required methodology is a longitudinal age study. The practical problems of conducting such a study (e.g., support, personnel, testing equipment maintenance, subject attrition, obsolescence of methods, etc.) are, unfortunately, staggering.

Nondriving Research Recommendations

The conceptualization of the components of psychomotor performance developed was for general psychomotor skills of which driving tasks are a special class. The methodology developed is directly applicable to industrial psychomotor skills also.

A Note on Applications to Driver Licensing

Perhaps the most direct application of this research is driver licensing. Licensing officials may look to this research and other aging research as a guide to determining the competency of aged

drivers to drive safely. In its crudest form the licensing decision is to either grant or deny the permission to drive. This dissertation does provide evidence that the ability of aged drivers is probably somewhat lessened than younger. However, this work, does not resolve the question of adequacy to drive and to drive safely.

What this study does demonstrate is the large variation in performance capabilities from one aged subject to the next. Some subjects could hardly be distinguished from young while others showed large deviations. The narrow range of age and physical and visual health of the subjects, in fact, probably greatly underestimates the range of behavior of the entire aged population of drivers. This all points to the fact that chronological age alone is a very poor indicator of an individual's capability to drive. The only way to determine that is to test his psychomotor capabilities.

If drivers are required to return periodically for reexamination, then a testing strategy can be developed. The battery could begin with simple psychomotor tests in the office, followed by a test in an off-street lot. It has been suggested that the combined effects of changes in the psychomotor components would be most pronounced in an emergency situation. Thus, it would seem appropriate to develop a test that simulates this behavior. The measures in the test should include not only scores for the examiner's use, but should provide the aged driver with immediate and obvious feedback concerning his actual performance (i.e., knocking cones over). An example of such a test might include a narrow approach lane lined with cones (automatic reset and count), and a decision point with three lanes and

three lights, above the lanes. At the start of the task the center light is green, the two side lanes are red. If there is no change the driver proceeds on through. If the center turns red and one of the others turns green, the driver must maneuver to that lane. If the center turns red, and none of the others changes to green, the driver must stop. This test will tax various capacities such as motor capacity (maintaining lateral position in the approach lane, turning to the through lane), visual search (monitoring the lights), choice (determining which action to take), and overall response time (stopping too late or turning too late). Poor performance in this test will be obvious to the driver and will also signal the examiner of the need for further diagnostic tests. The results of diagnostic tests can provide the licensing agency the information needed to determine licensing restrictions, potential for retraining to counter particular deficiencies, or corrective actions for some deficiencies.

Periodic reexamination by the licensing agency is not a completely satisfactory approach. Not only is cost a problem, but the rate of reexamination may be too low to keep track of possibly rapid changes in performance within an individual with time. One alternative is to provide drivers a self test which they can use to determine the possible changes in their capacity, if required request additional diagnostic testing. A properly automated test station using the test described above could provide drivers the quantitative and self-evident performance measures.

One final note on the nature of reduced ability to drive and licensing must be made. That is many officials view the reduced

ability to drive mainly as a consequence of gross medical handicaps to drive caused by disease or injury, such as near paralysis, near blindness, advanced senility, etc. No one would argue that these factors result in extreme disability to drive. This dissertation however, emphasizes that even in the absence of these medical handicaps, many capacities in normal aged persons to perform psychomotor skills are drastically reduced and some driving measures likewise show changes. All of these changes are subtle to a casual observer of these subjects and were revealed only in controlled testing and quantitative measurement. Furthermore, it seems reasonable that these reduced capacities are relevant to ability to drive safely. Thus while some aged persons do have gross medical handicaps to driving safely, the majority of aged drivers who are without these medical handicaps are still subject to changes in capacity to drive safely. The widely ranging rates of these changes and their subtlety can easily be overlooked without individual driver testing.

It is hoped that the current research along with future studies of aging will be conceived of as providing information for more than just the decision to grant permission to drive or not. It seems clear that as the driver's abilities decline some situations may well be beyond the safe driving capabilities of that individual. The appropriate licensing action can be to restrict the places persons drive, or the times or even the situations. Research can provide the necessary diagnostic tools to guide this decision. Other solutions may also be appropriate, for example retraining to specifically

counter particular deficiencies. Beyond the licensing application aging research can lead to better vehicle and roadway design to accomodate the capacities of elderly drivers.

Finally, consideration must be given to the broad system in which aging research must apply. When the time comes that none of the remedial actions are adequate, and driving ceases, consideration must be given to meeting the mobility needs of the elderly with other forms of safe, convenient transportation. This broad view of the elderly driver in the transportation system is essential if society is to truly benefit by the research, and the aging driver, who after all is every one of us, can look forward, not with fear, but with peace of mind to those golden driving years.

APPENDICES

APPENDIX A

DETAILED DESCRIPTION OF LABORATORY TESTS

A. Introduction

Each of the laboratory tests is designed to provide an operational quantitative measure of one of the basic functional component skills as shown in the conceptualization of psychomotor skills in Figure 7. In addition to providing an index of efficiency of each basic mechanism, the tests were chosen to meet the following criteria:

1. Each test could be mastered by a subject within a few trials (i.e., repeated visits to the lab were not feasible).
2. The entire test battery needed to be completed within about two hours in a single session. (Any more time than this may fatigue the subjects and repeated lab visits were not feasible.)
3. Equipment for the tests had to be available within the labs or made available within limited constraints of time and money.
4. The measures of performance for each test were required at least theoretically to consist mainly of performance arising from the basic mechanism of concern.
5. Each test was designed or modeled from tests which, from previous laboratory studies have shown declines with age.

Ideally, it would be desirable to have a test battery which consists of at least several tests for each basic mechanism. This would facilitate a better estimate and understanding of the efficiency of the basic mechanisms. As noted above however, this was not possible due to time constraints. Nor was it feasible in this study to include lab tests of other concepts such as pacing, divided attention, or laboratory eye movements. Thus, time constraints, equipment constraints, as well as the lack of a theoretical basis in harmony with the conceptualization proposed in Figure 1 eliminated such tests.

With these general statements in mind, the proceeding sections are intended to give the reader important details of the purpose of each test. The experimental layout, the equipment used, procedures, instructions and measures of performance.

B. Motor Test

Purpose

The purpose of this test is to provide an index of the efficiency of the basic mechanism formed - capacity to control motor movements. This test is modeled after tests developed by Fitts (1967), and also by N. Welford (1959), to determine capacity changes with age.

Layout and Equipment

The subject sits at a table holding felt tip pen. The pen has been blunted and wrapped with tape to give a firm grip. In front of the table is a large sheet of paper containing two one-inch diameter circles drawn in black ink. In one case the centers of the circles are 12 inches apart and in the other, the circles are 24 inches apart. The subject is required to dot the felt tip pen within one circle, lift the pen and dot within the other circle, and to continue to go back and forth as quickly as possible.

Instructions

The subject is told the following instructions before testing:

"In this test you will be grasping this pen and dotting between these two circles as quickly as you can (demonstrated a couple of cycles). Try to keep the dots within the outline of the circle, however,

an occasional miss is not serious; just keep on going and dotting as quickly as possible. I will tell you when to start by saying 'go' and when to stop by saying 'stop'. We will do this a number of times. Are there any questions?"

Procedures

If there are no questions, the subject is asked to position the large paper with the two dots so that they are most comfortable for him. The paper is then taped to the table to prevent slipping. At this point the subject is asked to practice a couple of cycles. To begin a trial, the subject is asked to trace the pen touching inside one of the circles before receiving the instruction to start.

The experimenter holds a stop watch and simultaneously tells the subject to "go" and starts the watch. The experimenter counts the number of cycles to the nearest half cycle. When the clock reaches .30 minutes (or 18 seconds) the experimenter tells the subject to "stop". The experimenter records the number of cycles (to the nearest half). The time interval is constant for all trials. The paper is removed and a new paper secured for the next trial. The subject performs eight trials; four at 12" and four at 24". The order of trials is constant; 12", 12", 24", 24", 12", 24", 12", 24". The first forms are considered practice. Times varied little from the 5th and 6th to the 7th and 8th. Subjects did not report fatigue from the number of trials or trial lengths.

Typical Response Patterns

As shown in the figure below, young subjects frequently dotted outside the circle, while aged subjects usually dotted in a very compact pattern well within the circle.

Conversely, younger subjects appeared to have faster times. An analysis of these patterns is contained within the main body of the paper.

Measures of Performance

The classical measure of performance in this test is to combine the time and accuracy scores into a single measure of capacity to centrally control motor movements using the formula:

$$\text{time per move} = a + b \lg_2 \left(\frac{24}{W} \right)$$

where

A = Amplitude in inches (12" or 24")

W = Target width

$$\text{Time/move} = \frac{18.0 \text{ sec.}}{\# \text{ cycles} \times 2 \text{ moves/cycle}}$$

One system of scoring would assume that since the target was predefined as 1", this was the W to be used in the formula. (The nature of the test resulted in almost all the positioning and control to take place within the left and right direction so vertical dispersions did not seem relevant to this task.) On the other hand, response patterns clearly indicated that many aged subjects had an effective target width of less than one inch at the expense of time. Thus, the actual target

width was estimated as the width (horizontal) whose size enclosed all the dots for that circle. The W in the formula then was the average width for both dots in the trial of concern.

The time per move and the average effective accuracy attained in each case (12", 24") were also retained as measures. An analysis of these measures is contained in the main section of the paper.

C. Embedded Figures Test

The purpose of this test is to provide an index of the efficiency of the basic mechanism termed - perceptual capacity.

This test measures the subject's ability to quickly locate a simple geometrical figure in a larger complex geometrical figure. This ability to perceptually disembed requires the subject to locate the essential cues from other distracting and confusing cues. The greater the influence of the background cues, the longer the times, the greater field dependent a subject is said to be.

This test was developed by Witkins and is available in kit form with standard instructions (1971).

Layout and Equipment

The kit is provided with booklet, cards, scoring sheets, and tracing pencil. The experimenter provides a stop watch. The cards consist of two kinds, a group of twelve containing complex figures with straight lines and colors, and a group containing simple figures with straight lines. The cards are white background about 2 1/2" x 5" with complex figures about 1 1/2" to 2" in size, and simple figures about 1" in size (all black lines). The simple figures are always contained within the complex figure.

Instructions and Procedures

Instructions and Procedures are contained in the booklet provided with the kit. The testing begins with a practice set. Instructions begin with:

The Subject should be seated on the side of the table next to the Examiner so that the Examiner can present the cards and observe the Subject's tracing easily. He then says:

"I am going to show you a series of colored designs. Each time I show you one, I want you to describe it in any way you wish. I will then show you a Simple Form which is contained in that larger design. You will then be given the larger design again, and your job will be to locate the Simple Form in it. Let us go through a practice trial to show you how it is done."

The Examiner shows the Practice Complex Figure (P-X) for 15 seconds. He then covers it by placing the Practice Simple Form (P) over it. After 10 seconds he says:

"I will now show you the colored design again and you are to find the Simple Form in it. As soon as you have found The Simple Form let me know, and start tracing the Simple Form with this stylus. When you are tracing, do not let the stylus touch the surface of the card."

The Examiner then exposes the Complex Figure again by removing the Simple Form and turning it over. The Examiner now starts timing from zero. As soon as the Subject says he sees the Simple Form, the Examiner notes the time; if the Subject traces the Form correctly, this time is recorded on the data sheet as the solution time for the Practice Item.

Subjects usually have no difficulty finding the Simple Form in the Practice Complex Figure. If a Subject does have trouble, the Examiner may expose the Simple Form again and show the Subject where it is located in the Complex Figure.

After the Practice Item, the Examiner then says:

"This is how we will proceed on all trials. In every case the Simple Form will be present in the larger design. It will always be in the upright position, so don't turn the card around. There may be several of the Simple Forms in the same design, but you are to find and trace only one. Work as quickly as you possibly can, since I will be timing

you, but be sure that the form you find is exactly the same as the original Simple Form in shape, size and proportions. As soon as you have found the form, tell me at once and then start to trace it. If you ever forget what the Simple Form looks like, you may ask to see it again, and you may do so as often as you like. Are there any questions?"

The order of presentation of the twelve pairs is the same for all.

During the testing the subject is not allowed at any time to view the complex and simple form simultaneously.

Scoring

Present the first Complex Figure (1-A) and proceed as above on this and the remaining 11 test items; i.e., exposing each Complex Figure card for 15 seconds; then covering it for 10 seconds with the Simple Form which goes with it; and finally removing the Simple Form and beginning the timing. Be sure to turn the Simple Form over to its blank side when removing it, so that the Simple and Complex Figures are never visible to the Subject simultaneously. Be careful to present the correct Simple Form for each Complex Figure.

During the initial 15-second exposure of each Complex Figure, the Subject should be asked to describe it in any way he pleases. The purpose of this procedure is to impress the organization of the Complex Figure upon the Subject.

Timing

1. The stopwatch is started from zero as soon as the Simple Form is removed and the Subject is requested to locate and trace it in the Complex Figure.

2. As soon as the Subject reports that he sees the Simple Form, the Examiner should note the time elapsed but not stop the watch. If the Subject's tracing is correct, the time noted before the tracing began is recorded in Column 3 ("Time Data") of the Data Sheet.

3. If the Subject's tracing is incomplete or inaccurate, the Examiner should say: "No, that's not it," and continue to let the watch run. He records the time when the Subject first reports he has found the Simple Form in Column 3, with an (X) after it to indicate the solution was incorrect. When the Subject again reports he has found the Simple Form, the Examiner notes this time, but does not record it until the tracing itself is also correct.

4. If the Subject has not found the Simple Form in 3 minutes, say: "Let's try another one," and turn to the

next item. Record the solution time as 180" (F).

5. The Subject may examine the Simple Form again if he forgets it. Stop the watch and place the Simple Form over the Complex Figure for no more than 10 seconds. (Since the stopwatch is off at this time, the Examiner can determine the 10-second interval by counting to himself.) When the 10-second period is up, remove the Simple Form, exposing the Complex Figure, and restart the watch. For example, if the Subject asks to see the Simple Form after 34 seconds, stop the watch and show him the Simple Form for no more than 10 seconds, then remove the Simple Form and start the watch from 34 seconds. Record "S" on the Data Sheet each time the Subject is reshown the Simple Form, and the time at which he was shown it. The Subject may be shown a Simple Form as often as he requests it.

Determining the Subject's Score

The time of solution for each item should be converted into seconds and recorded in the last column on the Data Sheet. Failed items are entered as 180". The solution times for the 12 items are summed and divided by 12. The resulting value, which is the mean solution time per item, is the Subject's score for the tests. Other data recorded on the Data Sheet (such as times of incorrect solutions, number of incorrect solutions, and number of times the Simple Form has been reshown to the Subject) may be useful for research purposes and in individual clinical assessment.

Note one deviance from above, the experimenter stopped timing once the subject indicated he had located the form, if the tracing was correct, even if it was his second or third try. This does not affect young subjects' scores who usually traced the first correctly, and slightly underestimated aged subjects' scores who usually tried more than once. After 3.00 minutes transpired for a given card, the timing was stopped and the subject was shown the correct tracing, till he indicated his acknowledgement of its position. Even in this procedure, both types of cards were not presented simultaneously.

Typical Response Patterns

Young subjects took only a few seconds to locate the simple forms, but usually were slowed to a minute or more on one or two of the card pairs. Aged subjects were frequently unable to solve some card pairs, but occasionally took only a few seconds to locate a simple figure. The 12 problems are presented in the same order for all subjects.

Measures of Performance

The standard measure of performance for this test is the mean time per item (for the 12 items, or card pairs). In addition the standard deviation of a subject's times is also available as a measure. The data recording also noted the number of times a subject requested to reexamine the simple figure. Thus, another measure is available, the mean number of looks at the simple figure per item.

D. Choice Reaction Time Test

Purpose

The purpose of this test is to provide an index of efficiency of the basic functional mechanism termed "central translation". In this specific test, the behavior of interest is the ability to transmit stimulus information to response information in an information conservation task. The main focus in this test is the central decision or choice capacity. Though this ability has shown mixed results with respect to age changes (Welford, 1959), there is some indication this ability may well be related to poor driving ability, or poor accident records (Harano, 1970).

Experimental Layout and Equipment

The design of this type of test ideally involves a great deal of training with the experimental equipment and set-up so that all of the elements of performance in the test are so standard and overlearned that when changing the information load required to transmit, the only significant changes in scores can be attributed to changes in the central capacity to decide. Contributions due to motor time, response key search time, etc. are assumed to be constant. Unfortunately, constraints of experimental time for this one lab test (i.e., an entire battery of tests had to be given in a 2-hour session) did not permit the luxury of well practiced subjects. A version of this test was available as a program on the PDP8 computer and companion ASR type 33 teletype.

The surface of the teletype is masked save a narrow window just above the key punch area. Digits are printed below the teletype and are presented to the subject every 4 seconds. The subject responds by hitting the teletype key. The response is timed and the time is printed under the mask prior to the presentation of the next stimulus.

Instructions and Procedures

After seating the subject at the teletype, a sample stimulus presentation and key response are demonstrated. The experimenter then gives the following instructions:

"In this test the stimulus, a number, will suddenly appear in the window, as I have just shown you. As soon as it does, you are to respond as quickly as possible by hitting the key with the same number as the stimulus. Please use only one finger. In this set of trials,

you will only be required to respond to the '5' and '6' which are being presented in a random fashion. I've covered the other keys with tape. The first few trials are practice. Are there any questions?"

As noted in the instructions, the keys not of concern were covered with tape. The subject was told to put his finger back to a constant resting position. During testing subjects rested their finger above the center of the row of keys of concern.

Three levels of choice were available: 1-bit (2 choices, the digits 5 and 6), 2-bit (4 choices, the digits 3, 4, 5, 6) and 3-bit (8 choices, the digits 1, 2, 3, 4, 5, 6, 7, 8). Each bit condition was presented in a block of 16 trials. The first six were considered practice trials while the last ten were considered data. Each subject received a block of 2-bit trials followed by a 1-bit block and a 3-bit block. Stimuli sequence were determined randomly but held constant for all subjects. Instructions were altered to match the bit condition. The test took about ten minutes to perform.

Measures

The classical procedure is to fit a regression line with time as the dependent and bit level as the independent variable. The inverse of the slope is in units of bits/sec. Of course, the 0-bit reaction time can be predicted and used as a measure, as well as the average time to respond at each bit level, and the standard deviation of response times at each level.

E. Serial Choice Reaction Time Test - No Memory

Purpose

This test has two vital functions. One is to provide a baseline condition and a practice condition for the serial choice reaction time tests with memory loads. The other is to provide an estimate of the universally observed phenomenon of slowing of performance with age. This slowing is considered to consist of a combination of changes in efficiency of one, some, or all of the basic mechanisms. It is not intended to measure any particular one. Although each test in the lab battery has a measure of time, the efficiency of a single basic mechanism is considered mainly to give rise to such times. The SCRT test is designed to tax all (or most) functions. It is also ideally suited to the requirement of providing a reliable measure of slowing since it is easily mastered and a great number of trials can be performed in a few minutes.

Experimental Layout and Equipment

A program was written for the PDP-8 mini computer and teletype. The entire surface of the teletype is masked save a narrow window near the top of the roller. Digits are printed beneath the mask and are advanced to the window. The subject responds by hitting the key with the same number as the stimulus in the window. The test is demonstrated to the subject by way of example, while the following instructions are given:

"This test is very much like the test you just completed (choice reaction time) in that when a number appears in the window you are to hit the appropriate key as quickly as possible. However, it is different, since as soon as you hit the key the next stimulus appears in the window. You must respond as quickly as possible to this one

which again brings the next stimulus into the window. The numbers one through eight will be included and appear in random fashion. Please use only one finger. Let's go through a practice trial to give you the idea."

A short practice sequence of six or seven numbers is given. If the subject requests it, another short practice trial is given. The subject is then presented three blocks of 30 trials each. At the end of each block the computer prints beneath the mark the individual response times, their accuracy and a summary of the percent of correct responses, mean response time, and standard deviation of response times. Stimuli sequences were determined randomly, but held the same for all subjects.

Total test time is about 10 minutes.

Measures of Performance

Due to the possibility that subjects may not have been prepared for the first stimuli of each block that statistics provided were adjusted to eliminate this one time. The mean time, correct percent of responses, and standard deviation of times are measures for this test.

F. Serial Choice Reaction Time Test - Light Memory Load

Purpose

This test was given as a practice or introduction to the SCRT with heavy memory load.

Experimental Layout and Equipment

This test is identical to the SCRT - with no memory save one

detail. The stimuli are organized so that the number to be responded to is not the number that is currently in the window, but the number that was just in the window. Actually, if short term memory is not taxed at all, the test acts very much like a preview test, and subjects can respond even more quickly than in the case with no memory. This was the case for a number of subjects. The test is not a measure of simple memory where nothing else is required of the subjects except to store some information for later retrieval. This ability has not been shown to change much with age.

On the hand, when other activities interfere with memory, and must be performed simultaneously with maintaining memory, changes with age are noted (Kirchner, 1958). This test is modeled after Kirchner's. Subjects are given a series of short practice trials till they and the experimenter are certain the subject understands the test. Subjects perform three blocks of thirty trials.

Measures of Performance

Measures are the same as SCRT except that the first and last responses in the block are eliminated from the computations due to the possible biases introduced starting and stopping the block of trials.

This test was easily mastered by all subjects and was not used to score memory. It served as practice for the next set of trials with heavy memory load.

G. Serial Choice Reaction Time Test - Heavy Memory Load

This test provides an index of efficiency of the basic functional mechanism termed "short term memory" with a heavy load. It is like the

SCRT light load test except that the subject responds to the second number behind the window. Scores are corrected to eliminate the first two and last two responses.

H. Visual Search Test

Purpose

The purpose of this test is to provide an index of efficiency of the basic functional mechanism termed "visual search." Past research with the aged (Talland, 1966) indicates that his ability declines with age. Furthermore, it is commonly acknowledged that search for information is an important component skill in automobile driving.

Experimental Layout and Equipment

A series of 24 slides are presented to the subject with a 35mm carousel projector. The subject is seated approximately 4 feet in front of the screen. The visual field covered by the target is approximately 25°. The target consists of 25 circles. Most of the circles contain a line bisecting the circle; the line always forms an angle of 30° with the vertical. A few of the circles are open, with no line bisecting them. Each slide contains one, two, three, or four open circles. A set of twelve slides is presented twice (unknown to the subject) where the first twelve are considered practice. Within the set of twelve, the slides with the number of open circles appear the following number of times:

<u>slide type - no. of open circles</u>	<u>no. of times presented</u>
4 open	2
3 open	4
2 open	4
1 open	<u>2</u>
	12 slides

The order of slide presentation is randomly determined but the same for all subjects. The position of the open circle(s) within the array is randomly determined with the following restrictions on randomization: a) the first and the last circles are always closed, and b) two open circles could not appear adjacent.

The array size and type were chosen based on a pilot with different numbers, sizes, and spacing of circles. For easier arrays, responses appeared to be so rapid as to preclude visual search or require fixations. More difficult arrays appeared to approach possible confounding with acuity. The response times for arrays chosen were about 2 seconds, which appeared to: a) be much larger than a simple reaction time without fixations, b) but not so long as to tax the acuity capability of the subjects or the perceptual skills in identifying and recognizing targets.

The slide is advanced to the show position and then flashed onto the screen with a tachistoscopic device. The onstart of the flash triggers an electronic timing device. The subject responds by hitting a microswitch which stops the timer. Times are recorded to the nearest 1/1000 of a second.

Instructions and Procedures

The subject is seated at the booth and shown a sample slide with three circles to demonstrate the two types of circles to be seen, open

and closed. The subject is then told, "You will be shown a series of slides with a whole row of circles, most of which have lines through them like the sample circles. Let me show you quickly what I mean by a row." A slide from the practice set is flashed for a fraction of a second to demonstrate the width of a row. Then the sample slide of three circles is turned on again and the instructions continue, "As soon as the slide flashes on, I want you to look it over as quickly as possible and determine how many circles are open. As soon as you are sure how many are open, push this switch. As soon as you push the switch the slide will turn off (demonstrated to the subject). As soon as you have pushed the switch, tell me how many circles were open. The first few trials are practice. However, you should note that there will always be at least one open circle, but never more than four. Thus, your verbal response will always be 'one', 'two', 'three', or 'four'." The experiment then commences and questions are answered, if required early during the practice set. The slide is triggered on by the experimenter and triggered off again as soon as the subject responds (as noted by the electronic clock stopping). Times and number of targets seen are manually recorded.

Response Patterns

Subjects generally responded in two to four seconds, much longer times than reaction times; thus most of the response time can be considered visual search time. Wrong reports were rare.

Measures

The measures for this test were mean response time as well as standard deviation of response time.

APPENDIX B

TABLE 25

SUBJECT RESPONSES TO APPLICATION QUESTIONNAIRE

Subjects	Drive Daily?	Drive Freeway?	Drive at Night?	Glasses to Drive?	Accidents- last 3 yrs.	Violations- last 3 yrs.	Car now driv- ing full size, power	Miles driven last year	Like to Drive	Age Now	Age 1st Drove	Years Driv- ing Exp.	Current Occupation	# Years Retired	Previous Occupation if Retired
Y01	Y	Y	Y	N	N	N	Medium	10,000	Y	29	16	13	S	--	-----
Y02	N	Y	Y	N	N	1	Full	5,000	Y	22	16	6	S	--	-----
Y03	Y	Y	Y	Y	N	N	Medium	15,000	Y	23	16	7	S	--	-----
Y04	Y	Y	Y	N	N	N	Medium	10,000	Y	23	17	6	S	--	-----
Y05	Y	Y	Y	N	N	2	Small	20,000	Y	22	16	6	S	--	-----
Y06	Y	Y	Y	N	N	1	Small	14,000	Y	21	16	5	S	--	-----
Y07	Y	Y	Y	N	N	N	Small	16,000	Y	25	16	9	S	--	-----
Y08	Y	Y	Y	N	N	1	Medium	10,000	Y	22	13	9	S	--	-----
Y09	Y	Y	Y	N	N	1	Medium	15,000	Y	24	16	8	S	--	-----
Y10	Y	Y	Y	Y	N	N	Medium	----	Y	21	16	8	S	--	-----
A01	Y	Y	Y	N	N	N	Full	6,000	Y	65	16	49	R	6	Sales
A02	Y	Y	Y	Y	N	N	Full	10,000	Y	67	20	47	R	4	Professor
A03	Y	Y	Y	N	Y	Y	Full	15,000	Y	62	16	46	R	1 mo.	Machinist
A04	Y	Y	Y	Y	N	N	Full	12,000	Y	64	14	50	R	1 mo.	Accountant
A05	Y	Y	Y	N	N	1	Full	25,000	Y	70	11	59	Florist	--	-----
A06	Y	Y	Y	Y	N	N	Medium	6,000	Y	63	12	51	R	2	Foreman
A07	Y	Y	Y	Y	N	N	Medium	25,000	Y	67	9	58	Ind. Sup.	--	-----
A08	Y	Y	Y	Y	N	N	Full	25,000	Y	68	9	59	R	3	Electrical Contractor
A09	Y	Y	Y	Y	N	N	Full	7,500	Y	67	16	51	R	4	Athletic Club Manager
A10	Y	Y	Y	Y	N	N	Full	20,000	Y	60	14	46	Eng. Tech.	--	-----
A11	Y	Y	Y	Y	N	N	Full	20,000	Y	62	19	43	R	1/2	Supervisor
A12	Y	Y	Y	Y	N	N	Full	9,000	Y	69	9	60	R	3	Public Relations
A13	Y	Y	Y	N	N	N	Full	6,000	Y	67	16	51	R	3	Sales

APPENDIX C

TABLE 26
RESULTS OF VISION EXAMS

Subject	Far Acuity	Glasses	Exam Method	Accommodation
Y01	20/20	No	TITMUS	--
Y02	20/17	No	TITMUS	--
Y03	20/20	Yes	TITMUS	--
Y04	20/35	No	TITMUS	--
Y05	20/17	No	TITMUS	--
Y06	20/13	No	TITMUS	--
Y07	20/18	No	TITMUS	--
Y08	20/15	No	OPTOM	7.0
Y09	20/17	No	TITMUS	--
Y10	Not Tested	Yes	Not Tested	Not Tested
A01	20/35	No	OPTOM	1.0
A02	20/13	Yes	TITMUS	--
A03	20/17	No	TITMUS	--
A04	20/20	Yes	OPTOM	1.50
A05	20/40	Not in Day	TITMUS	--
A06	20/20	No	OPTOM	1.50
A07	20/25	Yes	OPTOM	0.50
A08	20/20	Yes	OPTOM	1.50
A09	20/20	Yes	OPTOM	1.00
A10	20/25	No	OPTOM	0.05
A11	20/20	Yes	OPTOM	0.75
A12	20/20	Yes	OPTOM	0.75
A13	20/30	Yes	OPTOM	1.0

**Consent to Serve as a Subject in Research
on the Project
"Age-Related Changes in Drivers' Visual Search Patterns
and Driving Performance"**

I consent to serve as a subject in the research investigation entitled "Age-Related Changes in Drivers' Visual Search Patterns and Driving Performance." The nature and general purpose of the experimental procedure, experimental equipment, and the known and unknown risks involved have been explained to me by _____.

I understand that I will be driving an instrumented vehicle on the highway while I perform a number of driving tasks. Many of the tasks are those performed in normal driving. During several other tasks, procedures different than normal driving will be used. For some of these tasks, I understand that I will be asked to close my eyes for brief periods while driving, and in others I will be driving without the use of the speedometer. I also understand that during part of the driving time, I will be wearing the helmet and bitebar required to stabilize the eye movement recording equipment, as demonstrated to me. I also understand that at any time during the driving should the helmet and bite bar become uncomfortable, I may indicate so to the experimenter who will immediately instruct me to pull to the road shoulder and who will readjust or remove the helmet and bite bar to relieve the discomfort.

I understand that the primary risks associated with the driving for the research study are those normally associated with automobile driving. In addition there are potential, but unknown risks associated with experimental procedures in driving, and with wearing the helmet and bite bar.

The experimenter is authorized to proceed on the understanding that I may terminate my service as a subject in this research at any time I so desire. It is also understood that the experimenter may terminate the experiment at any time at his discretion.

I understand also that it is not possible to identify all potential risks in an experimental procedure, and I believe that reasonable safeguards have been taken to minimize both the known and the potential but unknown risks.

Witness _____ Signed _____
(investigator) (subject)

Date _____

APPENDIX E

ROAD TESTS INSTRUCTIONS

Task A, Freeway, Light Traffic

Please drive the car in your normal manner at about 50 or 60 mph and try to have a clear road ahead of you as much as possible. Are there any questions?

Task E

Please drive in your normal manner and exit at I-270 West. Are there any questions?

Task B, Freeway, Car Following

The lead car will be traveling ahead of you at a constant speed. We would like you to drive behind the lead car (as if you were on a two-lane highway attempting to pass, but were unable to do so because of oncoming traffic in the left lane) and try to hold this car at that distance as well as you can. Are there any questions?

Task C, Freeway, Occlusion, Open Road

During this part of the experiment, we want you to drive this car in your normal manner at about 50 or 60 mph. Please stay in the right lane.

In addition, we would like you to drive with your eyes closed as much as possible, but make sure you keep the car within the white lane markers. The safety man seated next to you will take care of any unusual events. Are there any questions?

Task F, Rural Highway Curves

During this part of the experiment, we would like you to drive in your normal manner to a place where we will tell you to turn around. At that time I will ask you to estimate how much time it took to make the trip. We will then ask you to turn around and drive back the same way we came, and again ask you to estimate the time for the trip. Please obey the speed limit signs at all times. Are there any questions?

Task D, Freeway Occlusion, Car Following

The lead car will be traveling ahead of you at a constant speed. We would like you to drive behind the lead car as if you are on a two-lane highway attempting to pass but were unable to do so because of oncoming traffic in the left lane. Try to hold the car at that distance as well as you can. In addition, we would like you to drive with your eyes closed as much as possible, but make sure you keep the car within the white lane markers. As before, the safety man seated next to you will take care of any unusual events. Are there any questions?

Tasks G and H: Velocity Estimation (with Time Est.) and Time Estimation

During this part of the experiment, you will be driving the vehicle without the use of the speedometer. I will instruct you to a certain speed by telling you to "slow down" or "speed up" informing you when you have achieved the proper speed. I want you to maintain that speed as accurately as you can. While maintaining that speed, I will present an interval of time signified by the words, "start" and "stop." I then want you to give me two numbers--first, your estimate of that speed, and, second, your estimate of the time interval. Are there any questions?

APPENDIX G

TABLE 27
SEQUENCE OF ROAD TEST BATTERY AND LAB TEST BATTERY

Subjects	Order				Procedure			
	1st	2nd	3rd	4th	LT	DR	NL	NH
Y01	DR	NL	NH	LT	4	1	2	3
Y02	DR	NL	NH	LT	4	1	2	3
Y03	NH	NL	LT	--	3	--	2	1
Y04	NL	NH	LT	--	3	--	1	2
Y05	NH	NL	LT	--	3	--	2	1
Y06	DR	LT	--	--	2	1	--	--
Y07	DR	LT	--	--	2	1	--	--
Y08	DR	LT	--	--	2	1	--	--
Y09	DR	LT	--	--	2	1	--	--
Y10	LT	--	--	--	1	--	--	--
A01	LT	DR	NL	NH	1	2	3	4
A02	NH	NL	LT	DR	3	4	2	1
A03	NL	NH	LT	DR	3	4	1	2
A04	NL	LT	NH	DR	2	4	1	3
A05	NH	NL	DR	LT	4	3	2	1
A06	LT	DR	--	--	1	2	--	--
A07	LT	DR	--	--	1	2	--	--
A08	LT	DR	--	--	1	2	--	--
A09	LT	DR	--	--	1	2	--	--
A10	LT	--	--	--	1	--	--	--
A11	LT	--	--	--	1	--	--	--
A12	LT	--	--	--	1	--	--	--
A13	LT	--	--	--	1	--	--	--

LT lab test
DR day run
NL night lo
NH night hi

APPENDIX H

ORDER OF ROAD TESTS SESSION

The question of which order subjects performed each road session can be interpreted from several points of view. Recall that most of the subjects participated also in the studies on carbon monoxide, but only the data from the NO CO dose was analyzed in the current project. Thus, one method of interpreting order effect is to determine the session number of the data analyzed in this study, as shown in Table 28. Some subjects participated in night as well as day runs, and the order of this condition is shown in Table 29. In the current study, only the data from one, or at most two sessions, were analyzed. Furthermore, the major concern of the run order is the effect of the novelty of the first time wearing the equipment on driving the complete road session. Thus, the order can be reduced to two states, 1 = the first time participating, and 2 = second or later session number. Table 30 shows the order for each subject's session utilizing this coding scheme. For convenience of referencing, this order for various subsets of subjects is shown separately. Note that the order was reasonably balanced, or similar for the groups of young and aged within each condition (day, night).

Table 28

Driving Session Number of the
Session Used in This Project

Subject	Day Session Analyzed	Night Session Analyzed	Total # of sessions par- ticipated in (All Studies)
Y01	2	3	1
Y02	1	3	4
Y03	-	2	2
Y04	-	1	2
Y05	-	2	2
Y06	1	-	2
Y07	4	-	4
Y08	1	-	1
Y09	1	-	2
A01	1	2	3
A02	3	2	3
A03	3	1	3
A04	3	1	3
A05	3	2	3
A06	1	-	1
A07	1	-	1
A08	1	-	1
A09	1	-	1

* Session numbers not shown were "Hi-Co" runs. Also, the open road and car-following tasks were always performed within a test session and in the same order, OR, CF.

Table 29
Order of Condition (Day, Night)
of Driving Session

Subject	Day Condition	Night Condition
Y01	1	2
Y02	1	2
Y03	-	1
Y04	-	1
Y05	-	1
Y06	1	-
Y07	1	-
Y08	1	-
Y09	1	-
A01	1	2
A02	2	1
A03	2	1
A04	2	1
A05	2	1
A06	1	-
A07	1	-
A08	1	-
A09	1	-

Table 30

Road Session Order, First Versus Non First

All Road Subjects			Occlusion Study Subjects				Eye-Movement Study Subjects			
Subject	Day	Night	S	Day	S	Night	S	Day	S	Night
Y01	2	2	Y01	2	Y01	2	Y01	2	Y01	2
Y02	1	2	Y02	1	Y02	2	Y02	1	Y02	2
Y03	-	2	Y06	1	Y03	2	Y06	1	Y03	2
Y04	-	1	Y07	2	Y04	1	Y07	2	Y04	1
Y05	-	2	Y08	1	Y05	2	Y08	1	Y05	2
Y06	1	-	Y09	1			Y09	1		
Y07	2	-								
Y08	1	-	A01	1	A01	2	A01	1	A01	2
Y09	1	-	A02	2	A02	2	A02	2	A02	2
			A03	2	A03	1	A03	2	A03	1
A01	1	2	A04	2	A04	1	A04	2	A04	1
A02	2	2	A05	2	A05	2	A05	2	A05	2
A03	2	1	A06	1			A06	1		
A04	2	1	A07	1			A07	1		
A05	2	2	A08	1			A08	1		
A06	1	-	A09	1						
A07	1	-								
A08	1	-								
A09	1	-								

APPENDIX I

TABLE 31
Intercorrelations of Occlusion Measures - Open Road, Daytime

CORRELATION MATRIX Aged and young combined, N=15

VARIABLE NUMBER	1	2	3	4	5	6
		b				
1	1.000	0.766	0.189	0.342	-0.600	0.645
2		1.000	0.226	0.252	-0.700	0.735
3			1.000	0.511	-0.700	-0.057
4				1.000	-0.038	0.216
5					1.000	-0.047
6						1.000

CORRELATION MATRIX Aged only, N=9

VARIABLE NUMBER	1	2	3	4	5	6
1	1.000	0.579	-0.607	0.025	-0.932	0.981
2		1.000	-0.419	0.016	-0.405	0.674
3			1.000	0.145	-0.862	-0.600
4				1.000	0.129	0.002
5					1.000	-0.961
6						1.000

CORRELATION MATRIX Young, N=6

VARIABLE NUMBER	1	2	3	4	5	6
1	1.000	0.887	0.836	0.562	-0.824	0.000
2		1.000	0.708	0.818	-0.741	0.555
3			1.000	0.851	-0.304	0.528
4				1.000	-0.033	0.556
5					1.000	-0.826
6						1.000

^a Variable number	Variable Description
1	Mean open time (sec)
2	Std. dev. of open time
3	Mean closed time (sec)
4	Std. dev. of closed time
5	percent time closed
6	Perceptual uncertainty index

^b Circled numbers significant at $\alpha \leq .05$

TABLE 32
Intercorrelations of Eye-movement Measures - Open road, Daytime

CORRELATION MATRIX (SAMPLE SIZES IN PARENTHESES)										
VARIABLE NO. a	1	2	3	4	5	6	7	8	9	10
1 *	1.00000 (14)	0.86152 (14)	0.10078 (14)	0.00348 (14)	-0.29202 (14)	0.91511 (14)	0.51758 (14)	0.88336 (14)	0.77142 (14)	-0.33860 (14)
2 *		1.00000 (14)	-0.02627 (14)	-0.13259 (14)	0.01579 (14)	0.87101 (14)	0.53622 (14)	0.86458 (14)	0.71342 (14)	-0.37121 (14)
3 *			1.00000 (14)	0.80046 (14)	0.11128 (14)	-0.16441 (14)	0.06194 (14)	-0.08576 (14)	-0.06293 (14)	-0.08717 (14)
4 *				1.00000 (14)	0.09244 (14)	-0.14589 (14)	0.21980 (14)	-0.05079 (14)	0.18726 (14)	-0.22536 (14)
5 *					1.00000 (14)	-0.18677 (14)	0.43123 (14)	-0.01426 (14)	-0.20108 (14)	-0.46725 (14)
6 *						1.00000 (14)	0.62581 (14)	0.96610 (14)	0.79998 (14)	-0.37020 (14)
7 *							1.00000 (14)	0.73635 (14)	0.58943 (14)	-0.76882 (14)
8 *								1.00000 (14)	0.83569 (14)	-0.47934 (14)
9 *									1.00000 (14)	-0.45467 (14)
10 *										1.00000 (14)

TABLE 32 (cont'd)

VARIABLE NO. (CONTINUED)			
	11	12	13
1 *	0.31398 (14)	<u>-0.75703</u> (14)	0.36631 (14)
2 *	0.18544 (14)	<u>-0.58762</u> (14)	0.12794 (14)
3 *	-0.07926 (14)	0.54719 (14)	-0.16075 (14)
4 *	-0.25787 (14)	0.22714 (14)	-0.21847 (14)
5 *	-0.57761 (14)	0.36625 (14)	<u>-0.71254</u> (14)
6 *	0.26978 (14)	<u>-0.72550</u> (14)	0.20642 (14)
7 *	-0.41172 (14)	-0.20462 (14)	-0.27461 (14)
8 *	0.12174 (14)	<u>-0.66668</u> (14)	0.15121 (14)
9 *	-0.01332 (14)	<u>-0.56135</u> (14)	0.02976 (14)
10 *	<u>0.65271</u> (14)	0.26311 (14)	<u>0.63643</u> (14)
11 *	1.00000 (14)	-0.28382 (14)	<u>0.82790</u> (14)
12		1.00000 (14)	-0.35390 (14)
13			1.00000 (14)

a

No.	Variable description
1	Mean fixation time
2	Std. dev. of fixation time
3	Mean travel distance in visual degrees
4	Std. dev. of travel distance
5	Concentration index, 3x3 degrees
6	Mean time per area
7	Percent time in scene ahead, 3x6 degrees
8	Mean time per look in scene ahead
9	Std. dev. of look times in scene ahead
10	Percent in-view time away from scene ahead
11	Std. dev. of look times away from scene ahead (all)
12	Activity index, degrees per second
13	Mean time per in-view look away from the scene ahead

b

Circled numbers significant at $\alpha = .05$

APPENDIX J

TABLE 33
REGRESSION COEFFICIENTS FOR
CHOICE REACTION TIME TEST DATA

Subject	a	Std. dev. a	b	Std. dev. b	Information Processing Rate 1/b
Y01	.440	.022	.051	.0101	19.61
Y02	.348	.044	.127	.0203	7.84
Y03	.358	.020	.087	.0092	11.43
Y04	.371	.052	.102	.0241	9.76
Y05	.330	.032	.114	.0147	8.77
Y06	.318	.034	.111	.0157	9.01
Y07	.342	.055	.115	.0257	8.70
Y08	.407	.044	.090	.0205	11.05
Y09	.412	.028	.073	.0129	13.70
Y10	.315	.021	.087	.0110	11.43
A01	.719	.103	.180	.0476	5.57
A02	.331	.089	.196	.0414	5.10
A03	.312	.066	.209	.0304	4.77
A04	.428	.055	.096	.0254	10.42
A05	.532	.054	.111	.0249	9.05
A06	.372	.024	.068	.0111	14.71
A07	.433	.091	.116	.0423	8.66
A08	.510	.042	.066	.0193	15.27
A09	.403	.055	.099	.0253	10.05
A10	.466	.033	.079	.0151	12.66
A11	.359	.072	.197	.0332	5.08
A12	.470	.061	.106	.0282	9.43
A13	.597	.116	.088	.0535	11.36

* $T = a + bx$ where a = coefficient for '0' bit reaction time,
b = coefficient for bit level
x = bit level
T = time

APPENDIX K

TABLE 34
Linear Regressions on Motor Test Data for Age Groups

Subject Group	Data Type - Nominal Target Width on Actual Target Width	Average Index of Difficulty* 12" amplitude	Average Index of Difficulty 24" amplitude	Results of Fit						
				Estimate of a	Std. Dev. of a	Estimate of b	Std. Dev. of b	Std. Dev. before fit	Std. Dev. after fit	1/b - Motor Capacity in bits/sec.
Young	Nominal	4.58	5.58	-0.08749	0.12471	0.09554	0.02443	0.0723	0.05163	10.47
Young	Actual	4.06	5.12	0.01155	0.0539	0.08402	0.01159	0.0723	0.0375	11.90
Aged	Nominal	4.58	5.58	-0.07498	0.21017	0.13203	0.04117	0.12293	0.10197	7.57
Aged	Actual	4.89	6.21	-0.03137	0.11566	0.11290	0.02613	0.12293	0.08364	8.80

* Index of difficulty $\lg_2 \left(\frac{2A}{W} \right)$ in the regression formula

$$t = a + b \lg_2 \left(\frac{2A}{W} \right)$$

Method for determining C, motor capacity scores for each subject.

1. Determine estimate of capacity for 12" amplitude trials

$$C_{12} = 1/b \frac{\lg_2 \left(\frac{2A_1}{W} \right) - \lg_2 \left(\frac{2A_{12}}{W_{12}} \right)}{t - t_{12}}$$

where W_{12} = average actual target width for the two trials at 12" amplitude

t_{12} = average actual target width for two trials at 12" amplitude

2. Likewise to step 1, determine C_{24} .

3. $C = \frac{C_{12} + C_{24}}{2}$.

Two alternatives are possible for estimating the slope of the equation, 1) compute the index of difficulty based on the nominal target width (W) of one inch, or 2) compute the index of difficulty based on the actual target width used. The choice of which method is significant, since the resulting estimates of b and 1/b, are greatly affected. One reasonable criterion for making this choice is to determine which alternative provides the better fit to the combined data¹ of the subjects in each age group. The table shows the resulting equations for each age group and each model, including estimates of a, and b, their standard deviations, and 1/b. For both age groups, the equation using actual target widths provided a much better fit than the nominal target widths (i.e., the variance of the coefficients were lower, and the variance of the fit was lower using the actual target widths). Furthermore, the intercept constant, a, was not significantly greater than zero (i.e., 90% confidence intervals included 0) for the resulting equations. Thus, the reduced form for Fitt's Law is

$$t = b \lg_2 \left(\frac{2A}{W} \right)$$

where

t = time in seconds

b = slope

A = 12" or 24"

W = actual target width

¹Each subject performed 4 trials, two trials at the 12" amplitude, and two trials at the 24" amplitude. The trial times and trial accuracies were averaged for the two 12" trials, to provide one data point per subject (time, accuracy) and likewise the times and accuracies for the 24" trials to provide a second data point per subject (t, a) 24".

This formula can be solved for motor capacity equal to $1/b$ as:

$$C = 1/b = \frac{\lg_2 \left(\frac{2A}{W} \right)}{t}$$

The above form for C was used to solve for the motor capacity for each subject's data (see Table for method and data).

APPENDIX L

ANALYSES OF VARIANCE AND CONTRASTS FOR
EFFECTS OF TRIALS IN LABORATORY TESTS

The general form for the analysis for each test and measure was a 2-factor model with subjects as one factor and trial as the other. Separate ANOVA's were run on each age group using the BMD program with the following terms,

S - subjects (random) young = 10, aged = 13

T - trial (fixed, ranging from 3 to 12 levels), and

ST - interaction which served as the error term for testing factor T.

In some analyses, specific trials were contrasted to analyze the significance of a treatment condition or learning. Scheffe's method of multiple comparisons was used here.

A summary of the ANOVAs and the contrasts is given in Table 35.

Table 33

Summary of ANOVAS and Contrasts for Trials in Laboratory Tests

Laboratory Test	Test Measure	ANOVA						Contrast					Contrast				
		Age Group	Number of Trials	$\frac{MS_T}{MS_{ST}}$	Critical F _{2, 105}	Significant	Trial Combination	Interpretation of the Combination	F	Critical F	Significant	Trial Combination	Interpretation of the Combination	F	Critical F	Significant	
Embedded Figures	Mean Time	Young	12	5.69	2.00	Yes											
Embedded Figures	Mean Time	Aged	12	8.25	1.96	Yes											
Search Test	Mean Time	Young	7	9.57	2.17	N.S.											
Search Test	Mean Time	Aged	7	9.44	2.17	N.S.											
Choice Reaction 1 bit	Reaction Time	Young	10	1.75	2.00	N.S.											
Choice Reaction 2 bit	Reaction Time	Young	10	2.09	2.00	Yes	(Tr 1, 2, 3, 4, 5) - (Tr 6, 7, 8, 9, 10)	Learning	2.53	18.0	N.S.						
Choice Reaction 3 bit	Reaction Time	Young	10	3.91	2.00	Yes	(Tr 1, 2, 3, 4, 5) - (Tr 6, 7, 8, 9, 10)	Learning	1.00	18.0	N.S.						
Choice Reaction 1 bit	Reaction Time	Aged	10	0.82	2.00	N.S.											
Choice Reaction 2 bit	Reaction Time	Aged	10	0.91	2.00	N.S.											
Choice Reaction 3 bit	Reaction Time	Aged	10	2.45	2.00	Yes	(Tr 1, 2, 3, 4, 5) - (Tr 6, 7, 8, 9, 10)	Learning	0.00	18.0	N.S.						
Motor Test	Mean Time	Young	4	111.5	2.95	Yes	(Tr 1 + 2) - (Tr 3 + 4)	Learning	1.72	8.64	N.S.	(Tr 1 + 3) - (Tr 2 + 4)	Amplitude	111.0	8.64	Yes	
Motor Test	Actual Target Width	Young	4	0.69	2.95	N.S.											
Motor Test	Mean Time	Aged	4	103.5	2.88	Yes	(Tr 1 + 2) - (Tr 3 + 4)	Learning	0.05	8.4	N.S.	(Tr 1 + 3) - (Tr 2 + 4)	Amplitude	103.0	8.4	Yes	
Motor Test	Actual Target Width	Aged	4	6.82	2.88	Yes	(Tr 1 + 2) - (Tr 3 + 4)	Learning	0.20	8.4	N.S.	(Tr 1 + 3) - (Tr 2 + 4)	Amplitude	18.9	8.4	Yes	

Table 35 (cont'd)
Summary of ANOVAs and Contrasts for Trials in Laboratory Tests

ANOVA					Contrast			Contrast								
Laboratory Test	Test Measure	Age Group	Number of Trials	$F = \frac{MS_T}{MS_{ST}}$	Critical $F_{\alpha = .05}$	Significant	Trial Combination	Interpretation of the Combination	F	Critical F'	Significant	Trial Combination	Interpretation of the Combination	F	Critical F'	Significant
Serial Choice Reaction Time (SECRET)	Mean Time	Young	3	0.72	3.55	N.S.										
	Sol. Devs. of Times	Young	3	1.21	3.55	N.S.										
SECRET	Mean Time	Agged	3	1.71	3.40	N.S.										
SECRET	Sol. Devs. of Times	Agged	3	2.05	3.40	N.S.										
SECRET with memory (SECRETM)	Mean Time	Young	3	0.63	3.65	N.S.										
SECRETM	Sol. Devs. of Times	Young	3	0.23	3.65	N.S.										
SECRETM	Percent Correct	Young	3	8.11	3.55	Yes	Tf 2 - Tf 3	0.2	6.7	N.S.		2.1 (Tf 1) - (Tf 2 + 3)	Learning	16.0	6.7	Yes
SECRETM	Mean Time	Agged	3	1.72	2.40	N.S.										
SECRETM	Sol. Devs. of Times	Agged	3	1.74	3.40	N.S.										
SECRETM	Percent Correct	Agged	3	6.63	3.40	Yes	Tf 2 - Tf 3	0.3	6.6	N.S.		2.1 (Tf 1) - (Tf 2 + 3)	Learning	10.3	6.6	Yes

APPENDIX M

MEMORY TEST SCORE DEVELOPMENT

The following method of scoring the effect of memory was developed to 1) incorporate measure of time from the serial choice reaction with memory test (SCRTM), 2) incorporate the measure of response percent accurate in the SCRTM, and 3) to compare subjects' performance in the SCRTM test to his base line the SCRT without memory.

When a correct response is made, the subject has successfully transferred the information in the stimulus to a response. The stimulus alternative included 8 digits or alternatives of information. An incorrect response results in a transfer of no information. If all responses are correct, then the rate of information transfer is $\frac{8}{(\text{mean response time})}$ for correct responses or stated another way, the rate of information transfer per correct response. In the SCRT without memory, since all responses were essentially correct, this represents the rate without memory. In the SCRTM, mean response times increased and thus the rate of information transfer decreased. However, in the SCRTM, not only did mean times increase for correct scores, but the percent of correct responses decreased. This may be incorporated into the rate by multiplying,

$$\frac{\text{Rate of information}}{\text{correct response}} \times \text{proportion correct response}$$

which reduces to a rate per response. As the proportion decreased, this rate decreases. For the SCRT without memory let the rate be R_0 , and for the SCRTM, let the rate be R_m . By subtracting R_m from R_0 , the relation effect of memory, M , for this test can be quantified in units of rate of information per response (reduced or lost by introducing memory).

Note that the above formulation does not make use of the response times for incorrect responses. These times are generally longer than times for correct responses, and given that the response is incorrect, no information is transferred. A word of caution is in order with respect to interpretation of the metric developed. Although the units are familiar, rates of information, the actual values obtained are specific to those task conditions and should only be interpreted as relative values for the subjects.

The values obtained for each subject for R_o , R_m , and M are given in Table 36.

Table 36

Memory Test Data for Score Development

Subject	R_o Information Rate Without Memory (alternatives per second)	R_m Information Rate With Memory	Effect of Memory M
Y01	8.32	8.70	-0.37
02	7.71	4.07	3.64
03	7.70	5.57	2.27
04	8.68	3.88	4.80
05	8.01	5.54	2.47
06	8.15	5.41	2.74
07	8.25	5.06	3.20
08	7.63	5.47	2.16
09	7.83	4.56	3.27
10	9.32	5.33	3.99
A01	6.15	3.25	2.90
02	6.71	3.26	3.45
03	6.30	2.61	3.69
04	7.21	3.62	3.59
05	6.38	0.78	5.60
06	7.53	3.78	3.75
07	7.01	1.79	5.22
08	5.87	1.90	3.96
09	7.20	2.04	5.16
10	6.75	3.27	3.47
11	6.36	1.59	4.77
12	7.21	2.70	4.51
A13	6.65	1.79	4.86

APPENDIX N

Summary Descriptions of Subject Samples in Research Studies on Aging

Author (s)	Year	Subject Sample Description
Bebin & Shimmin in (Craik)	1969	Not Stated
Bell	1972	< 19 yr. = 225 20 - 30 yr. 98 30 - 40 yr. 38 40 - 50 yr. 26 50+ yrs. 16 403 total # Subjects
Birren	1964	All Ranges
Botwinick	1970	65+ Ranges
Braun	1959	All Ranges
Broadbent & Heron	1962	18 - 25 yr. 34 45 - 60 yr. 40 (mean age 51)
Brown (in Welford)	1958	All Ranges
Burg	1967	16 - 92 yr. 17,500
Burg	1968	16 - 92 yr. 17,479
Canestrari	1968	Exp. I: 30 - 39 yr. 32 40 - 49 yr. 52 50 - 59 yr. 35 60 - 69 yr. 15 164 total Exp. II: 50 - 73 yr. 27 (mean age 62.41) 16 - 27 yr. 27 (mean age 20.19)
Carp	1971	67.5 yr. mean age # 709

Author (s)	Year	Subject Sample Description
Carpenter		74 subjects 45 year range
Case, Hulbert, & Beers	1970	17 - 50 yr. simulator 51+ yr. = 216
		Instrumented Vehicle 30 yrs. = 12 53 - 71 yrs. = 7
Christie & Fisher	1966	Exp. I: 17 - 65 yrs. = 16 Exp. II: 10 - 70 yrs. = 122 Exp. III: 25 - 65 yrs. =
Connolly	1967	18 - 79 yrs.
Crook (in Braum)	1959	teens to fifties, N = 176
Craik	1969	Not Stated
Crossman & Szafram (in Welford)	1959	(20 - 39 yrs.) (40 - 59 yrs.), over 60 yrs.
Davies	1968	All Ranges
Eisner	1972	10 - 14 yrs. 20 14 - 17 yrs. 20 18 - 21 yrs. 20 22 - 29 yrs. 20 30 - 39 yrs. 20 40 - 49 yrs. 20 50 - 59 yrs. 20 60+ yrs. 20 100 total
Forbes, Pain, Bloomquist & Vanosdall	1969	15 - 19 yrs. 70 20 - 29 yrs. 70 30 - 39 yrs. 64 40 - 49 yrs. 70 50 - 59 yrs. 67 60+ years 55 396 total

Author (s)	Year	Subject Sample Description
Forbes & Vanosdall	1973	15 - 19 yrs. = 28 20 - 29 yrs. = 119 30 - 39 yrs. = 60 40 - 49 yrs. = 83 50 - 59 yrs. = 49 60+ yrs. = 32 371 total
Freeman	1972	All Ranges
Gianturco, Ramm & Erwin	1973	45 - 70 yrs. = 347
Goldfarb (in Welford)	1959	18 - 64 yrs. = 100
Goldstein	1964	All Ranges
Griew "A Note ..."	1958	24 - 31 yrs. = 10 42 - 50 yrs. = 10
Griew "Age Changes"	1958	21 - 28 yrs. = 6 45 - 56 yrs. = 6
Jerome	1959	All Ranges
Kay (in Welford)	1959	15 - 72 yrs.
Kirchner	1958	Young 18 - 25 yrs. Elder 64 - 78 yrs.
Koga & Morant	1923	All Ranges, Hundreds
Leonard (in Welford)	1959	20's yrs. & 60's yrs.
Marsh	1960	All Ranges
McFarland & O'Doherty	1959	All Ranges
McFarland, Tune, & Welford	1964	All Ranges
Planek	1974	All Ranges
Planek & Fowler	1969	55+ yrs.

Author (s)	Year	Subject Sample Description
Szafran (in Welford)	1958	20 - 59 yrs.
Talland	1966	Exp. I: 20 - 29 yrs. = 40 30 - 39 yrs. = 40 40 - 49 yrs. = 40 50 - 59 yrs. = 40 60 - 69 yrs. = 40 Exp. II: 20 - 29 yrs. = 12 40 - 49 yrs. = 12 60 - 69 yrs. = 12 Exp. III: 20 - 29 yrs. = 12 40 - 49 yrs. = 12 60 - 69 yrs. = 12
Tilley, Erwin & Gianturco	1973	20 - 69 yrs.
Tsongos & Schwab	1970	20 - 29 yrs. 10 50+ yrs. 10
Verville & Cameron (in Braun)	1959	Young 16 - 23 yrs. 100 Aged 35 - 56 yrs. 30
Wallace	1956	20's, 60's, 70's
Waller	1967	All Ranges
Weale	1965	All Ranges
Weiss	1959	All Ranges
Welford	1969	All Ranges
Welford	1958	All Ranges
Welford	1959	All Ranges
Welford N. (in Welford)	1959	All Ranges
Weston (in Welford)	1958	20 - 45 yrs. 12
Whiteside	1973	4 - 62 yrs. 20
Wolf	1972	15 - 91 yrs. large number

APPENDIX P

Table 37

Lab Scores of the Subject Sample in Driving Tests

	Embedded Figures time			Visual Search time			Motor Capacity			InforPro Rate			Memory Effect			SCRT Response		
	N	$\bar{X}$	σ	N	$\bar{X}$	σ	N	$\bar{X}$	σ	N	$\bar{X}$	σ	N	$\bar{X}$	σ	N	$\bar{X}$	σ
Aged Lab study full sample	13	1.50	.56	13	3.18	.85	13	9.5	1.27	13	9.4	3.56	13	4.23	.84	13	1.20	.10
Aged day occlusion sample	9	1.36	.53	9	2.98	.88	9	9.2	1.22	9	9.3	3.86	9	4.12	.94	9	1.20	.09
Aged day eye move sample	8	1.26	.47	8	2.88	.90	8	9.2	1.31	8	9.2	4.11	8	4.02	.92	8	1.21	.10
Aged night road sample	5	1.15	.38	5	3.10	.79	5	9.3	1.56	5	7.0	2.57	5	3.84	1.03	5	1.22	.08
Young lab study full sample	10	.22	.09	10	2.28	.57	10	11.7	1.08	10	11.1	3.45	10	2.82	1.39	10	.98	.08
Young day road sample	6	.19	.11	6	2.12	.28	6	11.5	1.07	6	11.7	4.43	6	2.44	1.47	6	1.00	.04
Young night road sample	5	.21	.07	5	2.44	.75	5	12.0	1.41	5	11.5	4.73	5	2.56	1.93	5	.99	.03

¹None of the differences between the road study samples means and lab study full samples are statistically significant ($\alpha = .20$)

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