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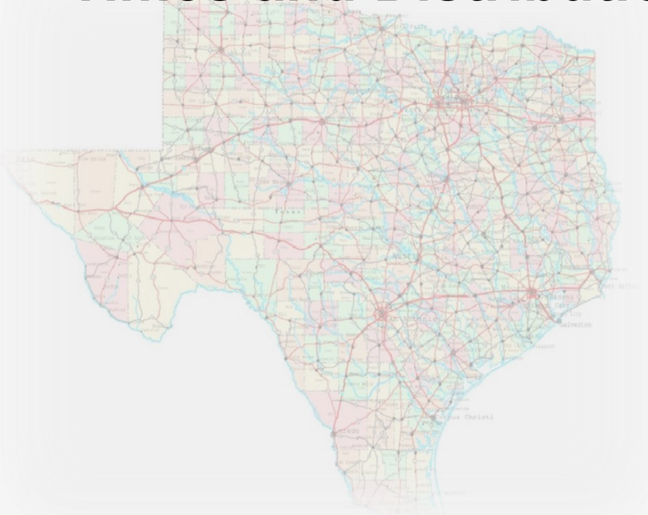

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Predicting Driver Distraction Using Computed Occlusion Task Times: Estimation of Task Element Times and Distributions

Report: ATLAS-2015-01, UMTRI-2015-8

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16. Abstract

To determine conformance with NHTSA's visual-manual interface distraction guidelines and to reduce the associated number of crashes, NHTSA recommends a visual-occlusion test procedure. As an alternative to testing subjects following that procedure, this report provides experimentally based estimated times for in-vehicle task elements (e.g., *flick*, *press button*). Those estimated times can be summed and then adjusted using Pettitt's method (which assumes that visual tasks progress only when the test goggles are open) to estimate total task occlusion time. The estimated times were determined from a frame-by-frame analysis of data from an occlusion experiment evaluating a next-generation Hyundai navigation radio.

That analysis revealed the mean element time for middle-aged subjects (45-55) was only about 16% longer than young (25-35) subjects, whereas the mean task time was 44% greater, primarily because there were 32% more occurrences of elements to complete tasks.

The elements and their mean times were *flick* (0.50 s), *flick/scroll return* (0.38 s), *press button* (0.64 s), *quick flick* (0.35 s), *reach for button* (0.42 s), *reach for center console* (0.75 s), *read instructions* (0.53 s), *scroll* (0.66 s), *search* (0.54 s), *stop screen* (0.24 s), *turn knob* (0.43 s), *reposition hand on knob* (0.33 s), *wait-loading* (0.90 s), *wait after loading* (0.92 s), *wait for goggles-known location* (1.34 s), and *wait for goggles-unknown location* (0.92 s). Most element distributions were lognormal. Interestingly, 45% of all element occurrences were when the goggles were closed or in open-closed or closed-open periods. Given this, the assumptions of Pettitt's method need further thought.

17. Key Words	18. Distribution Statement
Human factors, Ergonomics, Driver distraction, Driver interfaces, Usability, Visual occlusion, Task time	No restrictions.

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TABLE OF CONTENTS

List of Figures

List of Tables

INTRODUCTION/BACKGROUND

Why is driver distraction a concern?

Driver distraction has certainly attracted significant attention in the popular news media. Articles have appeared in *USA Today* --"Feds Limit Driver Distraction in Cars" (April 23, 2013) and "Cellphone Use Causes Over 1 in 4 Car Accidents" (May 28, 2014) and *The New York Times* -- "Distracted Drivers and New Drivers a Perilous Mix" (January 2, 2014) and "Agency Aims to Regulate Map Aids in Vehicles" (June 15, 2014).

So, what is distraction? Foley et al. (2013, p. 60) define distraction as "the diversion of attention away from activities critical for safe driving toward a competing activity, which may result in insufficient or no attention to activities critical for safe driving." Further, they identify five types of distractions:

1. Visual distraction involves glances (e.g., looking at the price at a gas station).
2. Manual distraction involves physical manipulation (e.g., reaching for a fallen object).
3. Auditory distraction involves having to listen (e.g., listening for feedback from a navigation system).
4. Vocal distraction involves speaking (e.g., talking on a cell phone).
5. Cognitive distraction involves a driver focusing thoughts elsewhere (e.g., thinking about a conversation.

These types can also be combined in multiple ways (e.g., visual-manual or auditory-vocal-cognitive).

Driver distraction has garnered attention because of the associated number of deaths and injuries. In the United States in 2012, there were 3,328 deaths reported for distraction-affected crashes (U.S. Department of Transportation 2014). As shown in table 1, the percentage of crashes associated with distractions has remained stable for the last five years. However, the number of crashes attributed to various types of distraction seems to be slowly increasing.

Table 1. Police Reported Crashes and Crashes Involving Distraction, 2006-2010 (GES)
Source: U. S. Department of Transportation 2013, p. 22

Year	Number of Police-Reported Crashes	Police-Reported Crashes Involving a Distracted Driver	Distraction-Related Crashes Involving an Integrated Control/Device*	Distraction-Related Crashes Involving an Electronic Device*
2006	5,964,000	1,019,000 (17%)	18,000 (2%)	24,000 (2%)
2007	6,016,000	1,001,000 (17%)	23,000 (2%)	48,000 (5%)
2008	5,801,000	967,000 (17%)	21,000 (2%)	48,000 (5%)
2009	5,498,000	957,000 (17%)	22,000 (2%)	46,000 (5%)
2010	5,409,000	899,000 (17%)	26,000 (3%)	47,000 (5%)

* The categories for Integrated Control/Device and Electronic Device are not mutually exclusive. Therefore the data *cannot* be added or combined in any manner.

What are the current guidelines to reduce distraction?

Several guidance documents have been developed to reduce the extent to which driver interfaces are distracting. They include the UMTRI guidelines (Green et al. 1993), the HARDIE project guidelines (Ross et al. 1996), the EU guidelines (Commission of the European Communities 1999, 2007), the Battelle guidelines (Campbell, Carney, and Kantowitz 1997), SAE Recommended Practice J2364 (Society of Automotive Engineers 2004), the JAMA guidelines (Japan Automobile Manufacturers Association 2004), the AAM Guidelines (Alliance of Automobile Manufacturers 2006), the Transport Research Laboratory guidelines (Stevens and Cynk 2011), and most recently, the NHTSA Visual-Manual Guidelines.

Key NHTSA guidelines include:

- The driver's eyes should usually be looking at the road ahead.
- The driver should be able to keep at least one hand on the steering wheel while performing a secondary task (both driving related and nondriving related).
- The distraction induced by any secondary task performed while driving should not exceed that associated with a baseline reference task (manual radio tuning).
- Any task performed by a driver should be interruptible at any time.
- The driver should control the pace of task interactions, not the system/device.
- Displays should be easy for the driver to see, and content presented should be easily discernible.

How has distraction been assessed and predicted?

To verify that designs comply with these guidelines, user tests are often conducted. Many methods have been used (table 2). NHTSA has listed six methods that were initially considered to determine compliance with their guidelines (table 3). Subsequently, two methods were identified as preferred: eye-glance testing using a driving simulator and occlusion testing.

Table 2. Procedures for Assessing Driver Distraction
Source: Kang et al. 2013, p. 1-2

Document	Method and Criteria	Acceptance Criterion
SAE J2364 (Society of Automotive Engineers, 2004)	Static method: While not driving in a simulator, real vehicle, or laboratory mockup, after practice, at least 10 participants perform the tasks of interest and task time is measured.	mean task time < 15 s
	Interrupted vision (occlusion) method: after practice, at least 10 participants perform the tasks of interest while wearing occlusion goggles. The recommended open time is 1.5 s (range 1.0 to 2.0 s) and the closed time is 1.5 s	total task time <20 s
SAE J2365 Society of Automotive Engineers, 2002)	calculate static task time using keystroke-level model (KLM) estimates for mental operations, key presses of various types, searching, and so forth.	mean task time < 15 s (in SAE J2364)
AAM Guidelines (Alliance of Automobile Manufacturers, 2006)	Alternative A: while driving in a simulator or test vehicle and performing the task	single glance durations =< 2 s; total glance time < 20 s
	Alternative B: lateral position control	# lane departures for reference task (manual radio tuning) >= # departures for task being evaluated
	Alternative B: gap variability	gap variability reference task (manual radio tuning) >= gap variability for task being evaluated
	Visual occlusion method with open time of 1.5 s and close time of 1.0 s	total shutter open time (TSOT) <= 15.0 s
	eye-fixation monitoring while driving simulator or real vehicle	mean glance duration < 2.0 s for 85% of the test sample and mean total glance time for task < 20 s for 85%
JAMA Guidelines (Japan Automobile Manufacturers Association, 2004)	occlusion time during a bench test	total shutter open time (TSOT) <= 7.5 s

Table 3. Methods Examined by NHTSA

Method and Criteria	Acceptance Criterion
Eye-glance testing using a driving simulator (EGDS)	85% glances < 2.0 s mean of glances < 2.0 s total glance time <= 12.0 s
Occlusion testing (OCC)	sum of open times < 12.0 s
Step counting (STEP)	# steps < 6
Driving simulator with benchmark (DS-BM)	standard deviation lane departure (SDLP) <= benchmark # lane departures <= benchmark
Driving simulator with fixed criteria (DS-FC)	performance measures <= benchmark
Dynamic following detection with benchmark (DFD-BM)	EGDS glance criteria + SDLP, following delay, % visual targets detected, visual detection RT
Dynamic following detection with fixed criteria (DFD-FC)	EGDS glance criteria + perform. measures < specified values

The EGDS driving simulator method involves (1) installing the interface of interest in a driving simulator, (2) having a group of subjects perform the tasks of interest, and then (3) examining the number and duration of glances for each task. Obviously, this task requires a fully functional interface, a driving simulator with the car-following task, and a highly reliable and accurate eye-fixation recording system. The effort to reduce and analyze the data is substantial.

In the occlusion method, a participant wears goggles that open and close for alternating 1.5-second intervals. The time the goggles are closed simulates a participant looking at the road, and the time the goggles are open represents a participant looking at the in-vehicle display. The NHTSA version of the occlusion method is based on International Standards Organization (ISO) standard 16673 and Society of Automotive Engineers (SAE) Recommended Practice J2364. The occlusion method is the less costly of the two methods and is the focus of this report.

A major drawback of all testing methods described involving subjects is that they require a reasonably complete and functioning driver interface, typically not available until the end of the project, close to when the interface is shipped. In fact, if interface development is behind schedule, there is often pressure to ship the interface almost immediately, making few or no changes. Furthermore, if something is found to be unsatisfactory, the correction can be very expensive.

Accordingly, alternative methods have been sought to predict how distracting an interface will be, an approach similar to other fields of engineering, where results from mathematical formulations (Ohm's Law, Kirchoff's Law, Newton's Laws, etc.) are the primary evidence for making design decisions.

One central tenet of driver distraction is that exposure matters. The longer a task takes, the more likely it is to be distracting (Angell et al. 2002). Accordingly, total task time is a key predictor of distraction. Within industrial engineering, there is a long tradition of determining task times, first using stopwatches, and later using other timing and recording devices. Observation of many tasks (and jobs) led to the realization that there were often repeated elements in the work–that the same motions underlie many activities. Emerging from these observations was the development of many systems to predict task times, the most preeminent of them being methods-time measurement (MTM) (Maynard, Stegemerten, and Schwab 1948). MTM was created to describe a range of tasks that a person could complete, such as moving an object a certain way or cranking a lever. There are many other standard time systems as well (e.g., MODAPTS – Carey et al. 2001). The use of predetermined time systems to determine task times is standard industrial engineering practice, particularly for repetitive factory jobs, but for many other jobs as well. Furthermore, many undergraduate industrial engineering programs require completion of a course entitled work measurement, or something similar, which includes a unit on predetermined time systems.

The emphasis of traditional predetermined time systems has been on physical activities. However, as the nature of human work has shifted from physical to mental activities and as human-computer interaction became increasing important, prediction systems for those purposes have been developed. Most notable among them are the keystroke-level model (KLM) and the model human processor (Card, Moran, and Newell 1980). The keystroke-level model times (table 4) are assumed to be for young adults.

Table 4. Original Keystroke-Level Model Values

Code	Operation		Time (s)
K	Key press and release (keyboard)	best typist (135 wpm)	0.08
		good typist (90 wpm)	0.12
		poor typist (40 wpm)	0.28
		average skilled typist (55 wpm)	0.20
		average non-secretary typist (40 wpm)	0.28
		typing random letters	0.50
		typing complex codes	0.75
		worst typist (unfamiliar with keyboard)	1.20
P	Point the mouse to an object on screen		1.10
B	Button press or release (mouse)		0.10
H	Home: Hand from keyboard to mouse or vice versa		0.40
M	Mental preparation		1.35
R(t)	User waiting for the system to respond		t
$D(n_D l_D)$	Draw n_D straight lines of length L_D centimeters		$0.9n_D$

Source: Card, Moran, and Newell 1980, p. 399.

To develop task times for driver interfaces, SAE Recommended Practice J2365 was developed, using data from MTM, the keystroke-level model, and various UMTRI studies on driver interfaces (Nowakowski, Utsui, and Green 2000.)

SAE J2365 was created to provide estimates of task times for one of the test methods described in SAE J2364 to assess in-vehicle information systems at an earlier stage of development. This was the first document produced to be used solely to predict task times as a measure of distraction and will be revised and updated using this report. As shown in table 5, times are given for two age groups, with times for other age groups estimated using linear regression, the midpoint of each age range, and the associated times. To estimate the time it takes to complete a task, the task is divided into a series of steps (reach for the center stack, find and press navigation button, etc.). For each step, the associated J2365 operators are identified and listed in a spreadsheet, along with their times. Those times are added up to determine the total task time.

Table 5. Operator Times from SAE J2365

Code	Name	Operator Description	Time (s)	
			Young Drivers (18-30)	Older Drivers (55-60)
Rn	Reach near	from steering wheel to other parts of the wheel, stalks, or pods	0.31	0.53
Rf	Reach far	from steering wheel to console	0.45	0.77
C1	Cursor once	press a cursor key once	0.80	1.36
C2	Cursor 2 times or more	time/keystroke for the second and each successive cursor keystroke	0.40	0.68
L1	Letter or space 1	press a letter or space key once	1.00	1.70
L2	Letter or space 2 times or more	time/keystroke for the second and each successive letter or space keystroke	0.50	0.85
N1	Number once	press the number key once	0.90	1.53
N2	Number 2 times or more	time/keystroke for the second and each successive number key	0.45	0.77
E	Enter	press the enter key	1.20	2.04
F	Function keys or shift	press the function keys or shift	1.20	2.04
M	Mental	time/mental operation	1.50	2.55
S	Search	search for something on the display	2.30	3.91
Rs	Response time of system-scroll	time to scroll one line	0.00	0.00
Rm	Response time of system-new menu	time for new menu to be painted	0.50	0.50

Since J2365 was developed, many studies have been conducted that provide data to supplement the keystroke-level model, primarily for human-computer interaction. However, there also has been automotive-specific research (Schneegass et al. 2011). Their data is shown in Table 6.

Table 6. Times from Schneegass et al. 2011

Operator	Description	Time (s)
H	homing wheel – system homing system – wheel	0.89 0.81
K	button pressed once button pressed twice button pressed x times	0.54 1.76 2.12 + 0.22(x-3)
T	turn 45 deg clockwise turn 90 deg clockwise turn 180 deg clockwise turn 45 deg counterclockwise turn 90 deg counterclockwise turn 180 deg counterclockwise	1.10 1.16 1.74 0.80 1.14 1.40
F	move finger between controls	1.14
R	response time–depends on system	t
AS	predictable list unpredictable list	0.30 1.12
M	after R operator after M operator	1.35 1.18

The operators in this table need some explanation. The H (*homing* operator is similar to the *reach-far* operator in J2365 -- reaching from the steering wheel to a control or vice versa), but the duration is slightly longer and depends on the direction in which the subject moves. The time to the interface is slightly longer because the location to which the subject reaches varies from reach to reach, requiring considerable visual guidance, whereas the return is always to the steering wheel, whose location does not vary (and for which visual guidance is not required). The original time in SAE J2365, drawn from MTM, used a case that most likely underestimated the extent to which there was a priori knowledge of the exact endpoint of the reach. In fact, the reach-far times in J2365 are similar in value to the homing (H) times in the keystroke-level model, which tend to be shorter reaches to a well-known location (e.g., from a keyboard to a mouse).

In contrast, the K (*keystroke*, press a key) values in Schneegass et al. are much less than those in J2365 and comparable to typing random letters in the keystroke-level model. This operator, because it occurs so often, needs careful consideration. One possible explanation is that the J2365 values were based on an interface with very small keys (chicklet-sized).

The *turn* operator, associated with turning a knob, is new. The time increases with the angle of rotation, and is slightly faster for counterclockwise than clockwise movements, which was not expected. Why this occurred needs further examination.

The *move finger between controls* (on the center console) is a new element and is comparable to the mouse-movement time in the keystroke-level model. It may be that the inclusion of this term explains the difference in the keystroke times between J2365 and Schneegass's measures. In

J2365, the movement between key was included in the keypress time, whereas that may not have been the case for Schneegass. This needs to be confirmed.

AS is the *attention shift*, something not modeled explicitly within a KLM and is important when tasks are performed simultaneously and for browsing lists. The value depends upon whether the list is predictable (e.g., the track list of a CD player or a phone directory, $AS_{predictable}$ = 0.30 s) or unpredictable (e.g., unknown menu structure or web-based search results, $AS_{unpredictable}$ = 1.12 s).

Finally, with regards to mental preparation (M), Schneegass proposes using the value in KLM (1.35 s) except for when confirming a turn (T), in which case the value is 1.18 s. In contrast, the value for M in SAE J2365 is always 1.5 s.

What is Pettitt's Method and why is it of interest?

As was noted earlier, compliance with the NHTSA guidelines (the total task time limit) is most commonly determined using the occlusion method. As an alternative, Pettitt (2008) developed a method to estimate total task times in occlusion experiments. In brief, one follows the SAE J2365 Recommended Practice to estimate static task times (the time to complete a task while the vehicle is parked). Those times are adjusted to account for the assumption that tasks demanding vision do not proceed when the occlusion goggles are closed. Specifically, three assumptions are made:

1. During the 1.5 s periods of vision, the task can progress without interruption.
2. An element that begins when the goggles are open can continue into a 1.5-second occlusion period so long as the element is not specifically associated with vision.
3. An element can only begin when the goggles are closed if vision is not required at any point to complete the element.

At UMTRI, task times are calculated following the procedure in SAE Recommended Practice J2365. Times are entered into an Excel spreadsheet to predict static task time. In addition, Pettitt's method has been implemented as a simple Excel macro, providing instantaneous and reasonable estimates of occlusion task times (Kang et al. 2013). Thus, there is the potential of not needing costly and time-consuming human-subject testing at all, but basing all checks of compliance with the NHTSA distraction guidelines entirely on calculation.

However, additional research is needed, before subject testing can be eliminated entirely (or at least for those tasks that will clearly pass or fail the guidelines based on calculations). Accordingly, the objective of this project (and a follow-on ATLAS project) is to check the validity of Pettitt's assumptions. In addition, this report provides information that can be used to update SAE J2365 to include task elements associated with interfaces (e.g., touch screens) not in wide use when J2365 was developed. Although the assumptions of Pettitt's method are reasonable as a first approximation, inconsistencies with those assumptions were observed during the experiment reported by Kang et al. (2013). Many times a participant would start to move a hand toward the knob or another general area during the time the goggles were closed to prepare for the next element. Thus, the simple Excel macro used to convert the static task times into occlusion time estimates (used in Kang et al. 2013) may need some adjustments.

What questions are to be examined?

This research examines the assumptions in Pettitt's method using data from the Kang et al. experiment. In addition, data are provided to develop time estimates for elements not in SAE J2365.

This report addresses eight questions, listed below. The initial questions concern task times during vision intervals and are intended to update J2365. Other questions concern errors and how they affected task completion time, and more generally, how occlusion affected when tasks began and ended. All of this information, along with the literature, additional analyses, and other information will eventually be used to suggest new task times for SAE J2365.

1. How were the task elements partitioned and what were those elements?

   Those elements were:

read instructions	quick flick
search	scroll
reach for center console	stop screen
reach for button	flick/scroll return
press button	wait–loading
turn knob	wait after loading
reposition hand on knob	wait for goggles—known location
flick	wait for goggles—unknown location

2. Exactly how long were the goggles open, and how accurate was the timing?

3. What are the task-completion times for the visual-manual tasks when tested using the NHTSA occlusion procedure?

4. What are the major factors that affected task time?

5. Overall, what affected the times of each element, especially the goggle state?

6. Overall, when did elements occur relative to the goggle state?

7. What were the times and distributions for each element?

8. What kinds of errors and error correction occurred?

METHODS

System and test equipment

The interface tested in Kang et al. was the Hyundai-Kia Generation 4 Navigation-radio (figure 1). The interface consisted of a 7-inch touch screen, 2 knobs, and 10 physical buttons. The interface was mounted in a position that was approximately in the same location as in a production vehicle and allowed subjects to easily interact with the device, the experimenter to interact with the subject, and for multiple cameras to record the experiment. A Logitech Quicktime Messenger camera focused on the subject's face so an experimenter could record the open and close times of the goggles. A Logitech C920 camera focused on the screen so an analyst could track the actions, such as button presses and knob turns, the subject made. This camera was connected to Morae 3.3 (TechSmith, 2012) to record the screen interactions. For more information on the device and its setup, refer to Kang et al.

Figure 1. Hyundai-Kia Generation 4 Navigation-Radio used in the experiment

To achieve the occlusion effect of seeing and not seeing the navigation radio, subjects wore Occlusion Technologies PLATO goggles (figure 2). The goggle cycle was 1.5 s open and then 1.5 s closed.

Figure 2. PLATO Goggles
Source: http://www.translucent.ca/plato.html

Subjects

Twenty-four subjects were divided evenly between two age groups (ages 25-35 and 45-55). There were six men and six women in each age group, and all were licensed drivers. Information regarding how subjects were chosen, how they were compensated, and subject skill requirements can be found in Kang et al.

Tasks

As shown in table 7, each subject completed five practice trials (without goggles) before completing three test trials (with goggles) for each of the seven tasks (*tune radio, call a contact, enter a street address, dial a phone number, select a point of interest, select a radio preset, and play a song*). The number of trials selected is consistent with SAE Recommended Practice J2364. To counterbalance for sequence effects, half of the subjects from each age and gender group completed the tasks in the opposite sequence. More details regarding task and task sequence can be found in Kang et al.

Table 7. List of Tasks

Block	Trial	Task
1 – Tune the radio	practice	tune the radio to FM 89.1
		tune the radio to FM 97.1
		tune the radio to FM 96.3
		tune the radio to FM 100.9
		tune the radio to FM 107.1
	yest	tune the radio to FM 92.5
		tune the radio to FM 97.7
		tune the radio to FM 102.7

Block	Trial	Task
2 – Call a contact	practice	find and call the contact Ale
		find and call the contact Charles Winchester
		find and call the contact Jessica Alba
		find and call the contact Midge Igna
		find and call the contact Ricky Ricardo
	test	find and call the contact Daniel Grass
		find and call the contact Kristina Elder
		find and call the contact Pretty Neat
3 – Enter a street address	practice	enter and go to the address 628 Pathway Dr, Howell, MI
		enter and go to the address 2101 S Main St, Adrian, MI
		enter and go to the address 4000 Baldwin Rd, Auburn Hills, MI
		enter and go to the address 1717 Broadway St, Ann Arbor, MI
		enter and go to the address 6067 Markel Rd, Marine City, MI
	test	enter and go to the address 374 Jackson Rd, Ann Arbor, MI
		enter and go to the address 2901 Forton Rd, Ann Arbor, MI
		enter and go to the address 620 S State St, Ann Arbor, MI
4 – Dial a phone number	practice	dial the number 586-943-0931
		dial the number 517-402-7637
		dial the number 810-765-9452
		dial the number 313-856-2896
		dial the number 586-951-7193
	test	dial the number 313-793-2846
		dial the number 646-139-5079
		dial the number 979-317-6428
5 – Find a POI	practice	find and go to Willow Run Airport
		find and go to ARB
		find and go to Livingston County Airport
		find and go to OZW
		find and go to Detroit Metro-McNamara Arrivals
	test	find and go to Ann Arbor Municipal Airport
		find and go to YIP
		find and go to Detroit Metro-McNamara Departures
6 – Find a radio preset	practice	tune the radio to preset 1
		tune the radio to preset 5
		tune the radio to preset 3
		tune the radio to preset 9
		tune the radio to preset 7
	test	tune the radio to preset 4
		tune the radio to preset 8
		tune the radio to preset 12

Block	Trial	Task
7 – Play a song	practice	find and play the song “Against The Wind”
		find and play the song “Better Together”
		find and play the song “Bron-Yr-Aur”
		find and play the song “Christmas Vacation”
		find and play the song “Custard Pie”
	test	find and play the song “Clocks”
		find and play the song “Feliz Navidad”
		find and play the song “High Fidelity”

Task elements

To analyze the data, each task was divided into smaller elements such as pressing a button or searching. How tasks were partitioned into elements was based on a number of considerations including (1) consistency with prior work such as MTM-1, SAE J2365, Schneegass, et al., and Kang et al., (2) having a sound or movement that provided a distinct end point, (3) balancing details that identified differences with keeping the set small and simple, and (4) distinguish aspects of the task that required different resources (visual, auditory, cognitive, perceptual, motor). Most breaks occurred when the subject’s hand changed directions. Even after the elements were selected, there was ongoing discussion within the team of analysts, removing unnecessary elements or combining them with others. An overview of each element used in this experiment is provided in table 8, which is quite lengthy. For a more detailed description of each element, see Appendix A.

Table 8. List of Task Elements

Element	Description (When subject's ...)	Start Position/Time	End Position/Time	Comments
Read				
Read instructions	Eyes and/or head move up towards instructions or subject is reading the instructions. Goggles must be open.	Instant goggles open if eyes are already focused on instructions or instant subject's head or eyes start moving upward towards the instructions.	0.01 s before goggles close if eyes are already focused on instructions or 0.01 s before subject's eyes refocus on screen.	The subject is either double-checking to make sure what they entered was correct or they forgot what they must do next.
Search				
Search	Eyes are moving about the screen looking for something such as a button or menu entry or looking at the screen and no finger or hand movement are occurring. Goggles must be open.	Instant goggles open or 0.01 s after last element.	0.01 s before goggles close or hundredth of a second before next element.	The subject could be searching for the next button, reading the screen or could be thinking about something irrelevant.
Reach				
Reach for center console	Hand moves from steering wheel or body to the center console.	Instant subject's hand or arm starts moving from steering wheel or body towards the center console.	0.01 s before subject touches the screen/center console or 0.01 s before subject's hand stops moving forward to the center console.	This always occurs at the beginning of each task. Some subjects believe they must return their hand to the wheel each time the goggles close resulting in more repetitions of this element.

Element	Description (When subject's ...)	Start Position/Time	End Position/Time	Comments
Reach for button	Hand reaches for a target button (area) but does not press that button before another element begins. Goggles must be open.	Instant subject's hand starts distinctively moving towards a button.	0.01 s before goggles close or 0.01 s before subject's hand changes direction or stops moving.	The subject's hand is reaching for the next button they intend to press but they do not press it because they realize it's wrong or the goggles close.
Press Button				
Press button	Finger presses a virtual button on the touchscreen.	Instant subject's hand starts moving towards a button.	0.01 s before subject removes finger from button.	The subject attempts to press the button their hand is moving towards. There are no hard buttons pressed in this experiment.
Knob Actions				
Turn knob	Hand turns the knob counterclockwise or clockwise.	Instant subject starts turning the knob.	0.01 s before subject releases grip on the knob.	This is how the subjects select among the radio stations in the Tune Radio task.
Reposition hand on nnob	Hand is repositioned to turn the knob again. Movement must be after subject stops turning the knob.	Instant subject releases grip on knob after turning and starts moving fingers back to original position.	0.01 s before subject starts turning the knob again or begins another element.	After turning the knob, the subject's hand will be at an uncomfortable angle. They usually will return their hand to the original position on the knob before starting another element.
Touch Screen Actions				
Flick	Hand or finger moves to advance through a list. The screen continues moving after subject's hand has left screen.	Instant subject's hand moves towards screen to start flicking.	0.01 s before subject's hand is no longer moving in direction of flick.	This is used when the subject is still scanning the screen but wants to move through the list quickly.

Element	Description (When subject’s ...)	Start Position/Time	End Position/Time	Comments
Scroll	Finger scrolls through a list. The screen does not continue to move after subject's hand has left the screen.	Instant subject's hand moves towards screen to start scrolling.	0.01 s before subject's hand leaves screen or 0.01 s before subject's hand stops moving on screen.	This is typically used when the subject is close to the desired target in the list (e.g. In the C’s looking for the song “Clocks”).
Flick/scroll return	Finger or hand moves from bottom to top of the screen, but sometimes from top to bottom of the screen to prepare for next flick/scroll. Movement must be after a Flick, Quick Flick, or Scroll.	Instant subject's hand starts moving back towards top or bottom of screen to prepare to flick/scroll.	0.01 s before next flick/scroll, or hundredth of a second before subject's hand stops moving.	This will almost always follow a Flick, Quick Flick, or Scroll.
Stop screen	Finger contacts the screen to stop scrolling during select from list tasks. Movement must be after Flick or Quick Flick	Instant subject's hand moves towards screen to stop screen.	0.01 s before subject's hand leaves screen or hundredth of a second before subject's hand stops moving on screen.	This happens if the subject thinks they are close to the desired target in the list. This can only be used after Flick or Quick Flick.
Quick flick	Hand or finger moves to advance through a list. Movement of preceding flick/scroll return must be less than 1 s.	Instant subject's hand moves towards screen to start flicking.	0.01 s before subject's hand is no longer moving in direction of flick.	This is typically used when a subject has a long way to go before reaching their desired target in the list. The subject is probably not scanning.

Delays (No subject control over the duration).				
Element	**Description**	**Start Position/Time**	**End Position/Time**	**Comments**
Wait – Loading	While system is loading information requested By the subject.	Instant after subject Finishes pressing a button that requires the screen to change.	Instant new Screen has completely loaded.	Some machine loading Times are excessive (song tasks).
Wait After Loading	After system loading is complete but the goggles are still closed, so the subject cannot proceed. The subject does not know if screen has refreshed, so they continue waiting. Goggles must be closed. Movement must be after machine loading.	0.01 s after Machine Loading.	0.01 s second before goggles open or 0.01 s before next element.	This is the time that the subject is waiting on the computer even though the computer is done loading because they have no way of knowing that it is done loading.
Wait for goggles– nown location	When the goggles are closed and the destination is known. For a button, the location of the button is fixed and therefore always known. Goggles must be closed.	Instant goggles close or 0.01 s after last element.	0.01 s before goggles open or 0.01 s before next element.	If the subject knows where the next button is, they will reach for that button. If the subject does not know where the next button is, they may leave their hand where it was, rest it on the console, or return it to the wheel until the goggles open again.

Wait for goggles–unknown location	When the goggles are closed and the destination is unknown. During this period, the subject may be moving to a location. For scrolling, in particular, the subject can contact the screen in a variety of locations to perform the action, so the location can be unknown or indefinite. For knob operation, the location is considered unknown if the subject's hand is not on the knob). Goggles must be closed.	Instant goggles close or 0.01 s after last element.	0.01 s before goggles open or 0.01 s before next element.	The subject does not need to be near a target button to flick/scroll or turn, so this element was created for tasks where those elements were used.

All 24 subjects used similar methods for completing the tasks because they were taught and instructed to do such. Many of the same elements were used in every task. Table 9 shows which elements were associated with each task. So, for example, the element turn knob was only observed in the tune the radio task.

Table 9. Elements Observed in Each Task

Element	Tune the Radio	Call a Contact	Enter an Address	Dial a Phone Number	Find a Point of Interest	Find a Radio Preset	Find a Song
Read							
Read Instructions	x	x	x	x	x	x	x
Search							
Search	x	x	x	x	x	x	x
Reach							
Reach for Center Console	x	x	x	x	x	x	x
Reach for Button		x	x	x	x	x	x
Press Button							
Press Button	x	x	x	x	x	x	x
Knob Actions							
Turn Knob	x						
Reposition hand on Knob	x						
Touch Screen Actions							
Flick Up		x			x	x	x
Flick Down		x					x
Quick Flick Up		x			x	x	x
Quick Flick Down		x					x
Stop Screen		x				x	x
Scroll Up		x			x	x	x
Scroll Down		x			x		x
Return Down		x			x	x	x
Return Up		x				x	x
Delays							
Wait - Loading	x	x	x	x	x	x	x
Wait for Goggles - Known Location	x	x	x	x	x	x	x
Wait - After Loading	x	x	x	x	x	x	x
Wait for Goggles - Unknown Location	x	x				x	x

Tables 10 through 16 provide further detail, showing the minimum elements needed to complete each task without errors of any type. Further, this list assumes that some subtasks, such as flicking to a point in a contact list, can be done with a single flick, which may not be true. Further, the assumption is that in completing each task, subjects do not make mistakes, either corrected or uncorrected. In fact, this is not always true, but without this assumption, and with so many error possibilities, the calculation of task times can become unreasonably difficult. However, even if the assumptions are not true all of the time, the estimates can be reasonable and useful. Making assumptions about things that are not true but reasonable is common within engineering, such as objects with no mass, frictionless surfaces, and triangular objects with 37-degree angles.

Table 10. Tune the Radio

Element	Note
Reach for Center Console	from steering wheel to center console
Press Button	radio button
Wait - Loading	
Turn Knob	through radio frequencies

Table 11. Call a Contact

Element	Note
Reach for Center Console	from steering wheel to center console
Press Button	Bluetooth phone button
Wait - Loading	
Press Button	contacts button
Wait - Loading	
Flick/Scroll	through contact list
Press Button	contact’s name
Wait - Loading	
Press Button	contact’s phone number
Wait - Loading	

Table 12. Enter a Street Address

Element	Note
Reach for Center Console	from steering wheel to center console
Press Button	search button
Wait - Loading	
Press Button	address button
Wait - Loading	
Press Buttons	enter numbers
Press Button	street button
Wait - Loading	
Press Buttons	enter letters

Press Button	town/zip code button
Wait - Loading	
Press Buttons	enter letters
Press Button	done button
Wait - Loading	
Press Button	Ann Arbor button
Press Button	go button
Wait - Loading	
Press Button	change destination button
Wait - Loading	
Press Button	start guidance button
Wait - Loading	

Table 13. Dial a Phone Number

Element	Note
Reach for Center Console	from steering wheel to center console
Press Button	Bluetooth phone button
Wait - Loading	
Press Buttons	enter numbers
Press Button	send button
Wait - Loading	

Table 14. Find a POI

Element	Note
Reach for Center Console	from steering wheel to center console
Press Button	search button
Wait - Loading	
Press Button	POI category button
Wait - Loading	
Press Button	near current position button
Wait - Loading	
Press Button	travel button
Wait - Loading	
Press Button	airport button
Wait - Loading	
Press Button	select destination
Wait - Loading	
Press Button	change destination button
Wait - Loading	
Press Button	start guidance button
Wait - Loading	

Table 15. Find a Radio Preset

Element	Note
Reach for Center Console	from steering wheel to center console
Press Button	radio button
Wait - Loading	
Flick/Scroll (Task 2 & 3 only)	through preset list
Press Button	select preset
Wait - Loading	

Table 16. Find a Song

Element	Note
Reach for Center Console	from steering wheel to center console
Press Button	song button
Wait - Loading	
Flick/Scroll	through song list
Press Button	select song
Wait - Loading	

How were these data reduced?

The data were reduced frame-by-frame and played back using the Morae Manager software. Resulting were 22,935 data points, more than enough so that given the many ways the data could be partitioned, there were always a few hundred data points to provide a distribution. There were multiple analysts and countless checks between analysts to make sure the data were reduced in agreement and the times were accurate and precise. The start and end time for each movement for each subject was recorded in an Excel spreadsheet. The time of each occurrence of the goggle opening and closing was also recorded.

Many problems with the recordings were identified during data reduction. For some subjects, there were various delays between the face camera and the screen camera (desynchronization). Any delay greater than 15 ms (about two frames) was corrected in the data files. However, for some delays, the positioning of the cameras did not allow the analyst to determine how long the delay was, so those delays were not corrected.

There were also instances where the goggles did not seem to have a constant 1.5 s cycle, analyzed in detail later. Goggle cycle times typically varied between 1.13 and 1.8 s but there were instances of times as brief as 0.6 s and as long as 2.07 s. The long times were due to an obvious freezing of the face camera during video playback. The authors do not know of any published data that have reported actual goggle cycle times.

After the data was reduced, the data was checked to verify that the tasks and elements were identified correctly and the times were reasonable. Using the JMP statistical software package, the distributions were examined for outliers using various categories of the data (by subject, by task, by time, etc.). Summary tables to check the number of occurrences of elements and element condition combinations were also created. Examination of these distributions and tables led to many corrections. Additional details appear in the results. The result of this long, involved effort was a high quality database concerning what happened during each open and close period of the goggles in an occlusion experiment that the authors believe is highly reliable and comprehensive.

RESULTS

The data were analyzed in considerable and multiple levels of detail to support the development of time estimates for various in-vehicle tasks. Depending on the need for accuracy and the time available, the granularity of the estimate may vary. Some analysts may just use the mean time for each element and use those means for all instances in which that element occurs. Others may wish to improve those estimates by examining differences due to age. Still others may consider different cases for each element. For example, one can use different mean times for each type of a button press (e.g., letters, function keys) instead of the same time for all button presses. Finally, other analysts may wish to create Monte Carlo simulations of in-vehicle tasks, for which distribution types and parameters are required.

Beyond merely presenting the data, there is some effort to explain why these values were obtained. However, statistical tests were not provided for every difference of interest to avoid making this section unreadable. The section on the precision and accuracy of the data collected should provide a yardstick for such judgments.

Given these multiple goals, there are numerous tables and figures presenting data that does not exist elsewhere in this detail and quality. This information will allow researchers and engineers to better predict how long in-vehicle tasks will take, and ultimately, how distracting those tasks will be.

Exactly how long were the goggles open and how accurate was the timing?

The experiment was designed so that the goggles were open for 1.5 s and closed for 1.5 s. In fact, that did not always occur (figure 3). The mean goggle time (15,137 events) was 1.49 s with a standard deviation of 0.09 s. Thus, although not exactly the time desired, the times observed were quite close to the desired time of 1.5 s. What is noteworthy was that there was some binning of times due to how accurately times were recorded, a topic that is covered in the next section. Some of the small errors reported in goggle open/close times may in fact be delays in the analysis software, not errors in the actual open/close times.

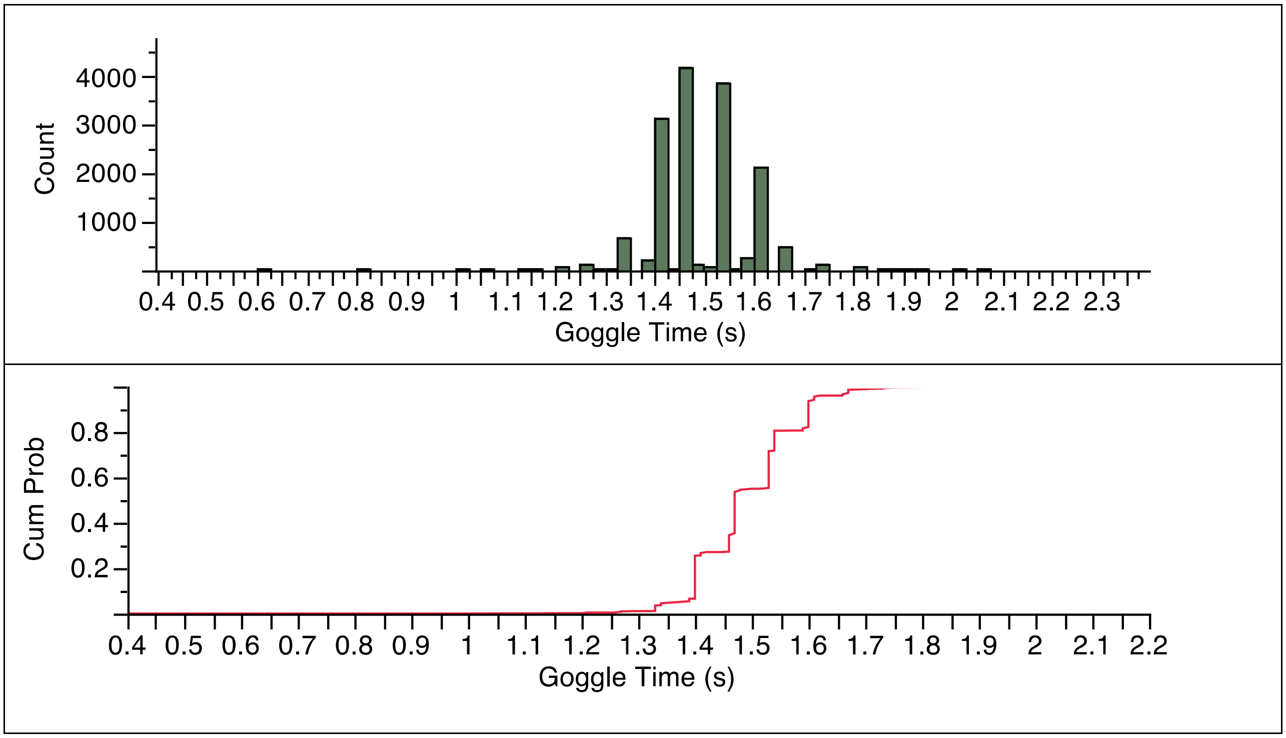


Figure 3. Goggle Time (s) Distributions

Figure 4 shows the complete distribution of all element times with the missing (zero) values removed. Notice that the distribution is not smooth, primarily because the aggregate distribution shown is the combination of several distributions with different means and shapes, but also because of binning effects, described next.

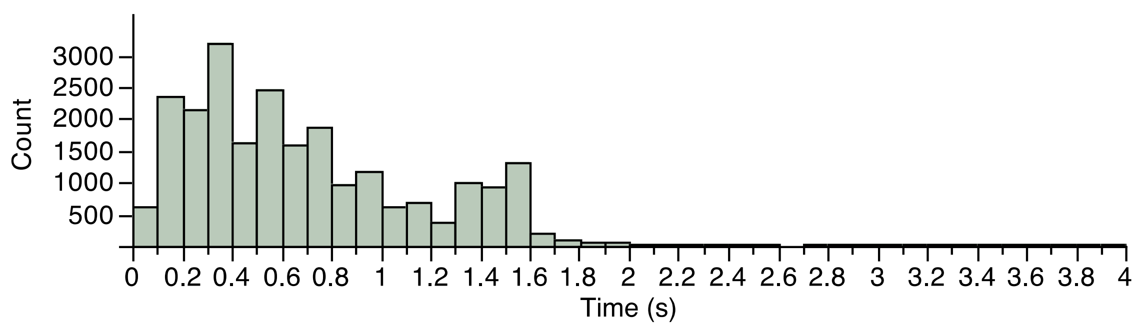


Figure 4. Data for 22,922 Element Times (s)

Note: For 13 data points, the times were missing

In figure 5, the scale has been expanded to the nearest 0.01 in the range of 0.2 to 0.6 s, the heart of the distribution. Notice that there is some periodicity to the data. This occurs because the data theoretically could be recorded at 30 Hz (nearest 33 ms), but the rate was actually much slower, about half of that, in part due to Morae, whose update rate was slower and slightly variable. In addition, human analysts determined the time when each event occurred by watching the video recordings, and there is an unconscious human bias toward rounding off to whole numbers, for example, to the nearest 0.1 s. The periodicity in the data appears to occur about every 0.07 to 0.08 s, and thus differences less than those values may not reflect real differences. For the purpose for which this data is to be used, this accuracy is sufficient.

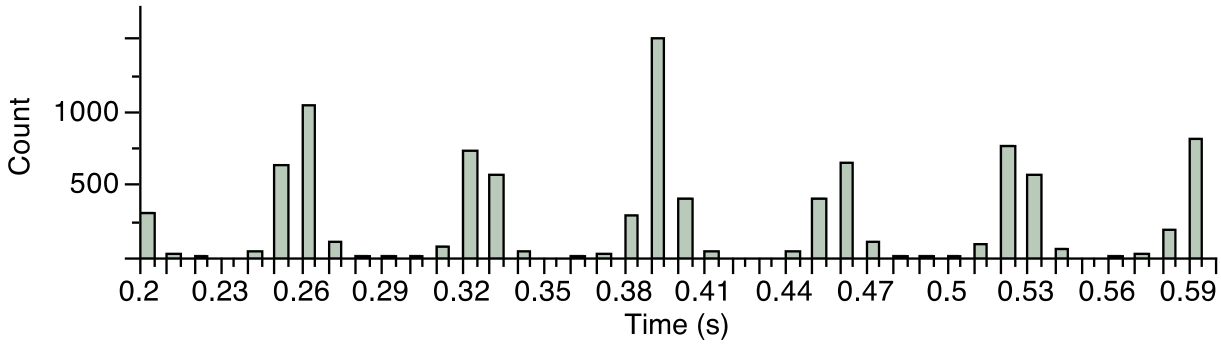


Figure 5. Expanded Scale for Element Times

What are the task completion times for the visual manual tasks when tested using the US DOT occlusion procedure?

The task-completion time was measured from the instant the subject started reaching for the center console to the instant the machine had loaded the final screen of the task. This completion time is calculated while the subjects are wearing the occlusion goggles. Therefore these times are a rough estimate of how long these tasks could take on the road, because the goggles simulate looking back and forth between the road and the center console.

Although an analysis of the total task time was reported previously (Kang et al. 2013), those data were reexamined here using an improved data file to estimate the task times. The goal is to understand the factors that matter and provide insights into the analysis of the task-element data.

As shown in Table 17, there is a substantial difference in the mean task times between tasks. The mean time for all tasks was 32.3 seconds with a standard deviation of 24.4 seconds. The longest task (*enter a street address*) took a mean time of about 83 s where the shortest task (*find a radio preset*) took a mean time of only about 7 seconds. In the NHTSA occlusion procedure to assess distraction, the task-completion time cannot exceed 12 s (U.S. Department of Transportation, 2013). The only task that was within the 12-s requirement was the *find-a-radio-preset* task. However for trials 1 and 2 of the *tune-the-radio task*, the mean completion times were less than 12 s. There were a few instances of younger subjects completing the *dial-a-phone-number task* and the *call-a-contact task* under the 12-s threshold.

Table 17. Occlusion Task Completion Times (s)

Block	Task	Trial			Mean
		1	2	3	
1	tune the Radio	**11.5**	13.9	**11.3**	12.2
2	call a contact	20.9	23.0	24.3	22.7
3	enter a street address	88.6	84.7	76.1	83.1
4	dial a phone number	25.4	24.5	26.0	25.3
5	find a POI	27.3	24.0	26.0	25.8
6	**find a radio preset**	**5.4**	**7.4**	**7.2**	**6.7**
7	play a song	35.8	44.9	70.6	50.4
Mean		30.7	31.8	34.5	32.3

Note: Tasks completed within the 12 s guideline are shown in bold.

The number of practice trials was adequate because the performance was reasonably stable throughout the test trials. The only exception is the third trial of the *play-a-song* task. This was because the song in that trial was much further down in the song list compared with the songs from the first two trials, so the task time should increase considerably, which it did by about 60%. Subjects spent much more time flicking and scrolling through the list to find the song because of its location. Without the *play-a-song* task, the mean times by trial for this experiment were 29.9, 29.6, and 28.5 s, remarkably similar values.

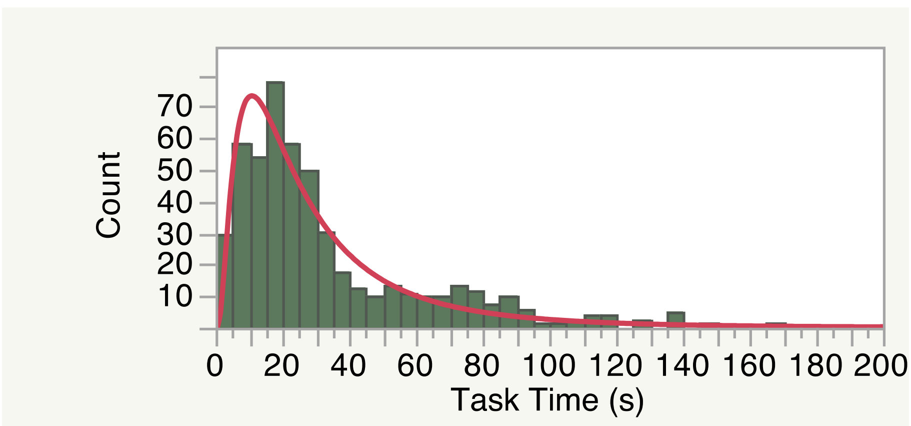


Figure 6. Distribution Times for All Tasks

What are the major factors that affected task time?

An ANOVA was computed for the task times, with Age, Gender, Age*Gender, Subject (Age*Gender), Trial, Task, and Age*Task as the main effects. Other terms unlikely to be statistically significant were not included and were folded into the error terms. This may correct a potential error in previous analysis, where missing data (13 out of 22,935 data points) was coded as having zero time.

In that ANOVA, the effects of Age, Subject (Age, Gender), Task, and Age*Task were all highly significant (p<0.0001). Gender was significant at p=0.03 and Age*Gender at p=0.007. The effect of Age was quite pronounced with middle-aged subjects taking 44% longer than younger subjects (table 18). These differences are reflected in the subject differences, with mean task times varying from 21.32 s to 50.25 s, more than a factor of 2.

Table 18. Total Mean Task Time: Effects of Age and Gender

Age	n	Female	Male	Mean
Young	250	26.17	26.86	26.51
Middle	246	39.86	36.45	38.16

Similarly, there were major task differences (table 19). Notice that the age differences varied considerably with the task, from 24.2% to 50.5%. This all suggests that age and subject differences need to be examined carefully for each task element.

Table 19. Total Task Time: Age Differences between Tasks.

Task	**n**	**Age**		
		Young	**Middle**	**% Difference**
Address	70	68.11	97.46	43.1
Contact	72	18.14	27.29	50.5
Dial	72	20.58	30.05	46.0
POI	69	22.55	29.33	30.1
Preset	72	5.63	7.72	37.0
Radio	69	10.96	13.62	24.2
Song	72	41.95	58.86	40.3

Thus, these data suggest a pattern for examining the individual element times–to look at the (1) Age*Gender interaction, whose effect may differ from case to case, (2) element differences, and (3) sometimes, Age*Element interactions.

Overall, what affected the times of each element, especially the goggle state?

This section examines elements (reach, delay, etc.), a series of which comprise a task. Accordingly, the analysis in this section is more detailed than that in the previous section and more diagnostic.

As a reminder, figure 7 shows the overall distribution for all 22,935 element times, which includes 13 data points coded as 0. With those data points the range was from 0 s to 10 s, with a mean of 0.70 s and a standard deviation of 0.52 s. Notice that the data are somewhat lognormal overall. However, as will be shown later, this distribution is composed of several other distributions (at least seven, one per element), some of which are quite distinct. Hence, the distribution appears bimodal and discontinuous. Binning, as described later, also contributes to what appears to be discontinuity.

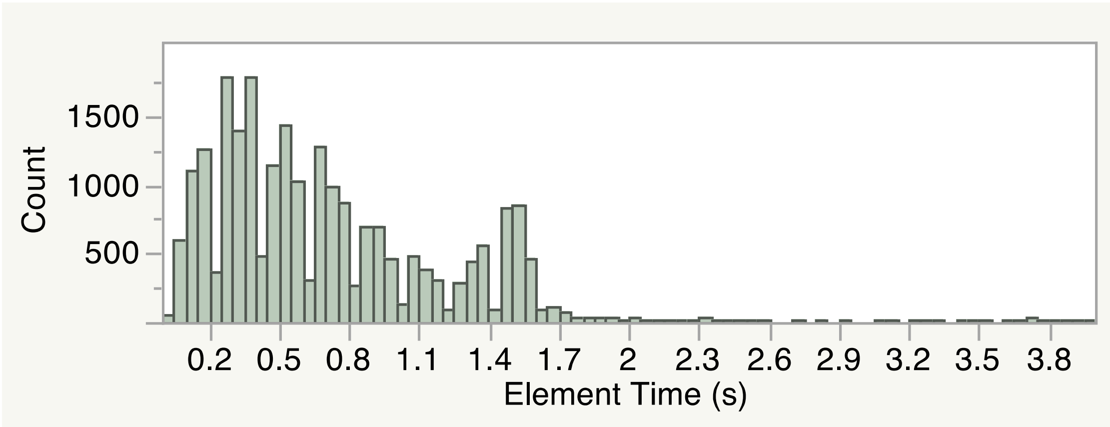


Figure 7. Element Times (s): Distribution

The analysis of the element times was similar to that for the overall task times, with main effects of Age, Gender, Trial, Element, Subject (Age*Gender) and the Age*Gender and Age*Element interactions. The Element, Subject (Age*Gender), and Age*Element interaction were all highly significant ($p<0.001$). Also significant were Age ($p=0.005$) and Gender ($p=0.04$).

As shown in Table 20, there were differences in the number of elements that various age and gender groups experienced. Middle-aged women completed the largest number of elements, and the mean time per element was7% greater for middle-aged than young subjects. Thus, the reason that middle-aged subjects took 44% longer to complete tasks was that there were more elements to complete (32% more).

Table 20. Element Data (s): Effects of Age and Gender

Age	**Female**	**Male**	**Mean Times (s) (Total n)**
Young	0.66 (4884)	0.67 (5012)	0.67 (9896)
Middle	0.71 (6838)	0.72 (6188)	0.72 13026

Table 21 provides additional detail (by subject), with the number of elements varying from 604 to 1,319, more than a factor of 2 difference. All 13 missing responses were for the element *wait-loading*.

Table 21. Element Data: Number of Responses by Subject
Note: Number of missing entries is in parentheses.

		Age Group		Total
Gender	Subject	Young	Middle	
female	1	728	1,149 (1)	
	2	1,099 (1)	1,319 (1)	
	3	803	779 (2)	
	4	786	1,055	
	5	671 (2)	847	
	6	928 (1)	1,043	
	subtotal	5,015	6,192	11,207
male	1	924	858	
	2	899	1,297	
	3	604 (1)	1,317	
	4	686 (1)	1,132 (1)	
	5	937	1136	
	6	838 (1)	1,100 (1)	
	subtotal	4,888	6,840	11,728
Total		9,903	13,032	22,935

Following is a detailed examination of each element. Given the analyses just described, age and subject differences needed closer examination. As a prelude to those analyses, an overall summary of the element times appears in table 22. Element times ranged from 0.24 s to 1.34 s, with all but one taking less than 1.0 s. Associated with each element were 146 to 2,865 data points, more than enough to estimate a mean and provide a first estimate of the distribution type and its parameters.

Table 22. Element Data: Descriptive Statistics

Element (alphabetical order)	n		Time (s)		Total n	Mean (s)
	Young	Middle	Young	Middle		
Flick	322	512	0.50	0.50	834	0.50
Flick/Scroll Return	984	1362	0.38	0.37	2346	0.38
Press Button	2,389	2,661	0.60	0.68	5050	0.64
Quick Flick	473	639	0.34	0.36	1112	0.35
Reach for Button	235	440	0.38	0.45	675	0.42
Reach for Center Console	551	534	0.73	0.76	1,085	0.75
Read Instructions	197	248	0.48	0.57	445	0.53
Reposition hand on knob	194	280	0.36	0.32	474	0.33
Scroll	249	171	0.62	0.72	420	0.66
Search	1,067	1,906	0.48	0.58	2,973	0.54
Stop Screen	93	53	0.25	0.24	146	0.24
Turn Knob	291	373	0.50	0.38	664	0.43
Wait - Loading	990	1028	0.84	0.95	2,018	0.90
Wait After Loading	390	418	0.92	0.93	808	0.92
Wait for Goggles - Known Location	1,102	1,763	1.33	1.34	2,865	1.34
Wait for Goggles - Unknown Location	369	638	0.91	0.93	1,007	0.92

Overall, when did elements occur relative to the goggle state?

As a reminder, a key hypothesis of Pettitt's method is that elements needing visual guidance stop when the goggle shutter is closed and continue when the shutter opens. Further, if the goggles are closed, the start of the element is delayed until the shutter opens.

As shown in Tables 23 and 24, there are many exceptions to Pettitt's assumptions. The first of these two tables shows how often each element occurred for single states (only open or only closed), two states (open and closed), with all combinations of more than two states pooled (as other). The second table provides detail for the four elements for which there were occurrences of more than two states. The data were partitioned in this manner to avoid a large and difficult to read table of all elements and all observed state combinations for which most cells would be empty. Except for one button press element, two *turn-knob* elements, and one *scroll* element, the only element that required more than two states was *machine loading*. How to deal with this element in determining occlusion time needs further thought.

Table 23. Element Data: Count for Each Goggle State Combination

Element (alphabetical order)	Open	Open, Close	Close	Close, Open	Other (>2)	Total n
Flick	472	121	221	20	0	834
Flick/Scroll Return	1,132	274	833	107	0	2,346
Press Button	4,006	843	181	19	1	5,050
Quick Flick	543	114	394	61	0	1,112
Reach for Button	675	0	0	0	0	675
Reach for Center Console	886	63	56	80	0	1,085
Read Instructions	445	0	0	0	0	445
Reposition hand on knob	196	44	198	36	0	474
Scroll	181	119	98	21	1	420
Search	2,973	0	0	0	0	2,973
Stop Screen	50	12	78	6	0	146
Turn Knob	291	103	218	50	2	664
Wait - Loading	828	655	286	96	166	2,031
Wait After Loading	0	0	808	0	0	808
Wait for Goggles - Known Location	0	0	2,865	0	0	2,865
Wait for Goggles - Unknown Location	0	0	1,006	1	0	1,007
Total Ignoring Waits	11,850	1,693	2,277	400	4	16,224
Grand Total	12,678	2,348	7,242	497	170	22,935

Table 24. Element Data Counts: Occurrences of Other (>2) States

Element	Close, Open, Close	Close, Open, Close, Open	Close, Open, Close, Open, Close	Close, Open, Close, Open, Close, Open, Close	Open, Close, Open	Open, Close, Open, Close	Open, Close, Open, Close, Open	Open, Close, Open, Close, Open, Close	Total
Press Button	0	0	0		1	0	0	0	1
Scroll	1	0	0		0	0	0	0	1
Turn Knob	1	0	0		1	0	0	0	2
Wait - Loading	31	12	5	1	61	47	6	3	166

What is noteworthy in these data is how often elements that should require vision were performed when the goggles were closed. Some 73% of the elements occurred while the goggles were open, 10% when they were open then closed, 14% while closed, and 2% when closed and then open. In fact, every element (except *search* and *read instructions*) occurred while the goggles were closed. Thus, although Pettitt's assumptions represent what happens most of the time, there appear to be numerous exceptions. How often these exceptions occur is examined in the sections that follow.

Table 25 provides a sense of the effect of goggle state on mean times, with only the first two state combinations give for the sake of legibility. The prior tables give the n's. Interestingly, the element times for when the goggles were closed were often less for when the goggles were open, possibly because subjects only elected to perform less demanding elements when the goggles were closed.

Table 25. Element Mean Times: Goggle State Effect

Element (alphabetical order)	Open	Open, Close	Close	Close, Open
Flick	0.52	0.53	0.43	0.54
Flick/Scroll Return	0.36	0.57	0.31	0.54
Press Button	0.62	0.77	0.47	0.97
Quick Flick	0.36	0.39	0.31	0.43
Reach for Button	0.42			
Reach for Center Console	0.71	1.04	0.65	1.02
Read Instructions	0.53			
Reposition Hand on Knob	0.29	0.44	0.32	0.52
Scroll	0.57	0.86	0.54	0.82
Search	0.54			
Stop Screen	0.21	0.47	0.23	0.30
Turn Knob	0.36	0.75	0.30	0.68
Wait - Loading	0.33	0.97	0.54	1.53
Wait After Loading			0.92	
Wait for Goggles - Known Location			1.34	
Wait for Goggles - Unknown Location			0.92	1.11

What were the times and distributions for each element?

This section contains the times for each element along with information on the goggle states as it relates to element time. Data on errors that occurred for each element is in the section after this section.

Read Instructions

The *read-instructions* element occurred when subjects forgot some or all of what they were instructed to do or were double-checking that they had entered the correct information. This element is included to improve the predictions of the experiments, but may not be an element to be included in routine task time calculations. There were 445 instances of subjects reading instructions (figure 8). The mean time was 0.53 s with a standard deviation of 0.25 s. Read times ranged from 0.06 s to 1.6 s. The distribution was log normal, with $\mu = -0.75$ and $\sigma = 0.49$.

As an aside, for the convenience of the reader, all of the figures showing element distributions in this section, with one exception, have the same x-axis to facilitate comparison.

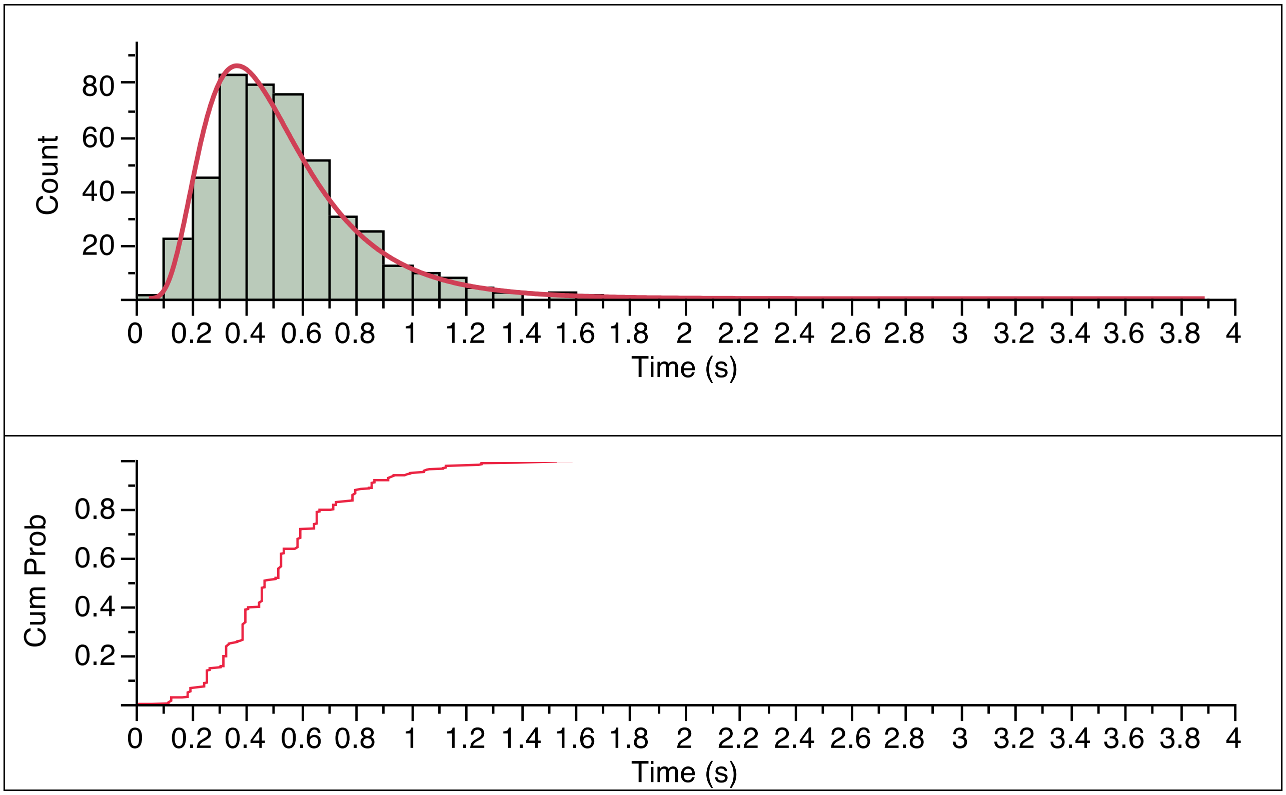


Figure 8. Read Instructions Time Distributions

As shown in table 26, middle-aged women were more likely to read instructions than other subject groups by about 40%, but interestingly, the mean reading time for young women was less than for other groups. The number of occurrences of *read-instructions* elements varied from 6 to 39 per subject. No subject appeared to be anomalous in having far fewer or far more read instruction occurrences than other subjects.

Table 26. Read Instructions Element: Age and Gender Effects

Age	Gender		Mean Time (s) (Total n)
	Female	Male	
Younger	0.41 (97)	0.54 (100)	0.48 (197)
Middle	0.55 (143)	0.60 (105)	0.58 (248)

How often subjects read instructions depended upon the task, and in particular the amount of information to be remembered (table 27). As a first-cut estimate, the mean number of reads per trial per task was estimated by dividing the total number of occurrences per task by the total number of trials per task (3 trials x 24 subjects = 72 trials).

What remains unknown is how to deal with the *read-instructions* element when estimating occlusion time. Note for the address, contact and song tasks, there were on average more than two reads/trial, which adds more than a second to the total task time, and potentially two glances. In real-world situations, the subject may have memorized the desired information, so the *read-instructions* element would not occur. In other cases, the subject may look at a piece of paper or smartphone for the information desired. Fortunately, the tasks for which this occurs exceed the NHTSA guidelines, so this may not be an issue.

Table 27. Read Instructions Element: - Task and Age Effects

Task	n			Mean Reads/Trial	Mean Time (s)	
	Young	Middle	Total		Young	Middle
Address	59	87	146	2.03	0.45	0.60
Contact	5	3	8	0.11	0.37	0.35
Dial	85	104	189	2.63	0.52	0.57
POI	0	7	7	0.10		0.48
Preset	4	1	5	0.07	0.51	0.39
Radio	14	22	36	0.50	0.42	0.48
Song	30	24	54	0.75	0.45	0.57

No analysis of goggle state is provided because instructions were only read when the goggles were open.

Search

Search is when the subject is looking for something, such as a button or menu entry. There were 2,973 occurrences of the *search* element, with times ranging from 0.04 s to 1.79 s. The mean time was 0.54 s with a standard deviation of 0.39 s. Times ranged from 0.04 s to 1.79 s. As shown in figure 9, the distribution was lognormal with $\mu = -0.90$ and $\sigma = 0.84$. However, although the fit left something to be desired, it was the best fit one could expect with a continuous distribution.

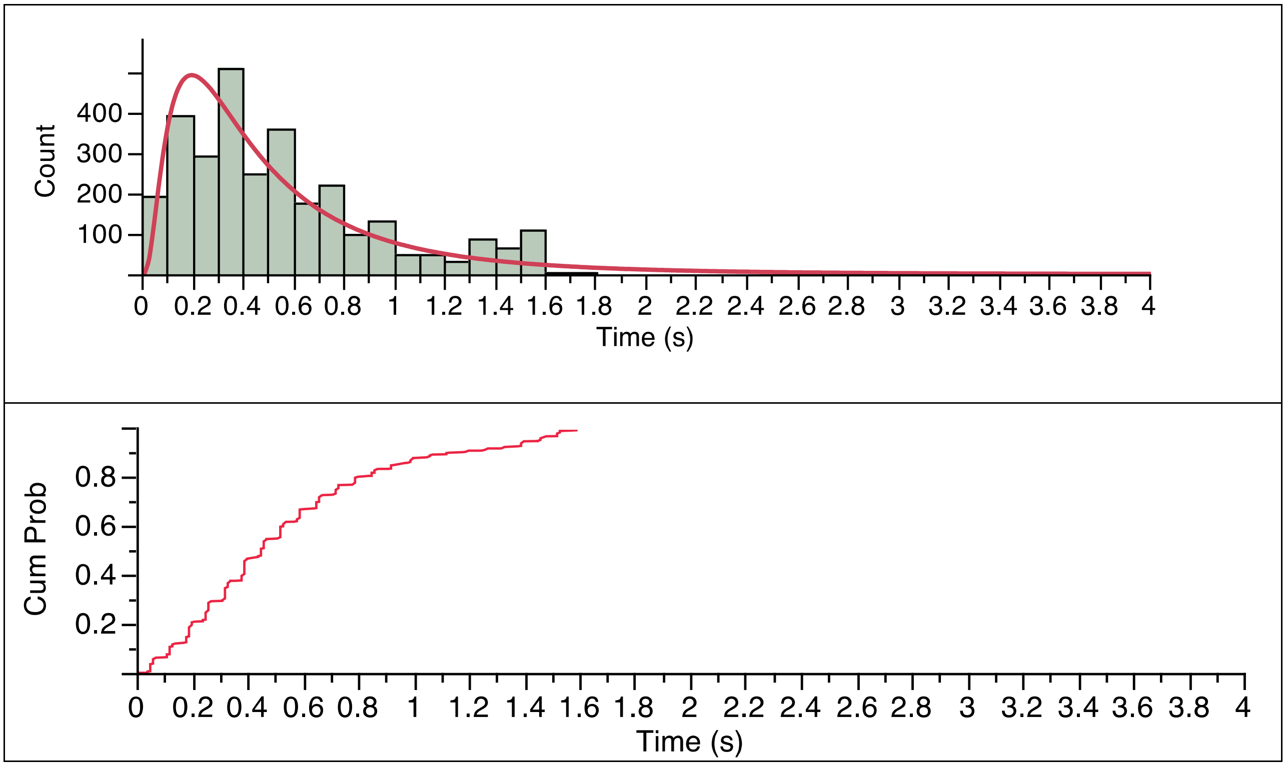


Figure 9. Search Time Distributions

A possible explanation for the jaggedness of the search time distribution may be that there are different types of search occurring (table 28). Notice that the radio-preset selection time is less than others, some of which involves selecting from arrays and some of which involves lists.

Table 28. Search Element: Task and Age Effects

Task	n			Mean Time (s)	
	Young	Middle	Total	Young	Middle
Address	396	794	1190	0.47	0.58
Contact	98	181	279	0.50	0.66
Dial	91	151	242	0.40	0.51
POI	169	241	410	0.53	0.52
Preset	20	43	63	0.44	0.62
Radio	65	94	159	0.39	0.37
Song	228	402	630	0.53	0.65

As shown in table 29, middle-aged subjects had 18% longer search times, with middle-aged women having far more search occurrences than other subject groups. The number of occurrences ranged from 50 to 237 per subject, with mean times of 0.39 s to 0.66 s.

Table 29. Search Element: Age and Gender Effects

Age	Gender		Mean Time (s) (Total n)
	Female	Male	
Young	0.47 (570)	0.50 (497)	0.49 (1067)
Middle	0.58 (1170)	0.58 (784)	0.58 (1954)

Finally, for search, the state of the goggles was not examined because search only occurred with the goggles open, which makes perfect sense.

Important for this element is a sense of what subjects were searching for. As shown in table 30, the next element that occurred most often was waiting for the goggles to open. Occurring less often were pressing a button and reaching for the center console.

Table 30. Search: Next Element After Search

Next Element (sorted by n)	n	%
Wait for Goggles - Known Location	1,210	40.7
Press Button	632	21.3
Wait for Goggles - Unknown Location	248	8.3
Reach for Center Console	178	6.0
Flick	130	4.4
Turn Knob	111	3.7
Reach for Button	106	3.6
Flick/Scroll Return	99	3.3
Read Instructions	93	3.1
Quick Flick	85	2.9
Scroll	65	2.2
Stop Screen	10	0.3
Reposition Hand on Knob	3	0.1
Search	1	0.0
Wait After Loading	1	0.0
Wait - Loading	0	0.0
Total	2972	100.0

Reach: Reach for Center Console

Reach for center console is when the subject's hand moves from steering wheel or body to the center console. There were 1,085 occurrences of the reach for center console element, with times ranging from 0.12 s to 1.72 s. The mean time was 0.74 s with a standard deviation of 0.27 s. As shown in figure 10, the normal and lognormal distributions fit the data equally well, with μ and σ of 0.74 and 0.27 for the normal distribution and -0.36 and 0.38 for the lognormal distribution. As all reaches involved reaching to the same location, differences by task were not examined. However, some of the variation is due to whether the reach began with the goggles open or closed, or if there was a change in goggle state during the reach.

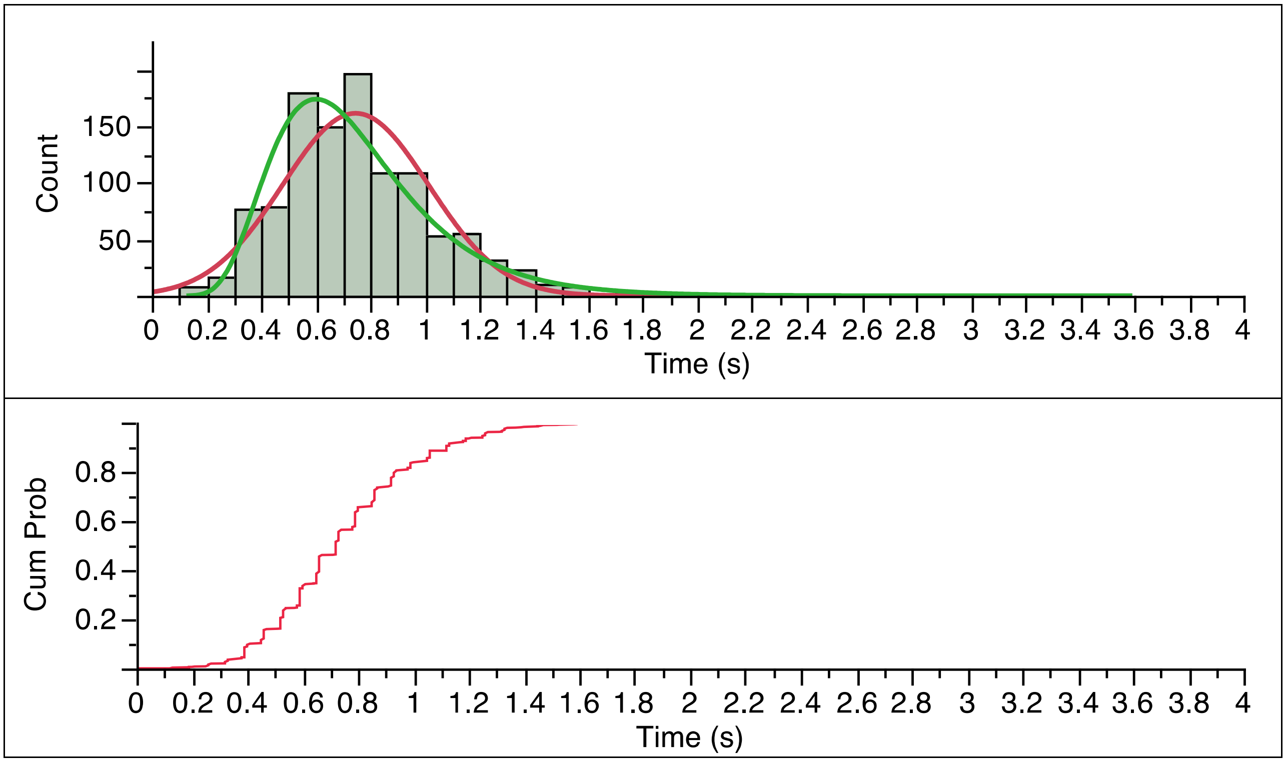


Figure 10. Reach for Center Console Time Distributions

As shown in table 31, there were no differences in the mean times of this element by age or gender or the number of occurrences. The number of occurrences per subject ranged from 21 to 170 with mean times of 0.57 s to 1.04 s. However, there were two clearly different strategies for reaching for the center console. Two male subjects (one young and one middle-aged) had 122 and 170 reaches respectively, reflecting a strategy of returning their hands to the steering wheel at times, for example, while the shutter was closed. Of the remaining 22 subjects, the largest number of reaches was 79. This presents a challenge for computing occlusion time because subjects may not choose the quickest method to perform the task.

Table 31. Reach for Center Console: Age, Gender, and Subject Effects

Gender	Age				Overall	
	Young		Middle			
	n	Mean Time (s)	n	Mean Time (s)	Total n	Mean Time (s)
Male	24	0.99	21	0.88		
	34	0.67	170	0.77		
	27	1.04	35	0.67		
	21	0.79	23	0.62		
	122	0.57	21	0.70		
	31	0.87	22	0.64		
subtotal	259	0.73	292	0.74	551	0.74
Female	48	0.58	30	0.86		
	43	0.78	46	0.83		
	51	0.82	24	0.93		
	79	0.79	30	0.83		
	23	0.84	75	0.66		
	23	0.69	62	0.72		
subtotal	267	0.75	267	0.77	534	0.76
Overall	526	0.74	559	0.75	526	0.74

One would expect that time to reach for the center console depends on what one is reaching for, an idea that is part of the MTM-1 reach-element coding. As a first-cut look at the *reach-for-console* element, the elements were shifted one row and the transitions examined. As elements are listed one after the other without gaps, this simple coding scheme will lead to misleading results if the reach was the last element of a task. This is because elements following the last element of a task will the first element for the next task for that subject, or the first element for the next subject. Because tasks do not end with a reach for the center console, this simple coding should provide accurate results.

Table 32 presents the summary of that analysis ordered by mean time. The wait elements, all being similar and associated with a delay, have been separated from the table. The flick/scroll return has the shortest times, but there were too few occurrences for a meaningful analysis. The longest time was associated with reading instructions. Also associated with long times were two reach times (one occurrence each), one for reaching for the center console and a second reaching for a button. Overall, the most common element following a reach to the center console was press a button (73% of the occurrences).

Table 32. Reach for Center Console: Next Element Effect

Next Element (alphabetical order)	n	Mean Time (s)
Flick/Scroll Return	5	0.61
Flick	72	0.68
Quick Flick	26	0.72
Scroll	30	0.73
Press Button	802	0.73
Turn Knob	14	0.78
Search	33	0.86
Reach for Button	1	0.87
Reach for Center Console	1	0.92
Read Instructions	19	1.18
Reposition Hand on Knob	0	
Stop Screen	0	
Wait After Loading	5	0.47
Wait - Loading	1	0.79
Wait for Goggles - Known Location	61	0.81
Wait for Goggles - Unknown Location	15	0.91

Finally, there were a number of occurrences where reach for center console continued after the goggles were closed or began when they were closed (table 33). The primary effect of a change of goggle state on this element was to increase the mean time. The distributions for each goggle state are normally distributed, suggesting that the reason that a lognormal distribution may approximate the complete data set is because the set consists of four underlying distributions, two of which occur much less often and have larger means.

Table 33. Reach for Center Console: Goggle State Effect

Goggles	n	Mean Time (s)	SD
Open	886	0.71	0.23
Open, Close	63	1.04	0.34
Close	56	0.65	0.28
Close, Open	80	1.02	0.29

Reach: Reach for Button

Reach for button occurs when the subject is reaching within the console area because he or she has moved from the instrument panel and stopped to search for a specific button or menu, or has completed a button or menu action and is preparing to complete another. There were 675 occurrences of the *reach-for-button* element, with times ranging from 0.04 s to 1.19 s. The mean time was 0.42 s with a standard deviation of 0.25 s, a bit more than half of the time to reach for the center console. As shown in figure 11, the lognormal distribution fit the data reasonably well, with μ and σ values of -1.09 and 0.75.

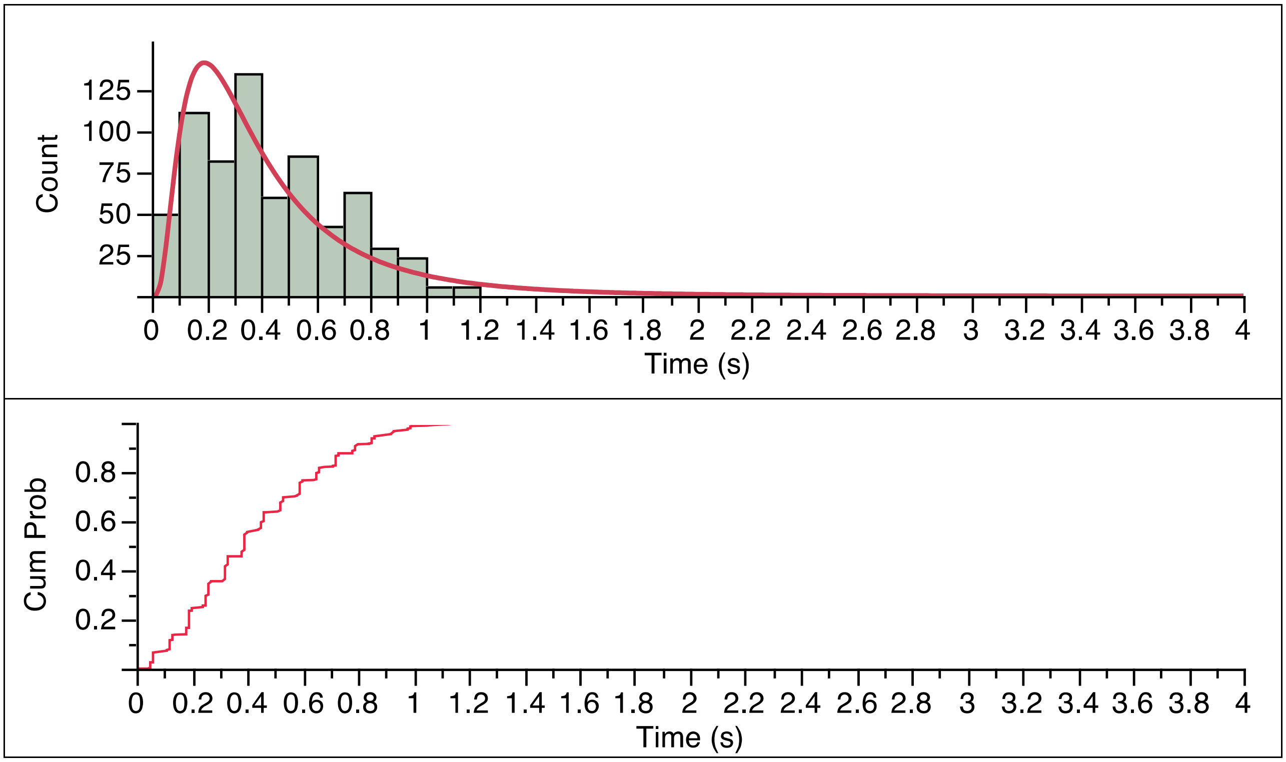


Figure 11. Reach for Button Time Distributions

As shown in table 34, the mean times for middle-aged subjects was about 18% greater than young subjects but there were 87% more occurrences of the *reach-for-button* element. The number of occurrences per subject ranged from 3 to 56 with mean times of 0.27 to 0.52 s. It is noteworthy that the number of occurrences of this element was in the single digits for only one subject.

Table 34. Reach for Button: Age and Gender Effects

Age	Gender		Mean Time (s) (Total n)
	Female	Male	
Young	0.39 (114)	0.37 (121)	0.38 (235)
Middle	0.44 (229)	0.46 (211)	0.45 (440)

In contrast to the *reach-for-center-console* element, there was not much of an opportunity for the following element to affect that time, primarily because the next element was usually to wait for the goggles (90% of the occurrences, table 35).

Table 35. Reach for Button: Next Element Effect

Next Element (sorted by n)	n	Mean Time (s)
Press Button	27	0.47
Reach for Button	22	0.67
Search	8	0.65
Read Instructions	6	0.58
Reach for Center Console	1	0.65
Flick	1	0.72
Flick/Scroll Return	0	
Quick Flick	0	
Scroll	0	
Stop Screen	0	
Reposition Hand on Knob	0	
Turn Knob	0	
Wait for Goggles - Known Location	606	0.41
Wait for Goggles - Unknown Location	2	0.46
Wait After Loading	2	0.39
Wait - Loading	0	

As shown in Table 36, the time to reach for a button depended upon the type of button for which the subject was reaching with presets taking slightly less time than other buttons and action buttons taking more time.

Table 36. Reach for Button: Key Type Effect

Key Type	n	Mean Time (s)
preset	5	0.26
space	39	0.37
number	111	0.38
letter	320	0.42
list entry	47	0.42
function	75	0.44
action	78	0.53
shift	0	

For the *reach for button* element, the goggle state was not examined because this element only occurred when the goggles were open.

Press Button

Press a button involves pressing (and releasing) a virtual button. There were 5050 occurrences of the *press-button* element, with times ranging from 0.55 s to 1.99 s. The mean time was 0.64 s with a standard deviation of 0.31 s. As shown in figure 12, both the normal and lognormal distributions fit the data equally well, with μ and σ of 0.64 and 0.31 for the normal distribution and -0.60 and 0.60 for the lognormal distribution.

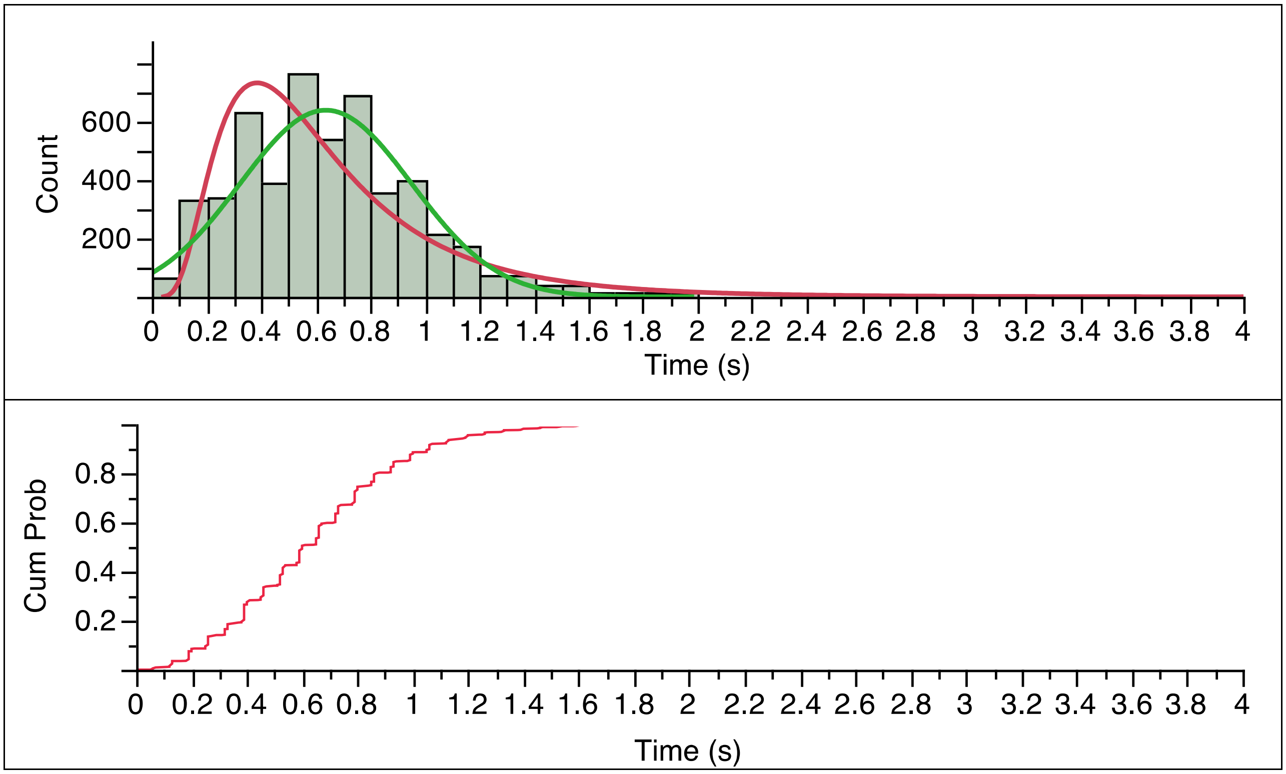


Figure 12. Press Button Time Distributions

As shown in table 37, the mean times for middle-aged subjects was about 13% greater than young subjects but there were 11% more occurrences of the *reach-for-button* element, smaller differences than found for other elements. As with many other elements, there were no overall gender differences. The number of occurrences per subject ranged from 182 to 256 with mean times of 0.46 s to 0.78 s.

Table 37. Press Button: Age and Gender Effects

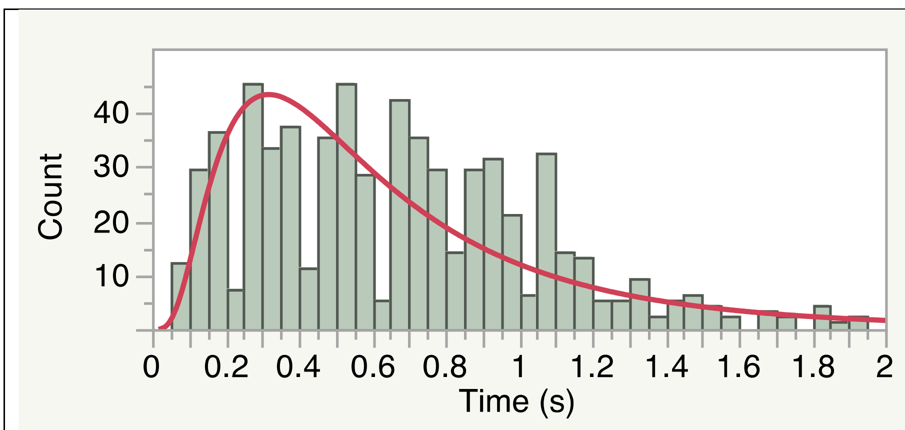
Age	Gender		Mean Time (s) (Total n)
	Female	Male	
Young	0.59 (1159)	0.60 (1230)	0.60 (2389)
Middle	0.63 (1351)	0.73 (1310)	0.68 (2661)

The time to press a button depended upon the button type ($p<0.001$) as indicated by an ANOVA that examined Age, Gender, Age*Gender, Key Type, Age* Key Type, and Subject (Age, Gender). Notice that there is a fairly consistent age difference, with the middle-aged subjects requiring about 15% more time (Table 38).

Table 38. Press Button: Age and Key Type Effects

Key Type	n			Mean Time (s)		
	Young	Middle	Total	Young	Middle	Mean
action	276	363	639	0.60	0.70	0.65
function	596	608	1204	0.51	0.57	0.54
letter	580	689	1269	0.68	0.74	0.71
list entry	273	287	560	0.63	0.71	0.67
number	520	535	1055	0.55	0.65	0.60
preset	37	40	77	0.71	0.66	0.69
shift	0	3	3		0.90	0.90
space	107	136	243	0.67	0.78	0.73

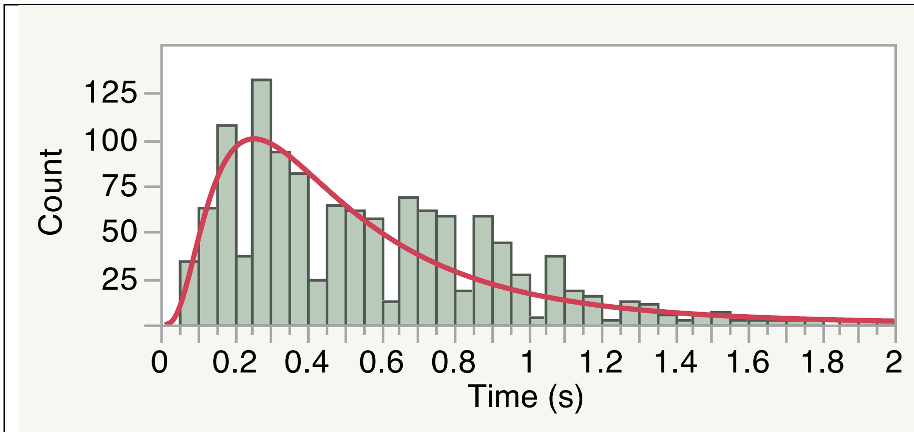
The frequency distributions suggest that there are several distinct distributions for key presses. Action and function are proposed as one group; letter, number, and list entry are proposed as a second; and preset, space, and shift are proposed as other groups (figure 13).



Action

Mean = 0.66
SD = 0.38

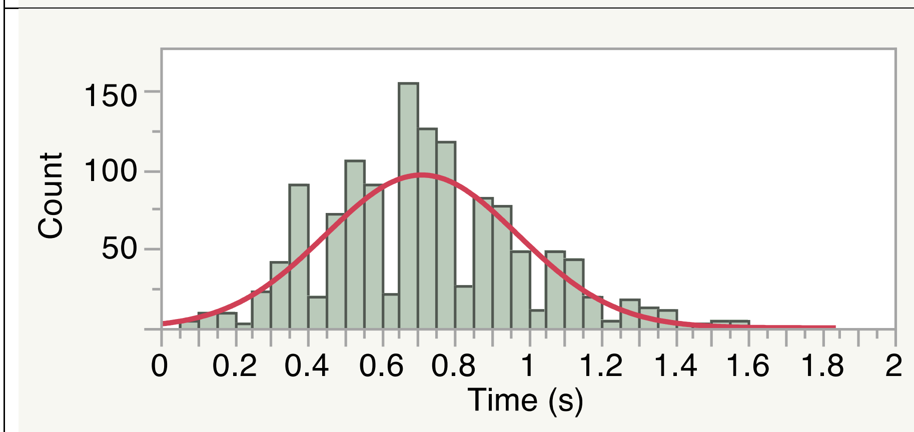
Lognormal
μ =-0.63
σ =0.71



Function

Mean = 0.54
SD = 0.34

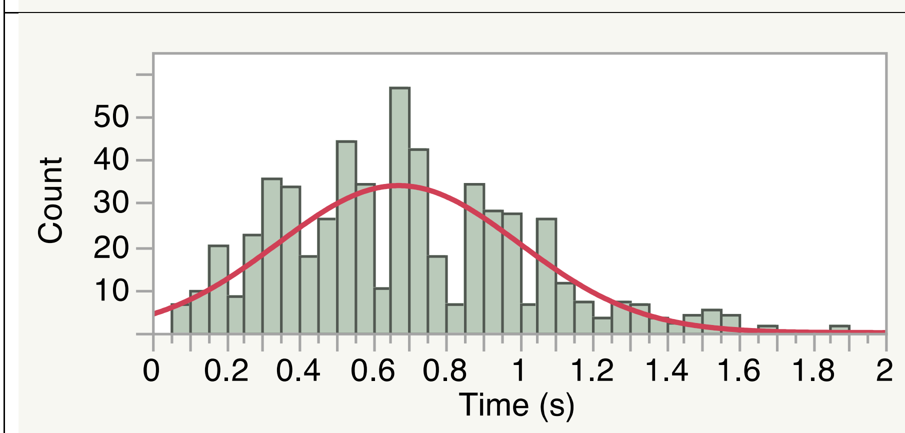
Lognormal
μ =-0.84
σ = 0.72



Letter

Mean – 0.7
SD = 0.26

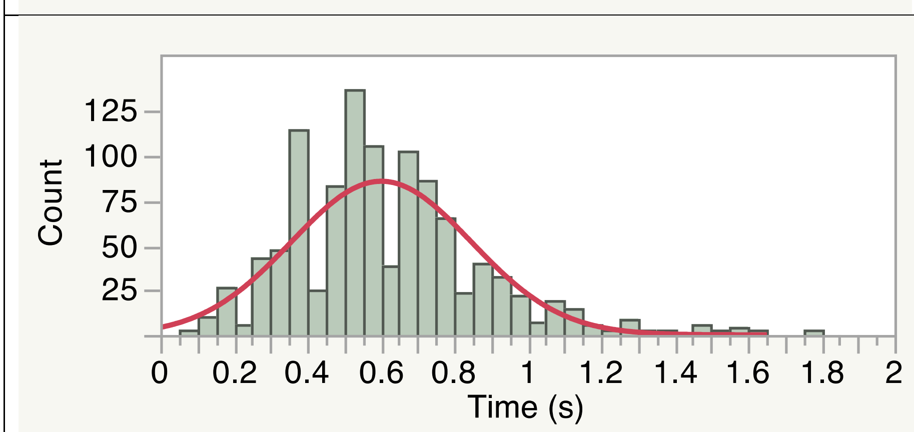
Normal
μ = 0.71
σ =0.26



List Entry

Mean =0.67
SD =0.33

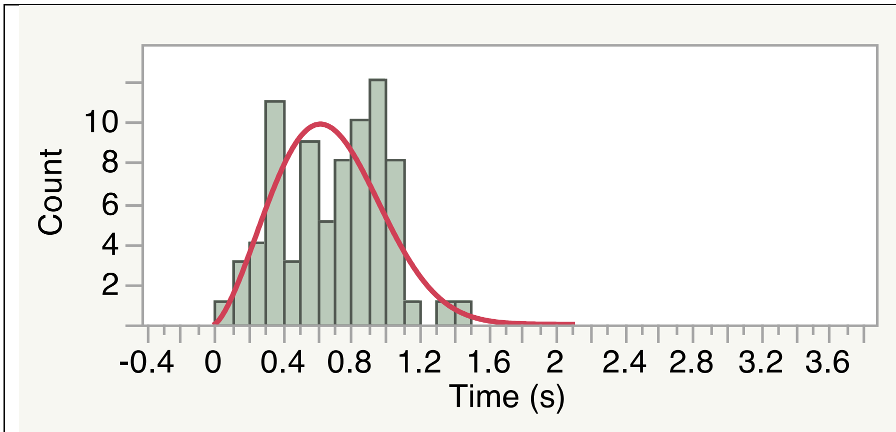
Normal
μ =0.67
σ = 0.33



Number

Mean = 0.60
SD = 0.24

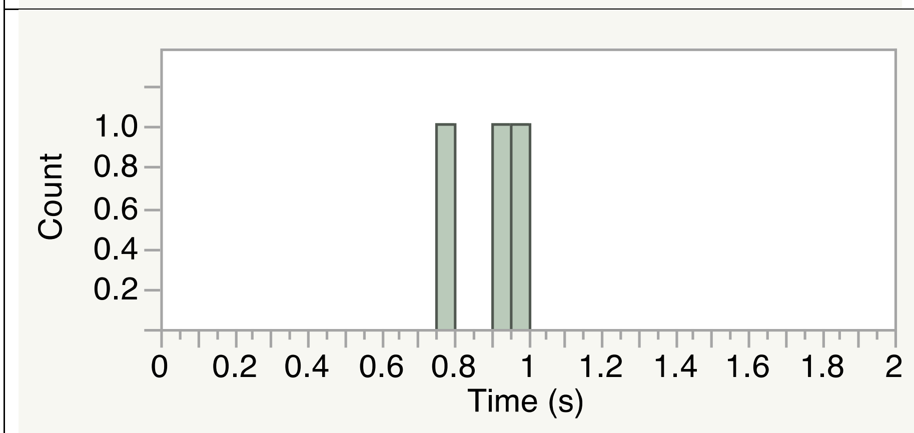
Normal
μ = 0.60
σ = 0.24



Preset

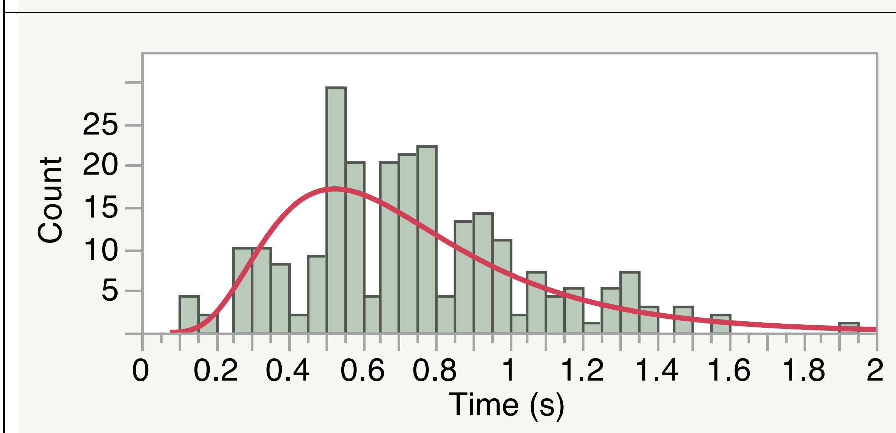
Mean = 0.68
SD = 0.30

Weibull
Scale α =0.77
Shape β α= 2.44



Shift

Mean = 0.89
SD = 0.10



Space

Mean = 0.73
SD = 0.31

Lognormal

μ = -0.41
σ = 0.48

Figure 13. Press Button: Key Type Frequency Distributions

The button-press-time distributions appear to be affected by the goggle state (table 39). All of the various distributions have a lognormal quality to them, but the distribution for when the element occurred in the close state (181 data points) almost appears exponential.

Table 39. Press Button: Goggle State Effect

Goggles	n	Mean Time (s)	SD (s)
Open	4006	0.62	0.30
Open, Close	843	0.77	0.36
Open, Close, Open	1	1.86	
Close	181	0.47	0.30
Close, Open	19	0.97	0.45

Knob Actions: Turn Knob

Turning a knob involves rotation of a knob. There were 664 occurrences of the *turn-knob* element, with times ranging from 0.05 s to 3.32 s. The mean time was 0.43 s with a standard deviation of 0.38 s. As shown in figure 14, the lognormal distribution fit the data well, with μ and σ of -1.19 and 0.87.

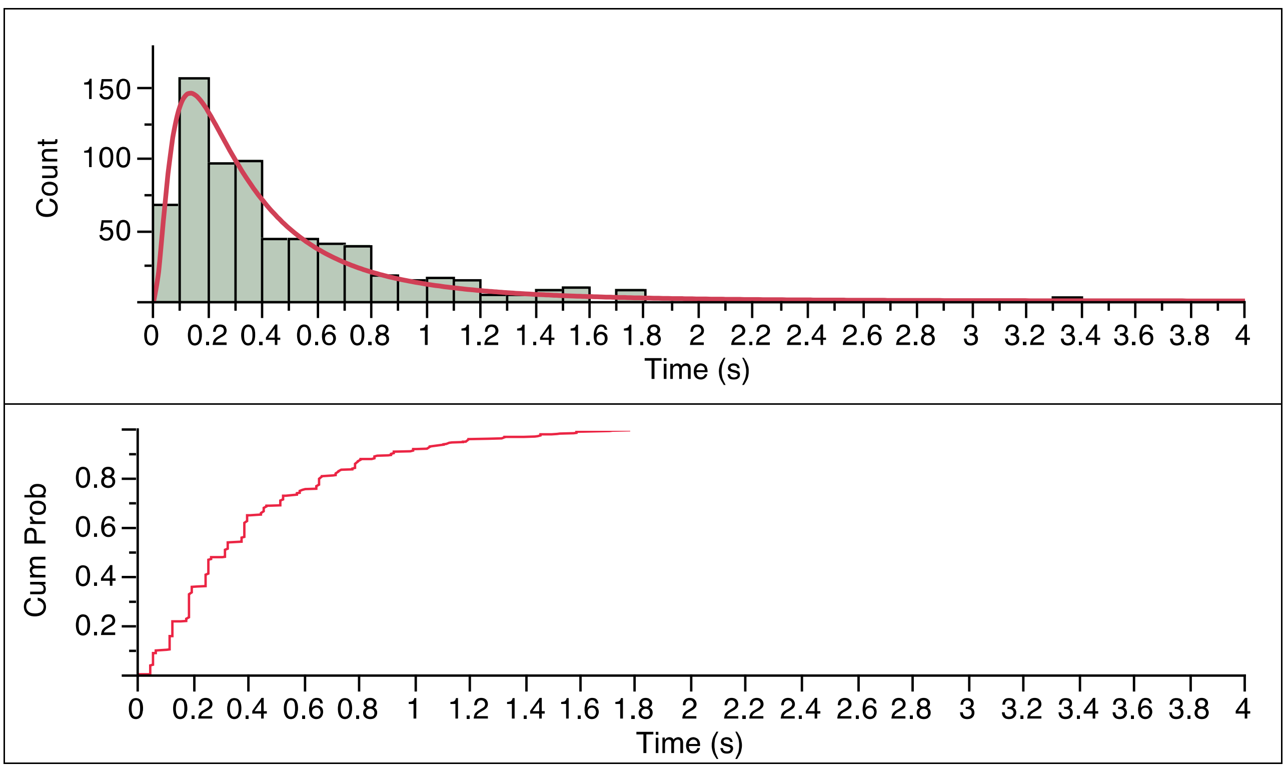


Figure 14. Turn Knob: Time Distributions

Overall, the mean times per subject for the *turn-knob* element ranged from 0.18 to 0.98 s. As shown in table 40, the mean times for young subjects were about 3% greater than they were for middle-aged subjects, the *opposite* of what was expected. Looking at the data in detail, there were several young men with long task times, but one subject (#5) had task times that were 34%

greater than any other subjects. Removing that one subject reduced that mean time for young men to 0.60 s.

The number of *turn knob* occurrences per subject ranged from 17 to 82, with all subjects but one having 50 or fewer occurrences. In addition, there was one subject for whom there were no *turn-knob* elements because that subject did not perform the task using the specified method. There were 26% more for the middle-aged women than any other group.

Table 40. Turn Knob: Age and Gender Effects

Age	Gender		Mean Time (s) (Total n)
	Female	Male	
Young	0.39 (170)	0.64 (121)	0.52 (291)
Middle	0.36 (215)	0.41 (158)	0.39 (373)

When rotating a knob, each click corresponds to changing the frequency by 0.2. One would expect that there would be a relationship between the time to turn a knob and the number of clicks because longer motions typically take more time. That was not the case, as shown in figure 15. In fact, the correlation between the two measures was 0.05. This could be because most of the time was spent positioning the hand over the knob and grasping it. The actual rotation time was quite small, and the rate of rotation varied from trial to trial. Furthermore, to reach a nearby destination, one would turn the knob slowly, whereas if the destination was far away, rotation would be rapid, at least initially.

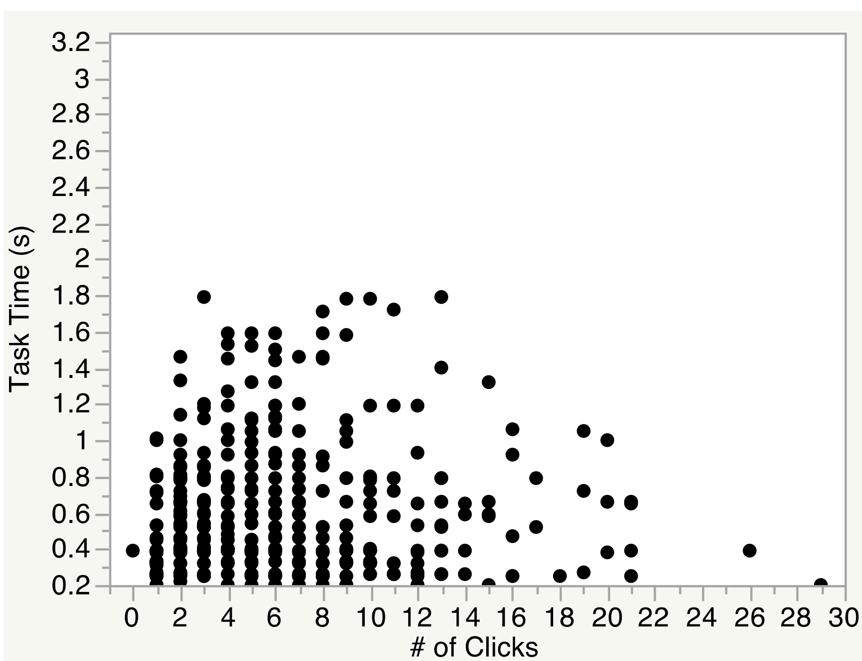


Figure 15. Turn Knob: Number of Clicks vs. Task Time (s)

This lack of a difference may be due to different strategies chosen by subjects (table 41). When turning the radio knob, subjects traded the number of actions for time/action. For example, the shortest mean time (for a young female subject) was 0.18 s per action. However, there were 50 such actions, the largest for any subject. Most of the knob actions were one of a series of motions to reach a distant value. Furthermore, there was no practical difference between turning a knob clockwise (482 occurrences, mean = 0.44 s) and counterclockwise (182 occurrences, mean = 0.43 s).

Table 41. Turn Knob: Subject Differences

Gender	Age				Overall	
	Young		Middle			
	n	Mean Time (s)	n	Mean Time (s)	Total n	Mean Time (s)
Male	20	0.51	24	0.46		
	22	0.73	42	0.57		
	24	0.49	40	0.29		
	27	0.67	28	0.38		
	14	0.98	0			
	14	0.58	24	0.33		
Subtotal	121	0.64	158	0.41	279	0.51
Female	50	0.18	24	0.24		
	33	0.35	82	0.32		
	22	0.66	33	0.60		
	17	0.61	23	0.29		
	27	0.40	26	0.24		
	21	0.50	27	0.50		
	170	0.39	215	0.36	385	0.38
Overall	291	0.50	373	0.38	664	0.43

As shown in table 42, in contrast to many elements, turning a knob occurred both when the goggles were open and when they were closed, and spanned multiple open-close cycles, though they were more likely to start and end when the goggles were open (291 occurrences) than when they were closed (218 occurrences). Note that there were also instances when the goggles were open and then closed (103 instances) and some instances where the goggles were closed, and turning the knob action started and continued until the goggles opened. Thus, for turning a knob, Pettitt's assumption is violated because a manual task occurs while the goggles are closed. What is noteworthy is that unlike touching a button, grasping a knob after the hand is nearby can be done without visual feedback, and to a significant degree, it can be turned without feedback, especially if the destination is far from the current location. Thus, deciding what is a visual, partially visual, or nonvisual task is not easy, and how this is quantified is to be determined.

Table 42. Turn Knob: Goggle State Effect

Goggle State	n	Mean Time (s)	SD (s)
Open	291	0.36	0.27
Open, Close	103	0.75	0.48
Close, Open, Close	1	1.72	
Open, Close, Open	218	0.30	0.27
Close	50	0.68	0.37
Close, Open	1	1.72	

Finally, for those instances where there was more than one data point, the distributions appeared to be lognormal.

Knob Actions: Reposition Hand on Knob

Repositioning the hand was necessary to turn a knob again. There were 474 occurrences of the reach for *the reposition-hand-on-knob* element, with times ranging from 0.05 s to 0.99 s. The mean time was 0.33 s with a standard deviation of 0.18 s. As shown in figure 16, the lognormal distribution fit the data well, with μ and σ of -1.25 and 0.59 respectively.

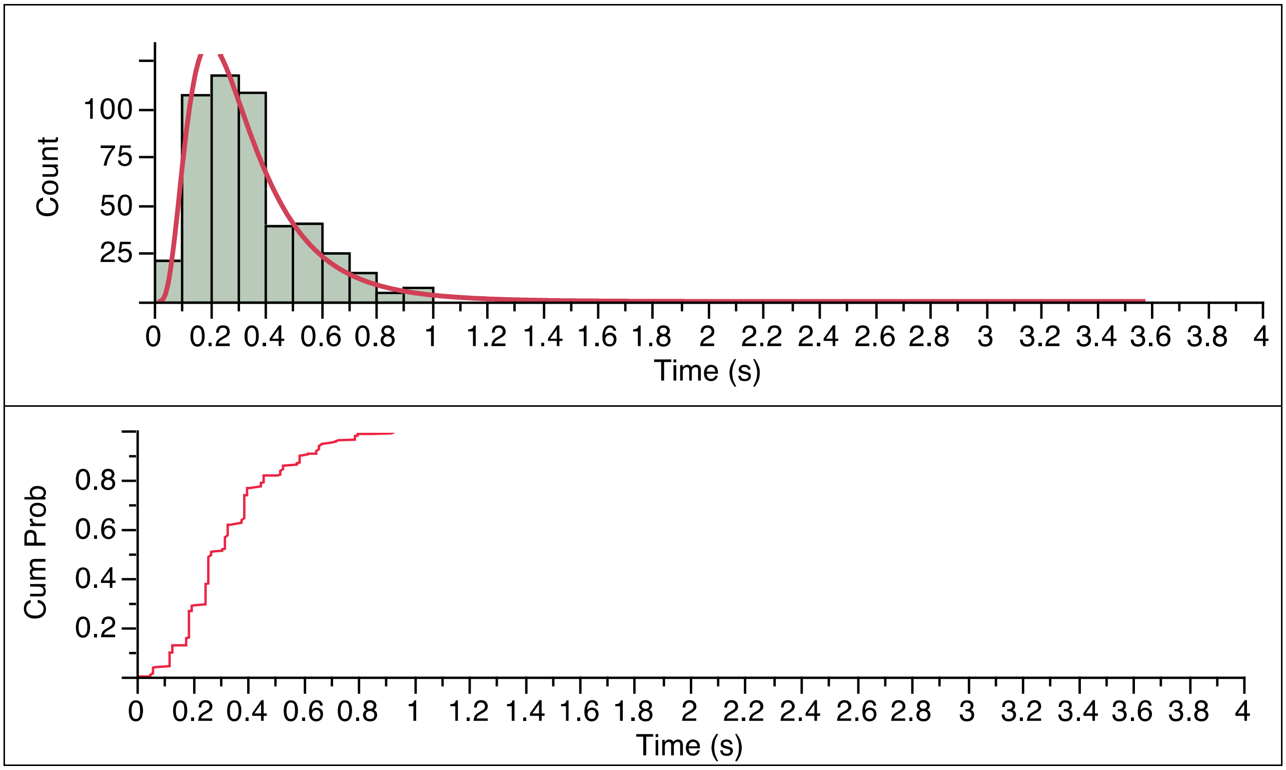


Figure 16. Reposition Hand on Knob: Time Distributions

The mean times per subject ranged from 0.19 to 0.53 s., except for one subject who did not utilize this element. Oddly, the young subjects were slower than the middle-aged subjects, but only by 0.03 s (table 43).

The number of occurrences per subject of the *reposition-hand-on-knob* element ranged from 6 to 63, with all subjects but one having 25 or fewer occurrences. That subject made more but briefer turns. In addition, there was one subject for whom there were no *turn-knob* elements because that subject did not perform the task using the specified method. There were 26% more for middle-aged women than any other group.

Table 43. Reposition Hand on Knob: Age and Gender Effects

Age	Gender		Mean Time (s) (Total n)
	Female	Male	
Young	0.36 (114)	0.35 (80)	0.35 (194)
Middle	0.33 (166)	0.31 (166)	0.32 (280)

Table 44 shows summary data for when the *reposition-hand-on-knob* element occurred by goggle state. All of the distributions appeared lognormal. As a reminder, an entry in the close state means that it occurred entirely in the close state, and an entry in the close-open state means that it started in the close state and ended in the open state. Notice that for the repositioning element, the number completed in the open state was almost equal to those in the closed state and the situation is similar for the open-close and close-open combinations. However, when there was a goggle transition, the time was increased. These results suggest that Pettitt's assumptions do not hold for the reposition-hand-on-knob element, possibly because minimal visual guidance is needed for this manual task. Thus, this reposition element occurs even when the goggles are closed. In fact, it was often the case that subjects needed to make a number of turns (*turn knob, reposition-hand-on-knob* pairs) before they were close to the desired station. In those instances, as the subjects' hands were positioned over the knob and they could feel it, they were able to perform several repeated actions without visual feedback. It is unknown if this behavior occurs in on-road driving where attention needs to be periodically directed towards the road scene.

Table 44. Reposition Hand on Knob: Descriptive Statistics vs. Goggle State

Goggles	n	Mean Time (s)	SD (s)
Open	196	0.29	0.15
Open, Close	44	0.44	0.19
Close	198	0.32	0.18
Close, Open	36	0.52	0.20

Touch Screen Actions: Flick

There were 834 occurrences of the *flick* element, with times ranging from 0.06 to 1.53 s. The mean time was 0.50 s with a standard deviation of 0.23 s. As shown in figure 17, the lognormal distributions fit the data moderately well, with μ and σ of -0.79 and 0.46. The lack of fit was due to the distribution not being continuous.

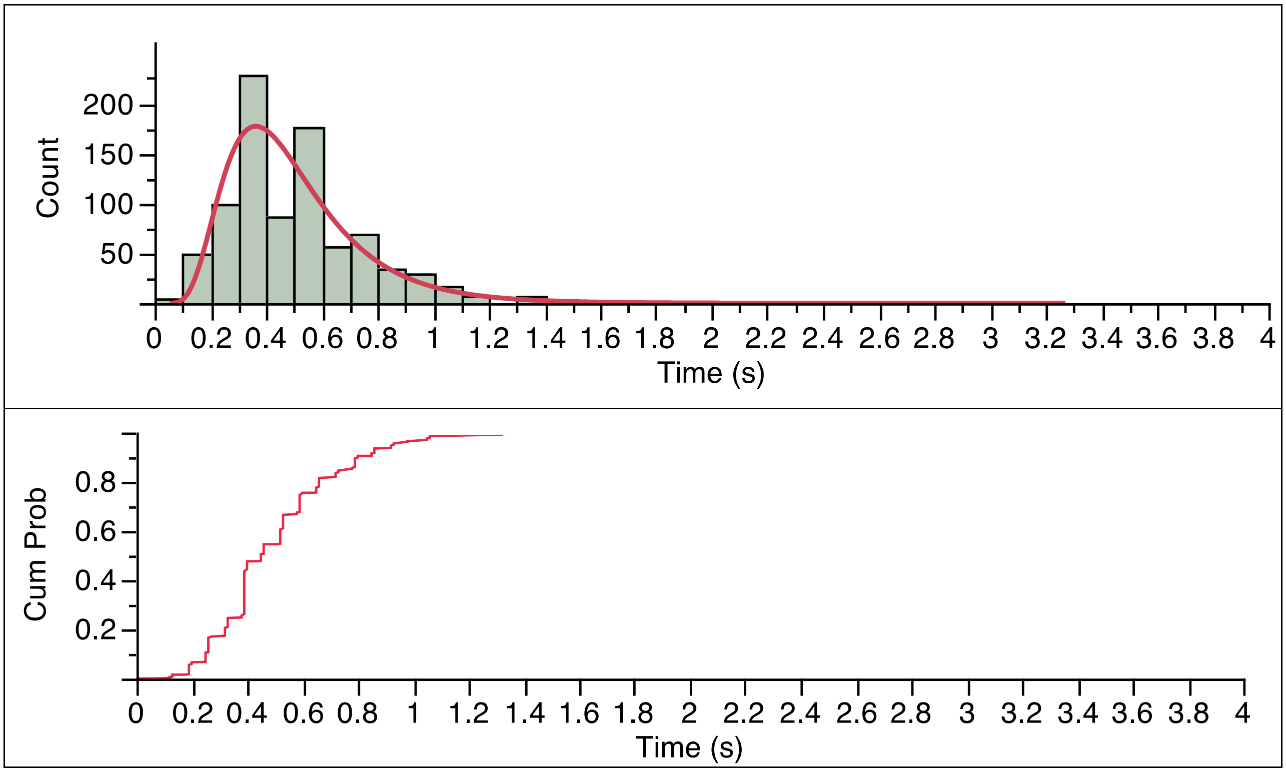


Figure 17. Flick Time Distributions

The mean times per subject ranged from 0.26 s to 0.92 s., with all subjects except for one having times of 0.70 s or less. There was no age difference of note (table 45).

The number of occurrences per subject ranged from 1 to 146, with the number of occurrences per subject being well distributed across the range. There were 26% more occurrences for middle-aged women than any other group.

Table 45. Flick: Age and Gender Effects

Age	Gender		Mean Time (s) Total n
	Female	Male	
Young	0.46 (168)	0.54 (154)	0.49 (322)
Middle	0.49 (324)	0.52 (188)	0.50 (512)

As shown in figure 46, there were a significant number of *flick* actions that occurred with the goggles closed, in fact, about half as many. There were also many instances where flicking occurred even after the goggles transitioned from open to closed. Interestingly, flicks that occurred when the goggles were closed took less time than when they were open.

Table 46. Flick: Goggle State Effects

Goggles	n	Mean Time (s)	SD (s)
Open	472	0.52	0.24
Open, Close	121	0.53	0.21
Close	221	0.43	0.18
Close, Open	20	0.54	0.28

As in previous cases, the distributions for this element for each goggle state appeared lognormal.

Touch Screen Actions: Quick Flick

There were 1,112 occurrences of the *quick-flick* element, with times ranging from 0.05 s to 1.60 s. The mean time was 0.35 s with a standard deviation of 0.16 s. The mean time of a *quick flick* is 60% of that of an ordinary *flick*. As shown in figure 18, the lognormal distribution fit the data, with μ and σ of -1.15 and 0.46, although the fit of the distribution was not particularly good.

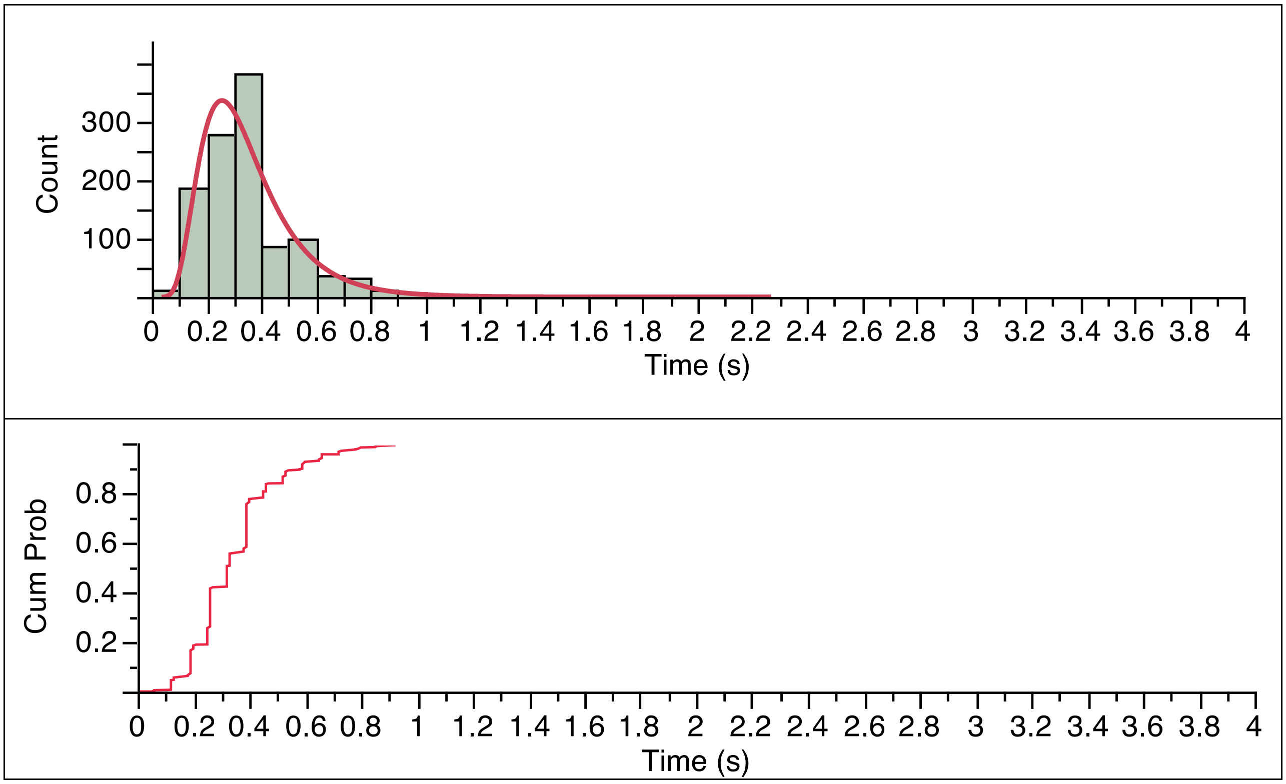


Figure 18. Quick Flick Time Distributions

The mean times per subject ranged from 0.26 s to 0.92 s., with all subjects except for one having times of 0.70 s or less. There was no age difference of note (table 47).

The number of occurrences per subject ranged from 1 to 146, with the number of occurrences per subject being well distributed across the range. There were 72% more occurrences for middle-aged women than any other group.

Table 47. Quick Flick: Goggle State Effects

Goggles	n	Mean Time (s)	SD (s)
Open	543	0.36	0.17
Open, Close	114	0.39	0.14
Close	394	0.31	0.13
Close, Open	61	0.43	0.23

The pattern for *quick flicks* as a function of goggle state is similar to that for *flicks*, only the times are less. As with that element, the distributions as a function of goggle state appear lognormal.

Touch Screen Actions: Scroll

Scroll differs from the *flick* and *quick-flick* elements in that the list did not continue to move when subjects removed their fingers from the screen. Thus, in some sense, it resembled a drag.

There were 420 occurrences of the *quick-flick* element, with times ranging from 0.05 s to 2.80 s. The mean time was 0.70 s with a standard deviation of 0.36 s. As shown in figure 19, the lognormal distribution fit the data, with μ and σ of -0.56 and 0.58.

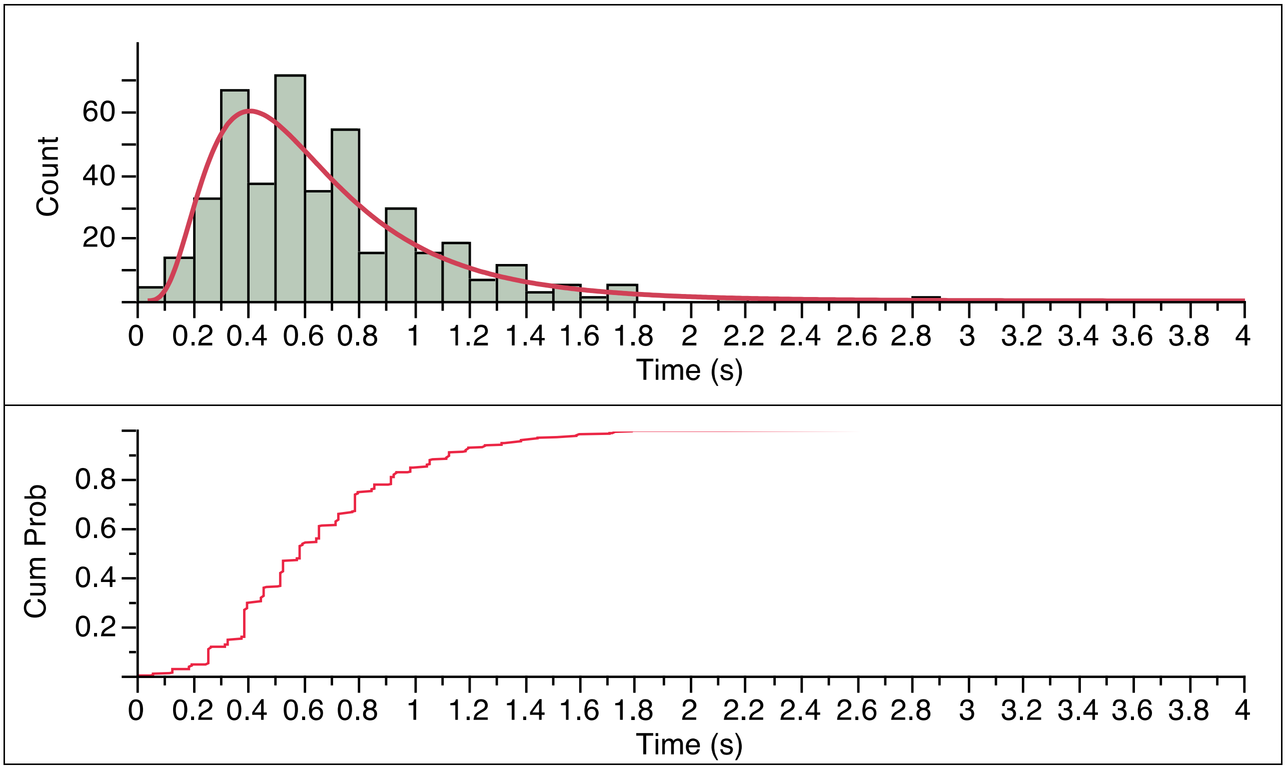


Figure 19. Scroll Time Distributions

As shown in table 48, there appears to be a pronounced tendency for men to scroll more than women and young subjects to scroll more than middle-aged subjects (45% more).

Table 48. Scroll: Age and Gender Effects

Age	Gender		Mean Time (s) Total n
	Female	**Male**	
Young	0.58 (92)	0.65 (157)	0.62 (249)
Middle	0.73 (70)	0.71 (101)	0.72 (171)

As shown in table 49, there were a significant number of scroll actions that occurred while the goggles were closed. In fact, the number that occurred only in the closed state was about half of those completely in the open state. It is uncertain if this same pattern would be found in tasks conducted on the road. An important aspect of several of the tasks examined was that multiple scroll actions were needed to reach desired items in menus, so the first few scrolls could be completed without much visual feedback.

Table 49. Scroll: Goggle State Effects

Goggles	n	Mean Time (s)	SD (s)
Open	181	0.57	0.28
Open, Close	119	0.86	0.40
Close	98	0.54	0.26
Close, Open	21	0.82	0.37

Touch Screen Actions: Stop Screen

Stop screen involves touching the screen to stop a list from moving, started by a preceding *flick* or *quick flick*. There were 146 occurrences of the *stop-screen* element, with times ranging from 0.05 s to 0.79 s. The mean time was 0.24 s with a standard deviation of 0.18 s, a very brief time. As shown in figure 20, the lognormal distributions fit the data quite well, with μ and σ of –1.69 and 0.77.

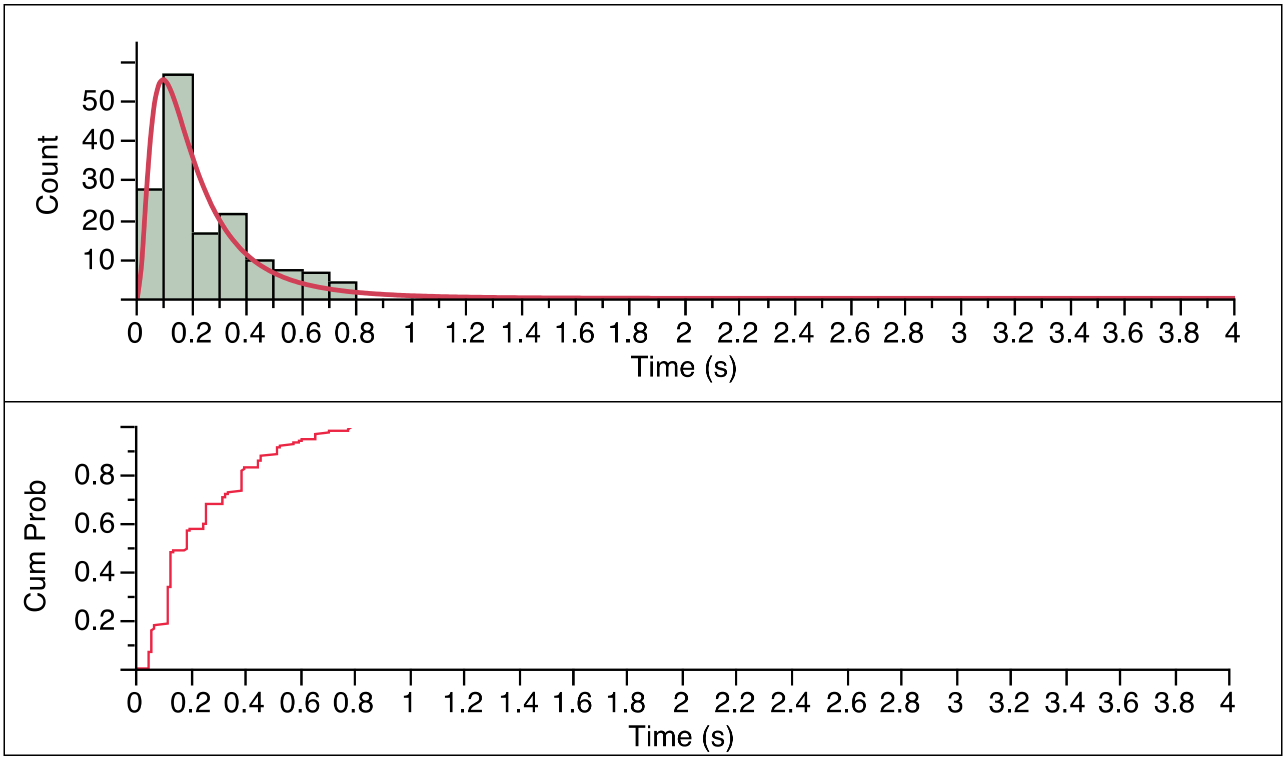


Figure 20. Stop Screen Time Distributions

The mean times per subject ranged from 0.12 s to 0.36 s. There were no age differences of note (table 50).

The number of occurrences per subject ranged from 0 (one subject) to 15. There were more stops for the young male group than any other group.

Table 50. Stop Screen: Age and Gender Effects

Age	Gender		Mean Time (s) (Total m)
	Female	Male	
Young	0.16 (29)	0.29 (64)	0.23 (93)
Middle	0.20 (13)	0.25 (40)	0.22 (52)

To the extent that one can draw conclusions from this smaller sample size, the goggle state had only a small effect on element time. What is most surprising is that stopping the screen occurred more often when the goggles were closed than when the goggles were open (table 51).

Table 51. Stop Screen: Goggle State Effects

Goggles	n	Mean Time (s)	SD (s)
Open	50	0.21	0.17
Open, Close	12	0.47	0.18
Close	78	0.23	0.18
Close, Open	6	0.30	0.14

Touch Screen Actions: Flick/Scroll Return

In this movement, the finger is repositioned after completing a *flick*, *quick flick* or *scroll* to being *another flick*, *quick flick*, or *scroll*. There were 2,346 occurrences of the *flick/scroll-return* element, with times ranging from 0.05 s to 1.69 s. The mean time was 0.38 s with a standard deviation of 0.24 s. As shown in figure 21, the lognormal distributions fit the data, with μ and σ of -1.15 and 0.61.

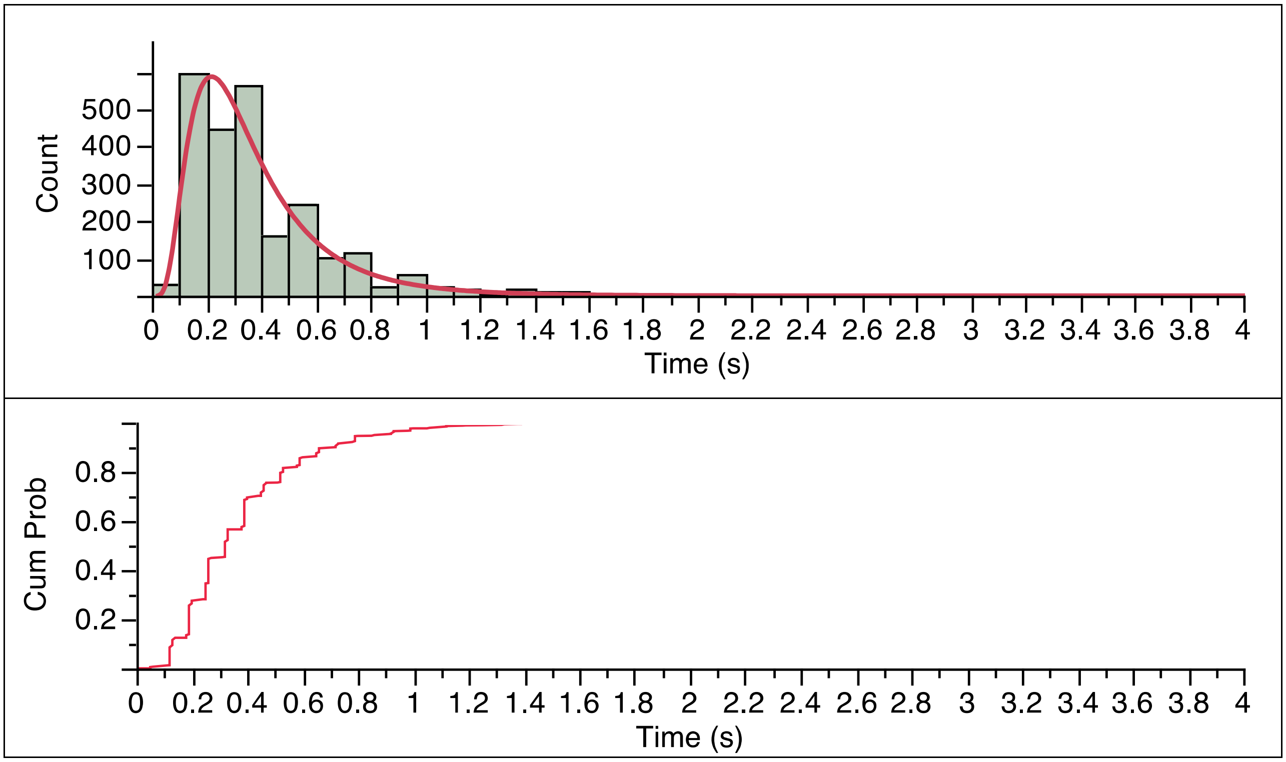


Figure 21. Flick/Scroll Return Time Distributions

The mean times per subject ranged from 0.28 s to 0.68 s. There was no age difference of note (table 52). The number of occurrences per subject ranged from 37 to 178. There more stops for the middle-aged subjects than for the young subjects.

Table 52. Flick/Scroll Return: Age and Gender Effects

Age	Gender		Mean Time (s) (Total n)
	Female	Male	
Young	0.39 (488)	0.38 (496)	0.38 (984)
Middle	0.38 (673)	0.37 (673)	0.37 (1362)

As shown in table 53, there was a significant number of instances where *flick/scroll* elements occurred when the goggle were closed. In fact, there were more occurrences when the goggles were sometimes closed during this element than when the goggles were only open. Again, this calls Pettitt's assumptions into question.

Table 53. Flick/Scroll Return: Goggle State Effects

Goggles	n	Mean Time (s)	SD (s)
Open	1132	0.36	0.20
Open, Close	274	0.57	0.32
Close	833	0.31	0.20
Close, Open	107	0.54	0.33

Delays: Wait – Loading

There were 2,031 occurrences of the *flick/scroll-return* element, with times ranging from 0.00 s to 10.0 s. The 13 values of 0 time are for missing cases. The mean time was 0.89 s with a standard deviation of 1.02 s. These values are substantially larger than those for any other element, and this was the reason for choosing the large maximum on the x scale of the frequency plots. As shown in figure 22, there appear to be multiple underlying processes, and even making that assumption, the fit is poor. In this instance, a three-parameter normal mixture was used with location means (μ) of 0.44, 1.44, and 3.77, dispersions (σ) of 0.27, 0.49, and 1.33, and probabilities (pi) of 0.73, 0.20, and 0.07.

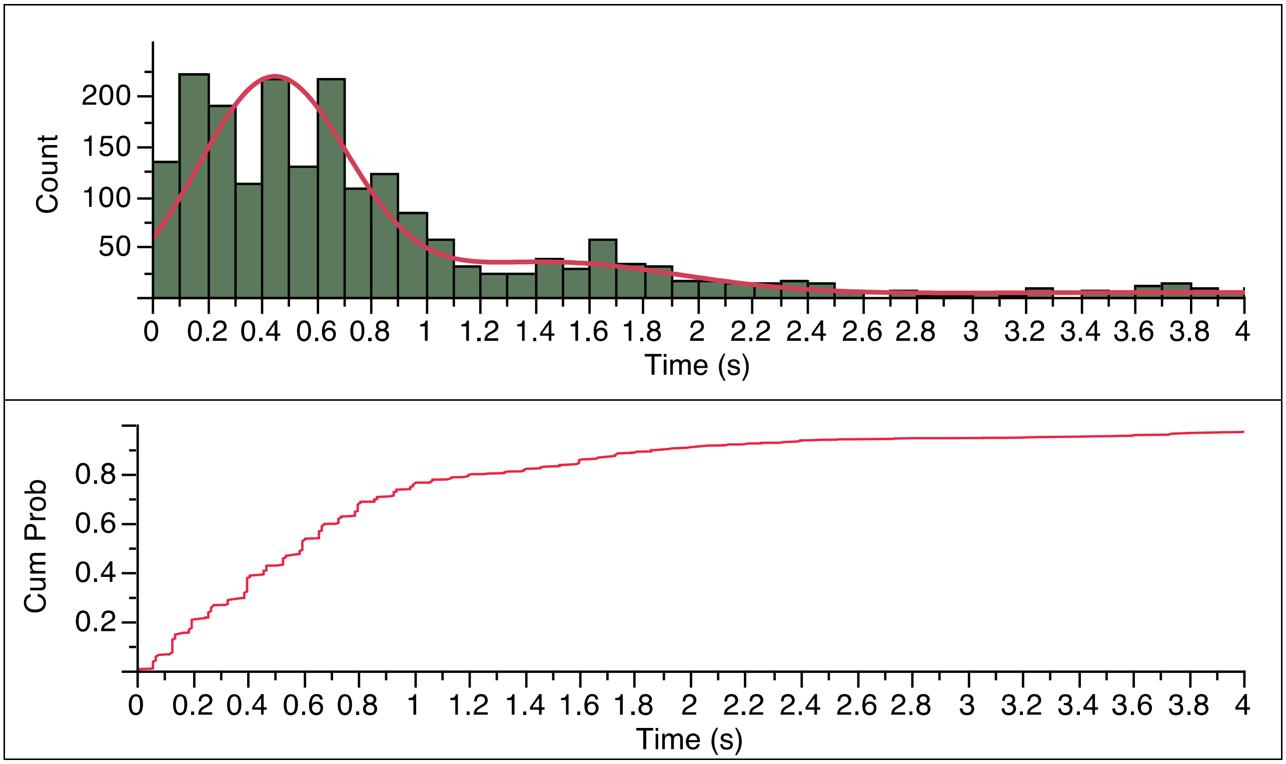


Figure 22. Wait Loading Time Distributions

The mean times per subject ranged from 0.75 s to 1.12 s. Middle-aged subjects waited slightly longer, and it is uncertain why this occurred as the element duration depended on operation of the device independent of the subject (Table 54).

The number of occurrences per subject ranged from 64 to 95. There more waits for the middle-aged subjects than for the young subjects.

Table 54. Wait Loading: Age and Gender Effects

Age	Gender		Mean Time (s) (Total n)
	Female	Male	
Young	0.85 (486)	0.82 (511)	0.83 (997)
Middle	1.02 (513)	0.86 (521)	0.92 (1034)

The *wait-after-loading* times and distributions depend on a number of factors, one of which was the task being performed (table 55) and vary in their duration, with some loading times being much greater than the others, at least for the interface examined. Loading times will be, of course, interface specific. Furthermore, the address, contact, POI, preset, and song frequency distributions were all bimodal.

Table 55. Wait Loading: Task Effects

Task	n	Mean Time (s)	Std Dev (s)
Address	580	0.59	0.57
Contact	320	0.71	0.42
Dial	144	0.99	0.41
POI	594	0.54	0.56
Preset	145	0.66	0.31
Radio	69	0.98	0.17
Song	179	3.41	1.46

A key distinction is what is being loaded. If it is the next screen of a sequence, and, for example, the subject proceeded down a menu tree, then the times tend to be short. If computation is required, such as computing a route, then the time is much longer. These times will be very implementation specific.

Delays: Wait After Loading

There were 808 occurrences of the *wait-after-loading* element, with times ranging from 0.05 s to 1.66 s. The mean time was 0.92 s with a standard deviation of 0.39 s. This element always began and ended with the goggles closed. No distribution fit the data very well for which there was a theoretical explanation, as the distribution is quite discontinuous (figure 23). However, using the "kitchen sink" approach (try every distribution the statistics package supports), the

Johnson Su distribution fit the data, with a shape-γ parameter of 71.33, a shape-δ parameter of 4.01, a location-θ parameter of 2.30, and a scale-parameter σ of 4.92e-8.

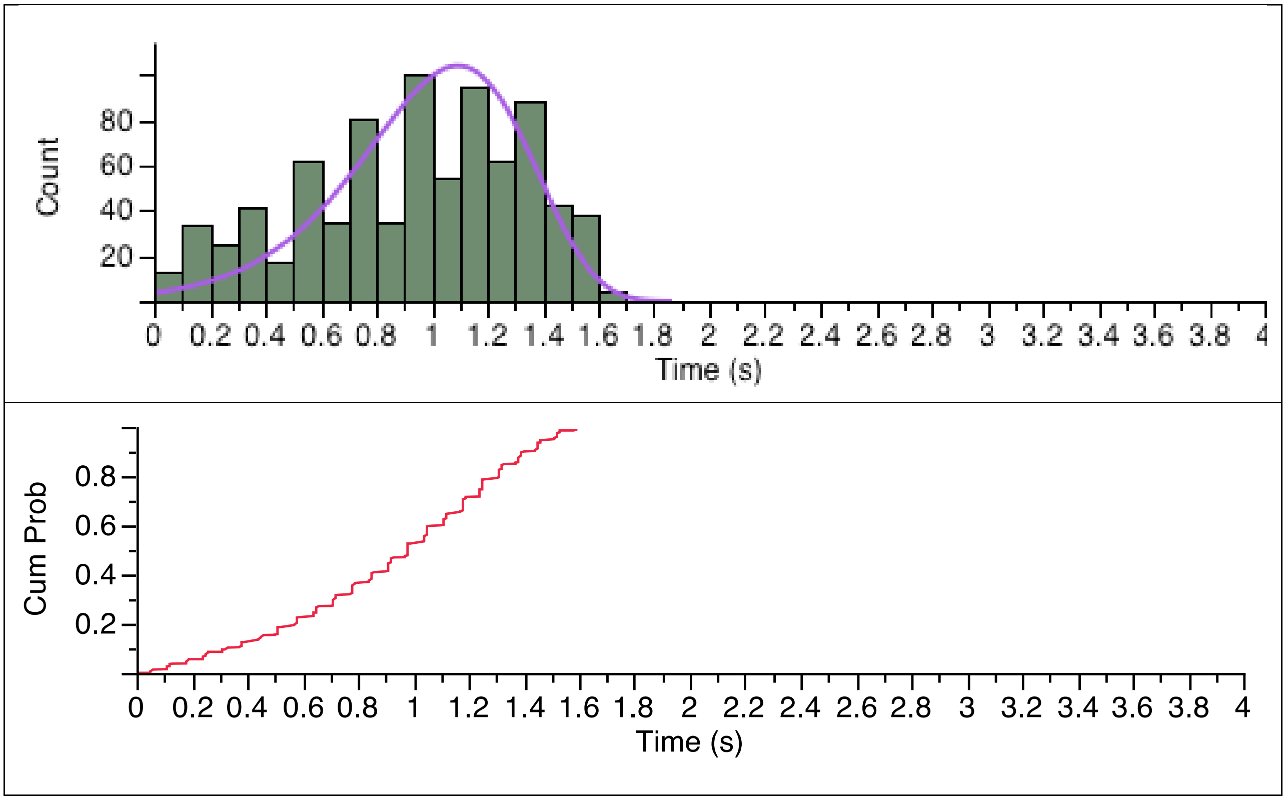


Figure 23. Wait After Loading Time Distributions

The mean times per subject ranged from 0.84 s to 0.1.03 s. Because the duration is primarily a device-related process, one would not expect age or gender differences, and in fact, that is the case (table 56).

The number of occurrences per subject ranged from 23 to 46.

Table 56. Wait After Loading: Age and Gender Effects

Age	Gender		Mean Time (s) (Total n)
	Female	Male	
Young	0.90 (186)	0.94 (204)	0.92 (390)
Middle	0.93 (208)	0.92 (210)	0.93 (418)

Determining how and why this element varies is difficult. There may be differences between tasks (table 57), but examining the distributions of this element by task reveals that all of these distributions are multimodal. This suggests that there are multiple underlying factors in each task.

Table 57. Wait After Loading: Task Effects

Task	n	Mean Time (s)	SD (s)
Address	216	0.97	0.40
Contact	135	1.00	0.31
Dial	61	1.07	0.32
POI	220	1.01	0.39
Preset	70	0.76	0.32
Radio	65	0.63	0.35
Song	41	0.52	0.34

Examining the effect of the preceding element is revealing (table 58). Notice that the most common preceding element for *wait –loading* was another *wait –loading*.

Table 58. Wait After Loading: Preceding Element Effects

Preceding Element (alphabetical order)	n	Mean Time (s)	SD (s)
Flick	2	0.35	0.23
Flick/Scroll Return	1	0.93	
Press Button	5	0.86	0.32
Quick Flick	0		
Reach for Button	2	1.15	0.13
Reach for Center Console	5	0.32	0.26
Read Instructions	1	1.52	
Reposition Hand on Knob	0		
Scroll	0		
Search	1	0.72	
Stop Screen	0		
Turn Knob	0		
Wait - Loading	790	0.93	0.39
Wait After Loading	0		
Wait for Goggles - Known Location	1	0.98	
Wait for Goggles - Unknown Location	0		

Delays: Wait for Goggles – Known Location

There were 2,865 occurrences of the *wait-for-goggles-known-location* element, with times ranging from 0.05 s to 1.99 s. The mean time was 1.34 s with a standard deviation of 0.30 s. As shown in figure 24, the data were fit with a Weibull distribution with a scale value α of 1.44 and a shape-β of 6.29. The Weibull distribution is one in which the failure rate is a power function of time. In this instance, that expression makes sense as the wait time is from whenever the subject completes the task until the goggles change, which can take up to 1.5 s. However, as was noted elsewhere, the change time in this experiment was not exactly 1.5 s, hence the variability at that duration. Furthermore, as subjects often try to complete tasks immediately after the goggles close rather than wait for the goggles to reopen, one would expect a large number of waits to be slightly less than 1.5 s.

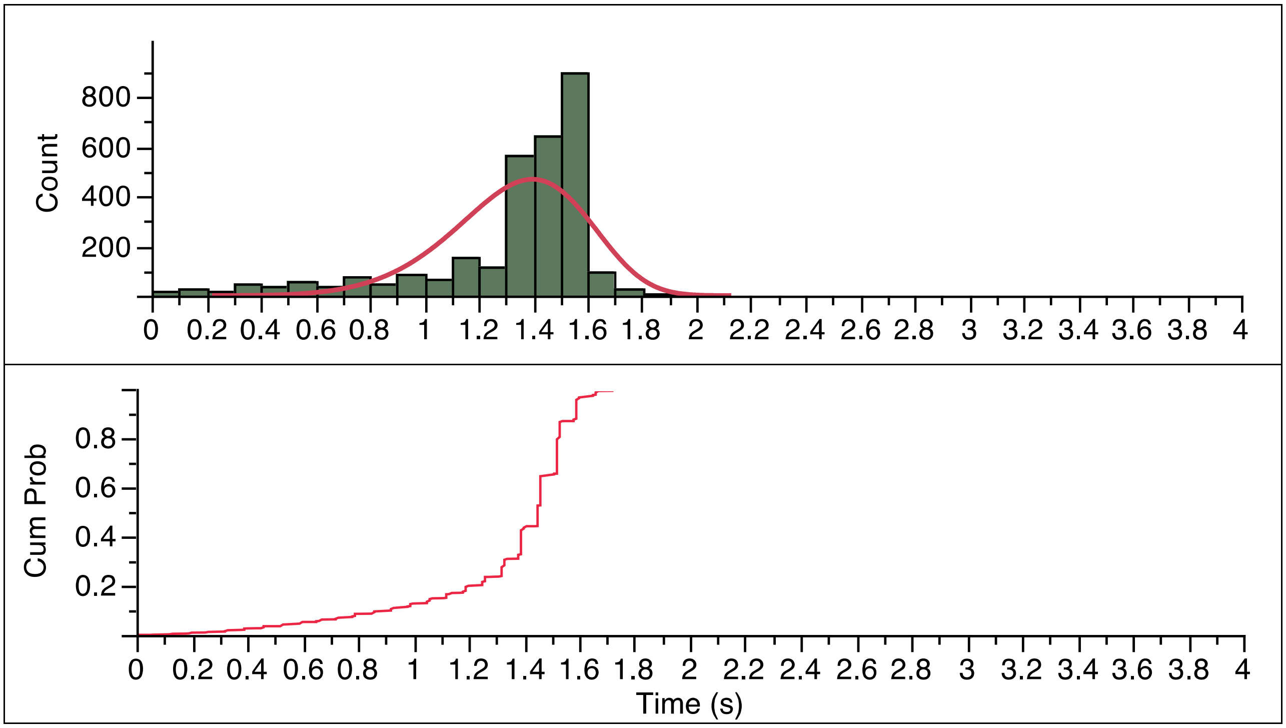


Figure 24. Wait for Goggles – Know Location - Time Distributions

The mean times per subject ranged from 1.01 s to 0.1.42 s. As the duration is primarily a device-related process, one would not expect age or gender differences, and in fact, that is the case (table 59).

The number of occurrences per subject ranged from 40 to 208. There were 60% more waits for middle-aged subjects, mainly because they performed more elements to complete tasks.

Table 59. Wait for Goggles – Know Location: Age and Gender Effects

Age	Gender		Mean Time (s) (Total n)
	Female	Male	
Young	1.35 (546)	1.31 (556)	1.33 (1102)
Middle	1.30 (924)	1.39 (839)	1.34 (1763)

Table 60 shows the frequency of occurrence and mean times for the element preceding the wait for goggles known location element, sorted from shortest to longest time. The wait times have been grouped together. Note that this wait most commonly occurs after searching, pressing a button, or reaching for a button.

Table 60. Wait for Goggles – Known Location: Effect of Preceding Element

Preceding Element (sorted by n)	n	Mean Time (s)	SD (s)
Search	1210	1.41	0.27
Press Button	699	1.22	0.29
Reach for Button	606	1.47	0.15
Read Instructions	96	1.39	0.31
Reach for Center Console	61	1.04	0.44
Flick	38	0.95	0.43
Scroll	31	1.08	0.30
Flick/Scroll Return	18	1.14	0.37
Stop Screen	11	1.17	0.22
Turn Knob	3	1.51	0.18
Quick Flick	0		
Reposition Hand on Knob	0		
Wait for Goggles - Known Location	73	0.82	0.31
Wait - Loading	15	1.23	0.27
Wait After Loading	2	0.76	0.24
Wait for Goggles - Unknown Location	2	0.56	0.62

Delays: Wait for Goggles – Unknown Location

There were 1,007 occurrences of the *reach-for-center-console* element, with times ranging from 0.05 s to 1.72 s. All of these occurrences were when the goggles were closed except for one instance when the goggles were closed and then open. The mean time was 0.92 s with a standard deviation of 0.48 s. As shown in figure 25, the distribution appears to be uniform as indicated by the frequency distribution and the linear cumulative probability function, with a peak at the end at the maximum wait time of 1.5 s. The reason for the periodicity in the distribution appears to be binning.

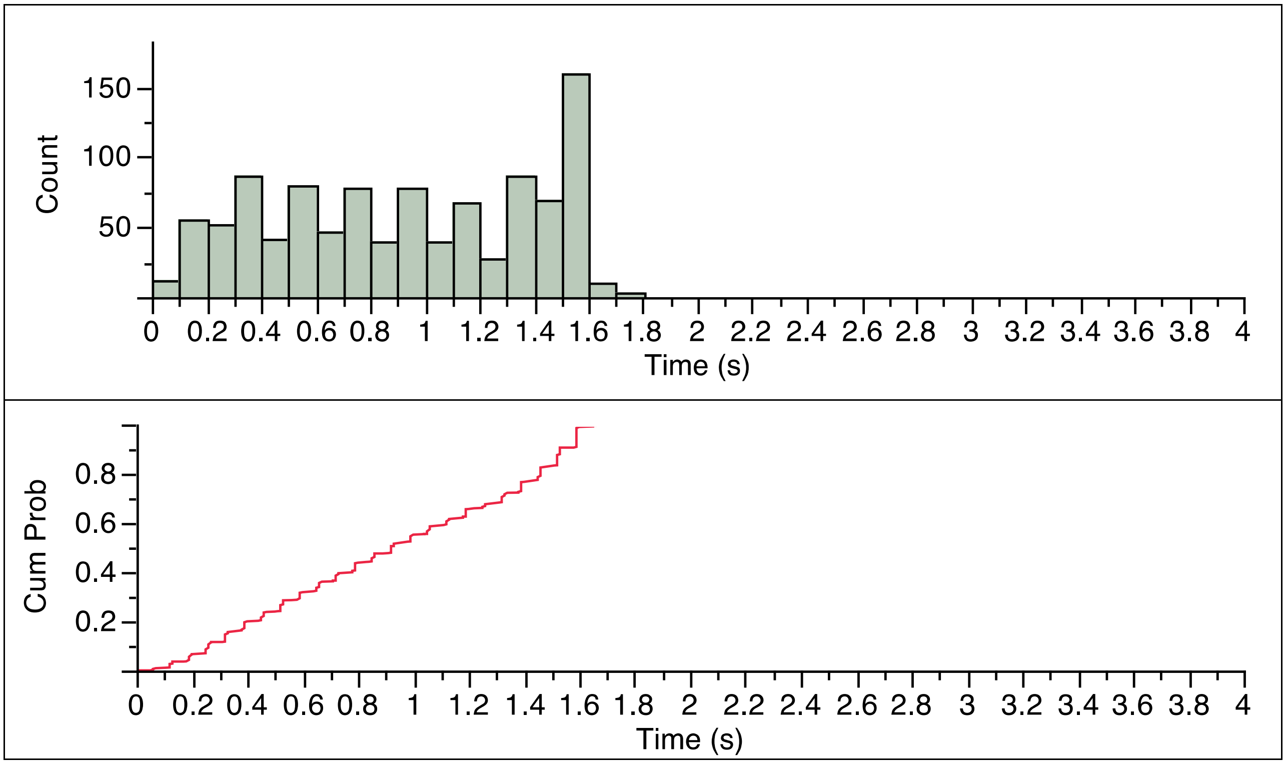


Figure 25. Wait for Goggles – Unknown Location - Time Distributions

The mean times per subject ranged from 0.65 s to 1.37 s. Because the duration is primarily a device-related process, one would not expect age or gender to affect the time distributions, and in fact, that is the case (table 61).

The number of occurrences per subject ranged from 12 to 99 with middle-aged females having far more of them than any other group (by 75%).

Table 61. Wait for Goggles – Unknown Location: Age and Gender Differences

Age	Gender		Mean Time (s) (Total n)
	Female	Male	
Young	0.94 (196)	0.87 (173)	0.91 (369)
Middle	0.98 (406)	0.85 (232)	0.93 (638)

This element commonly followed searches and flick/scroll return in that order, accounting for 45% and 25% of the occurrences of this event (table 62). There are certainly practical differences in these times.

Table 62. Wait for Goggles – Unknown Location: Preceding Element

Preceding Element (sorted by n)	n	Mean Time (s)	SD (s)
Flick/Scroll Return	458	0.87	0.43
Search	248	1.22	0.50
Reposition Hand on Knob	74	0.76	0.38
Stop Screen	61	0.71	0.40
Scroll	60	0.78	0.37
Flick	38	0.86	0.39
Turn Knob	36	0.59	0.34
Reach for Center Console	15	0.75	0.45
Read Instructions	11	1.04	0.59
Press Button	3	1.41	0.17
Reach for Button	2	1.49	0.14
Quick Flick	1	0.18	
Wait - Loading	0		
Wait After Loading	0		
Wait for Goggles - Known Location	0		
Wait for Goggles - Unknown Location	0		

What kinds of errors and error correction occurred?

According to ISO 16673, SAE J2364, and the NHTSA guidelines, as many as five practice trials must occur before the test trials begin so the number of errors is at a minimum. What constitutes an error can be interpreted in two ways. A terminal error is one in which the final entry (the outcome) is incorrect, for example, the wrong destination is entered. A process error is one in which some mistakes were made, for example a name was misspelled, which may or may not have been corrected.

The test procedures cited call for very few terminal errors and desire few process errors, but are often less specific about process errors. A description of the process errors and respective corrections for this experiment appear in table 63.

Table 63. Types of Errors and Corrections

Elements with Errors	Types of Errors	Description of Errors (The subject …)	Error Correction
Press Button	wrong	presses a button that is incorrect and must press backspace or a back button to continue completing the task	press a backspace or a back button
	miss	tries to press a button but it does not register on the machine	no correction necessary; just adds more time to complete the task
	extra	presses a button that is incorrect but no correction is required to continue completing the task	no correction necessary; just adds more time to complete the task
Flick	too far	flicks past the target song/name	flick or scroll back to the target song/name
	miss	tries to flick but it does not register on the machine	no correction necessary; just adds more time to complete the task
Quick Flick	too far	quick flicks past the target song/name	flick or scroll back to the target song/name
	miss	tries to quick flick but it does not register on the machine	no correction necessary; just adds more time to complete the task
Scroll	too far	scrolls past the target song/name	flick or scroll back to the target song/name
	miss	tries to scroll but it does not register on the machine	no correction necessary; just adds more time to complete the task
Turn Knob	too far	turns the knob past the target frequency	turn the knob back to the target frequency

As seen in table 64, most of the errors related to the entry process occurred during the *enter-an-address* and *find-a-song* tasks. Enter an address was one of the more demanding of the seven tasks and, depending upon the entry, could require more button presses than any other task. The list in the *find-a-song* task was quite long, allowing for many more errors due to flicking.

Table 64. Errors and Corrections: Task Effects

Task	Total Errors	Total Corrections
Dial	96	70
Address	372	29
POI	99	15
Contact	74	73
Song	229	204
Preset	19	0
Radio	67	70

Some tasks were more prone to process errors than others. For example, no subject completed the *enter an address* task, trial 2 without an error. The most error-free task and trial was *enter a preset*, trial 2. Twenty-one subjects completed that task without an error. Table 65 shows the percentage of subjects that were able to complete a trial without any errors.

Table 65. Error-Free Performance: Task and Trial Effects
(% of Subjects)

Task	**Trial**			**Mean**
	1	**2**	**3**	
Dial	46	50	50	49
Address	8	0	4	4
POI	30	44	30	35
Contact	29	67	46	47
Song	29	67	46	47
Preset	79	88	75	81
Radio	39	35	30	35

If there were beneficial effects of practice, the mean time per trial should decrease across the 3 trials. However, there was actually a 13.4% increase in the total number of errors in Trial 3 than in trial 1 and trial 2. This is mostly due to a large increase in the number of missed *flicks* and *quick flicks* and the number of times going too far when quick flicking. This is a reasonable explanation because in trial 3 of the *find-a-song* task, the target song was much farther down in the list than the past two trials. When trial 3 of the *find-a-song* task is removed from the data, the error decreases by 11.7% between trials 1 and 2 and decreases by 2.26% between trials 2 and 3, just as was predicted.

Finally, table 66 provides a first-cut estimate of the number of errors associated with key presses by key type. The not given/not key row refers to other elements in the data set that are not keys or for which a key is not identified. The values are listed here to provide context.

Table 66. Errors: Key Type and Category

Key Type	Missing	Extra	Missed	Wrong	Correct	Total
not given/not key	14,844	0	107	0	2,259	17,210
action	78	2	155	6	476	717
function	75	37	65	7	1,095	1,279
letter	320	0	111	13	1,145	1,589
list entry	47	32	19	39	470	607
number	111	0	29	71	955	1,166
preset	5	1	4	0	72	82
shift	0	3	0	0	0	3
space	39	1	70	9	163	282
Given Keys Only	675	76	453	145	4,376	5,725
Total	15,519	76	560	145	6,635	22,935

One simple way to use these data is to prorate the correct button-press times to account for errors. For example, suppose a person completed a task successfully 100% of the time, which is for what the NHTSA guidelines aim. As an example, if subjects were given an address to enter, the desired address was entered when the subject stopped. For simplicity, assume that only one button press is required and the time for that button press is x. Furthermore, assume that 10% of the time that subjects press the wrong button (with duration x), realize they did so, and press a correction button (also with duration x), and then the correct button (with duration x). In that case, the correction cost for each correction is 2x. However, as that occurs 10% of the time, then the added cost is .2x (0.1 x 2). Thus, an error-adjusted time estimate for that button press would be 1.2x. Of course, this inflation estimate ignores the fact that when making a correction, there are all sorts of reaches, cognitive activities, etc. that occur, so this quick method may underestimate of the cost of errors. Obviously, the correction overhead of errors can be computed more precisely, but that will take additional time that in some cases may not be available.

CONCLUSIONS

How were the task elements partitioned, and what are those elements?

Tasks (e.g., dial a phone number, find a song) were partitioned into smaller elements (e.g., *reach for button*, *scroll*) based on a number of considerations including (1) consistency with prior work such as MTM-1, SAE J2365, Schneegass, et al (2011), and Kang et al. (2013), (2) having a sound or movement that provided a distinct end point, (3) balancing details that identified differences with keeping the set small and simple, and (4) distinguishing aspects of the task that required different resources (visual, auditory, cognitive, perceptual, motor). Resulting were 16 elements that were divided into seven categories, which are shown in table 67. This list is not intended to be exhaustive for all in-vehicle tasks but is for the elements observed in this experiment. Additional elements are expected in a follow-on analysis of another experiment for a different interface supported by the ATLAS Center.

Table 67. Task Elements

Category	Element	Goggles	Comment
Read Instructions	Read Instructions	open	double checking or reading what they forgot
Search	Search	open	for next button, text, etc.
Reach	Reach for Center Console	open or closed	begins task, about 10% subjects moved their hands back and forth within tasks. Others hovered over the touch screen
	Reach for Button	open or closed	for next button
Press Button	Press Button	open or closed	
Knob Actions	Turn Knob	open or closed	
	Turn Knob Return	open or closed	reposition hand to turn knob again
Touch screen actions	Flick	open or closed	to move the list up or down often were many flicks in succession
	Quick Flick	open or closed	often were many quick flicks in succession
	Stop Screen	open or closed	after flick
	Scroll	open or closed	Similar to a flick or quick flick, but the screen does not continue to move when the movement ends. In some sense it could be called a drag.
	Flick Scroll Return	open or closed	to prepare to flick/quick flick again
Delay	Wait – Loading	open or closed	some are long, such as song loading

	Wait After Loading	closed	user does not know information is loaded
	Wait for Goggles – Known Location	closed	
	Wait for Goggles – Unknown Location	closed	

Exactly how long were the goggles open and how accurate was the timing?

The goggles were intended to be open 1.5 s and closed for 1.5 s. However, there were a number of instances where the duration appeared to be 1.4 s or 1.6 s, and a small fraction of cases where it was some other value. Freezing of the recording camera and recording-software limitations led to this uncertainty. Times appear accurate to about the nearest 0.07 s.

What are the task-completion times for the visual manual tasks when tested using the US DOT occlusion procedure?

Table 68 shows the task-completion times from the experiment reported previously. As a reminder, only the *find-a-radio-preset* task was completed with the time allowed by the NHTSA guidelines, and the *radio-tuning* task was close.

Table 68. Occlusion Task Completion Times (s)

Block	Task	Trial			Mean
		1	2	3	
1	**Tune the Radio**	**11.5**	13.9	**11.3**	12.2
2	Call a Contact	20.9	23.0	24.3	22.7
3	Enter a Street Address	88.6	84.7	76.1	83.1
4	Dial a Phone Number	25.4	24.5	26.0	25.3
5	Find a POI	27.3	24.0	26.0	25.8
6	**Find a Radio Preset**	**5.4**	**7.4**	**7.2**	**6.7**
7	Play a Song	35.8	44.9	70.6	50.4
Mean		30.7	31.8	34.5	32.3

Note: Tasks completed within the 12-s guideline are shown in bold.

What are the major factors that affected task time?

In an ANOVA of task time, the effects of Age, Subject (Age, Gender), Task, and Age*Task were all highly significant ($p<0.0001$). Gender was significant at $p=0.03$ and Age*Gender at $p=0.007$. The effect of age was quite pronounced with middle-aged subjects taking 44% longer than younger subjects. These differences are reflected in the subject differences, with mean task times varying from 21.3 s to 50.3 s, more than a factor of 2. Thus, in the analysis of task-element times, the Age*Gender and Age*Element interactions were given attention, and because it was the focus of this analysis, so were element effects.

Overall, what affected the times of each element?

The analysis of the element times was similar to that for the overall task times, with main effects of Age, Gender, Trial, Element, Subject (Age*Gender) and the Age*Gender and Age*Element interactions. The Element, Subject (Age*Gender), and Age*Element interaction were all highly significant ($p<0.001$). Also significant were Age ($p=0.005$) and Gender (p=0/04).

As shown in table 69, there were differences in the number of elements various age and gender groups experienced, with middle-aged women completing the largest number of elements, with the mean time per element being 7% greater for middle-aged than young subjects. Thus, the reason that middle-aged subjects took 44% longer to complete tasks was that there were more elements to complete (32% more).

Table 69. Element Data: Descriptive Statistics

Element (alphabetical order)	n		Time (s)		Total n	Mean (s)
	Young	Middle	Young	Middle		
Flick	322	512	0.50	0.50	834	0.50
Flick/Scroll Return	984	1362	0.38	0.37	2,346	0.38
Press Button	2,389	2661	0.60	0.68	5050	0.64
Quick Flick	473	639	0.34	0.36	1,112	0.35
Reach for Button	235	440	0.38	0.45	675	0.42
Reach for Center Console	551	534	0.73	0.76	1,085	0.75
Read Instructions	197	248	0.48	0.57	445	0.53
Reposition Hand on Knob	194	280	0.36	0.32	474	0.33
Scroll	249	171	0.62	0.72	420	0.66
Search	1,067	1,906	0.48	0.58	2,973	0.54
Stop Screen	93	53	0.25	0.24	146	0.24
Turn Knob	291	373	0.50	0.38	664	0.43
Wait - Loading	990	1,028	0.84	0.95	2,018	0.90
Wait After Loading	390	418	0.92	0.93	808	0.92
Wait for Goggles - Known Location	1,102	1,763	1.33	1.34	2,865	1.34
Wait for Goggles - Unknown Location	369	638	0.91	0.93	1,007	0.92

Overall, when did elements occur relative to the goggle state?

As shown in table 70, at a precise level, many elements that could have visual demand occurred when the goggles were closed, and that occurred with some frequency. That does not say the

Pettitt's assumptions are completely incorrect, because elements that were highly visual were completed predominantly when the goggles were open. It does say, however, that Pettitt's method needs some adjustment. What is unknown is whether, with those adjustment in place, the estimates will improve and by how much. As a first cut, the unadjusted elements in SAE J2365 provided useful, reasonable estimates of the task times in this experiment. See Kang et al. (2013).

Table 70. Element Data: Count for Each Goggle State Combination

Element (alphabetical order)	Open	Open, Close	Close	Close, Open	Other (>2)	Total n
Flick	472	121	221	20	0	834
Flick/Scroll Return	1,132	274	833	107	0	2,346
Press Button	4,006	843	181	19	1	5,050
Quick Flick	543	114	394	61	0	1,112
Reach for Button	675	0	0	0	0	675
Reach for Center Console	886	63	56	80	0	1,085
Read Instructions	445	0	0	0	0	445
Scroll	181	119	98	21	1	420
Search	2,973	0	0	0	0	2,973
Stop Screen	50	12	78	6	0	146
Turn Knob	291	103	218	50	2	664
Reposition Hand on Knob	196	44	198	36	0	474
Wait - Loading	828	655	286	96	166	2,031
Wait After Loading	0	0	808	0	0	808
Wait for Goggles - Known Location	0	0	2,865	0	0	2,865
Wait for Goggles - Unknown Location	0	0	1,006	1	0	1,007
Total Ignoring Waits	11,850	1,693	2,277	400	4	16,224
Grand Total	12,678	2,348	7,242	497	170	22,935

Interestingly, the element times when the goggles were closed were often less than when the goggles were open, possibly because subjects only elected to perform less demanding elements when the goggles were closed (table 71).

Table 71. Element Mean Times: Goggle State Effect

Element (alphabetical order)	Open	Open, Close	Close	Close, Open
Flick	0.52	0.53	0.43	0.54
Flick/Scroll Return	0.36	0.57	0.31	0.54
Press Button	0.62	0.77	0.47	0.97
Quick Flick	0.36	0.39	0.31	0.43
Reach for Button	0.42			
Reach for Center Console	0.71	1.04	0.65	1.02
Read Instructions	0.53			
Reposition Hand on Knob	0.29	0.44	0.32	0.52
Scroll	0.57	0.86	0.54	0.82
Search	0.54			
Stop Screen	0.21	0.47	0.23	0.30
Turn Knob	0.36	0.75	0.30	0.68
Wait - Loading	0.33	0.97	0.54	1.53
Wait After Loading			0.92	
Wait for Goggles - Known Location			1.34	
Wait for Goggles - Unknown Location			0.92	1.11

What were the times and distributions for each element?

As shown in table 72, many of the distributions for element times were lognormal, though the distribution parameters varied. In part this was because of zero value threshold effects, but also because some of the element distributions were a combination of other distributions with some predominating lower values and less likely greater values.

Table 72. Summary of Elements

Element (alphabetical order)	Total n	Mean Time (s)	Frequency Distribution
Flick	834	0.5	lognormal (-0.79, 0.46)
Flick/Scroll Return	2346	0.38	lognormal (-1.15, 0.61)
Press Button	5050	0.64	normal (0.64, 0.31) or lognormal (-0.60, 0.60)
Quick Flick	1112	0.35	lognormal (-1.15, 0.46)
Reach for Button	675	0.42	lognormal (-1.09, 0.75)
Reach for Center Console	1085	0.75	normal (0.74, 0.27) or lognormal (-036, 0.38)
Read Instructions	445	0.53	lognormal (-0.75, 0.49)

Reposition Hand on Knob	474	0.33	lognormal (-1.25, 0.59)
Scroll	420	0.66	lognormal (-0.56, 0.58)
Search	2973	0.54	lognormal (-0.90, 0.84)
Stop Screen	146	0.24	lognormal (-1.69, 0.77)
Turn Knob	664	0.43	lognormal (-1.19, 0.87)
Wait - Loading	2018	0.9	no good fit, multimodal
Wait After Loading	808	0.92	Johnson Su (71.33, 4.01, 2.30, 4.92e-8)
Wait for Goggles - Known Location	2865	1.34	Weibull (1.44, 6.29)
Wait for Goggles - Unknown Location	1007	0.92	Uniform (0-1.6)

Some other key points:

- The number of reads/trial varied with the task. For the address and dial tasks, the mean number of reads was two, which at about 0.5 s adds about 1.0 s to the task time. How this should be treated when compliance with the NHTSA guideline is assessed is to be determined.

- The key-type distributions could be grouped into several categories. Action and function comprise one group (all lognormal); letter, number, and list entry comprise a second (all normal); and preset, space, and shift represent other groups. Differentiating and categorizing button operations based on their mean operation times has been a focus of prior studies.

- There was no relationship between the time for each *knob-turn* element and the number of clicks (the angular degree of rotation). In part this was because some subjects chose to make a large number of short turns, and others chose to make fewer large ones. Furthermore, the purpose of many of the turn elements was to move in the direction of a particular setting, not to select the final value, so grasping and releasing the grasp were important potential contributors to the element time.

- *Quick flicks* were about 60% of the time of *flicks*.

- Delays associated with waiting for the system to load varied quite widely depending upon whether the item loaded was another screen, a song, address data, or something else. The time data is likely to be system specific.

What kinds of errors and error correction occurred?

Most distraction-assessment procedures assume the number of terminal errors is zero; that is, the task was successful. This section focuses on process errors, mistakes that were made along the way that may or may not have been corrected. Enter an address was one of the more demanding of the seven tasks and depending upon the entry, could require more button presses than any other task (table 73). The list in the *find-a-song* task was quite long, allowing for many more process errors due to flicking.

Table 73. Errors and Corrections: Task Effects

Task	Total Errors	Total Corrections
Dial	96	70
Address	372	29
POI	99	15
Contact	74	73
Song	229	204
Preset	19	0
Radio	67	70

More generally, even though tasks were only completed when the entry was correct, often subjects made minor but correctable errors when completing tasks (process errors), varying from 81% of subjects entering presets without errors to 4% (one subject) entering an address, on average. Again, these errors could be as simple as a spelling error that involve an incorrect letter, backspacing, and then entering the correct letter, to selecting the wrong field, entering text in it, and then backing up. To provide some context, there were 4,376 correct key entries but 5,725 total, or an extra 31%. Of course, there are other extra actions as well. Thus, when estimating actual task-completion time, adjustments will need to be made for corrected errors.

Closing thoughts

This report provides a wealth of data for elements associated with driver actions while operating in-vehicle devices, data that are needed to estimate occlusion task times and compliance with the NHTSA guidelines for driver distraction. What is notable about this report and the dataset on which it is based is the quality of the database and the extensive statistics reported. They include means, standard deviations, distribution types, and data on which occlusion-state elements occur, all information needed to compute occlusion times, both in simple Excel analyses and in Monte Carlo simulations. Furthermore, the process-error data presented provide a basis for adjustments for process errors that drivers correct while performance real tasks.

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APPENDIX A – TASK ELEMENT DETAILS

Goggles Open vs. Goggles Closed

For many of these elements, the state of the goggles has an important influence. The goggles are considered open when the subject's eyes are visible. If the subject's eyes are visible then the subject must be able to see and therefore the goggles must be open. The goggles are considered closed when the subject's eyes are not visible. The goggles usually have a phase in between open and close that is milky. Most often during this milky stage, the subject's eyes are visible so the goggles are considered open until that moment when they turn completely opaque and the eyes can no longer be seen.

Read

Read Instructions

This element concerns the time that the subject is rereading the instructions for the task that are located above the screen. The subject could have forgotten what comes next or could be double-checking. This element is determined by the subject's eye position. The subject's eyes must be focused on the instructions above the screen. Frequently, this element is done in parallel with other elements. This element can only be used when the goggles are open.

The start time for this element is usually when the subject first starts to move either the eyes or the head upwards. If the subject is already focused on the instruction when the goggles open, then the start time is the instant the goggles open. The end time for this element is the 0.01 s before the subject refocuses on the screen, even if moving towards a button in parallel. If the goggles close during the element, then the end time would be the hundredth of a second before the goggles close.

Search

This element concerns the time that the subject is thinking or searching for a certain button. The subject may have forgotten what button to press or needs to find where it is located on the screen. This element is determined by the subject's intention. If the subject's hand is preparing to start another task or completing a task this element is not used. Most often, the subject's hand is not moving during this element. This element can only be used when the goggles are open.

The start time for this element is the instant the goggles open or the hundredth of a second after finishing another element. The end time for this element is the hundredth of a second before the goggles close or the hundredth of second before another element is started.

Reach

<u>Reach for center console</u>

This element concerns the time it takes for the subject to move a hand from the steering wheel to the center console. It is always the first element of the task, but can also happen at any time during the task. This occurs if the subject moves the hand back to the steering wheel or his or her body and then attempts to return to the center console by a direct movement afterwards. This element can be used when the goggles are open or closed.

The start time for this element is when the subject makes their first move from either the steering wheel or their body (usually their lap) toward the center console. In most cases, this movement is a twitch in the shoulder, the hand leaving the steering wheel, or the subject leaning toward the center console. Sometimes it is difficult to determine if the subject has begun this element, because the video of the subject does not always show the subject's hands or shoulders. In this situation, the start time for this element is when a shadow appears on the console near the hard buttons at the bottom of the navigation radio. This is the subject's hand casting a shadow as he or she begins to reach for the center console. If the subject attempts to press a button, the end time for this element is the hundredth of a second before the subject touches the screen to press a button. If the subject stops reaching and lets a hand hover near the screen, the end time for this element is the hundredth of a second before the subject's hand stops making a direct motion to the screen.

<u>Reach for button</u>

This element concerns the time when the subject is clearly moving towards a certain target button. This time is usually included in a button press; however in this case, the move is interrupted, either by the goggles closing or when the subject realizes that he or she is moving towards the wrong button. There are three cases: (1) the subject may reach the general area of the target before the goggles close but does not press the button, (2) the goggles may close before the subject can press the button or (3) the subject changes direction to a different target which then becomes another move towards a button or a button press. This element can only occur when the goggles are open.

The start time for this element is the instant the subject starts to move his or her hand towards the target button. The end time for this element is the hundredth of a second before the goggles close or the hundredth of a second before the subject changes direction.

Press button

<u>Press button</u>

This element concerns the time required for the subject to press a button on the screen. If a subject is moving a hand toward a button, they are considered to be pressing that button, as long as they complete their attempt to press the button and do not stop mid-move. This element can occur when the goggles are open or closed.

The start time for this element is the instant the subject makes a direct move toward the target button. If the subject reaches for the center console and presses a button in a continuous, uninterrupted motion, the start time of this element is 0.01 s after the end time of the *reach-for-center-console* element. The end time for this element is the 0.01 s before the subject begins removing their hand from the button they have just pressed.

Knob actions

Turn knob

This element only occurs when a subject is tuning the radio. After the subject has adjusted their hand position on the knob, they will turn the knob to move through the radio stations. Turn knob left or turn knob right is specified depending on the direction of the turn. Clockwise is right and counterclockwise is left. This element can be used when the goggles are open or closed.

The start time for this element is the instant the subject begins to turn the knob. The end time for this element is the hundredth of a second before the subject's hand and thumb stop moving or the instant the subject releases their grip on the knob.

Reposition hand on knob

This element only occurs when a subject is tuning the radio. After turning the knob, the subject usually needs to return their hand to the original position in order to begin turning again or they may simply want to put their hand in a more comfortable position. This element can be used when the goggles are open or closed.

The start time for this element is the hundredth of a second after the *turn-knob* element. It is the instant the subject loosens their grip on the knob or begins moving their hand back to the position it was in before the subject began turning the knob. The end time is the 0.01 s before the subject's fingers begin moving again for the next knob turn or another element begins.

Touch screen actions

Flick

This element is used when a subject has to go through a list in order to finish a task. A flicking motion causes the list to move. During a flick, the screen will continue to scroll even after the subject's finger has left the screen. This element is determined by the time that the subject's finger is moving in the direction of the flick. Flick up or flick down is specified depending on the direction of the flick. This element can be used when the goggles are open or closed.

The start time for this element is the instant the subject's hand starts moving towards the screen with the intent to flick. The end time for this element is the time that the subject's finger stops moving in the direction of the flick even if their hand is no longer touching the screen. If a subject moves away from the screen, the end time is the hundredth of a second before this occurs.

Quick flick

This element is used when a subject has move through a list to finish a task. It is similar to the element flick, but the subject must return quickly (less than 1 s) and flick or scroll immediately following this element. This element is determined by the time that the subject's finger is moving in the direction of the flick. Quick flick up or quick flick down is specified depending on the direction of the flick. This element can be used when the goggles are open or closed.

The start time for this element is the hundredth of a second after the return element. The end time for this element is the time that the subject's finger stops moving in the direction of the flick even if their hand is no longer touching the screen. If a subject moves away from the screen, the end time is the hundredth of a second before this occurs.

Stop screen

This element is used when a subject has to go through a list to finish a task. It is similar to the *press-button* element but the subject’s goal is to stop the screen from moving instead of pressing a button. This happens when the subject gets close to their target or if they realized they have moved too far. This element can occur when the goggles are open or closed.

The start time for this element is the instant the subject's hand starts moving towards the screen with the intent to stop. The end time for this element is the 0.01 s before their hand leaves the screen. Sometimes the subject's hand does not leave the screen immediately. The subject could begin searching or is waiting for the goggles with their hand on the screen. In this case, the end time for this element will be the hundredth of a second before their hand stops moving.

Scroll

This element is used when a subject has to go through a list to finish a task. Some subjects may scroll slowly rather than flicking to find the target. Subjects may also use this technique when they are getting close to the target. During a scroll, the screen will not continue to move when the subject's finger has left the screen. Scroll Up or Scroll Down is specified depending on the direction of the scroll. This element can be used when the goggles are open or closed.

The start time for this element is the instant the subject's hand starts moving towards the screen with the intent to scroll or the hundredth of a second after the element Return. If the subject's finger is already on the screen, then the start time is the 0.01 s after the previous element such as search or stop. The end time for this element is the hundredth of a second before the subject's hand leaves the screen. Sometimes the subject's hand does not leave the screen right away; the subject could begin searching or is waiting for the goggles with their hand on the screen. In this case, the end time for this element will be the hundredth of a second before their hand stops moving.

Flick/scroll return

This element is used when a subject has to go through a list to finish a task. After flicking or scrolling, the subject usually needs to return their hand to begin another flick or scroll or they may simply want to put their hand in a more comfortable position. It is determined by the time that the subject's finger is moving back to the original flicking position. Return up or return down is specified depending on the direction of the return. Close return or open return is specified depending on whether the goggles are open or closed. This element can be used when the goggles are open or closed.

The start time for this task is 0.01 s after the elements flick, scroll, or quick flick or the instant the subject begins to move their hand back to the original starting position. The end time for this element is the hundredth of a second before the next flick, scroll, or quick flick or the instant the subject's hand stops moving back to the original starting position. If the subject's hand moves past the screen during a return, then the end time is the hundredth of a second before their hand is no longer on the screen.

Delays

Wait – Loading

This element measures the time it takes for the machine to respond to the subject’s actions. It happens only when the display changes, and there is nothing the subject can do to control this time. This element usually occurs after the subject has pressed a function button. This element can be used when the goggles are open or closed.

The start time for this element is 0.01 s after the end time of the Press Button element. The end time for this element is the instant the next screen loads completely. This means the buttons and words on the screen are completely legible, all street names have appeared on the maps, and all loading symbols are gone. If the screen looks like it has completely loaded but is very dim, the end time for this element is when the screen has reached its maximum brightness.

Wait for goggles - Known location

This element describes the location of the subject’s hand during the time that the goggles are closed. General means the subject is next to their target button. The subject must press the button that their hand is near before another button. If they move to a different button after the goggles open, the time that the goggles were closed is considered to be indefinite instead. This duration of this element is determined solely by the distance between the subject's finger and the button that will be pressed when the goggles open. The subject must clearly be near the next button pressed when the goggles open. It is not determined by the intention of the subject. If the subject is moving towards the target button when the goggles are closed and they do not reach the target button by the time the goggles open, it is considered to be Indefinite. The subject can already be near the target button or can move to the target button during the goggles close. This element is determined by the location of the subject's hand at the end time of this element. This element can only be used when the goggles are closed.

The start time for this element will almost always be the instant the goggles close. The exception is when the subject is in the process of another element while the goggles are closed, such as press button or flick. In this case, the start time would be the hundredth of a second after finishing that element. Most of the time the end time for this element is the hundredth of a second before the goggles open. The exception is if the subject starts another element before the goggles open. In this case, the end time would be the 0.01 s before the start of the next element.

Wait after loading

This element only occurs after the *wait-loading* element. The goggles must be closed. The subject does not know if the machine has loaded until after goggles open again, so the subject must wait. This element cannot be combined with machine loading because the machine has finished loading when this element is used. This element can only be used when the goggles are closed.

The start time for this element is the 0.01 s after the wait-loading element. The end time for this element is the 0.01 s before the goggles open.

Wait for goggles-Unknown location

This element is used when a subject has to go through a list or turn the knob in order to finish a task. It is the time that the subject is not doing anything because they are waiting for the goggles to open. This element occurs during the list and knob tasks because there is no indefinite or general location when scrolling, flicking, or turning. This element can only be used when the goggles are closed.

The start time for this element is the instant the goggles close or the 0.01 s after completing another element. The end time for this element is the hundredth of a second before the goggles open or the hundredth of a second before beginning another element.