



Research

Lighted Guidance Devices:
Intelligent Work Zone Traffic Control

Environmental Modulation of Drivers'
Perception of Vehicle Speed

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Lighted Guidance Devices: Intelligent Work Zone Traffic Control

ENVIRONMENTAL MODULATION OF DRIVERS' PERCEPTION OF VEHICLE SPEED

Final Report

Prepared by

Max Vercruyssen
Gayna Williams
Michael G. Wade

Human Factors Research Laboratory
Room 141 Mariucci Arena
1901 4th Street S.E.
University of Minnesota
Minneapolis MN 55455

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CONTENTS

Executive Summary	i
Lighted Guidance Devices Experiment 3 (LGD3)	1
Introduction	1
Background	3
Method	7
Results	17
Discussion	35
References	37
Applications of Lighted Guidance Devices (LGD4)	41
Appendices	47
A. Contributors	47
B. Participant Consent Form	49
C. General Questionnaire	51
D. Experimenter's Instructions to Participants	53
E. Post-Session Questionnaire	55
F. Order of Experimental Conditions	57
G. LGD3 Computer Protocol	61
H. Listing of Participants' Verbal Comments	67
I. Experimenters' Comments	69
J. Participant Recruitment Poster and Map	71
K. Individual Responses	73
L. LGD1&2 (Proceedings of 2nd ITS World Congress)	113
M. LGD3 (Proceedings of 2nd ITS World Congress)	121

EXECUTIVE SUMMARY

Audience: This report may be useful for communication systems designers, traffic engineers, human factors and safety engineers, developers of intelligent transport systems, systems managers, academicians, transportation researchers, and those interested in the effects of pulsing lights on apparent motion, the perception of vehicle velocity, and the velocity of vehicles through work zones and confined spaces.

Rationale: Each year thousands of highway workers risk serious injury and death at the hands of drivers who enter work zones too fast or accelerate after entering the zone and then, because of their excess speed relative to the environmental limitations, have insufficient time to avoid accidents in the zone. Vehicles traveling too slowly also pose a problem because they reduce traffic flow. Signage that explicitly states the optimal transit speed has been ignored by certain segments of the driving population. The primary purpose of this research was to investigate the effectiveness of manipulations of environmental lighting on driving behavior through a simulated work zone without implicit or explicit instructions for drivers to attend to the lights or their speed within the zone. Specifically, this research tested the hypothesis that pulsing lights alongside the roadway can modulate traffic flow causing a regression to a criterion speed, i.e., to slow the speed of vehicles entering the zone faster than a criterion speed, and to raise the speed of vehicles entering the zone slower than the criterion speed.

Method: The implementation of this regression-to-criterion-speed was attempted by the introduction of a system of pulsing lights, that gave the illusion of moving (the Phi phenomenon), positioned parallel and lateral to the roadway of a simulated work zone in the virtual world of a driving simulator. By sending pulses of lights moving alongside the driver, it was hoped that drivers would spontaneously and unconsciously modulate their speed to synchronize with that of the light pulses. Forty drivers participated in the Light Guidance Devices 3 (LGD3) experiment: 20 young (10 female, 10 male; 21-42 yrs) and 20 older adults (10 female, 10 male; 55-87 yrs). Each participant made 15 passes through a work zone in the virtual world of a driving simulator: a control pass with stationary white lights (40 mph entry), two control passes with no lights (40 mph entry), and 12 passes of test conditions -- 2 colors (red / green) x 3 apparent pulse speeds

(-80, 0, and +80 mph) x 2 zone entry speeds (40 mph / 70 mph). Each pass simulated driving conditions at dusk on a straight single-lane road of one mile in which the last 0.7 mile contained a work zone that was delineated by a concrete wall (Jersey barrier) on each side of the roadway. Drivers were instructed to enter at a specified speed and then to "drive in a comfortable manner, in a similar way to how you would in your own car at night through a construction zone." Other than the pulsing lights, the only velocity cue markings in the zone were standard yellow lane separation stripes on the highway. Completing all 15 passes took approximately 30 minutes.

Results: Age, sex, and zone entry speed differences were found, but overall, (1) backward moving lights (-80 mph) caused drivers to reduce their vehicle speed, (2) forward moving lights (+80 mph) caused drivers to increase their vehicle speed, (3) stationary light and control lights had little or no effect, and (4) green produced stronger effects than red. Backward moving lights caused the greatest slowing in the young while forward moving lights caused the greatest acceleration in the old males and young females. Effects of the lights on vehicle velocity, determined by the drivers' perception of their driving speed, were most influenced by zone entry speed: when entering at 40 mph there more possibilities for and a tendency toward acceleration while when entering at 70 mph (maximum image display rate of 95 mph) there were more possibilities and a tendency toward deceleration.

Interpretation: In the absence of speed advisory information and other signage, manipulation of optical flow information, especially the characteristics of pulsing lights on each side of the roadway, influences the driver's perception of vehicle velocity and causes acceleration and deceleration in predictable manners.

Proceedings Version: This research project was presented at the 2nd ITS World Congress in Yokohama in November of 1995 (see Appendix L and Appendix M at the end of this final report).

LIGHTED GUIDANCE DEVICES EXPERIMENT 3

Introduction

The Intelligent Transport Systems (ITS) program and its affiliated professional societies has promised to improve the safety record of ground transportation in the United States (and in other countries). This represents a most arduous endeavor but one that must be fulfilled if the basic aims of the conception are to be realized. With respect to safety, this report examines an approach to control traffic flow through work zones. Work zones prove particularly dangerous to drivers since they present uncertain conditions with multiple cues of a novel and sometimes ambiguous nature. Work zones are even more troublesome for workers who may be required to perform functions mere feet from passing vehicles with little or no protection. Little wonder incursions into work zones are frequent and most destructive events. The present work concerns a lighted guidance device (LGD) to promote safe and efficient passage through the work zone. While lighted guidance may provide cues to directional control, the present research focuses on the perceptual field for vehicle velocity control.

This project consists primarily of the third experiment in a series of investigations of the hypothesis that pulsing lights alongside the roadway could modulate traffic flow causing regression to a criterion speed, i.e., slowing vehicles entering the zone faster than a criterion speed and raising the speed of vehicles entering the zone slower than the criterion speed. This research was conceived as a project of the Intelligent Work Zone Partnership (3M Company's Traffic Control Materials Division, Minnesota Department of Transportation, and the University of Minnesota's Human Factors Laboratory). Experiments 1 and 2 were primarily sponsored by the 3M Company and Experiment 3 by the Minnesota Department of Transportation with all activities conducted in the automobile simulation facilities of the Human Factors Research Laboratory with technical assistance from Psy-Med Associates.

All experiments employed a system of pulsing lights that gave the illusion of movement (the Phi phenomenon), positioned parallel and lateral to the roadway of a simulated work zone in the virtual world of a driving simulator. By sending pulses of lights moving alongside the driver it

was hoped that drivers would spontaneously and unconsciously modulate their speed to synchronize with that of the light pulses.

LGD Experiment 1 examined the effects of driver age, driver sex, light pulse characteristics (all lights on; all lights off; 50 mph forward pulses, 5 on / 5 off; 50 mph forward pulses, 7 on / 3 off), speedometer feedback, and vehicle location within the zone. Despite age and sex differences, 24 drivers showed vehicle acceleration throughout the zone associated with forward pulsing lights compared to control conditions.

LGD Experiment 2 investigated the effects of driver sex, light pulse direction (25 mph forward, stationary, and 50 mph backward), light color (red & green), zone entry speed (40 & 70 mph), and location within the zone on vehicle speed and lane tracking for 24 drivers. Results replicated those of Experiment 1 showing vehicle acceleration to forward pulses and slowing to backward pulses plus a slight advantage of green lights compared to red and white lights. Based on the results of Experiments 1 and 2, LGDs appear to affect drivers' perception of velocity and vehicle speed: green lights atop jersey barriers pulsed in a forward direction at 25 mph or faster increases the speed of vehicles entering the zone at 40 mph or less and backward pulsing lights at 50 mph or faster decrease the speed of vehicles entering the zone at 70 mph.

Experiments 1 and 2 provided initial evidence that apparent motion and one's perception of velocity could be systematically manipulated to influence the speed at which volunteers drove through work zones in the virtual environment of a driving simulator. However, the magnitude of this effect was small, varied according to a number of variables, and not demonstrate in a single experiment with all variables of interest included. Experiment 3 was designed to manipulate the variables from Experiments 1 and 2 that most influenced LGD effects in order to increase the power of LGDs in modulating vehicle speed. Specifically, the purpose of this experiment was to investigate the effects of driver age, driver sex, pulse direction, pulse color, zone entry speed, and location within the zone on vehicle speed and lane deviation. This research is reported in conventional experiment format with a section added for LGD Applications (LGD4) and Appendices of relevant materials.

Background

The theoretical basis for the effect of roadway pulsing lights on driving behavior through enclosed or restricted areas lies in the psychophysical constructs of apparent motion and optical flow.

Apparent Motion

Apparent motion (AM) is the perception that lights positioned and flashed on and off in a sequential pattern are moving. An example is the familiar pulsing of lights seen on theater marquis. Pulses of light appear to circumnavigate the marquis, as if they were physical entities traveling at some fixed speed. Classical "optimal" or "beta" AM occurs when two stimuli are shown in rapid succession to an observer, with presentation 2 displaced both in time and space from presentation 1 (Wertheimer, 1912). The relationship of time and spatial separation has been expressed in Korte's Third Law of Apparent Movement (Korte, 1915), which essentially states that, AM will be seen if an increase in the distance between two successively-displayed stimuli is accompanied by an increase in the time between the successive presentations and is mathematically described as

$$D = kS$$

where the distance between objects in two successive frames is proportional to the speed of the AM desired. Variables such as shape of the object, contrast, and color appear to affect AM very little, provided of course that shapes and colors remain relatively similar across successive frames, and that contrasts retain their sign and remain above threshold values at all times (Anstis, 1980).

Although original experiments on AM were done solely in two-dimensional displays, the perception of AM also has been found to occur in three-dimensional environments (Attneave & Block, 1973). This is an important precedent because theater marquis and other such AM displays are perpendicular in relation to the viewer whereas LGDs along the roadway present

themselves to the viewer longitudinally with each light optically expanding from a dot on the horizon to a full-size 4 inch flasher light as it passes by the viewer.

Optical Flow

Optical flow (OF) refers to the two-dimensional pattern of motion vectors derived from a moving scene across time. J.J. Gibson (1959) was the first to describe characteristics of the OF field and its usefulness to perception and navigation. Since there is a geometric relationship between an observer and the environment, OF can be used to derive information about relative depth of objects and the relative velocity of an observer moving through some scene (Thompson & Barnard, 1981). For instance, with practice, a driver can learn to estimate speed while driving, without reading the speedometer. By associating current OF velocities with previously-learned OF-velocity relationships, a moderately good estimate of current velocity can be made. Furthermore, when the AM of a significant portion of an observer's environment is altered, this becomes equivalent to a significant manipulation of the observer's OF. Since an observer's estimation of speed and direction of heading (velocity) is a function of OF, then the specific relationship of manipulations becomes

$$\mathbf{VE} = \mathbf{f}(\mathbf{OF} = \mathbf{g}(\mathbf{AM})) = \mathbf{f}(\mathbf{g}(\mathbf{AM}))$$

where VE is velocity estimation. This partial formulation makes clear the variables involved--VE being the dependent perceptual variable, AM an independent environmental variable, and OF an intervening perceptual variable.

In a more general case, experimental manipulations can be quantified as

$$\mathbf{VE} = \mathbf{f}(\mathbf{g}(\mathbf{AM}, \mathbf{E}))$$

where E represents a vector of environmental stimuli ("the static environment"), and AM is taken to be a manipulated vector of dynamic cues. This more complete formulation encompasses all the cues to motion available in the OF. In the current research, the variable E is taken to represent the vector of static objects in the driving simulator virtual world. Apparent motion is represented

by a set of lights on both sides of the road, whose characteristics must be exactly specified. Actually, E itself can be partialled out further as

$$\mathbf{E} = [\mathbf{E}_m + \mathbf{E}_n]$$

where E_m constitutes environmental features that can serve as cues to motion and E_n constitutes environmental features that cannot serve as cues to motion.

All theories of motion detection depend on image segmentation. Image segmentation theories all fall into one of two categories--edge-based and region-based (e.g., Haynes & Jain, 1983). Hence, all theories of motion detection fall into the two same categories. Because it is possible to arrive at motion detection via two routes, the precise formulation of the contents of E_m and E_n are highly debatable. Some theorists argue that edges are necessary for motion detection. Others argue that it can be done only with regions. Still others resolve the problem by noting that edges and regions are simply the high spatial frequency (HSF) and low spatial frequency (LSF) components of a visual display, yet they are both spatial frequency components, and differ simply in periodicity. This leads to the possibility that motion detection could utilize both HSF and LSF information.

For the current research, it is not necessary to specify whether E_m is edge-based, region-based, or both, because it is primarily applied research and theory is given at this point for clarification and prediction. Therefore, the final symbolization of environmental and perceptual variables becomes

$$\mathbf{VE} = \mathbf{f}(\mathbf{g}(\mathbf{AM}, \mathbf{E}_m))$$

The absence of E_n (non-contributing environmental objects) in the final equation is simply because E_n represents "neutral" elements of the environment that do not contribute to motion effects.

In summary, the theoretical basis of the LGD effect can be easily described as the systematic manipulation of VE to permit alterations in AM. In practice, this was accomplished by having participants drive through a simulated world with lights on both sides of the road. These lights pulsed in AM alongside the vehicle. Such alterations in OF and their effect on AM are

expected to influence the drivers perception of self motion (e.g., their own vehicle's speed) and modulate their driving behavior.

Specific theoretical prediction for LGD effects, according to OF theory, are that drivers should accelerate in the presence of pulsing lights when the pulse direction is in the same direction as the direction of travel on the road. Conversely, drivers should decelerate in the presence of pulsing lights when the pulse direction is in the opposite direction of travel. In the control conditions involving either no lights or constantly-lit lights, there should be no tendency to change speed in the work zone.

Method

Participants

Forty healthy drivers volunteered to be participants in this experiment. Twenty young participants were recruited from the University of Minnesota population, including both students and employees. The twenty senior participants were predominantly recruited from the University Retirees Volunteers Association, or their friends. Participant demographics are shown in Table 1. Participants described themselves to be health, in good to excellent health, and drove 8-12 hours per week.

Each participant received ten dollars upon completion of the experiment.

Table 1. Demographic Characteristics of Participants

<i>Item</i>	<i>Younger Female</i>	<i>Younger Male</i>	<i>Older Female</i>	<i>Older Male</i>	<i>Description</i>
Volunteers per group	10	10	10	10	healthy drivers
Mean age (years)	26.5	30	71.7	71.1	
Age range (years)	21 - 36	22 - 42	66 - 78	55 - 87	
Years driving	10.8	13.5	52	54.7	
For your age do you consider your health to be?	4.2	4.1	4.9	4.1	1 poor, 2 below average, 3 average, 4 good, 5 excellent
Highest level of academic training:	2.8	3	1.9	2.7	1 high school, 2 undergraduate degree, 3 masters, 4 doctoral
Rate of physical fitness:	3.6	4.4	4.2	4.1	1 very low, 2 low, 3 moderate, 4 high 5 very high 6 unusually high
Rate of physical activity:	3.6	4.6	3.6	4.1	1 almost none, 2 little, 3 moderate, 4 much, 5 much 6 very much, 7 extremely active.
Hours driving per week	8	11.9	8.1	10.5	
Driving: hours each week					
A - light daytime	3.1	3.7	4.3	6.0	
B - heavy daytime	2.1	2	2.3	2.1	
C - night time	2.4	1.8	1.4	1.7	
Yearly mileage	10,111	11,570	5,812	9,500	
Weekly mileage	216.7	165	67	161.7	
Distance to work (miles)	10.7	4.2	0.8	3.3	
Area driven (%)					
A - urban	0.75	0.76	0.75	0.53	
B - suburban	0.15	0.19	0.25	0.27	
C - rural	0.1	0.05	0	0.2	
Frequency of driving on :					
A - highways	1.7	1.9	2.8	2.1	1- frequently
B - city streets	1.6	1.6	1.1	1.9	2- often
C - rural	3.9	3.9	4.2	3.5	3- moderately
D - congested	3.2	3.4	3.1	3.4	4-occasionally
					5- seldom
					6-never

Experimental Task

Each participant completed a driving simulator session that lasted approximately 30 minutes, during which they drove 15 times down a straight road in the simulator's virtual environment. On separate passes, each participant was required to reach each of two speeds before entering the work zone: 40 or 70 mph. After entering the work zone, the participant was to drive in a comfortable manner, similar to how (s)he would in his/her own car at night through a construction zone. In the experimental conditions lights appeared on top a 36 inch high wall on each side of the roadway. The lights were manipulated in three ways: they were on all the time, they gave the appearance of moving at 80 mph towards the driver, and lights gave the appearance of moving away from the driver at 80 mph. The color of the lights were either green or red. At the beginning and end of the session a control condition was implemented. This condition required the driver to reach a speed of 40 mph before entering the construction zone, and there were no lights on the concrete walls. A catch trial was completed in the middle of the 15 conditions that required participants to reach a speed of 40 mph before entering the construction zone and then drive through stationary white lights.

The Automobile Simulator

This experiment was conducted on a fixed-based front display driving simulator using a 1990 Honda Accord and equations of motion that modeled this vehicle. Essentially, driver behaviors like accelerator, brake, and steering movements were converted from analog to digital signals through a VMI VME-3118 64-channel A/D board (using voltage divider circuits) and made input information into a model that approximated driving characteristics of the vehicle. Outputs from this model were then used to adjust the eyepoint of the driver in the environment according to the inputs provided. Changes in the virtual visual environment were made in near real-time at least 15 times per second (in most experimental situations the cycle times are 30Hz or better) making the perception of the driver one of actual driving. Scene fidelity was controlled by the number of objects to be displayed: The greater the number of objects, the greater the calculational load and the lower the possible updating rate for any one fixed computer system.

Generation of virtual environments was controlled by a Silicon Graphics IRIS 4D/310 VGXT graphics mini-computer with a 4-channel video splitter using custom software developed on VAPS, Multigen, and Designer's Workbench.

Figure 1 illustrates the simulator configuration. The front flat screen was 116.5 x 86.25 inches (26.5 inches from bottom of screen to ground) at a distance of approximately 104 inches from the eyes of the average height seated participant (eyes approximately 48 inches above the ground). An Electrohome ECP 3100 projector, mounted approximately 79 inches from lens center to ground and located 146 inches from the screen was used to generate all virtual environments. The projected image dimensions were 91.5 x 71.5 inches. The field of view height was 63 inches from the bottom of the projected image and the width included all of the projected screen (> 116.5 inches).

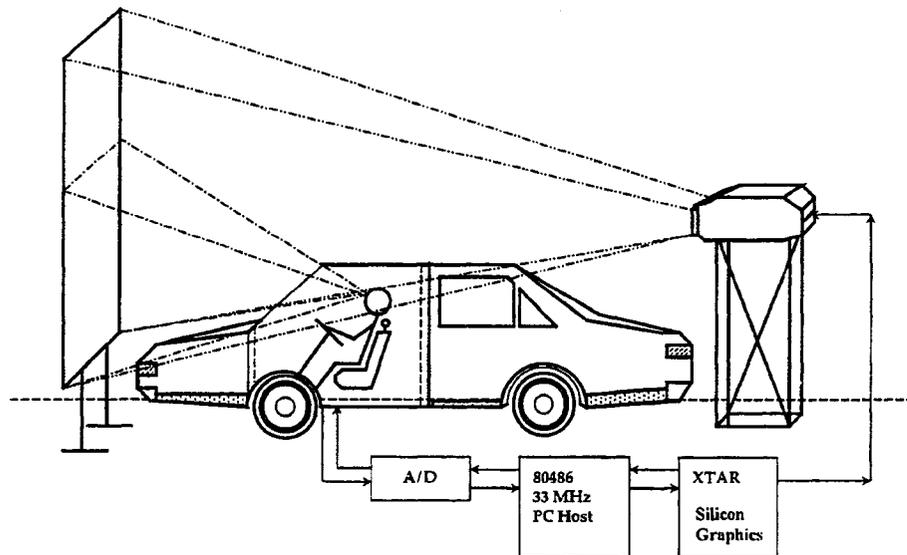


Figure 1. Automobile simulator configuration.

Virtual Environment. Objects were texture-wrapped polygons in convenient formats (e.g., rgb or tiff) to store pixel and color information. The maximum road width at the bottom of the image was 35 inches; the minimum road width at the horizon was 1.75 inches at 11.5 inches

above the bottom of the projected image frame. The simulated LGDs were round flashing lights (4 inches in diameter) characteristic of conventional roadway flashers, but synchronized for sequential flashing. The lights were spaced eight feet apart on each side of a flat, straight roadway, four feet outward from the edge of the pavement (i.e., on the shoulders), at an elevation of 40 inches (4" light atop of a 36" lane dividing barrier) above the roadway, and at a sufficient intensity to be visible at 2000 feet. The actual largest diameter of the light (at full looming) was 0.56 inches and its minimum diameter (at the horizon) was indistinguishable from the background. The roadway simulated was straight and flat 24' wide lane with about 1/3 of a left lane visible.

Based on findings from piloting and Experiments 1 and 2, the pulse width (i.e., distance between unlighted sections of the device) was set at 7 on / 3 off with motion simulated at 80 mph forward and backwards. Data collection began with no lights present for 0.15-mile before the 0.7-mile zone in which LGDs were tested and continued for 0.15-mile after with no lights present. Also, evening lighting conditions (moderate darkness) were simulated (approximately 20:00h).

Haptic noise was added to the steering to simulate uneven road surface and crosswind effect thereby making the simulator "feel" more like an actual car being driven on a typical roadway. The steering torque motor patterns of noise were designed to be completely random and nonintrusive to vehicle tracking within the lane.

Yellow skip line cues (4" x 10' with 40' spaces between lines) were provided on the pavement as a left-side lane divider and simulated "farmers' fields" of approximately 0.25-mile wide were presented on each side of the roadway to facilitate speed estimation. The right edgeline was white, continuous, and 4" wide.

Design

This experiment was designed to investigate the influence of direction of appearance of lights, and the color of the lights in the construction zone on the velocity of the driver. There were three directions of lights: towards the driver, stationary, and with the driver. There were two colors of lights: red or green. Two zone entry speeds were used: 40 and 70 mph. Two organismic factors of interest were age and sex. The final design was a 2 (age) x 2 (sex) x 3

(direction of lights) x 2 (color of lights) x 2 (entry velocity into construction zone) with repeats on the last three factors.

It was necessary for the driver to enter the construction zone at ± 5 mph of the intended entry speed otherwise the condition was repeated. This experiment was designed to counterbalance the conditions across participants and within groups, but due to difficulties encountered with five older females, and four older males, it was necessary to repeat trials thereby slightly altering the original counterbalance. In most cases a trial was repeated because the driver failed to reach the required zone entry speed in approaching the work zone. However, because there was little evidence to suggest a sequence effect would result from the order to trials there should be no consequence of this slightly altered order of conditions.

The first and last conditions were control conditions. The participant entered the construction zone at 40 mph, and no lights were given on top of the concrete wall. A catch trial was included in the middle of the trials in which the driver entered the construction zone at 40 mph to see stationary white lights in the construction zone.

Independent Variables

Direction of Lights. Three direction of lights were used in the study: 80 mph forward, stationary, and 80 mph backward. The apparent movement of the lights was achieved by the specification of which lights were switched on and for what time interval (see Human Factors/Ergonomics Consultants, 1995).

Color of Lights. In each trial the lights were all one color, either red or green. In the control condition no lights were switched on. In a catch trial the lights were all white.

Entry Speed into Construction Zone. The speed at which the participant entered the lighted zone was either 40 mph or 70 mph. The speed was controlled by the participant and therefore a degree of error occurred. The speed was determined to be satisfactory if it was within 5 mph of the target speed otherwise the pass was repeated at the end of the session. All participants performed within this limit on their first attempts.

Age and Sex of Drivers. In a cross-sectional design, an equal number of young and older adults were tested to observe age differences. Similarly, an equal number of males and females were used to explore the influence of sex/gender.

Dependent Measures

Velocity and Steering. Continuous velocity (mph) and steering (decimal miles) data were collected throughout each trial at a sample rate of at least 20 Hz, from the initiation of the trial, until the trial was terminated by the experimenter. A good trial was considered one where the participant entered the construction zone within 5 mph of the specified velocity (i.e., 40 or 70 mph). The work zone was divided into seven 0.1-mile sections and an additional 0.1-mile section was included prior to entering the zone. For each of the eight zone sections the mean velocity and lane deviation were calculated, by using all the values recorded over that section.

Rating Scales (Subjective Measures). After each trial participants were requested to complete a rating scale about how comfortable they felt whilst driving in the construction zone. The rating scale had values from 1 to 10, 1 meaning the driver felt very uncomfortable in the construction zone such that it had a negative effect on his / her driving, 5 meaning neutral, driving in the construction zone had no effect on his / her driving, 10 meaning the driver felt very comfortable in the construction zone such that it had a positive effect on his / her driving.

Post-Experimental Questionnaire. A post experimental questionnaire was completed that gave the participant an opportunity to express opinions and preferences for conditions. A complete copy of the questionnaire can be found in Appendix E.

Procedure

Participants were welcomed to the Human Factors Research Laboratory. Before the initiation of any discussion related to the study, participants were asked to sign an informed consent form (Appendix B). After the participants had signed the consent form they were taken to the driving simulator.

The participant was made to feel comfortable in the vehicle by being instructed on how to adjust the seat, in order to easily reach the pedals and view the projection screen. Instructions were given on how to drive the car in the simulated environment. Before the experimenter left the simulator room, each participant was informed that there was a microphone and speaker in the car in order for two way communication to take place during the session.

Volume of communications between the experimenter and the participant was adjusted so that instructions were heard clearly. The experimenter read standardized instructions (see Appendix D) to the participant. If the participant interrupted while instructions were being read, the experimenter answered their questions and continued the instructions. It was important that the instructions were read in their entirety so that each participant received a minimum number of instructions to complete the task, however it was also important for the participant to feel comfortable in the driving simulator environment. After the task had been explained to the participant, a request for questions from the participant was encouraged. The task was reiterated once more in a formal way.

The experimenter decided whether to provide extra instructions on how to drive in the simulator dependent upon the apparent comfort level of the participant. Extra instructions, usually only related to use of the accelerator, were informational and very brief.

The task required participants to enter a lighted construction zone at two speeds, 40 and 70 mph. The participant had use of the gas, brake, and steering wheel. The driver did not have access to the speedometer as it was distracting from the driving task (see Human Factors/Ergonomics Consultants, 1995), and therefore an awareness of speed was achieved by having the experimenter read aloud, the speed of the driver's vehicle as it was displayed only on the experimenter's computer console. The experimenter was well practiced in helping participants accelerate or decelerate as needed to insure drivers entered the zone at the specified speed. It was the intent of any such advice to assist the driver to reach the target speed prior to reaching the construction zone. If entrance speed was not ± 5 mph of the required speed the condition was repeated at the end of the session.

Treatment of Data

Exclusion Criteria. A total of forty-two participants took part in the study. Eleven young females and males were tested. Ten of each were selected for inclusion in the study. Two were rejected as they showed unusual behavior in each of the trials. One young female who was included in the analysis, successfully completed 14 of the 15 trials, in the missing trial the driver actually came to a halt and had to be encouraged to start again to leave the construction zone. An estimate for the performance for this trial has been based on the group mean for other young females for this trial.

Analyses of Objective Data. For both velocity and steering performance, data were analyzed according to a 2 (age) x 2 (sex) x 2 (color of lights) x 3 (direction of lights) x 2 (entry velocity into work zone) x 8 (location in work zone) mixed analysis of variance (ANOVA) design where the last four factors were repeated measures. For each entry velocity, for both velocity and steering performance, a 2 (age) x 2 (sex) x 2 (color of lights) x 3 (direction of lights) x 8 (location in work zone) mixed ANOVA with repeated measures on the last three factors was used.

The first and last trials were analyzed separately using a 2 (age) x 2 (sex) x 2 (trial) mixed ANOVA design. An ANOVA was also completed on all the trials at 40 mph, this included the controls, the white light condition, and the other six, 40 mph experimental conditions using a 2 (age) x 2 (sex) x 9 (conditions) design.

Raw data were summarized on the UNIX platform using descriptive statistics utility programs developed in C before conducting statistical analyses on summary data on an Intel microcomputer platform using DAS 3.0 (Vercruyssen & Olofinboba, 1994) and SAS PC-windows (SAS, 1994). Multifactor univariate ANOVAs and other statistical contrasts were made at the 0.05 level of significance using df correction procedures from the variance-covariance matrices. *Post hoc* tests were done manually using the Tukey *WSD* procedure (e.g., Vercruyssen & Hendrick, 1990).

Analyses of Subjective Measures (Rating Scale). The rating scale was analyzed by using a 2 (color of lights) x 3 (direction of lights) x 2 (entry speed) repeated measures ANOVA design.

Analyses of Post-Session Questionnaires. A descriptive interpretation of the open-ended questions posed in the questionnaire is provided with results of the preference questions reported as means for each age by sex group.

Results

Analyses were conducted to examine 12 sets of data, five of which are herein reported: (1) vehicle velocity data using combined zone entry speeds, (2) vehicle velocity data for zone entry at 40 mph, (3) vehicle velocity data for zone entry at 70 mph, (4) distance to synchrony data, (5) LGD effects compared with additional control conditions, (6) lane deviation data, and (7) subjective responses.

Velocity Change for Combined Entry Speeds

Analyses of vehicle speed through the work zone revealed thirteen significant contrasts: two main effects and eleven interactions. The direction of the light pulse was reported in nine of the effects and entry speed in six. Table 2 shows significant contrasts from analyses of the collapsed data. Figures 4-6 show the entry speed into the work zone to be 55 mph, that is a result of forcing drivers to enter the zone half of the passes at 40 mph and half of the passes at 70 mph.

Table 2.. Summary of Significant Results from ANOVA of Vehicle Velocity Collapsed Across Two Fixed Entry Speeds (40 and 70 mph).

<i>Factor</i>	<i>df</i>	<i>F Ratio</i>	<i>Prob</i>
Direction of lights	2,72	26.98	0.0001
Direction * age	2,72	3.22	0.0459
Direction * zone	14,504	20.67	0.0001
Direction * zone * age	14,504	2.02	0.015
Direction * zone * age * sex	14,504	2.11	0.0104
Direction * color * zone	14,504	3.5	0.0001
Direction * color * zone * age	14,504	1.74	0.0452
Entry speed	1,7	798.15	0.0001
Entry * zone	7,252	58.77	0.0001
Entry * zone * age	7,252	2.83	0.0074
Entry * zone * age * sex	7,252	3.57	0.0011
Direction * entry * color	2,72	4.29	0.02
Direction*entry*color*age*sex	14,504	2.43	0.0026

After collapsing data by entry speed, two four-way interactions were significant: age by direction of light pulse by light color by zone location ($F(14,504) = 1.74$; $p = 0.0452$), and age by sex by direction by zone location ($F(14,504) = 2.11$; $p = 0.0104$) illustrated in Figures 2 and 3, respectively. The two most extreme curves shown in Figure 2 are both for green lights: forward pulses cause an increase in vehicle speed through the zone, especially for older driver, and backward pulses cause a slowing of vehicles, especially for young drivers. On leaving the work zone, the highest speeds are found in the forward light condition for both age groups (young-green = 58.41, young-red = 59.01, old-green = 61.98, old-red = 57.65), and slowest for backward light condition (young-green = 46.29, young-red = 50.49, old-green = 50.40, old-red = 53.38), except for the older adults in the red light condition, that is almost the same as the exit speed in the older adults stationary red light pulse condition (stat = 54.86 , backward = 53.38).

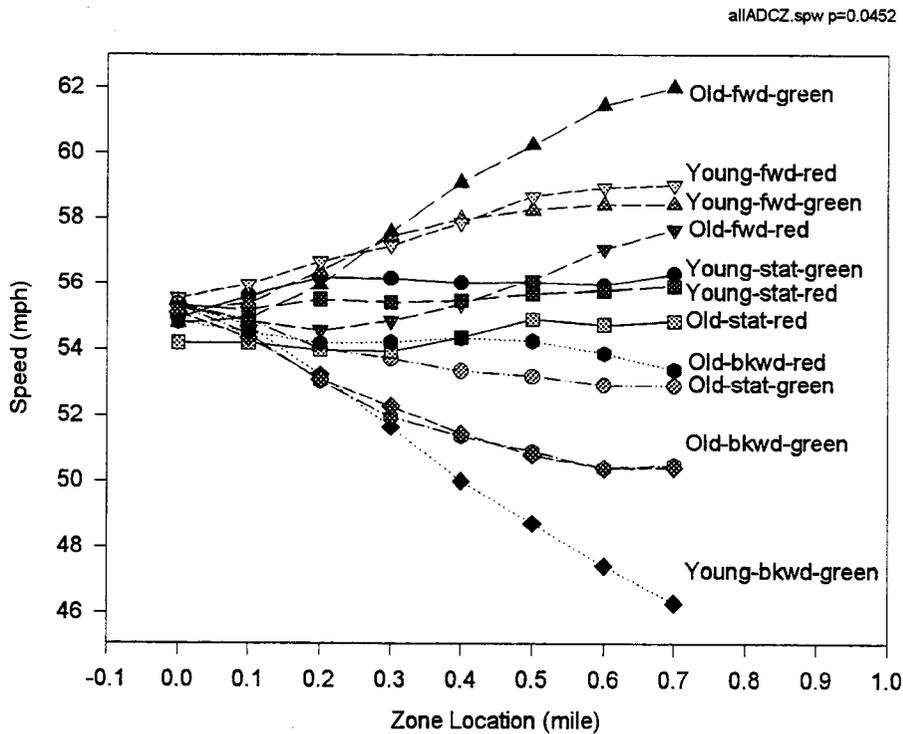


Figure 2. Mean vehicle velocity as a function of direction of the light pulses, color of lights, and zone location, collapsed over entry speed ($p = 0.0452$).

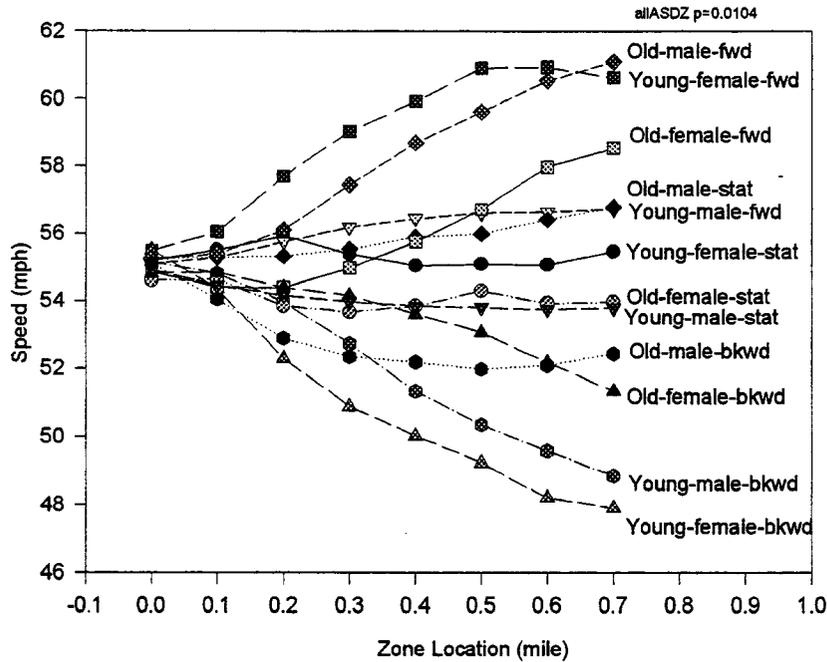


Figure 3. Mean vehicle velocity as a function of driver age, driver sex, direction of light pulse, and zone location, collapsed over entry speed ($p = 0.0104$).

There appears to be very little change in velocity throughout the work zone in response to the stationary pulse lighting condition. The effect of direction of pulse and color of lights can be seen clearly in Figure 4, which illustrates a three-way interaction of pulse direction by light color by zone ($F(14,504) = 3.5$; $p = 0.0001$). Figure 5 illustrates the age by pulse direction component of the interaction ($F(14,504) = 2.02$; $p = 0.015$), such that the older adult drivers appear to be more affected by the lights traveling in the same direction as they are driving, and less influenced by the lights moving against them (mean speed on zone exit: fwd = 59.82, stat = 53.88, bkwd = 51.89), both the directions of the pulse influence the behavior of younger drivers, unlike the stationary light condition (fwd = 58.71 stat = 56.10, bkwd = 48.39).

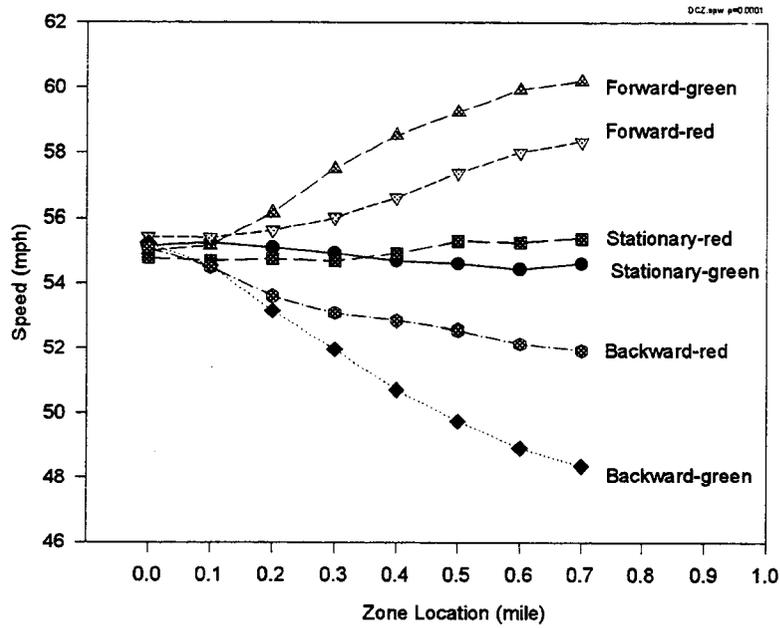


Figure 4. Mean vehicle velocity as a function of direction of light pulse, color of light, and location in zone ($p = 0.0001$).

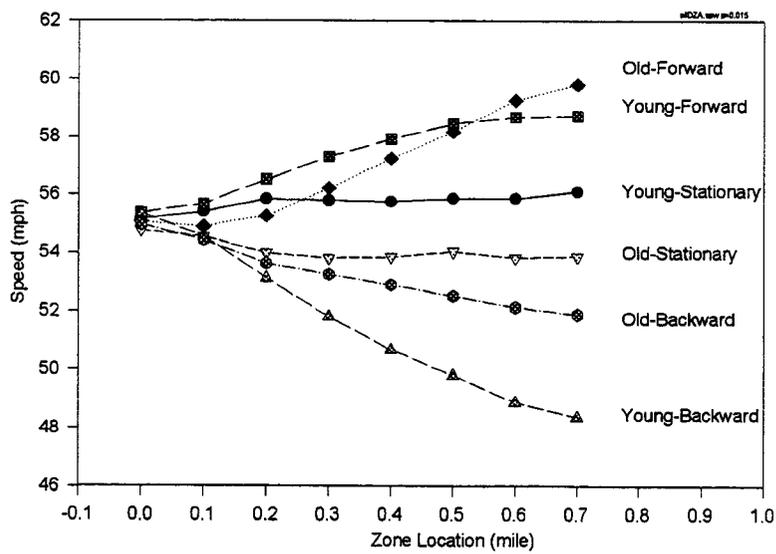


Figure 5. Mean vehicle velocity as a function of direction of light pulse, driver age, and zone location ($p = 0.015$).

In the second four-way interaction, Figure 3, the results relating the change in speed through the work zone with respect to the direction of the light pulse is the same (main effect: $F(2,72) = 26.98$; $p = 0.0001$ (forward > stationary > backward). Large changes through the work zone were found for the young females -- they appeared to drive fast when the lights were forwards (mean = 60.63) and slowly when the lights were pulsing backwards (mean = 47.90). In contrast the older females behavior was moderately effected by the direction of the lights (fwd = 61.10, bkwd = 52.44). The males appeared to show almost opposing behavior with regards age groups. The older males exited the zone in the forward condition the fastest, and yet in the backward light condition were the slowest (fwd = 61.10, bkwd = 52.44), and the opposite is virtually true for the younger males, who where the slowest in the forward light condition, and just ahead in speed of the young females in the backward pulsing condition (fwd = 56.79, bkwd = 51.34). Clearly the effects of LGDs varies as a function of age and sex. Figure 6 suggests that the effect of pulsating lights may be less prominent in older than in younger adults ($F(2,72) = 3.22$; $p = 0.0459$).

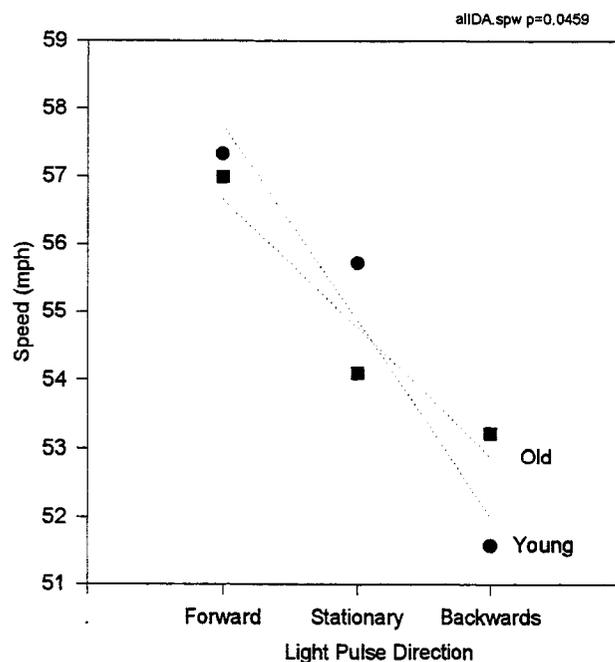


Figure 6. Age differences in LGD effects: Mean vehicle velocity throughout the work zone as influenced by the direction of light pulses for young and older drivers ($p = 0.0459$).

Velocity Data for Zone Entry at 40 mph

The ANOVA results (see Table 3) compared well with those of vehicle velocities through the zone when collapsed over the two entry speeds. For simplification in presentation of the results of the three-way and four-way significant interactions will be considered before the five-way interaction.

Table 3. Summary of Significant Results for ANOVA of Vehicle Velocity When Zone Entry Speed is 40 mph.

<i>Factor</i>	<i>df</i>	<i>F Ratio</i>	<i>Prob</i>
Direction	2,72	17.34	0.0001
Direction * age * sex	2,72	4.42	0.0154
Zone zone	7,252	11.64	0.0001
Direction * color	2,72	4.6	0.0132
Direction * zone	14,504	10.72	0.0001
Direction * zone * age * sex	14,504	2.46	0.0023
Direction * color * zone	14,504	3.44	0.0001
Direction*color*zone*age*sex	14,504	2.8	0.0005

The significant three-way interaction illustrated in Figure 7 is for direction by color by location ($F(14,504) = 3.44$; $p = 0.0001$). The relationship between the color of the lights and the exit speeds suggests that the red lights do not have as strong an effect in the pulsating light conditions as the green lights (fwd-green = 52.24, fwd-red = 49.18, bkwd-green = 43.57, bkwd-red = 43.57). The relationship between the absolute velocities on exiting the work zone and the direction of pulse of the light still presents the format of forwards lights producing higher speeds than the stationary than the backward condition as in the ANOVA results collapsed across entry speed (main effect: $F(2,72) = 17.34$; $p = 0.0001$). However in considering the relative velocity to which the driver entered the zone a new picture is presented. The forward pulsating lights produced a dramatic increase in speed from the entry speed of 40.78 mph to 50.71 mph,

and even an increase for the stationary condition, compared with stationary lights that produced the customary "slow entry acceleration" of 6 mph from the beginning to the end of the zone. The red light in the backward condition followed a similar increase to the green stationary condition but not as great. The condition that showed very little change, 1 mph increase across the zone, was exposure to the green backward pulsating lights.

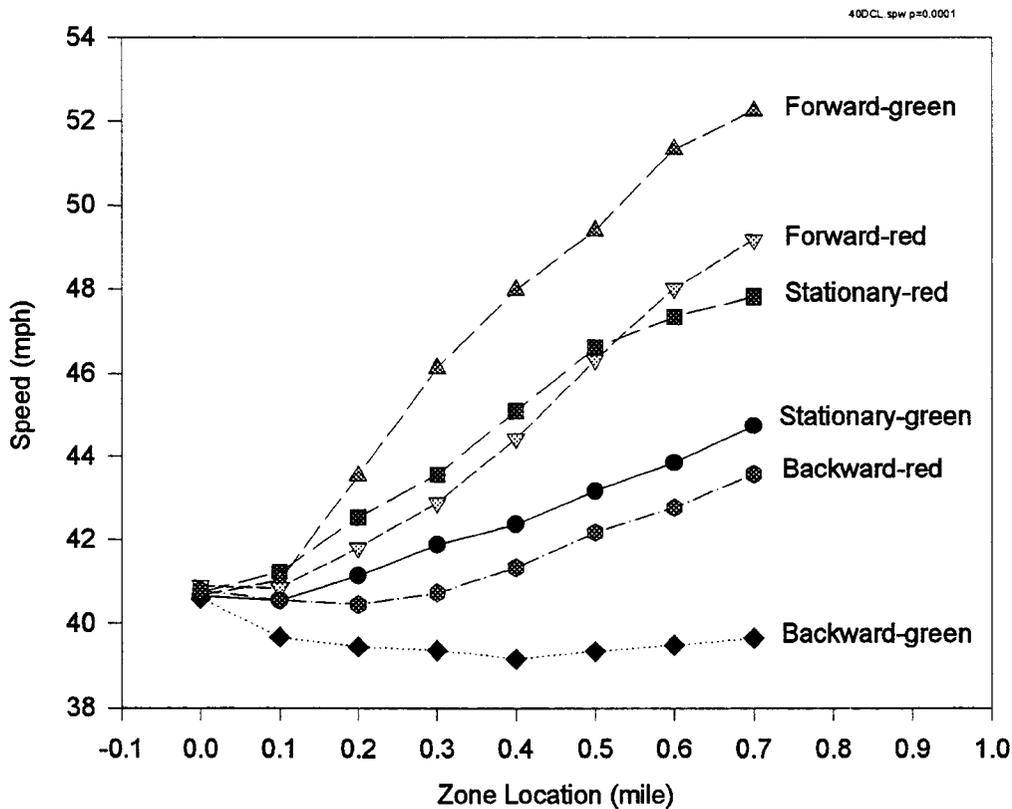


Figure 7. Mean vehicle velocity through the work zone following entry at 40 mph as a function of direction of light pulse, color of lights, and zone location ($p = 0.0001$).

The four-way interaction in Figure 8, illustrates a similar trend to the previous figure. Whenever vehicles enter at slow or fast speeds, relative to approximately 55 mph, there is a tendency to accelerate or decelerate, respectively, toward a middle speed. This is evident in these

data by observing the pattern of acceleration from 40 mph seen in the stationary lighting. Regarding LGD effects at slow entry speeds, four of the five lowest exit speeds are for the backward pulsing light condition and approximately equal the entry speed indicating that backward pulse here thwarted the tendency to accelerate through the zone. Apparently a "floor effect" is acting here to prevent further slowing of slow entering vehicles. The forward pulsing lights cause considerable acceleration, especially for young female and older male drivers. Of the four age by sex groups, young male drivers are the only group to violate the direction of the pulsating light effect as performance for the stationary condition provided a slightly faster time than for the forward condition (stat = 48.03, fwd = 45.84).

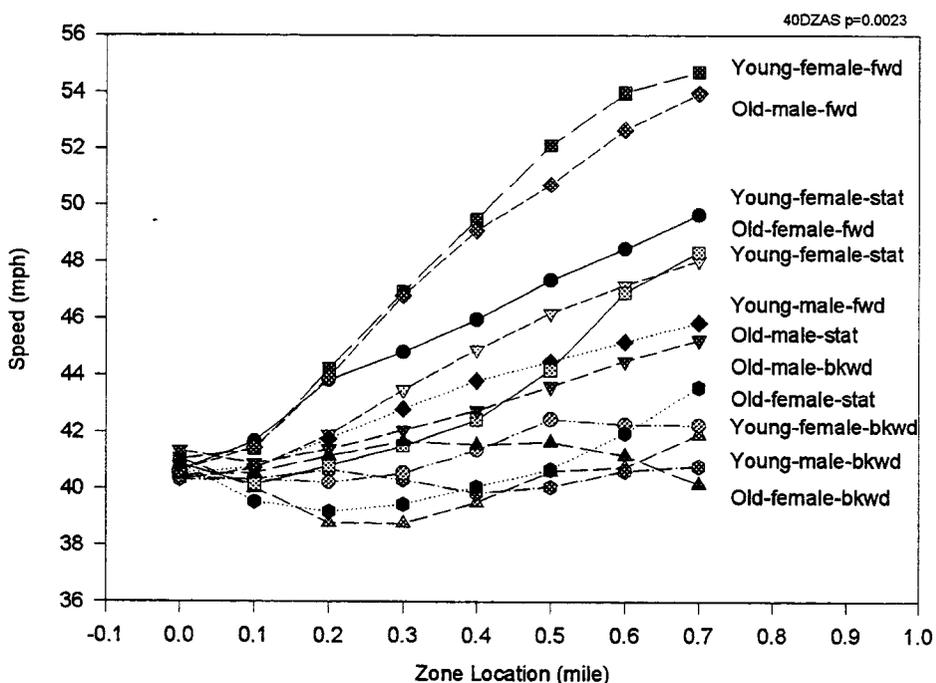


Figure 8. Mean vehicle velocity as a function of direction of pulsing lights, driver age, driver sex, and zone location ($p = 0.0023$).

The five-way interaction indicates that LGD effects vary as a function of all of the factors investigated. When entering work zones at 40 mph, backward pulses cause drivers to maintain their speed throughout the zone with little effect of driver age, driver sex, and color of lights. However, forward pulsing lights cause drivers entering the zone at slow speeds to accelerate and this effect is especially pronounced in young females when using green lights.

Velocity Data for Zone Entry at 70 mph

An ANOVA was completed on the 70 mph entry speed data and a summary of the significant main effects and interactions appears in Table 4. Only one, three-way interaction was significant: direction by color by zone ($F(14,504) = 1.85$; $p = 0.03$) as shown in Figure 9. When the entry speed is 70 mph there is some decrease in speed in all the conditions, as expected by the regression to the mean phenomenon. However, the decrease is negligible in the forward pulsing light (exit speeds of 68.16 mph for the green lights and 67.49 mph for the red lights) suggesting that the tendency to slow for fast entry vehicles was counteracted by the forward pulses to maintain a constant high speed at the ceiling of driver comfort through the zone. A larger decrease is found in the stationary condition, again with green being faster than red (64.44 and 62.94 mph, respectively). There is a reversal in the slowing order of the color of lights for the backward pulsating condition such that the exiting speeds are 60.29 mph for red and 57.03 mph for green. The decrease in speed caused by forward pulsing greens is dramatic (70 mph at entry to 57.03 mph at exit). Unlike individual responses for slow entering vehicles, age and sex of the driver were not significant factors affecting LGD effects for vehicles entering the zone at 70 mph.

Table 4. Summary of Significant Results for ANOVA of Vehicle Velocity Through the Work Zone When Speed is 70 mph.

<i>Factor</i>	<i>df</i>	<i>F Ratio</i>	<i>Prob</i>
Direction	2,72	11.06	0.0001
Direction*color	7,252	13.86	0.0001
Direction * zone	14,504	10.04	0.0001
Direction*color*zone	14,504	1.85	0.03

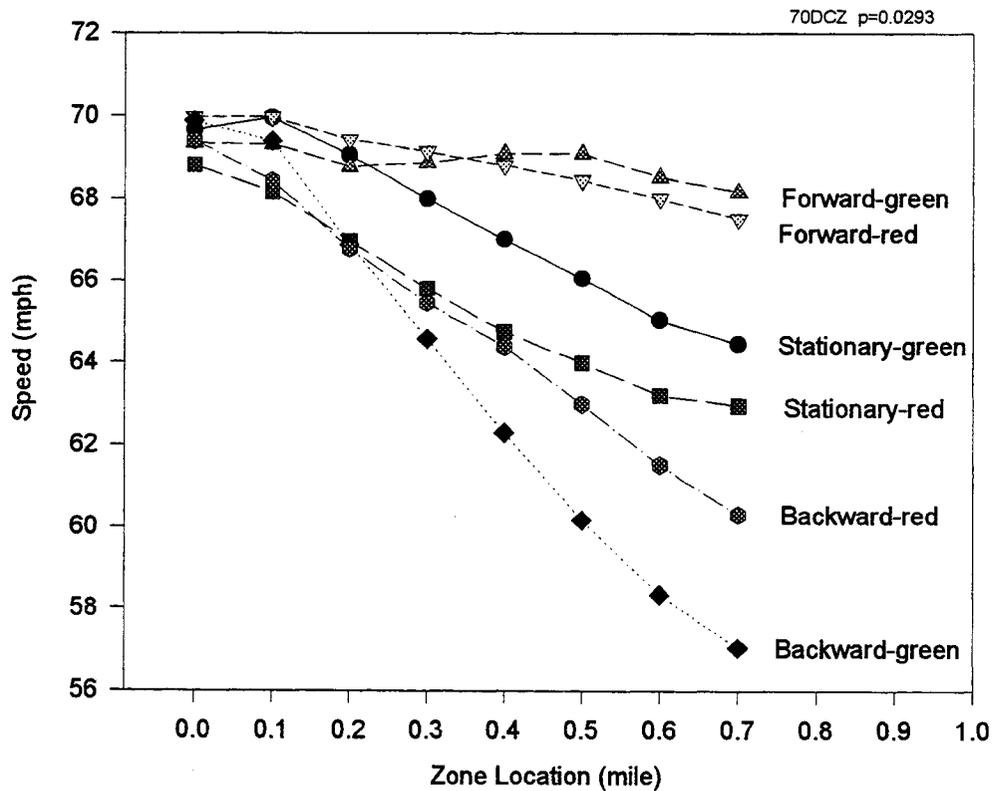


Figure 9. Significant interaction for direction of light pulses by color of light by zone location, for the 70 mph entry speed ($p = 0.0293$).

Extrapolation to Predict Synchrony

This experiment was designed to investigate the interaction of factors affecting the effectiveness of LGDs in modulating driving behavior through work zones. Given that vehicle velocity covaries with the direction, velocity, and color of pulsing lights, it became intuitively interesting to assess the point at which the drivers' perception of self-movement in relation to the optical flow of LGDs in the environment were comfortable or synchronous, i.e., the point at which, regardless of entry speed, the driver is comfortable with their speed in relation to the objects passing in their immediate environment. Assuming linear regression extrapolations are remotely appropriate here, Figure 10 illustrates the distance into the zone at which drivers might find LGD effects disappear, i.e., where the vehicle speed stabilizes regardless of whether entering the zone at 40 or 70 mph based on pulse direction and color of the lights. Taking these same data and collapsing over color, Figure 11 illustrates a simplified version of the logic of predicting driver comfort for perceptual monitoring of self-motion, environmental motion, and artificial devices producing apparent motion cues to synchronize events or to reduce mental effort.

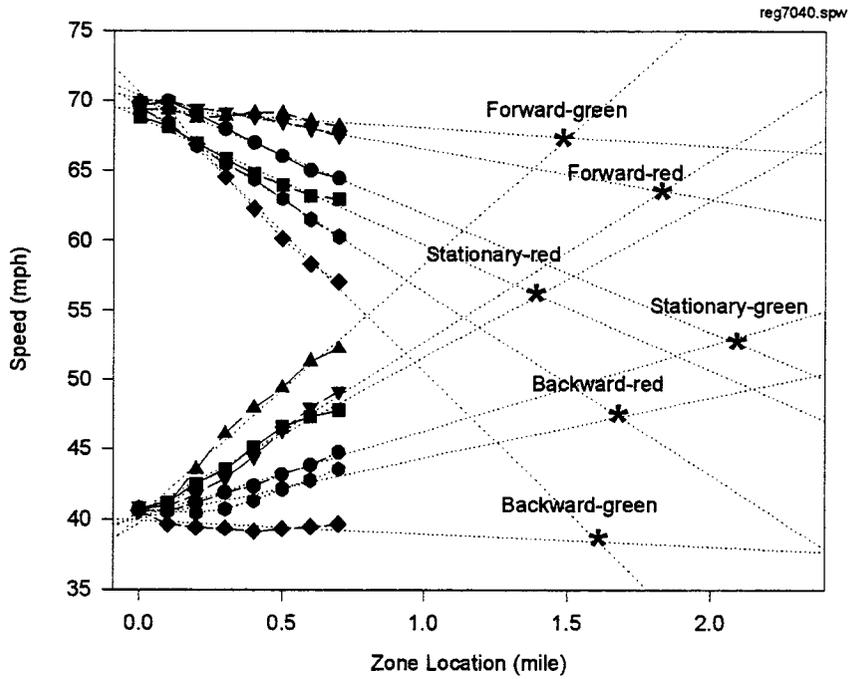


Figure 10. Point of comfort (*) within the zone where vehicle velocity stabilizes regardless of entering the zone at 40 or 70 mph as a function of color and pulse direction.

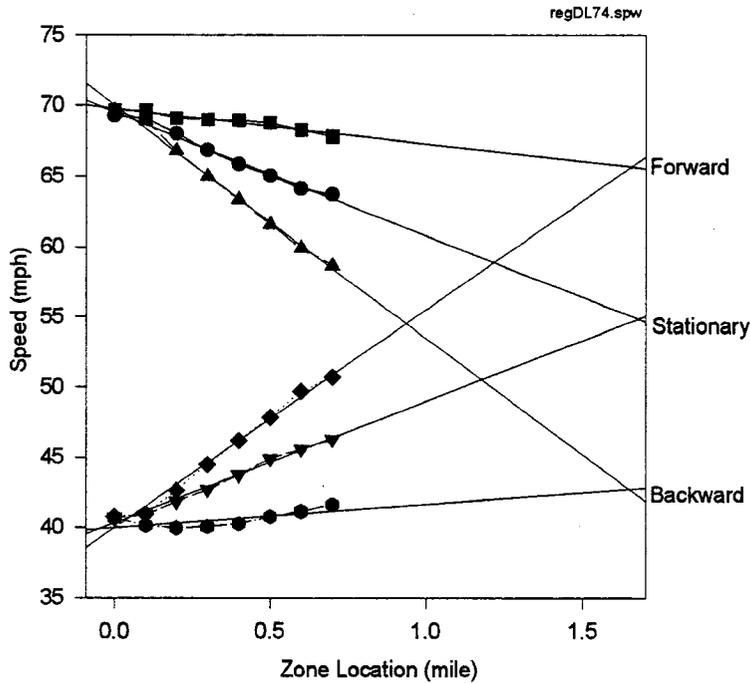


Figure 11. At 1.7 miles into the zone, vehicle velocity is predicted to stabilize regardless of entering the zone at 40 or 70 mph when displayed as a function of pulse direction.

Comparison With Additional Control Conditions

An analysis was completed considering each 40 mph entry speed condition as a separate condition, in this way it was possible to include the control conditions and the "surprise" white light condition. The summary of the significant results are listed in Table 5 and illustrated in Figure 12.

Table 5. Significant Results from both the speed and lane deviation data for all 40 mph entry speed conditions.

<i>Dependent Measure</i>	<i>Factor</i>	<i>df</i>	<i>F Ratio</i>	<i>Prob</i>
Speed	Condition	8,288	9.47	0.0001
	Zone	7,252	11.74	0.0001
	Condition * zone * age	56,2016	1.39	0.0310
	Condition * zone	56,2016	7.55	0.0001
	Condition*zone*age*sex	56,2016	1.41	0.02
Lane Deviation	Zone	7,252	5.42	0.0001

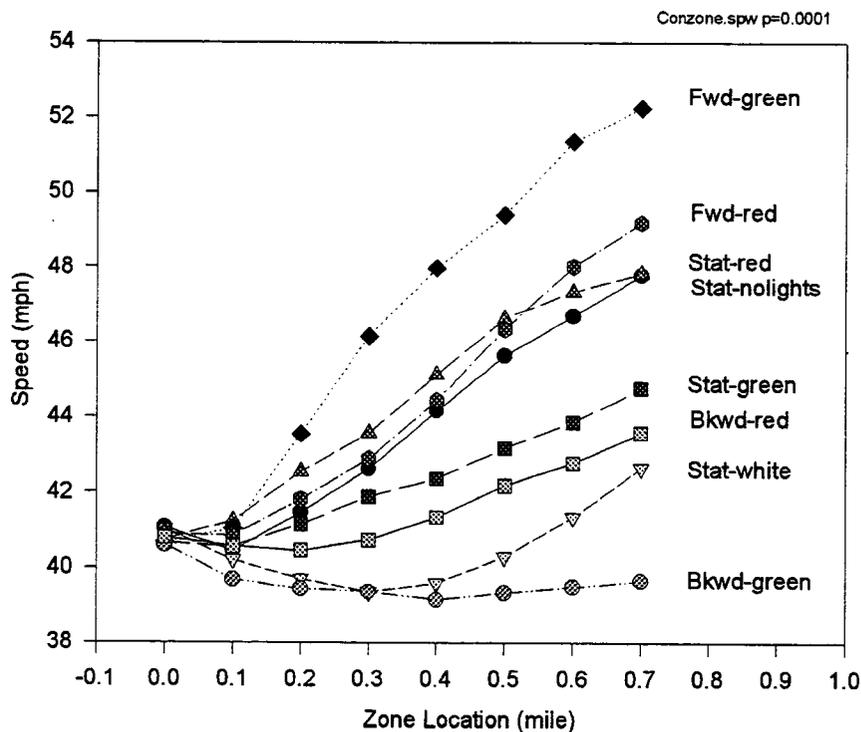


Figure 12. Mean vehicle velocity for all 40 mph entry speed conditions with the first and last treatment stationary no light conditions averaged for comparison with the stationary white light condition to compare against all other LGD conditions. The interaction of these nine conditions by zone location was significant ($p = 0.0001$).

Note that the no light condition is similar to the red light condition, suggesting that brightness of light, and contrast to the environment may influence the outcome. This is further suggested by noting that the white light stationary condition starts off very similar to the backward green light condition. Is this a product of the novelty of the white lights, as there was only one condition with white, or due to the brightness, and the contrast of white light against a black background.

Lane Deviation (Steering Swerve)

Lane deviation was carefully monitored as a measure of steering or tracking accuracy. However, despite finding significant changes in this measure the magnitude of these effects (mere inches of swerve on a highway) seems relatively unimportant. In other words, LGDs affect vehicle speed much more than they do steering behavior. Nonetheless, this section will present the significant and most interesting findings.

ANOVAs were conducted on data collapsing over entry speed and individually on the basis of entry speed as summarized in Tables 6 and 7. Figure 13 illustrates the most relevant four-way interaction: age by sex by direction by location ($F(14,504) = 1.76$; $p = 0.04$). This interaction was present for the 40 mph entry speed data but was not significant in the 70 mph entry speed data. In fact there were scarcely any contrasts for lane deviation that were significant. Figure 14 illustrates changes in lane deviation as a function of light pulse direction, light color, and entry speed ($F(2,72) = 2.27$; $p = 0.04$). While the pattern for deviation is similar for red lights regardless of entry speed and even, to some degree, for green lights at the 70 mph entry speed, there is clearly something different about the way in which drivers monitor lane position when entering the zone at 40 mph and being confronted with backward pulsing green lights. For this particular condition drivers become more accurate and greatly resist the tendency to accelerate when traveling through the zone. Why this combination of LGD factors produces such a strong stabilization effect is unclear at this time.

Table 6. Significant Results for ANOVA of Steering Deviation Collapsed Over Entry Speed.

<i>Factor</i>	<i>df</i>	<i>F Ratio</i>	<i>Prob</i>
Sex	1,36	10.82	0.0022
Zone	7,252	5.25	0.0001
Direction * age * sex * zone	14,504	1.76	0.04
Direction*color*entry speed	2,72	2.27	0.04

Table 7. Significant Results for ANOVA of Steering Deviation for Both Entry Speeds.

<i>Level of entry speed</i>	<i>Factor</i>	<i>df</i>	<i>F Ratio</i>	<i>Prob</i>
40 mph	Sex	1,36	9.01	0.0049
	Color	1,36	4.37	0.0437
	Zone	7,252	4.24	0.0002
	Direction*color	2,72	4.15	0.0196
	Direction*zone*age*sex	14,504	1.85	0.03
	Color * zone	7,252	2.29	0.03
70 mph	Sex	1,36	10.12	0.0030
	Zone	7,252	2.28	0.03

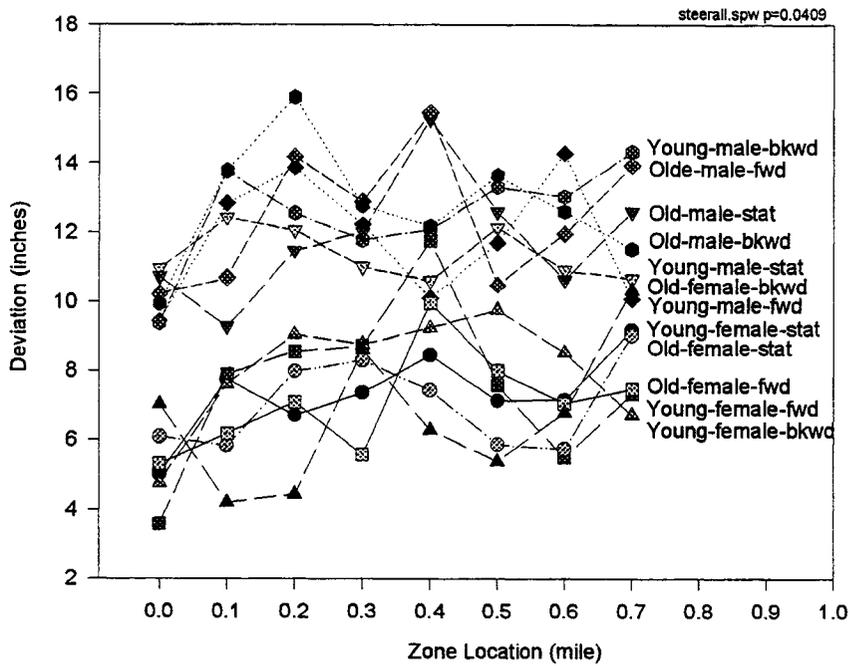


Figure 13. Mean lane deviation as a function of driver age, driver sex, pulse direction, and zone location ($p = 0.0409$).

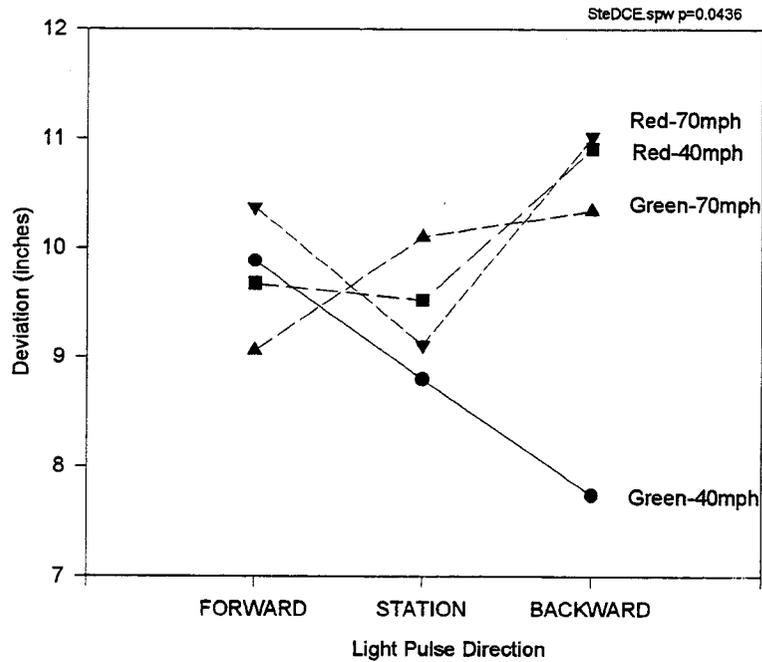


Figure 14. Mean lane deviation as a function of pulse direction, color of lights, and entry speed ($p = 0.0436$).

Subjective Responses

Subjective responses following each pass and on the post-session questionnaire are not reported here, but a listing of participants' verbal complaints from post-session debriefing are presented in Appendix H.

Discussion

The effect that LGDs can be expected to have on vehicle velocity is limited by such factors as the presence of other vehicles and distracting images in the driving environment, characteristics of the lights (e.g., size, intensity, color, location in field of view), zone entry speed (e.g., drivers entering the zone at 40 mph or less are likely to slow and those entering at 70 mph or faster are unlikely to accelerate), and characteristics of the light pulse (e.g., direction, velocity, ratio of lights on and off). Presumably LGD effects can be enhanced for vehicles entering a work zone alone and at a moderate speed, but especially by having LGDs the most intense and obvious velocity cue in the driver's visual environment. For even a group of cars entering the zone, LGDs are likely to influence traffic flow by causing the first driver in the series to accelerate or decelerate depending on direction and velocity of the pulsing lights. Presumably traffic flow sensors could provide information for zone control processing units to calculate appropriate LGD velocity and direction parameters through each section of the zone in order to optimize traffic flow. The effects of LGDs should be even more pronounced in tunnels and in cases where the visual environment limited or controlled so that LGDs emerge as a dominant feature of the driver's visual field.

The findings of this research are unequivocal in their recognition of the velocity control factor in the manipulation of the environmental display. Founded in perceptual psychology, the present conception illustrates the interactional properties of color, direction, and speed in influencing driver velocity control. If this interactive 'field' of factors is more fully specified, it argues strongly that an effective control device can be instituted such that work zone speed may be changed according to the display presented. How such a manipulation will directly influence safety has yet to be theoretically and empirically articulated to its fullest extent. However, the present findings are most encouraging that this effect should be real. If successful, it might represent a true ITS technology to promote both driver and worker safety.

Based on review of the research literature, it appears that LGD Experiments 1-3 are the first attempts at systematically manipulating LGD parameters to determine their effects on perception of self motion and thereby influencing vehicle velocity through work zones, in either virtual or real environments. Much needed now are field applications that validate findings from

the laboratory. For a review of current and potential future applications see the Applications of LGDs section in this report (immediately following the References).

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APPLICATIONS OF LIGHTED GUIDANCE DEVICES (LGD4)

Substitution for Tasks 5 and 6 in Original Contract

Task 5 and 6 as originally proposed, require that the necessary modifications of the simulator software be made so that the lights displayed along the roadside in the virtual environment would approximate the display characteristics of the light tubes as manufactured by 3M. Originally the intent was to see if a commercially available light guidance device might be adapted to field testing. However, due to dissolution of the Intelligent Work Zone Partnership and the timing being awkward all parties involved to donate materials and effort to field pilot testing during the summer of 1994, an alternative task was arranged to serve as LGD4 to close-out the contract. As indicated in the two quarterly reports, Tasks 5 and 6 (LGD4) were redesigned based on a meeting held 05 November 1994 involving Michael Wade (co-PI responsible for LGD4), Marthand Nookala (Mn/DOT contract monitor), and Ron Cassellius (Mn/DOT financial officer). This meeting discussed alternative strategies for meeting the LGD4 requirements that were intentionally written vaguely in the original proposal because it was uncertain in April 1994 what research might be possible in the summer and fall. The meeting concluded to the satisfaction of all with the following task to serve as the project close out (two months effort).

LGD4, as indicated in the initial work plan, was to contain no formal experiments but it was hoped that certain variables might be manipulated in order to determine predictability of certain outcomes relative to implementing the 3M light tubes in highway construction and other scenarios. Thus, no funds were budgeted for extensive software alteration or development, payment for participants, or other resources necessary for conducting formal research. However, any type of research that assisted Mn/DOT, Minnesota Guidestar, and 3M in implementing LGDs on Minnesota highways would be seen as mutually beneficial.

When 3M was contacted several times in May and June 1994 regarding their interest in summer LGD4 pilots, both Sue Chrysler and Rich Newell indicated that 3M had no further funds available because the Intelligent Work Zone Partnership had been dissolved and they were no longer interested because focus groups failed to provide evidence of profit potential from the

manufacturing of such devices. Thus, there was no point in going ahead with Task 5 of the original proposal, i.e. to program the environments to convert the 4 inch lights to 4 foot tubes. The dollars designated to be used on this task were needed to help defray unexpected additional expenses incurred in conducting LGD Experiment 3 and could provide the necessary support for the revised LGD4 work task, i.e., the revised work plan could be completed within the original budget.

Current Uses of Light Guidance Devices

An extensive literature and current uses search was conducted nationally and internationally to determine in what physical locations light guidance devices are being used to manage traffic flow through work zones.

National Applications

Light guidance tubes are currently used in several United States cities including: (1) Reno, NV; (2) Little Rock, AR; (3) Milwaukee, WI; (4) Salt Lake City, UT; and (5) Minneapolis, MN. The tubes are generally mounted on the top of jersey barriers that run parallel to roads. Lighted guidance tubes have been installed either permanently (e.g., on sharply curving highway on- or off-ramps) or temporarily (e.g., in work zones) to aid guidance and navigation through stretches of hazardous roadway.

The light guidance tubes currently used in Reno, NV, have been placed in a temporary construction zone. The tubes are used on a section of highway consisting of three lanes heading north-west and three lanes heading south-east. When construction is finished, an elevated bridge will cross over the highway supported by cement columns embedded in the median area between the bi-directional traffic lanes. Traffic flowing in each direction needed to be diverted around the construction zone. Temporary lanes were constructed that circumvented the construction area, jersey barriers were placed along the inside wall of the leftmost lane, and lighted guidance tubes were mounted on top of the jersey barriers. The lighted guidance tubes were installed to facilitate navigation through the temporary construction zone. The traffic engineers involved with the construction project do not possess any quantitative data regarding the effectiveness of the light

tubes in reducing accident rates. However, anecdotal evidence indicates that the lighted guidance tubes are highly effective and appreciated by drivers who regularly travel the highway. Specifically, drivers who have used the highway indicated that driving through the construction zone is easy because the lighted guidance tubes 'tell them where to go.'

The light guidance tubes currently used in Little Rock, AR have been placed permanently on top of jersey barriers that surround the outer edge of a highway exit ramp. Unlike the scenario in Reno, the lighted guidance tubes were installed specifically to reduce the rate of accidents. The traffic engineers indicated that accidents typically occurred when drivers crashed into the existing jersey barriers when they had entered the exit ramp at an excessive speed and could not negotiate the sharp curve. Although no quantitative data has been gathered, traffic engineers stated that the lighted guidance tubes have been highly successful in reducing the number of accidents on the exit ramp. (Maybe this supports the use of LGDs at the Mn 694 / I94 interchange where this downward and abruptly turning exit ramp threatens driving safety, particularly for large trucks, because of the exceptionally high risk of accident.)

The Wisconsin Department of Transportation currently uses light guidance tubes in temporary construction zones to shift and direct traffic to alternate driving lanes. A traffic engineer indicated that light guidance tubes have been used with great success on highway construction projects that temporarily redirect traffic from two parallel highways to one highway with two-way traffic. The traffic engineer supported the contention that the light guidance tubes have been highly effective for guiding and shifting traffic. Like the previous cities, there are no quantitative data regarding the effectiveness of lighted guidance tubes.

In summary, it appears lighted guidance tubes have been used successfully in a variety of permanent and temporary locations across the United States. While no quantitative data are available regarding the effectiveness of the lighted guidance tubes for reducing the rate of accidents or controlling vehicle speed, anecdotal contributions from drivers and engineers suggest that lighted guidance tubes are well liked because of their navigation properties.

Light guidance devices appear effective, particularly at night, in allowing fairly rapid transit through work zones. These devices have the advantage of making road delineation navigational instructions so obvious to drivers that they see no reason to slow their transit through the work area.

International Applications

International information is still arriving for this report at the time of publication; however, enough is available to describe some of the projects discovered in Europe. Pietzsch Automatisierungstechnik, a German traffic systems devices company that makes the "PET" light has a 10 kilometer test roadway in Portugal and has completed an initial series of tests on the effects of LED-type sequential flashing lights on highway driving behavior. The large LEDs most closely represent the 4' flashers tested in the simulator experiment of LGD3. Hopefully the report enroute and subsequent collaborations with this group will prove fruitful. Initial contacts at the Intelligent Transportation Systems World Congress in Paris (Dec, 1994) found the general manager (Rigobert Opitz) very receptive to having the HFRL test their LED system in field pilot studies.

Recent work in The Netherlands suggests that it might be possible to generate optical flow phenomena by using stripes painted on jersey barriers and lane delineators to modulate traffic speed by generating the so-called 'Phi' phenomenon. Near Rotterdam, LED LGDs are being used very successfully in optimizing traffic flow through construction zones. Belgium often uses LED LGDs with road construction and repair. Italy and Sweden are probably the most frequent users of the 3M light tube LGDs.

Potential Future Applications

Returning to the central problem of light guidance and its use in intelligent work zones; in what ways can the speed of traffic through work zones be influenced to maintain reasonable traffic flow at speeds that optimize both traffic flow and the safety of individuals working in these areas? The LGD3 data and other corroborating results (e.g., see Konzak, 1994) suggest that the directionality of generated optical flow fields produces a change in perception of speed for drivers: backward pulses causing slowing of vehicles entering the zone fast and forward pulses causing acceleration of vehicles entering the zone slowly. Gary Thompson and Marthand Nookala of Mn/DOT have discussed potential applications of LGD technology in reviewing other research needed to slow traffic in work zones. Thus, the following types of empirical activities

may be developed both in laboratory experiments utilizing virtual LGDs in the soon to be completed wrap-around driving simulator in the Human Factors Research Laboratory at the University of Minnesota and in field studies of portable work zone using commercially available LGDs (e.g., light tubes and LEDs). Systematic manipulation of the optical flow field and its effect on driving behavior might also involve roadway narrowing and the use of stripes on jersey barriers.

1. Narrowing the roadway channel through intelligent work zones, to the point where the margin of error for the driver is reduced so that the individual is forced to slow or risk hitting the perceived or real barriers that narrow the width of the roadway, may be an effective means of slowing traffic and enhancing driver attentiveness. This "funneling" effect is especially obvious when drivers experience the disappearance of road shoulders upon entering tunnels. There seems to be some evidence that traffic (calming?) is affected by narrowing the width of the roadway (e.g., see the Portland Project).

2. Putting stripes on jersey barriers and narrowing the width of the roadway through the work zones, either with by using paint or some other devices (e.g., 3M diamond grade reflective strips) merit development as projects for wrap-around simulation and field trials in portable work zones. Currently, John Carmody (Underground Sciences) and Max Vercruyssen are conducting research for the UMN Center for Transportation Studies that investigates the effects of light, color, texture, and contrast of one's immediate surroundings (optical flow features) on aesthetic preference and driving behavior through confined areas (e.g., tunnels and work zones). Preliminary findings suggest that there are many ways in which driving environments can be manipulated to modulate driving performance, traffic flow, and transportation safety. Driving simulations, especially those that involve peripheral vision (as produced in the HFRL wrap-around simulator), may be the only way to initially investigate environmental modulator effects since this research method is ideally suited for economically (efficiently) investigating a variety of potential factors that might interact in countless ways to affect empirical results. Continued research in this area is necessary to identify the combination of environmental features that optimally affect drivers' perceptions and actions.

APPENDIX A.

Contributors

Many individuals contributed to this research. The project personnel and members of the Intelligent Work Zone (IWZ) Partnership (consisting of 3M Company's Traffic Materials Division--3M, Minnesota Department of Transportation--Mn/DOT, and the University of Minnesota's Human Factors Research Laboratory--HFRL) were directly involved in this research. M. Vercruyssen, with the HFRL during the project but now at the Intelligent Transportation Systems Institute, was the project leader for LGD experiments 1, 2, and 3, PI for this contract, and was responsible for technical aspects of this research, including the contents of this report. G. Williams recruited participants, collected the data, conducted preliminary analyses of the data, and is a co-author on reports and conference proceedings. M.G. Wade, the contract co-PI, contributed the section on potential applications of LGDs (LGD4) and was financial director for the project. S.T. Chrysler and P.A. Hancock created the LGD concept and initially proposed it for cost-sharing among the IWZ partners. B. Knecht developed portions of the background and, with Chrysler, designed initial experimental protocols for Experiment 1. R. Newell, D. May, S. Garber, and P. Siegfried from 3M provided guidance and initial funding to test prototypes and complete the first two experiments (LGD1&2 which are reported in a 3M technical report by Human Factors / Ergonomics Consultants and Psy-Med Associates, 1995, and in Appendix L). The University of Minnesota, Human Factors/Ergonomics Consultants, and Psy-Med Associates contributed hardware, software, and personnel resources to create the environment for testing the concept. J. Wright, from Minnesota Guidestar, and M. Nookala, G. Thompson, and D. Pickett, from Mn/DOT, encouraged early development of this project and arranged support for the current experiment and pilot studies. O. Olofinboba served initially as a co-investigator and then became the chief project engineer providing substantial technical support in hardware and software development for automating the data collection and analyses as well as the output graphics procedures. Silicon Graphics virtual environment software was developed by M. Coyle. T. Harrington provided valuable suggestions in interpretation of the findings. J. Boone, Director of Transportation Research at the Ministry of Transportation (ANWB), Rotterdam, NL, provided useful information about the use of flashing lights in Dutch construction zones. Computer

literature searches were conducted at the University of Minnesota (including Transportation Research Information Services) and at Technische Universiteit Eindhoven (TUE and Dutch national libraries system) with manual searches conducted in the TUE Institute for Perception Research.

APPENDIX B.

Participant Consent Form

Date: _____

Participant No: _____

Light Guidance Driving Simulator Experiments

You are invited to participate in a study of behavior in a simulated driving situation. We hope to learn about some of the perceptual and decision making processes involved in driving.

If you decide to participate, a researcher will ask you to sit in the driver's seat of a specially prepared automobile and use its controls to perform certain common driving maneuvers in a computer generated world. Various traffic scenes will be projected onto a screen in front of you using a computer and video projector. You will be asked to drive in your normal manner. The simulator will record your speed and lane position. These actions are being studied in order to better understand the way people perceive and respond to driving situations in construction zones. We expect the findings will lead to significant reductions in the number and /or severity of motor vehicle accidents.

Each different traffic scene will be followed by a brief pause. Your behavior in the simulator will be very much like normal driving but in an unfamiliar car. In order to prevent difficulties that may possibly arise in adjusting in adjusting back to your own vehicle, we strongly recommend that you do not operate a motor vehicle for about one hour after completion of a simulator session.

The entire session will last approximately one hour. Because the simulator is fixed-base system (nothing actually moves) and simulates moving about in a realistic manner you may feel some disorientation that makes you feel as if you are moving. This is a normal response. If this happens to you, closing your eyes or looking away from the screen should eliminate the discomfort. If you wish, you may discontinue participation. If at any time you wish to withdraw from the session, you are free to do so. Also, if you need to take a break simply let the research assistant know.

Any information obtained in connection with this study that can be identified with you will remain confidential and will be disclosed only with your permission. In any written reports or publications, no individual participants will be identifiable and only aggregate data will be presented. Your decision to participate will not affect your future relations with the University of Minnesota in any way. If you decide to participate, you are free to discontinue at any time without affecting such relationships. If you have any questions about the research and/or research subjects rights or wish to report a research related injury, please contact Dr. Max Vercruyssen (principal investigator) or Gayna Williams (research assistant) at:

Human Factors Research Laboratory Telephone 625-7884.
60 Norris Hall, 172 Pillsbury Drive, S.E.
University of Minnesota, Minneapolis, MN 55455

If you wish to participate please sign the following statement of consent:

You are making a decision whether or not to participate. Your signature indicates that you have read the information provided above and have decided to participate. You may withdraw at any time without prejudice after signing this form should you choose to discontinue participation in this study.

Statement of Consent:

I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

Participant's Signature

Date

Researcher's Signature

Date

APPENDIX C.

General Questionnaire

Date _____

Participant number _____

We would you like to answer the following questions.

1. For your age do you consider your health to be (please circle your answer):
Poor Below Average Average Good Excellent

2. What is your highest level of academic training, or the level you are currently studying at?
High School Undergraduate Degree Masters Degree Ph.D.

3. Please rate your physical fitness by circling one of the answers:
i.e., how much energy do you have to do things, compared to others your age?
Very Low Low Moderate High Very High Unusually High

4. Please rate the amount of physical activity you have by circling one of the answers: i.e., how many physically active things do you do, compared to others your age?
Almost none Little Moderate Much Very Much Extremely Active

5. Do you have a valid US driving license? Yes No

6. How many years have you been driving? _____ years

7. How many hours do you drive a week? _____ hours

8. Please divide up your driving hours into the following categories:

light daytime traffic _____ hours each week
heavy daytime traffic _____ hours each week
night time driving _____ hours each week

9. How many miles do you think you drive each year? _____
10. What is your estimated weekly mileage? _____
11. What is the distance you drive one way to work? _____
12. Is most of your driving: urban? _____
 suburban? _____
 rural? _____
13. How often do you drive on/in:
 (Scale: 1 - frequently, 2 - often, 3 - moderately, 4 - occasionally, 5 - seldom, 6 - never).
- Highways? _____
 City streets? _____
 Rural roads? _____
 Heavily congested conditions? _____
14. Do you need to wear glasses or contact lenses for driving? Yes No
 If yes, are you wearing them today for this study? Yes No
15. Are you near sighted? Yes No
16. Are you far sighted? Yes No
17. Do you have or wear bifocal lenses? Yes No
18. Do you have any other vision problem that you are aware of?
 Color blindness: Yes No
 Depth perception: Yes No
 Other: _____
19. Do you have any hearing problems? Yes No
 If yes, do you use any hearing devices when driving? Yes No
 If yes, did you use the hearing device today? Yes No
20. Are you predominantly right or left handed? Right Left
21. What is your age? _____ years
22. Are you a citizen of the United States? Yes No
 If no, what country are you a citizen of? _____

THANK YOU VERY MUCH FOR YOUR TIME

APPENDIX D.

Experimenter's Instructions to Participants

Welcome to the Human Factors Research Laboratory. I am going to read you some standardized instructions pertaining to this experiment.

Please adjust your seat so that you can comfortably reach the pedals and steering wheel. The seat adjustment is a pull-up lever under your right knee. (pause 6-10 seconds)

The steering wheel, brake pedal, and accelerator in this driving simulator works just like a car on the road. The only difference is that you don't have to put the car in gear for it to go. When the computer in the next room is activated a driving environment will be projected on the screen in front of the car and you will be able to maneuver this car through that artificial environment.

The road you will be driving on is similar to a major highway in a rural part of the state. You will be driving alone at night on a single lane of a divided highway that has a construction zone identified by jersey barriers on each side of your lane.

The purpose of this experiment is to study your driving behavior through a lighted construction zone at night. Your task is to drive as you normally would at night, in a manner that is comfortable for you, staying between your lane markings so that you don't drive on the shoulder, while getting to your destination without undue delay.

You will start driving on an empty road at night. At the start of each trial I will tell you a speed I want you to reach before you enter the lighted construction zone. There will be two speeds: 40 and 70 mph. The speedometer has been disconnected so you don't need to look at the instrument panel. I will tell you your speed until you enter the zone during which I will be silent. Drive through the zone as you normally would. You are allowed to adjust your speed in order to feel as comfortable as you usually do when you drive at night. Once you have left the lighted zone please keep driving until I ask you to stop. After a short pause we will start the next trial, at the beginning of another empty roadway. You will be driving 15 slightly different roadway scenes, each taking about two minutes to complete.

While you are in the lighted construction zone it is important that you drive in a comfortable manner. It is important that you don't drive differently in the simulator than how you would in your own car at night through a construction zone. Be relaxed, but pay attention to the road. There is nothing you will encounter that will scare you or come as a sudden surprise.

During this session I will be in the next room operating the computer. There is an intercom between the two rooms so we can communicate. There is a microphone in the car above your head to the left which will let me hear what you have to say. My voice is coming to

you through car speakers for the stereo system. If you want to stop or to take a break after any trial (pass through the construction area), don't hesitate to tell me.

Do you have any questions?

I will repeat the task once more. (pause 2 seconds) Your task is to drive at the speed I tell you until you reach the lighted construction zone. Once you start to drive through the construction work zone you may adjust your speed to whatever is comfortable, i.e., how you would normally drive under these circumstances. You are to keep driving until I ask you to stop, which will be a few seconds after you have left the lighted zone.

COMMONLY ASKED QUESTIONS:

How will I know how fast I'm going?

How will I know when I am in the construction zone?

How will I know how fast I'm supposed to be driving?

OBJECTIVE OF INSTRUCTIONS:

The instructions are meant to get participants to enter each zone condition at exactly the speed specified but then to drive in a manner similar to how they would if they were driving through a construction zone at night. The assumption is that these instructions will encourage the drivers to alter their speed to feel comfortable driving through the different zone environments. Two responses might occur: they slow down in order to compensate for discomfort or they accelerate to drive through the zone as quickly as possible in order to reduce the discomfort caused by the lights. If no discomfort is caused by the lights, drivers should reach a constant speed by the end of each trial and provide a favorable response on the comfort rating scale.

APPENDIX E.

Post-Session Questionnaire

Date: _____

Participant No. _____

1) When you were driving in the construction zone was it difficult to stay within the lane?

Yes / No

Comment: _____

2) Was it difficult to maintain a safe speed?

Yes / No

Comment: _____

3) Two colors of lights were used in the construction zone (red and green). Did either of the colors make you feel like changing speeds? Please circle that you consider the appropriate answer.

a) The RED lights made me feel like driving FASTER/ NO CHANGE / SLOWER.

Why? _____

b) The GREEN lights made me feel like driving FASTER / NO CHANGE / SLOWER.

Why? _____

4) Were there any scenes that made you feel unusually compelled to change your driving speed? Yes / No

If "yes" please indicate which direction you wanted to change your speed and describe the scenes (comment on the color of the lights, whether or not the lights appeared to move, and how fast you were traveling when you entered the construction zone).

- 5) Were there any scenes that made you feel unusually uncomfortable or ill?
Yes / No

If "yes" please describe the scenes (comment on the color of the lights, whether or not the lights appeared to move, and how fast you were traveling when you entered the construction zone).

- 6) If you had to categorize your driving habits, how would you categorize yourself in terms of driving on a road with good driving conditions, if the speed limit was 55 mph?
- | | |
|--|--|
| <input type="checkbox"/> I would average about 45 mph. | <input type="checkbox"/> I would average about 60 mph. |
| <input type="checkbox"/> I would average about 50 mph. | <input type="checkbox"/> I would average about 65 mph. |
| <input type="checkbox"/> I would average about 55 mph. | <input type="checkbox"/> I would average more than 65 mph. |

- 7) Do you have any other comments, observations, suggestions or improvements concerning this study?

THANK YOU FOR YOUR PARTICIPATION

APPENDIX F.

Order of Experimental Conditions

LIGHT GUIDANCE CONDITIONS

Light pulses

A = backwards- pulse speed = (pulse value = 1, speed = 118 ft/sec) -80mph

W = forwards - pulse speed = (pulse value = 0, speed = 118ft/sec) +80mph

Zero = zero - no pulse speed (pulse value = 0, speed = 1 ft/sec) 0

Color:

Red

Green

White - catch trial

No lights - control condition

Entry speeds:

Fast - 70 mph

Slow - 40 mph

Control trials:

Three controls will be used.

Trial 1: entry speed will be 40 mph
no lights on

Trial 8: entry speed will be 40 mph
white lights on

Trial 15: entry speed will be 40 mph
no lights on

GROUP : _____

sub	ctrl 1	2	3	4	5	6	7	ctrl 8	9	1
	c	S 3	F 4	S 1	F 2	S 11	S 5	c.	F 12	S
	c	S 7	F 10	F 8	F 6	S 9	F 12	c	S 5	S 1
	c	F 12	S 1	F 2	S 3	S 5	F 6	c	S 7	F
	c	F 10	S 9	S 11	F 8	F 4	S 7	c	F 6	S
	c	F 4	S 5	F 2	S 7	F 8	S 9	c	F 10	S 1
	c	S 3	F 6	F 12	S 1	S 11	F 10	c	S 9	F
	c	S 5	F 10	S 7	F 8	F 6	S 3	c	S 9	F
	c	S 1	S 11	F 4	F 12	F 2	S 9	c	S 3	F
	c	F 6	S 7	F 4	S 1	S 11	F 2	c	S 3	S
	c	S 9	F 10	F 12	F 8	S 5	S 3	c	F 2	S 1
	c	F 2	S 7	F 12	S 9	S 11	F 4	c	S 1	F 1
	c	S 5	F 6	S 3	F 8	F 10	S 1	c	F 4	S 1

1 b r s	2 b r f	3 b g s	4 b g f
5 f r s	6 f r f	7 f g s	8 f g f
9 stat r s	10 stat r f	11 stat g s	12 stat g f

b=backwards, f=forwards, stat=stationary, r=red, g=green, s=slow entry (40 mph) f=fast entry (70 mph)

LIGHT GUIDANCE EXPERIMENTS

NEW PARTICIPANT FILES

In the last LGD2 the participant files were labeled in the following way:

-e9 -s12 -t1 e-experiment, s-subject, t-trial

If possible for LGD3 the following name should be used:

-e3 -tf1 -t1 tf - teen female
 tm - teen male
 yf - young female
 ym - young male
 ef - elderly female
 em - elderly male

A participant file was set up as s999, to be used for setting up the experiment or demonstration purposes.

Once the changes have been made for one complete set of participants, then the files must be copied 5 times and renamed for the other participant groups.

Previously there were 14 trials for each participant. This time there will be 15.

The first and last control conditions have been changed. (see previous page for notes).

A third control condition has been placed in the middle of all the trials, trial 8. (see previous page for notes)

This means that the trial numbers in the file will need to be changed after trial 8, as this extra trial has been squeezed in.

Changes have been made to the speed of the lights. They have been changed so that they will be going at + and - 80 mph (118 ft/sec).

The counter balancing of all trials between participants remains the same.

APPENDIX G.

LGD3 Computer Protocol

* **Remember before scheduling participants to book Dexter (the blue, Iris-class Silicon Graphics computer) and the simulator testing area on the lab sign-up sheets.**

This protocol contains three sections: Before the participant arrives, running a participant, and treatment of data after participant leaves.

Before the Participant Arrives:

1. **Switching on the projector.**

Above the trunk of the car is the projector. The power switch is in the top right corner of the panel of buttons. To turn the system on, press and hold the button for about a second.

Find the remote control and adjust the brightness, color, contrast, and source to

brightness	1
color	5.5
contrast	4
source	slot 0, input 2

2. **Experimental conditions.**

The table of experimental conditions should be checked and a participant number assigned. Remember to write the participant number on the sheets to be completed by each participant.

3. **Initializing and starting the simulation software.**

Assuming all hardware and software are working properly, go to the proper subdirectory and execute the program according to the parameters identified.

```
cd /usr/driving/src/display  
pwd  
display -e9 -s12 -t1      (where e=experiment, s=subject, t=trial)
```

(for practice setup or demonstration use subject number 999, i.e., -s999)

It is useful to have two monitors active so while data are being collected at one workstation it is possible to see if the data are being stored properly at the other.

(the old keyboard required the break key to be pressed 3 times)

```
cd usr/driving  
cd usr/driving/data
```

```
ls -l e9s26.tdf
ls -l e9s26*odf
```

If a list of files are shown it suggest that the subject number has already been used. Check with other experimenters before using this number since its use may cause overwriting of someone else's data. Meanwhile, use another subject number. Don't forget to communicate with other experimenters about the use of this subject number because it should be either correctly logged in the record of participants or the data files should be purged from the system to conserve hard disk space.

Check the data files after each trial. Verify that the correct amount of data were stored in the data file and that the trial number is correct. (In the past, if "n" was pressed for too long the system would skip a trial.)

ctrl t to start a trial. Once this has been done data collection begins. No further instructions to the computer should be given after this point since data are being recorded.

ctrl n to stop a trial. This concludes the trial and data collection. It also changes the environment. NOTE: If you do not want to overwrite the next trial, as in the case of repeating a missed trial, do not use ctrl n to end a trial but instead use ctrl l to quit.

ctrl q to quit a trial. This will quit a trial and escape from the world. If this is done while running a participant the trial will be abandoned.

To repeat a trial, start the trial with **-e9 -s29 - tx** with the appropriate numbers added for the trial to be repeated.

4. **Verify That Everything is Ready for the Participant to Arrive.**

In addition to having hardware and software ready, make certain that all session procedures are understood, especially the order of treatment conditions, all forms are ready for the participant to read and complete, and comfort items are available (e.g., mineral water, cold water, soda, paper cups, parking permits, money, receipt book, comfortable chairs and table in waiting area with magazines and research articles to peruse,). Take the time to be prepared! Since participants are so difficult to obtain, especially older ones, be prepared to repeat trials as is necessary to salvage the session. Usually it is better to compromise the exact order of treatments by disregarding a bad trial and replacing it with a good one rather than including the bad data in analyses or having to omit all of the participants data. A rest break and some mineral water may allow a participant to complete the session rather than terminating their participation. Refine the way you treat the participants and be prepared to make adjustments in the procedures to get the data needed without compromising quality or integrity of the design, experiment, or lab. Be prepared for equipment and participant breakdown -- practice recovery procedures..... What will you do in a variety of scenarios. Practice, practice, practice ...

Running a Participant:

1. Ensure that participant forms have the correct participant number.
2. Greet participant, take coats etc., seat them at the participants' waiting area.
3. Ask them to complete the informed consent form and ensure that it is signed and dated.
4. Ask them to complete the general questionnaire.
5. Direct the participant to the car and ask them to sit in the driver's seat.
6. Instruct them to adjust the seat to make themselves comfortable.
7. Mention to them the intercom system, especially the microphone and speakers in the car.
8. Explain to them that you are in the very next room running the computers and using the intercom to communicate with them.
9. **Remember to switch OFF the lights in the simulator room as you leave.**
10. Once in the computer room speak with the participant and make intercom amplifier adjustments so that (s)he can hear you and you can hear them.
11. Again verify that the participant is comfortable before reading the standard instructions.
12. Read the instructions from the standard text.
13. Ask the participant if (s)he is ready to begin driving.
14. Enter **ctrl t** to initiate the trial
15. Ask the participant to start driving.
16. Provide feedback on speed prior to the zone to get entry speed within 5 mph of the designated velocity (i.e., 40 ± 5 mph or $70 \pm$ mph depending on the treatment). If entry is outside this range the trial should be repeated, but participants are not aware of the limits of this entry window.
17. Once the participant has exited the work zone wait 10 seconds and then say the trial is complete. Waiting 10 seconds should permit a sufficient amount of data to be recorded after the light zone.
18. Enter **ctrl n** to end the trial and load software for the next trial.

19. Explain the 1-10 comfort rating scale.

- 1 -- You felt very uncomfortable. You felt the lights effected your driving in a negative way.
- 5 -- Neutral response. You felt the lights had no effect on your comfort or the way you were driving.
- 10 -- You felt very comfortable when driving through the light zone. You felt it improved your driving performance.

On subsequent trials, participants need only be reminded that 1 is uncomfortable, 5 is neutral, and 10 is very comfortable.

20. Record the participant's comfort rating. Accept only one value (1-10) for how they felt while driving through the zone. Do not accept statements like "somewhere between 3 and 4." Record their response on the experimental condition table.

21. Check the data file: **ls -l e9s26*.odf** (or relevant numbers). Make certain that data files contain a reasonable amount of data and that no trials were skipped. If zero data were collected or the trial number doesn't match the experiment sheet then an error has occurred. It is important to run each participant in the assigned order of treatments, but on rare occasions something can go wrong. When it does, repeat the trial, or otherwise correct the situation, and notify Dr. V. of the event. Make a separate listing of all irregular occurrences like this so they can be so noted in the method section of the technical report and manuscripts for publication. Again, make careful notation of the exact trial numbers, what happened, what you did to correct or improve things, and whatever other information you feel is relevant and present your information to the principal investigator (Dr. V.) for feedback and advice.

At the end of a trial, it is possible to re-run the missed or inappropriate trial. Ask the participant to stay in the car while the system restarts.

Enter **display -e9 -s26 -tx** (where x = the trial number missed)

Run the condition again. After the trial has been completed press **ctrl q** to quit.

Should the results indicate sequence effects are present in the experiment it is very important that the order of treatments are adequately counterbalanced across participants. It is likely that with 40 participants the counterbalancing should wash-out sequence effects for the sample. Contact Dr. V. for more information. Meanwhile, if a retest is necessary, please try to do it immediately rather than at the end of the session.

If the order of experimental treatments is disrupted for one participant early in the experiment it is possible to adjust the orders of seven other yet untested individuals to keep the counterbalance schedule intact. Basically eight participants are needed to balance

a given order of treatments: within groups each order of conditions has a mirror opposite order (forward and backward) and there are four groups of participants (young male, young female, old male, old female). Alterations of the order later in the experiment will require additional analyses to determine if the action was detrimental.

22. Check the experimental condition sheet for the next trial condition. Inform the participant of the next condition. Either "The next condition requires a fast entry of the zone, so you must drive at 70 mph" or "The next condition requires a slow entry of the zone, so you must drive at 40 mph." Providing fast/slow and 70/40 mph in the instruction serves to provide redundancy for the participant and keeps the experimenter in check by the participant. For instance, if, because you are tired or whatever, you say fast condition at 40 mph, the participant might question your intent. For the 70 mph, remind the participant that it is necessary to accelerate quickly to reach the required speed before entering the zone.
23. Enter **ctrl t** to set the trial ready for the participant.
24. Inform the participant that they may begin driving.
25. Repeat steps 17 through 24 except for trial 8 which is the midpoint of data collection and has its own instructions (see #26).
26. For trial 8, the middle trial, remind participants of their task: "As we are now half way through the trials I would like to remind you to enter the work zone at the speed I ask but once in the zone you should drive in a manner that is comfortable." If it appears that the participant questions their usefulness, a statement of "You have been doing a good job so far" may encourage them to complete the session. However, non-relevant statements should be avoided in the simulator as statements could affect motivation in a non-uniform way to systematically affect driving and ratings. Generally, stick to the text and avoid impulses to make statements that reinforce or motivate.
27. For trial 15, the last trial, when the participant exits the work zone, count 15 seconds and ask for the comfort rating. Warn that you are about to end the last trial and that the screen will get very bright. Ask them to close their eyes while you press **ctrl n**.
28. Tell the participant to stay in the car until you put on some room lights.
29. Check to see if the participant is feeling okay -- ask if they would like a glass of water, soda, coffee, tea, etc. Let them talk to you freely about their experience, but do not comment in a way that might influence their responses to the next questionnaire.
30. Ask the participant to complete the post-session questionnaire. On completion of this form, debrief the participant and listen to (record if appropriate) their comments. For older participants, allow an extra 15-20 minutes in order to make the interchange enjoyable and not just a rushed experiment. It is especially important at this time to make

the volunteers know that you are grateful for their having "participated" in the collection of data for this research. Whatever you promise in follow-up debriefing is your responsibility to make happen. For instance, all promised reports and reprints must be mailed by you personally. Remember, seldom do elderly individuals volunteer to do research for the money. Usually it is for the sense of involvement and social networking. Each older volunteer may represent 10 more that are indirectly connected to them. If they find the experience gratifying, their friends will want to come when your current participant returns for a subsequent study. On the other hand, if they don't enjoy the experience, it is unlikely they or their friends will come to the lab. If you are working with older participants for the first time, see Dr. V's treatise on implied reciprocity in the recruitment of older participants and the development of a volunteer pool of older individuals.

31. Thank the participant for helping with the research and give them their payment. Don't forget to have them sign the receipt for our record of payment.
32. Escort older participants to their car or wherever they are going on campus. Escort younger participants at least to the door. Remember that liability for the participant's safety and well-being may be yours while traveling to, doing, and returning from the testing session. Don't forget to get the parking permit if they have one.

Treatment of Data After Participant Leaves:

1. Code/enter all subjective data for this session in the appropriate data files
2. Finish all record keeping and file forms in their proper locations.
3. Run UNIX summary statistics and graphics utility programs on the raw data, print out summary output, and save summary output as an append to the master file (SGI and IBM formats). It is important that, automatically if possible, before a participant leaves the lab the experimenter has an opportunity to examine the data gathered, retest if necessary, and maybe even share the results during the post-session debriefing. An individual graphics plot of the 15 trials should be automatically routed to the laser printer along with essential summary statistics. Even if all data, software, and hardware were destroyed, with these two sheets of paper on each participant tested, it is possible to complete the research and publish the findings. Don't underestimate the importance of post-testing treatment of the data.
4. Back up regularly all raw and summary data to Bernoulli cartridges. There should always be at least four copies of the data: (1) on the SGI, (2) on the SGI backup Bernoulli, (3) on the SGI archive Bernoulli cartridge that is not kept in the lab, and (4) on the Bernoulli cartridge that is specifically reserved for the experiment.

APPENDIX H.

Listing of Participants' Verbal Comments

This is a list of comments made by the participants during the study. The list is not inclusive, the experimenter wrote down comments and noted the trial in which they were given.

Younger Females

1. I'm going backwards (with green lights at 70 mph)

Older Females

1. Would you like me to drive on the road?
2. I'm going backwards! (at this point the participant was flooring the accelerator) (with green at 70 mph trial 12)
3. The lights were okay. I just couldn't slow the car down. It's not the speed that feels unsafe its the steering (against green at 70 mph trial 6).
4. Are the gray bits shoulder or concrete? (against red 70 mph trial 9).
5. I wouldn't normally be driving that fast. (with red 70 mph trial 3).
6. It was a wider road way. (zero green at 70 mph trial 4).
7. The lights help. (against red 40 mph trial 2).
8. I don't trust this wheel. (control trial 1).
9. I thought I could speed up without loosing it on that one. (zero red 40 mph trial 9).
10. Oh, I see. (After repeat instructions half way through study). (control trial 8).
11. And I'm suppose to go at my own speed when I get in? I haven't been doing that on the last couple of conditions. (against red 40 mph trial 14).
12. Gee, I am coming off the pedal. (When being asked to slow to 40 before entering the construction zone). (zero red 40 mph trial 10).

Older males

1. Steering felt different that time. (with green at 70 mph trial 6).

APPENDIX I.

Experimenters' Comments

Experimental instructions should have been given prior to leaving the participant in the car. This is especially true of older participants, as non-verbal communication is an important channel to determine if the instructions have been initially understood, and the degree of apprehension the participant may have to the task in general. The instructions were reiterated twice, however in practice they were given a third time, at the very beginning of the first trial. This was presented more as an example. Examples are very useful in instructions.

The design may not be suitable for drivers who are not comfortable with driving in the simulator from the onset. The software enforces that each condition follows simultaneously, the only way to repeat a trial is to reboot the system. This was necessary for some participants. When the experimenter is doing this it is important not to make the participant feel that s/he has failed at the task, and the repeats are necessary due to bad performance. Sometimes the experimenter blamed the repeats on her on mistakes, or equipment error. The experimenter needs to be prepared with a few phrases to console poor performance, patronizing comments do not work as they know what good driving performance is!

One participant actually came to a halt in the study.

Safety and statistics: We may find a significant difference in performance, however what is the effect on the other participants. Could the lights slow some drivers, but confuse and speed up a small number of drivers, and what are the consequence?

Did the participants understand the instructions? The instructions were repeated numerous times at the beginning of the study and once during the study, but still it was questionable how well the instructions had been comprehended. Listening to discussion afterwards made the experimenter aware that in some cases the instructions had not been clearly understood. For example one participant did not realize she had control over the car while she was in the construction zone. She thought it was on cruise control (yet at no time was this in the instructions!!).

It appeared that drivers who were approaching the specified speed continued to try to achieve it even though they were in the construction zone, i.e. continued to accelerate, or decelerate, especially if they were sharply trying to get to the target value (i.e., not traveling for a few seconds at around the target speed). On a few occasions the participant did ask something similar to "Have I reached the speed yet?", even though i was know longer reading out the speeds, such was the determination to achieve that objective.

Observations not seen in data: One older female participant in the first light condition (i.e. trial 2) hit the brakes hard before she got into the construction zone as she didn't want to go "whizzing" into the construction zone.

Natural deceleration. It is questionable as to whether participants felt comfortable with using the brake, as most appeared to use the accelerator to deal with the speed. The rate of deceleration therefore when entering the construction zone may be a function of the deceleration of the car rather than the participants' choice of speed.

For older drivers, especially females, was the behavior seen a function of the independent variables, or a function of the task of driving in a simulator?

APPENDIX J.
Participant Recruitment Poster and Map

Would you like to drive in our simulator?
... and get paid?

The **UMN Human Factors Research Laboratory** has been funded by the Center for Transportation Studies to conduct experiments on intelligent transportation systems, including the use of **collision warning devices and lights in construction zones.**

Researchers at the Human Factors Research Laboratory are looking for volunteers to participate in virtual reality driving experiments. All you have to do is come to our lab on the East bank campus (parking permit provided), and **drive in our simulator.** The study will take about 45 minutes to complete and you will receive **\$10** for your time.

Testing times are flexible to accommodate the busy schedule of the participants.

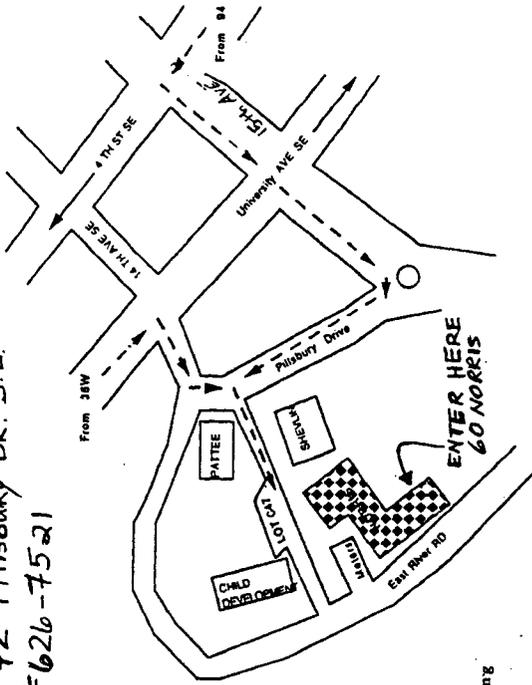
If you are interested please phone:

Gayna Williams

362-3660 Message machine

625-7884 Office hours

Human Factors Research Lab
 60 NORRIS HALL
 172 Pillsbury DR. S.E.
 #626-7521



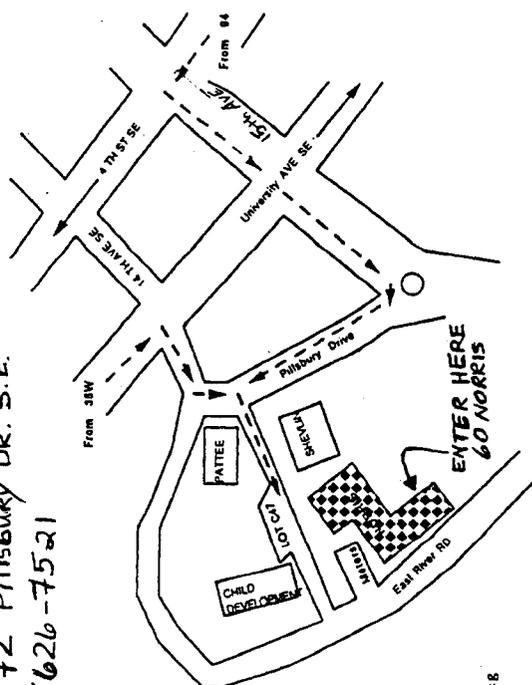
Parking

Coming From 94W:
 Take the U of M exit follow this road (Huron) until it curves left and becomes 4th ST. Take 4th ST until you reach 15th AVE. Co left. Take a right on Pillsbury Drive. Take a left into a narrow street. There should be a sign on the corner directing you to the Child Development Center. You will come to a small parking lot titled C47. Park between the signs as directed. In the event that there are no available spots, take a left onto East River RD. Take another left immediately into a small metered lot behind Norris Hall.

Coming From 35W:
 Take University/4th ST exit, go right on university. Take a right on 14th AVE. Take a left on Pillsbury Drive. Take the first right into a narrow street. There should be a sign on the corner directing you to the Child Development Center. You will come to a small parking lot titled C47. Park between the signs as directed. In the event that there are no available spots, take a left onto East River RD. Take another left immediately into a small metered lot behind Norris Hall.

We will provide a parking permit for lot C47.

Human Factors Research Lab
 60 NORRIS HALL
 172 Pillsbury DR. S.E.
 #626-7521



Parking

Coming From 94W:
 Take the U of M exit follow this road (Huron) until it curves left and becomes 4th ST. Take 4th ST until you reach 15th AVE. Co left. Take a right on Pillsbury Drive. Take a left into a narrow street. There should be a sign on the corner directing you to the Child Development Center. You will come to a small parking lot titled C47. Park between the signs as directed. In the event that there are no available spots, take a left onto East River RD. Take another left immediately into a small metered lot behind Norris Hall.

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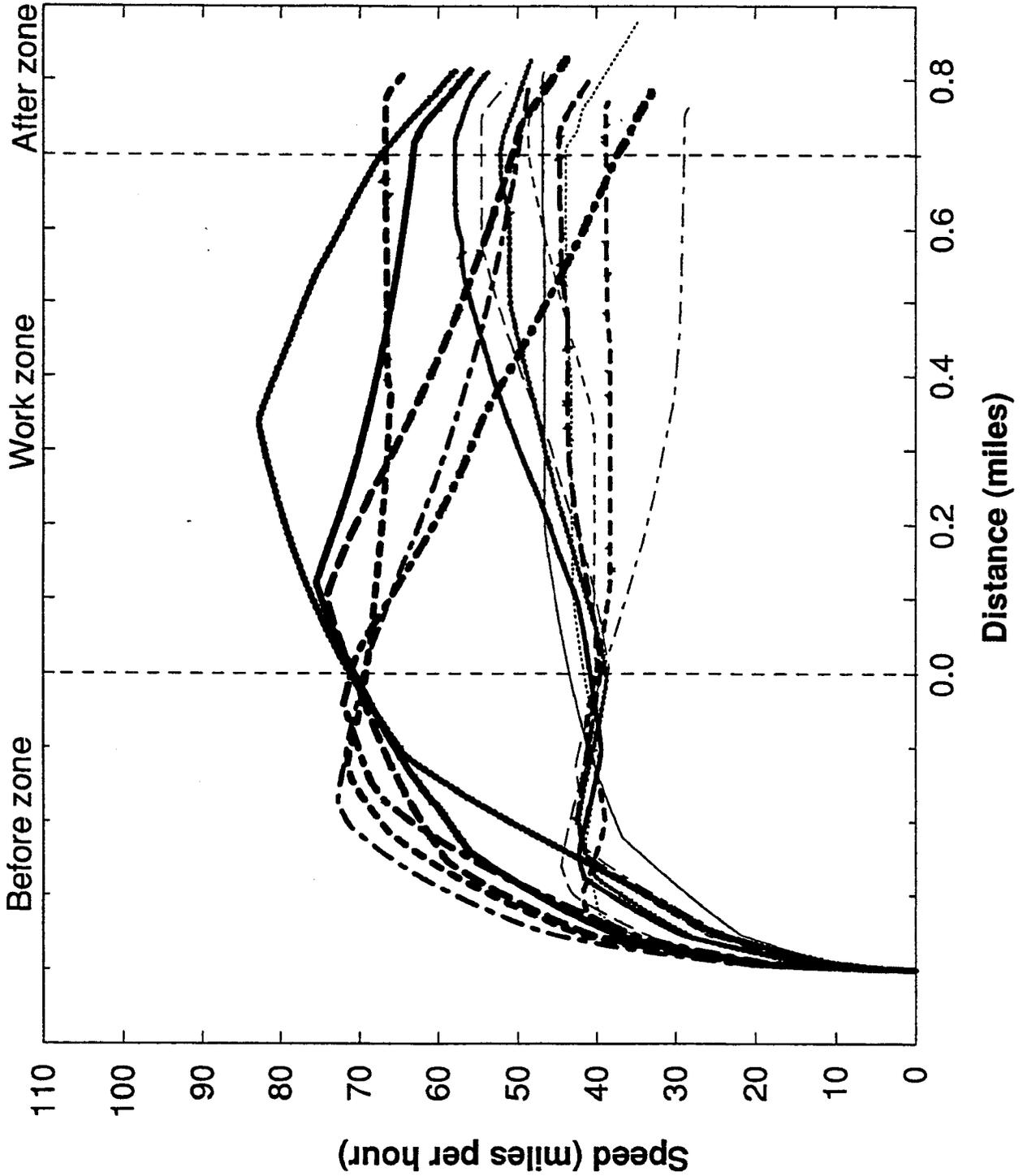
We will provide a parking permit for lot C47.

LGD Experiment 3 Subject: 1

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - 40; Green; Lt. stat (6)
- · 40; Green; Lt. fwd (14)
- · 40; Green; Lt. bwd (2)
- 40; Red; Lt. stat (10)
- ⋯ 40; Red; Lt. fwd (7)
- - 40; Red; Lt. bwd (4)
- · 40; White; Lt. stat (8)
- · 70; Green; Lt. stat (9)
- 70; Green; Lt. fwd (12)
- 70; Green; Lt. bwd (3)
- · 70; Red; Lt. stat (13)
- · 70; Red; Lt. fwd (11)
- · 70; Red; Lt. bwd (5)

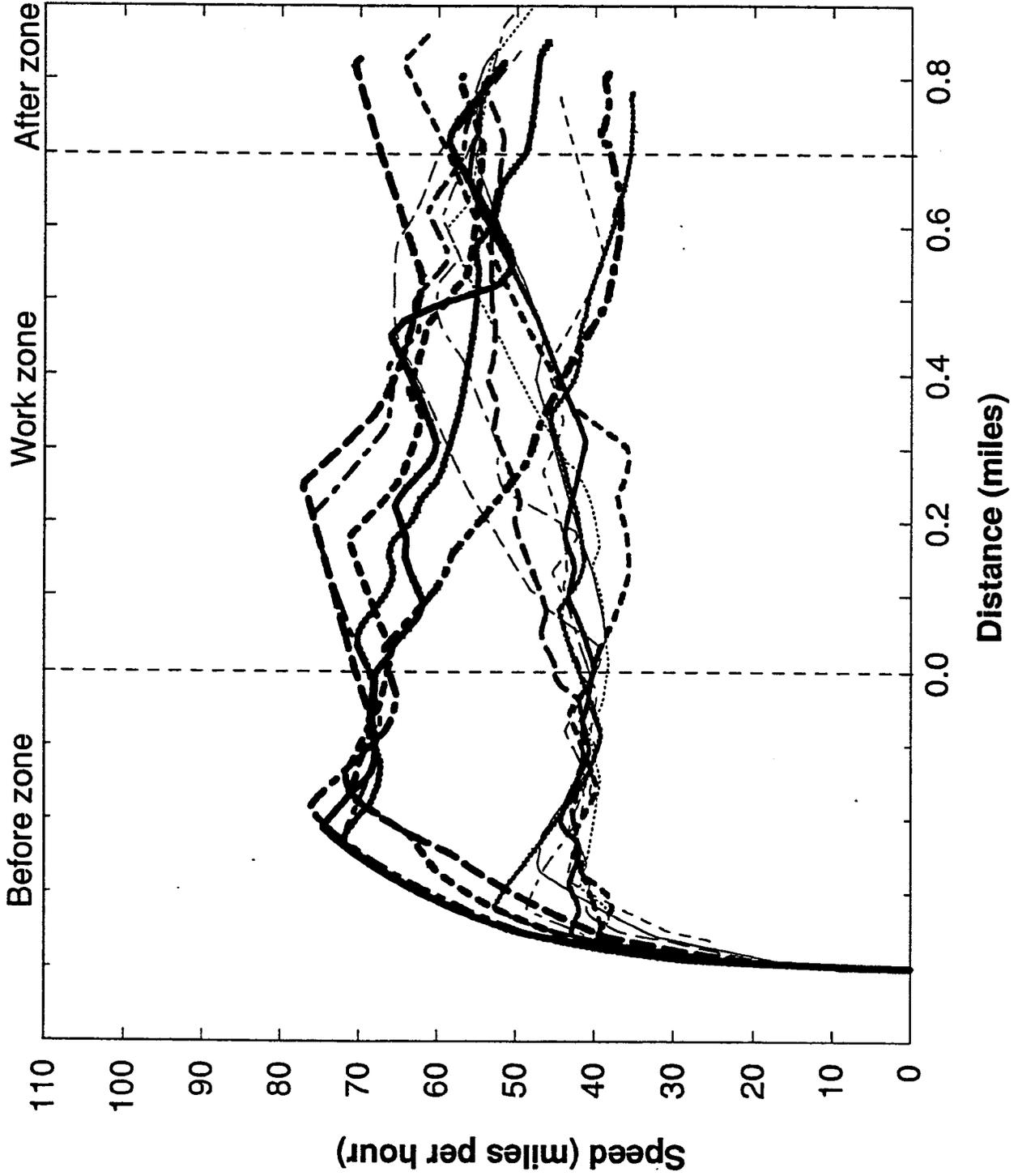
APPENDIX K.

Individual Responses



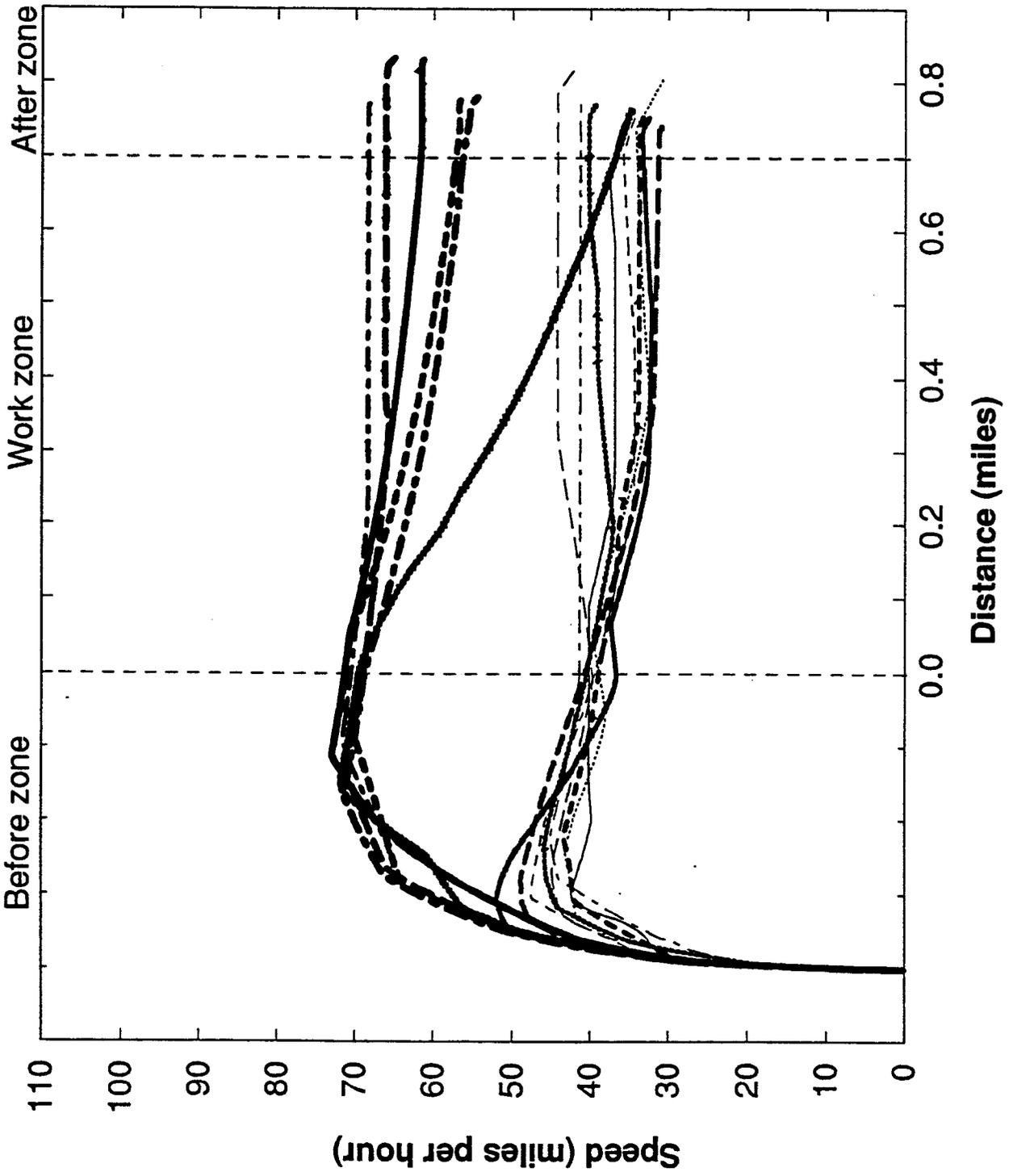
LGD Experiment 3 Subject: 2

- 40; No lights (1)
- 40; No lights (15)
- - - 40; Green; Lt. stat (10)
- - - 40; Green; Lt. fwd (2)
- - - 40; Green; Lt. bwd (14)
- 40; Red; Lt. stat (6)
- 40; Red; Lt. fwd (9)
- - - 40; Red; Lt. bwd (12)
- - - 40; White; Lt. stat (8)
- - - 70; Green; Lt. stat (7)
- 70; Green; Lt. fwd (4)
- 70; Green; Lt. bwd (13)
- - - 70; Red; Lt. stat (3)
- - - 70; Red; Lt. fwd (5)
- - - 70; Red; Lt. bwd (11)



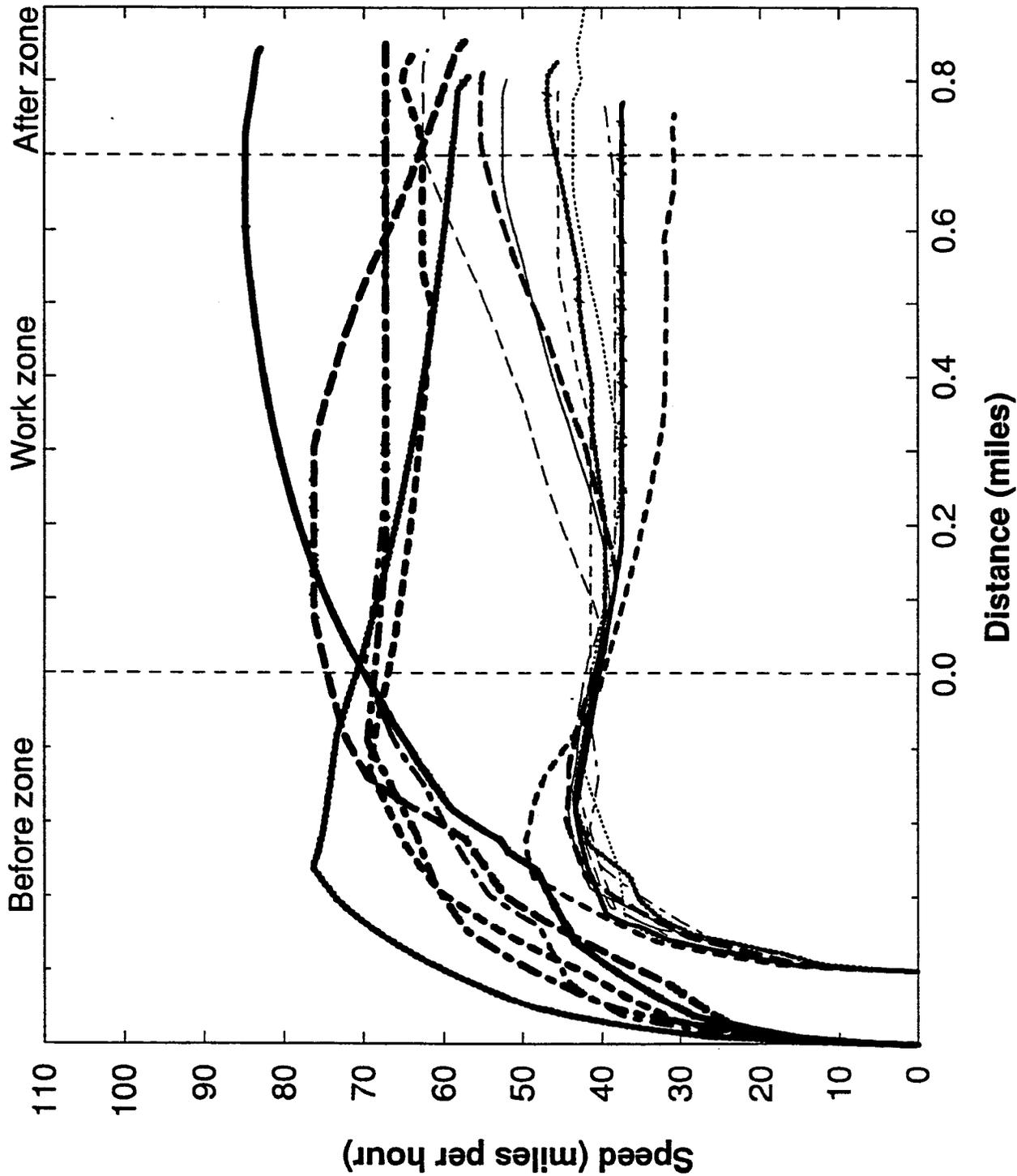
LGD Experiment 3 Subject: 3

- 40; No lights (1)
- 40; No lights (15)
- - - 40; Green; Lt. stat (12)
- - - 40; Green; Lt. fwd (9)
- - - 40; Green; Lt. bwd (5)
- 40; Red; Lt. stat (13)
- 40; Red; Lt. fwd (6)
- - - 40; Red; Lt. bwd (3)
- - - 40; White; Lt. stat (8)
- - - 70; Green; Lt. stat (2)
- 70; Green; Lt. fwd (11)
- 70; Green; Lt. bwd (10)
- - - 70; Red; Lt. stat (14)
- - - 70; Red; Lt. fwd (7)
- - - 70; Red; Lt. bwd (4)



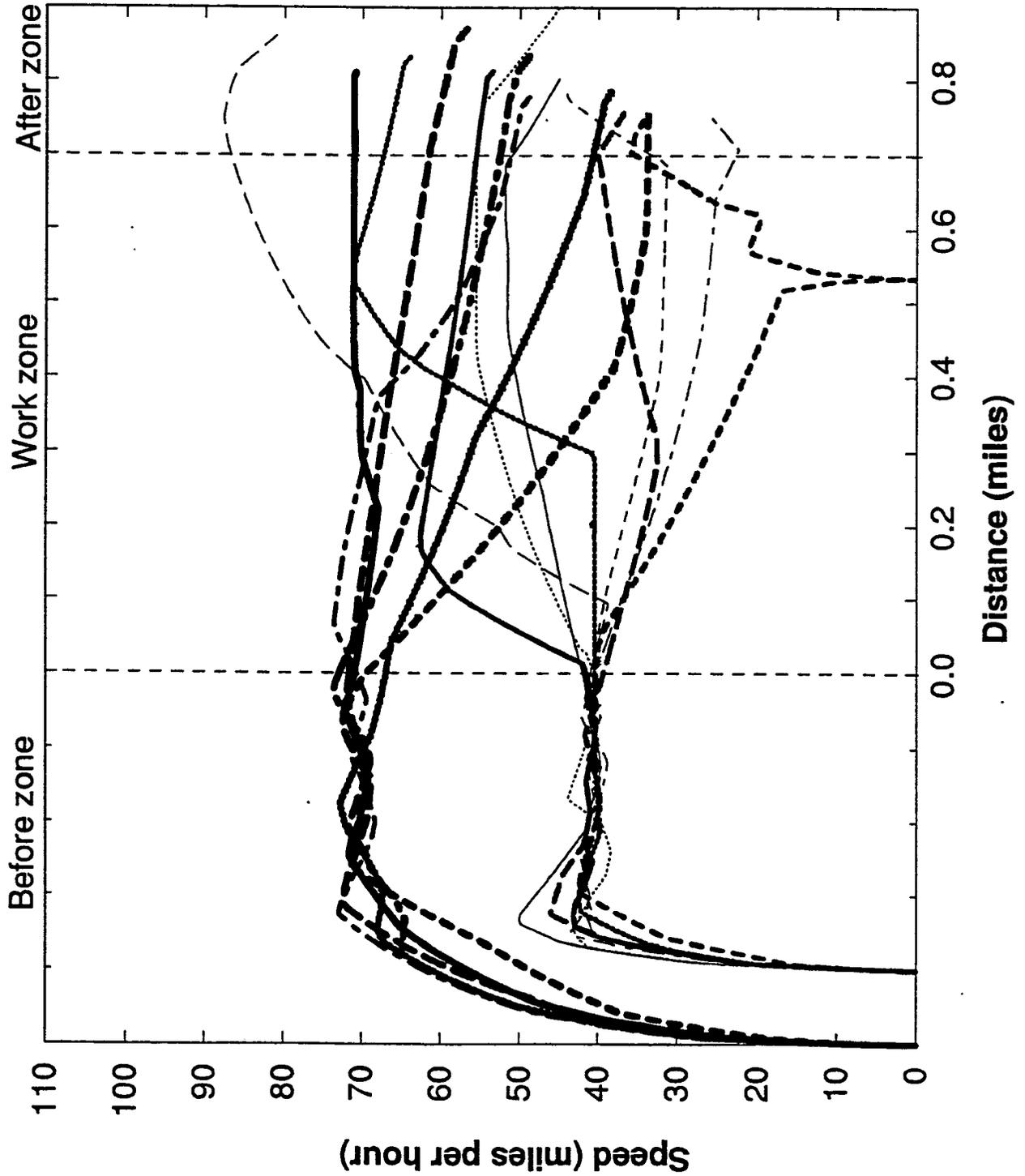
LGD Experiment 3 Subject: 4

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - - 40; Green; Lt. stat (4)
- · - 40; Green; Lt. fwd (7)
- · · 40; Green; Lt. bwd (11)
- 40; Red; Lt. stat (3)
- ⋯ 40; Red; Lt. fwd (10)
- - - 40; Red; Lt. bwd (13)
- · - 40; White; Lt. stat (8)
- · · 70; Green; Lt. stat (14)
- 70; Green; Lt. fwd (5)
- 70; Green; Lt. bwd (6)
- - - 70; Red; Lt. stat (2)
- · - 70; Red; Lt. fwd (9)
- · · 70; Red; Lt. bwd (12)



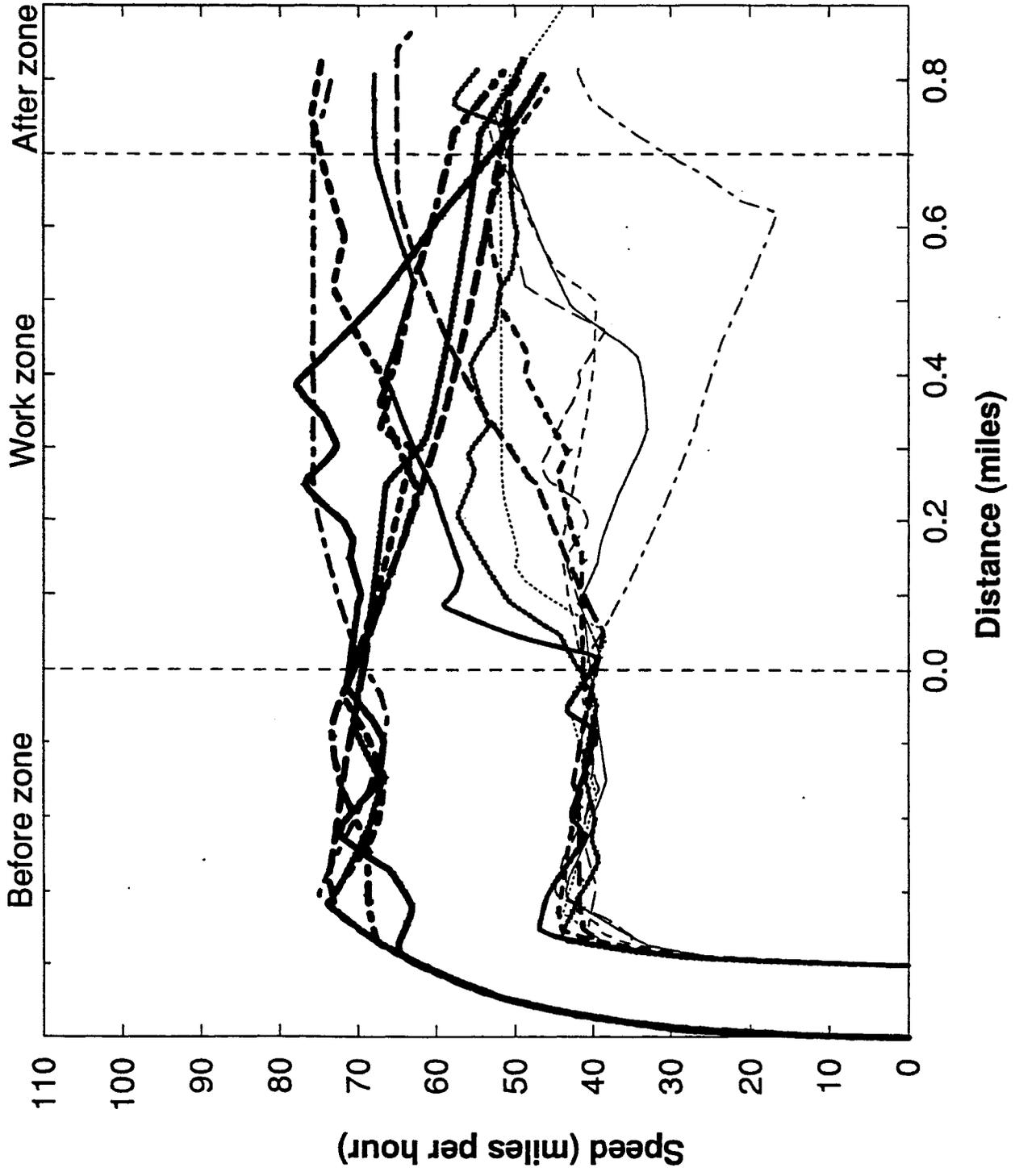
LGD Experiment 3 Subject: 5

- 40; No lights (1)
- 40; No lights (15)
- 40; Green; Lt. stat (10)
- 40; Green; Lt. fwd (5)
- 40; Green; Lt. bwd (14)
- 40; Red; Lt. stat (7)
- 40; Red; Lt. fwd (3)
- 40; Red; Lt. bwd (11)
- 40; White; Lt. stat (8)
- 70; Green; Lt. stat (12)
- 70; Green; Lt. fwd (6)
- 70; Green; Lt. bwd (2)
- 70; Red; Lt. stat (9)
- 70; Red; Lt. fwd (13)
- 70; Red; Lt. bwd (4)



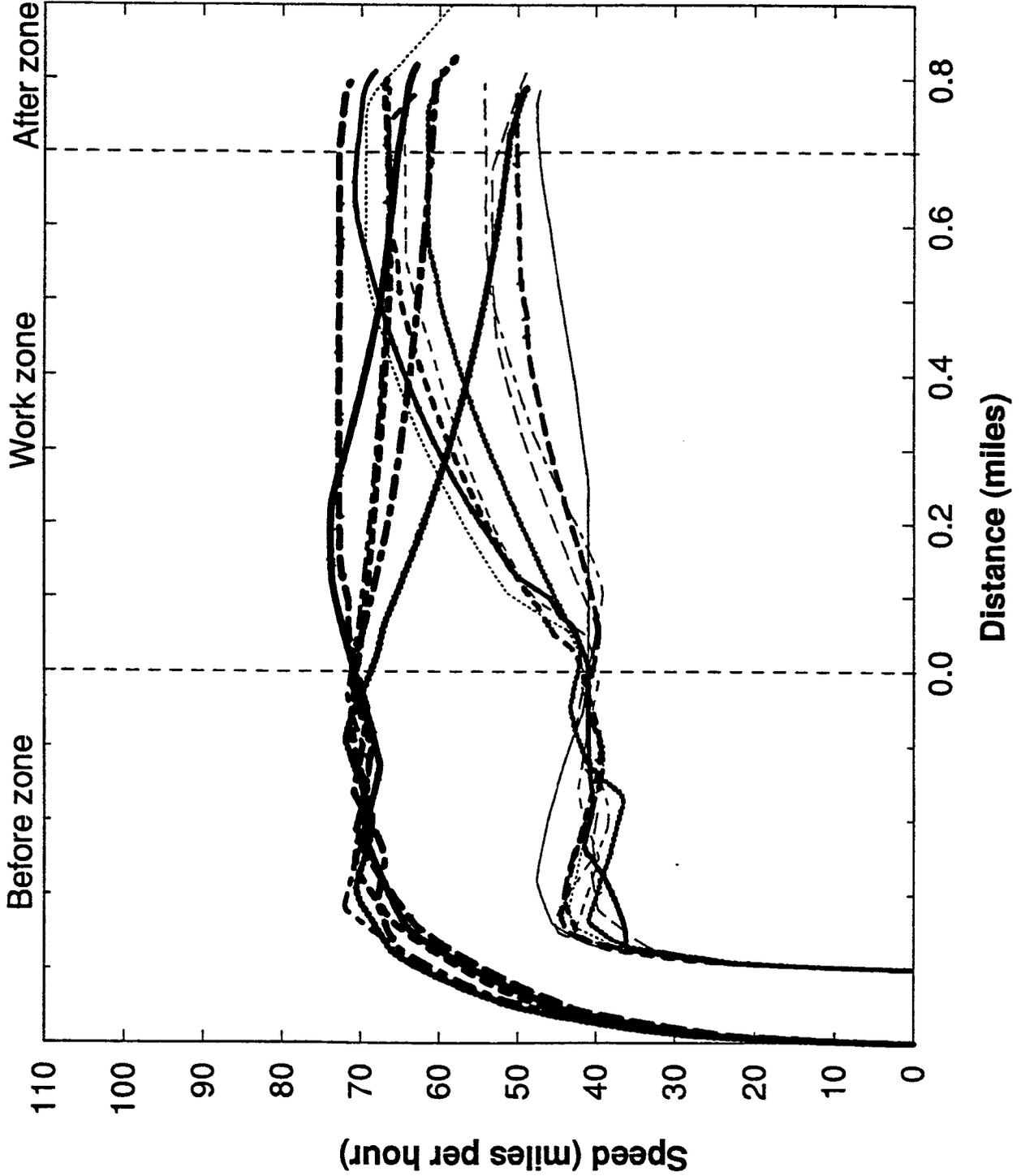
LGD Experiment 3 Subject: 6

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - 40; Green; Lt. stat (6)
- · 40; Green; Lt. fwd (11)
- · - 40; Green; Lt. bwd (2)
- 40; Red; Lt. stat (9)
- ⋯ 40; Red; Lt. fwd (13)
- - 40; Red; Lt. bwd (5)
- · 40; White; Lt. stat (8)
- · - 70; Green; Lt. stat (4)
- 70; Green; Lt. fwd (10)
- 70; Green; Lt. bwd (14)
- · - 70; Red; Lt. stat (7)
- · - 70; Red; Lt. fwd (3)
- · - 70; Red; Lt. bwd (12)



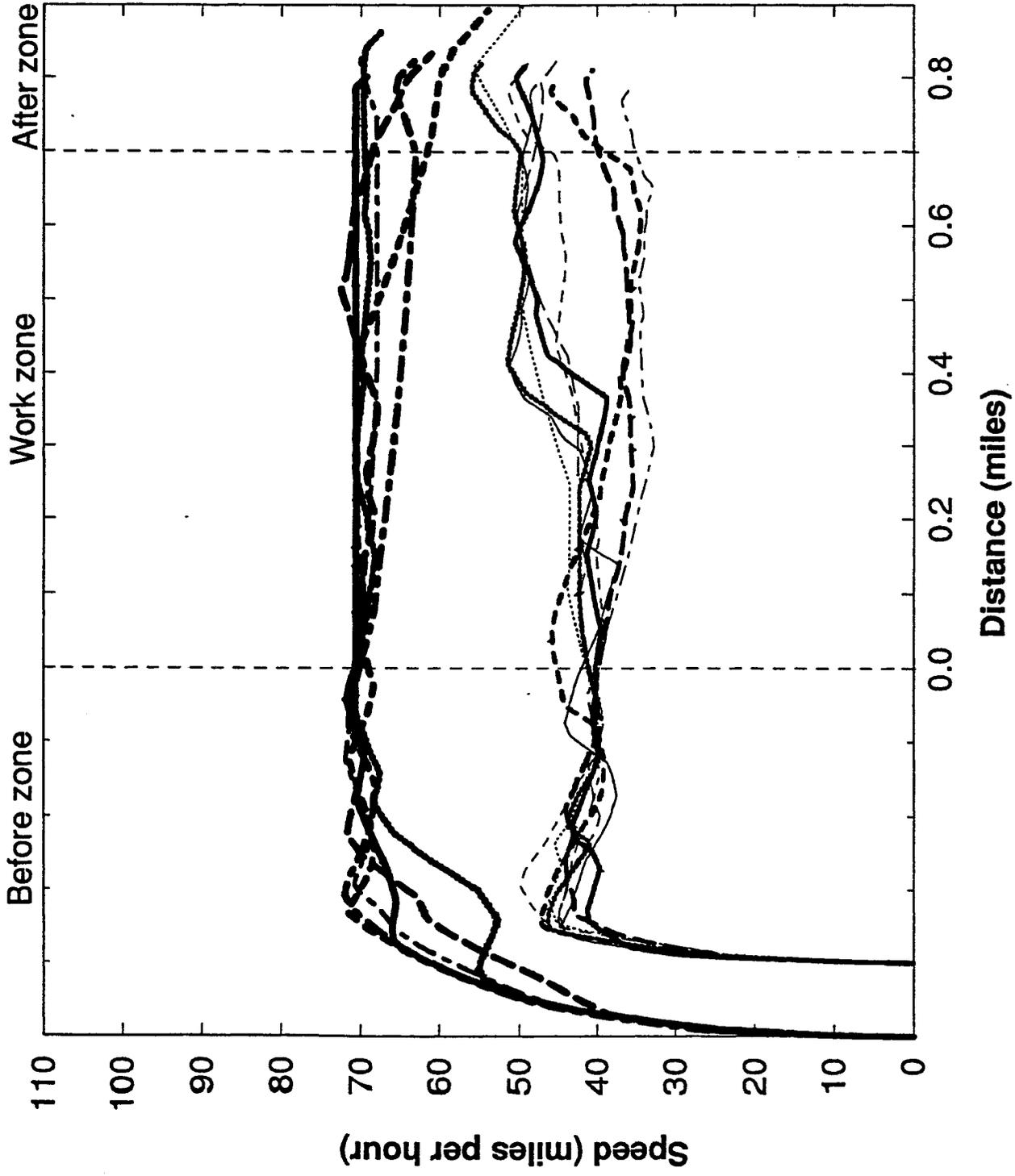
LGD Experiment 3 Subject: 7

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - 40; Green; Lt. stat (13)
- · - 40; Green; Lt. fwd (4)
- · · 40; Green; Lt. bwd (7)
- 40; Red; Lt. stat (9)
- · - 40; Red; Lt. fwd (2)
- · · 40; Red; Lt. bwd (14)
- - 40; White; Lt. stat (8)
- · - 70; Green; Lt. stat (11)
- · · 70; Green; Lt. fwd (5)
- 70; Green; Lt. bwd (12)
- · - 70; Red; Lt. stat (3)
- · · 70; Red; Lt. fwd (6)
- 70; Red; Lt. bwd (10)



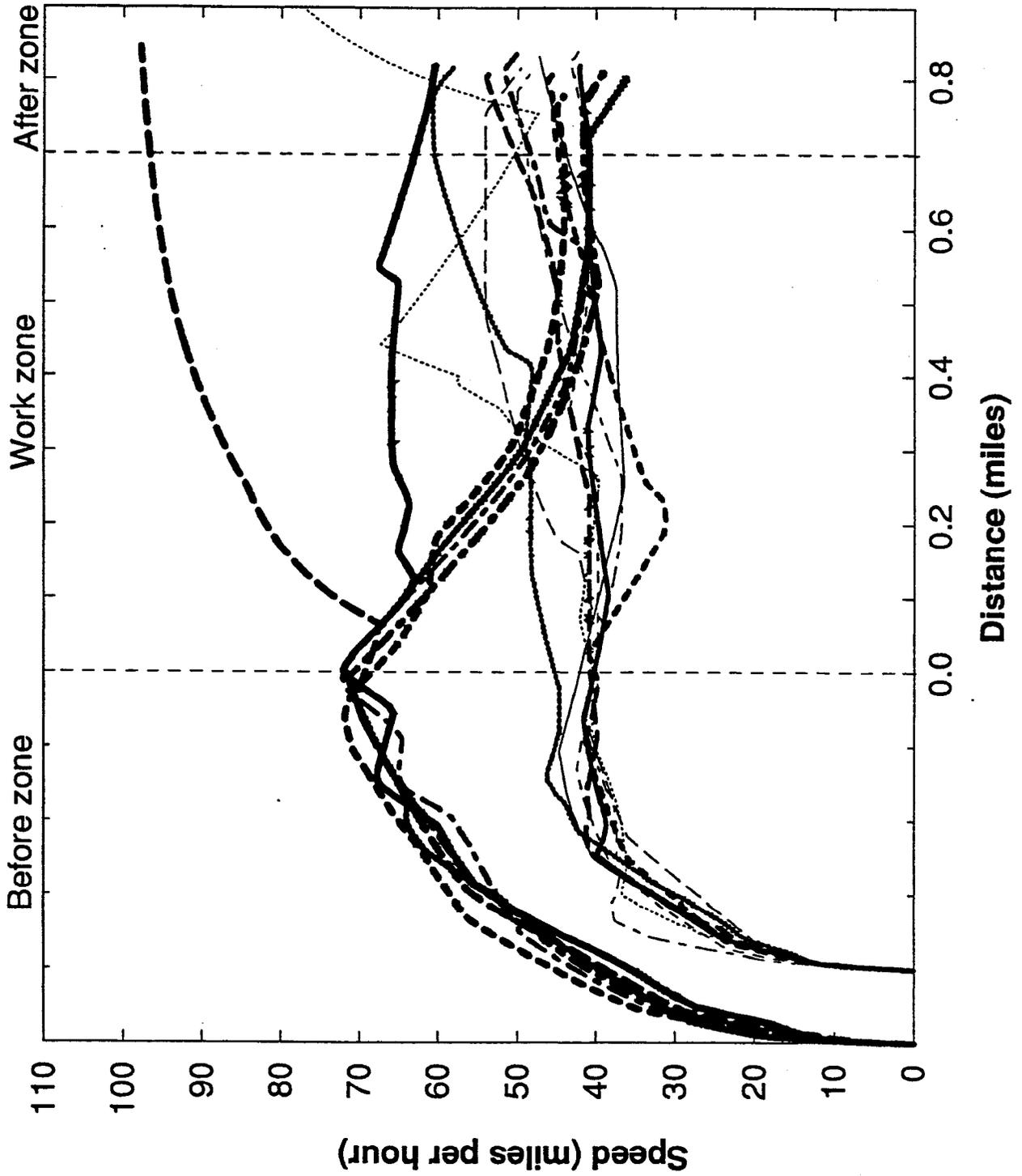
LGD Experiment 3 Subject: 8

- 40; No lights (1)
- 40; No lights (15)
- - - 40; Green; Lt. stat (3)
- - - 40; Green; Lt. fwd (12)
- - - 40; Green; Lt. bwd (9)
- 40; Red; Lt. stat (7)
- 40; Red; Lt. fwd (14)
- - - 40; Red; Lt. bwd (2)
- - - 40; White; Lt. stat (8)
- - - 70; Green; Lt. stat (5)
- 70; Green; Lt. fwd (11)
- 70; Green; Lt. bwd (4)
- - - 70; Red; Lt. stat (13)
- - - 70; Red; Lt. fwd (10)
- - - 70; Red; Lt. bwd (6)



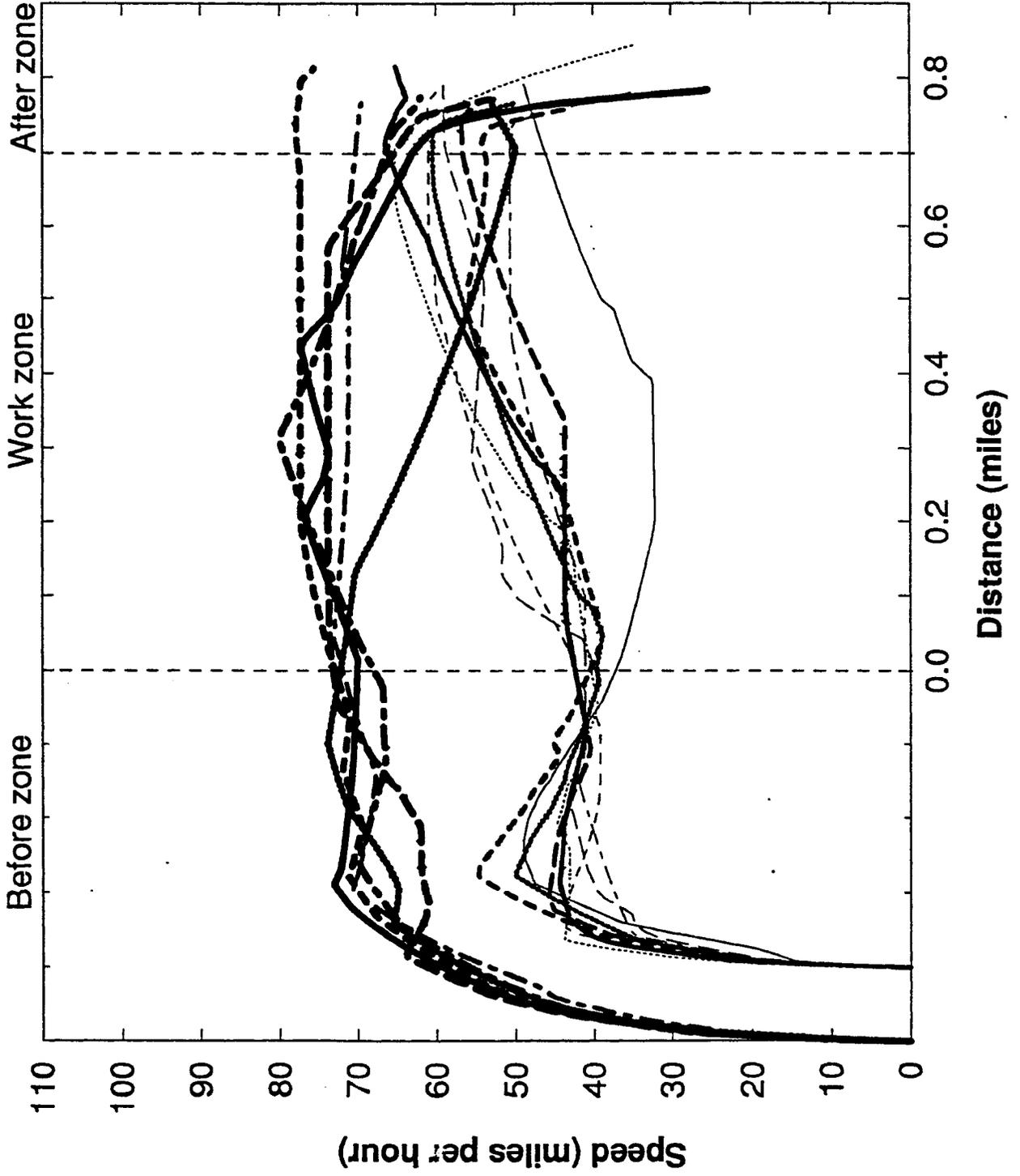
LGD Experiment 3 Subject: 10

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - 40; Green; Lt. stat (10)
- · - 40; Green; Lt. fwd (13)
- · · - 40; Green; Lt. bwd (7)
- 40; Red; Lt. stat (2)
- 40; Red; Lt. fwd (6)
- - 40; Red; Lt. bwd (11)
- · - 40; White; Lt. stat (8)
- · · - 70; Green; Lt. stat (4)
- 70; Green; Lt. fwd (5)
- 70; Green; Lt. bwd (12)
- · · - 70; Red; Lt. stat (3)
- · · - 70; Red; Lt. fwd (14)
- · · - 70; Red; Lt. bwd (9)



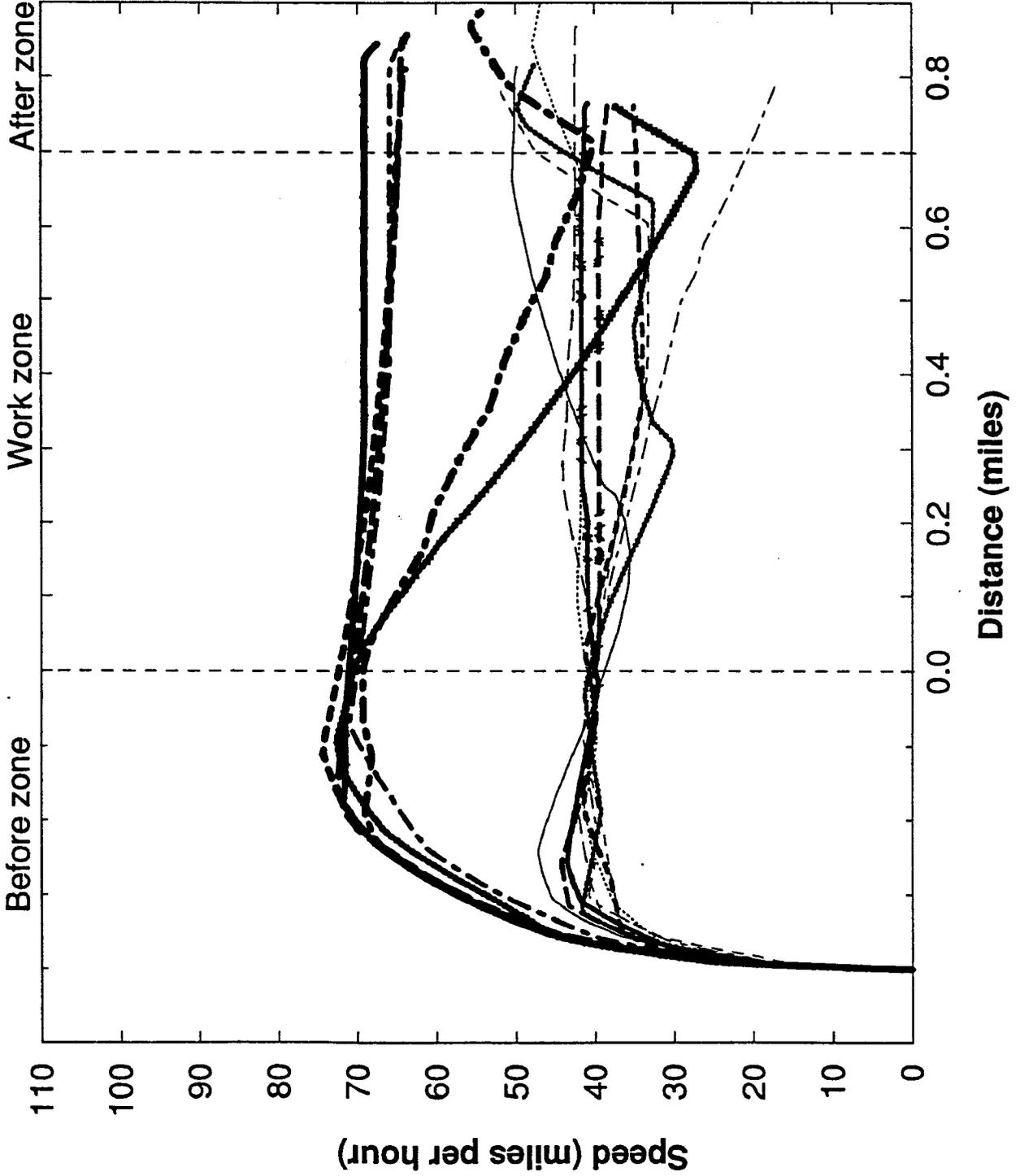
LGD Experiment 3 Subject: 11

- 40; No lights (1)
- 40; No lights (15)
- - - 40; Green; Lt. stat (6)
- - - 40; Green; Lt. fwd (3)
- - - 40; Green; Lt. bwd (12)
- 40; Red; Lt. stat (5)
- 40; Red; Lt. fwd (14)
- - - 40; Red; Lt. bwd (9)
- - - 40; White; Lt. stat (8)
- - - 70; Green; Lt. stat (4)
- 70; Green; Lt. fwd (11)
- 70; Green; Lt. bwd (7)
- - - 70; Red; Lt. stat (10)
- 70; Red; Lt. fwd (13)
- - - 70; Red; Lt. bwd (2)



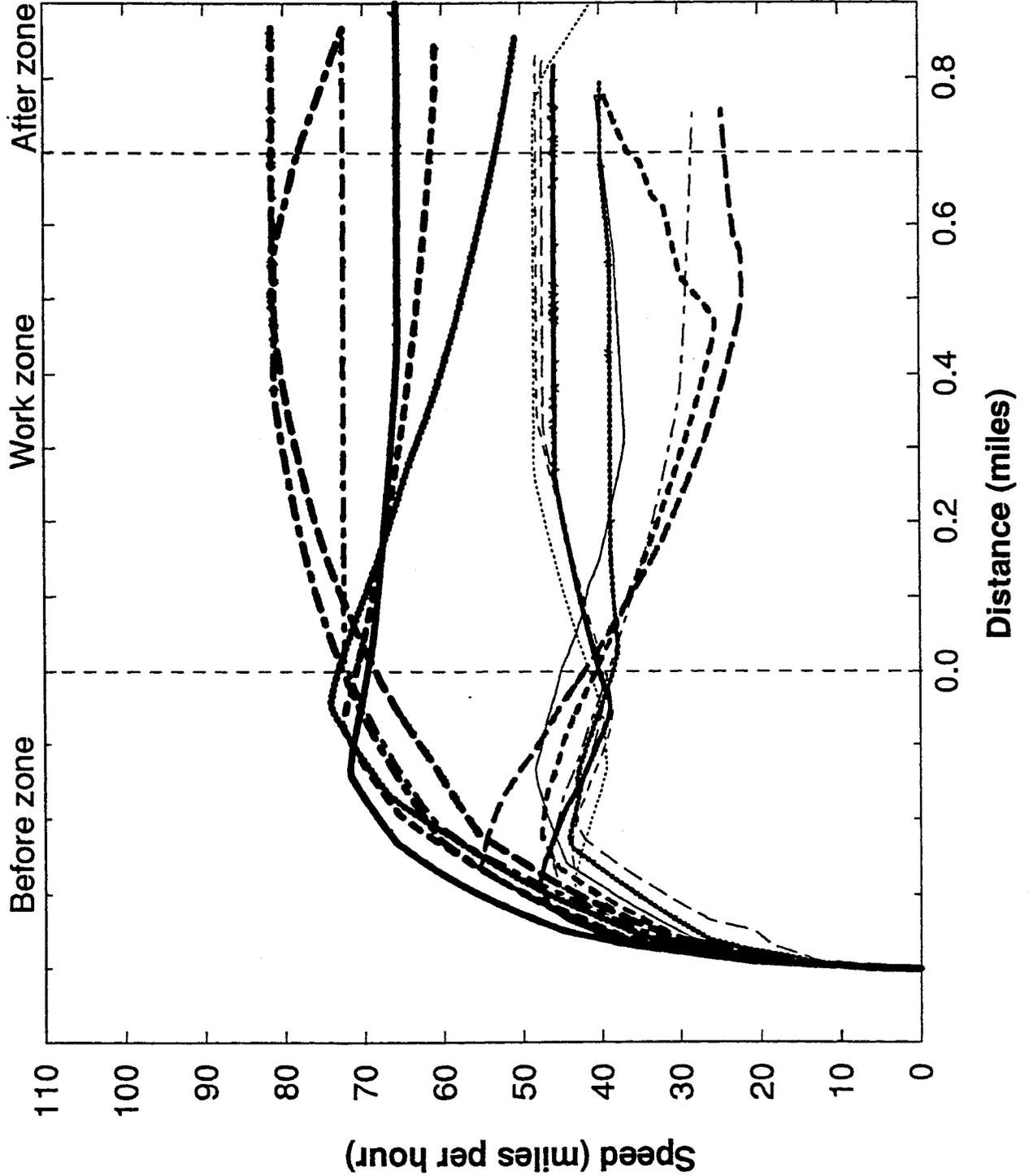
LGD Experiment 3 Subject: 14

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - 40; Green; Lt. stat (10)
- · 40; Green; Lt. fwd (2)
- · - 40; Green; Lt. bwd (14)
- 40; Red; Lt. stat (6)
- ⋯ 40; Red; Lt. fwd (9)
- - 40; Red; Lt. bwd (12)
- · 40; White; Lt. stat (8)
- · - 70; Green; Lt. stat (7)
- 70; Green; Lt. fwd (4)
- 70; Green; Lt. bwd (13)
- · - 70; Red; Lt. stat (3)
- · - 70; Red; Lt. fwd (5)
- · - 70; Red; Lt. bwd (11)



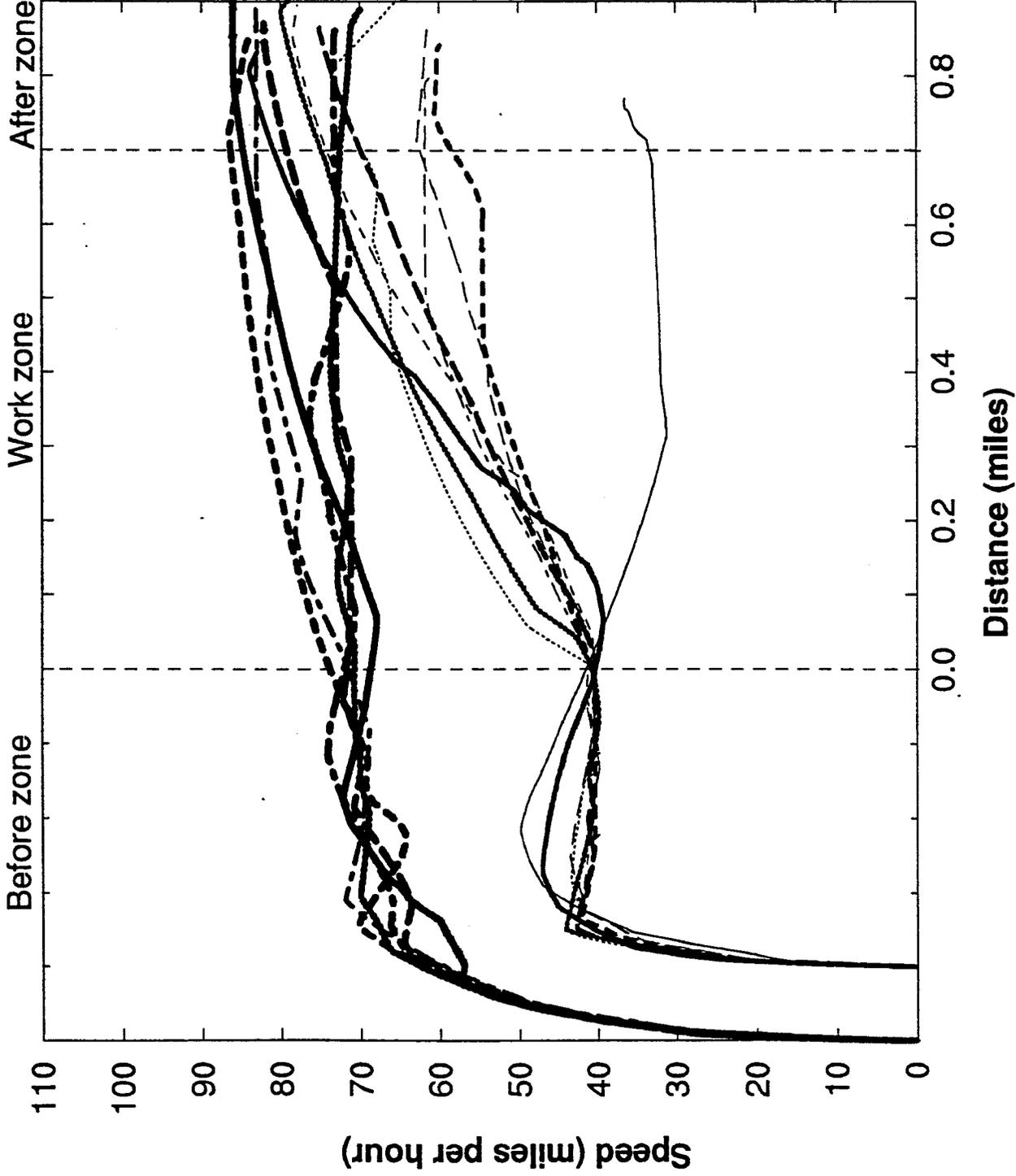
LGD Experiment 3 Subject: 15

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - - 40; Green; Lt. stat (12)
- · - 40; Green; Lt. fwd (9)
- · · 40; Green; Lt. bwd (5)
- 40; Red; Lt. stat (13)
- ⋯ 40; Red; Lt. fwd (6)
- - - 40; Red; Lt. bwd (3)
- · - 40; White; Lt. stat (8)
- · · 70; Green; Lt. stat (2)
- 70; Green; Lt. fwd (11)
- 70; Green; Lt. bwd (10)
- - - 70; Red; Lt. stat (14)
- · - 70; Red; Lt. fwd (7)
- · · 70; Red; Lt. bwd (4)



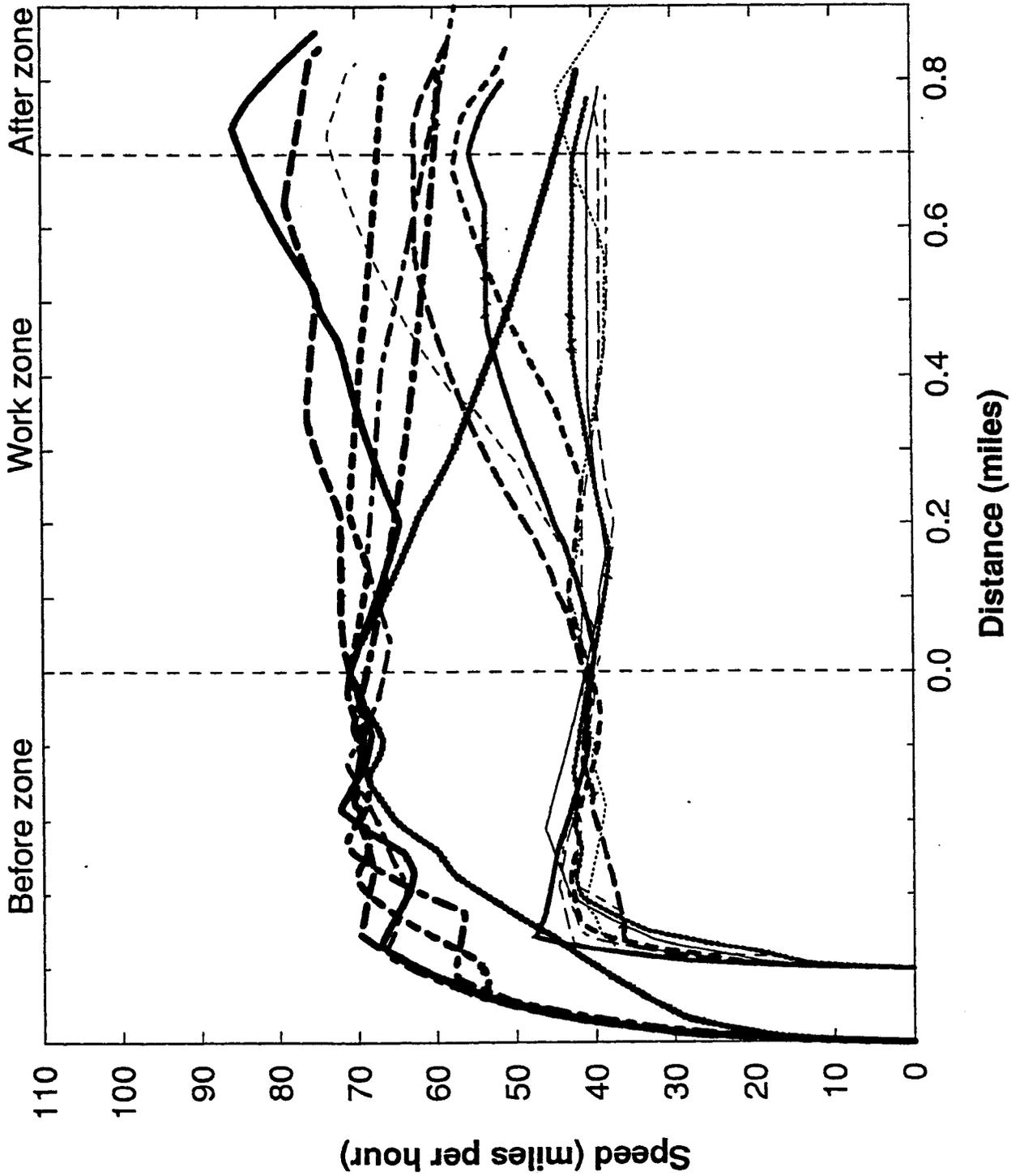
LGD Experiment 3 Subject: 16

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - 40; Green; Lt. stat (4)
- · - 40; Green; Lt. fwd (7)
- · · - 40; Green; Lt. bwd (11)
- 40; Red; Lt. stat (3)
- 40; Red; Lt. fwd (10)
- - 40; Red; Lt. bwd (13)
- · - 40; White; Lt. stat (8)
- · · - 70; Green; Lt. stat (14)
- 70; Green; Lt. fwd (5)
- 70; Green; Lt. bwd (6)
- - 70; Red; Lt. stat (2)
- · - 70; Red; Lt. fwd (9)
- · · - 70; Red; Lt. bwd (12)



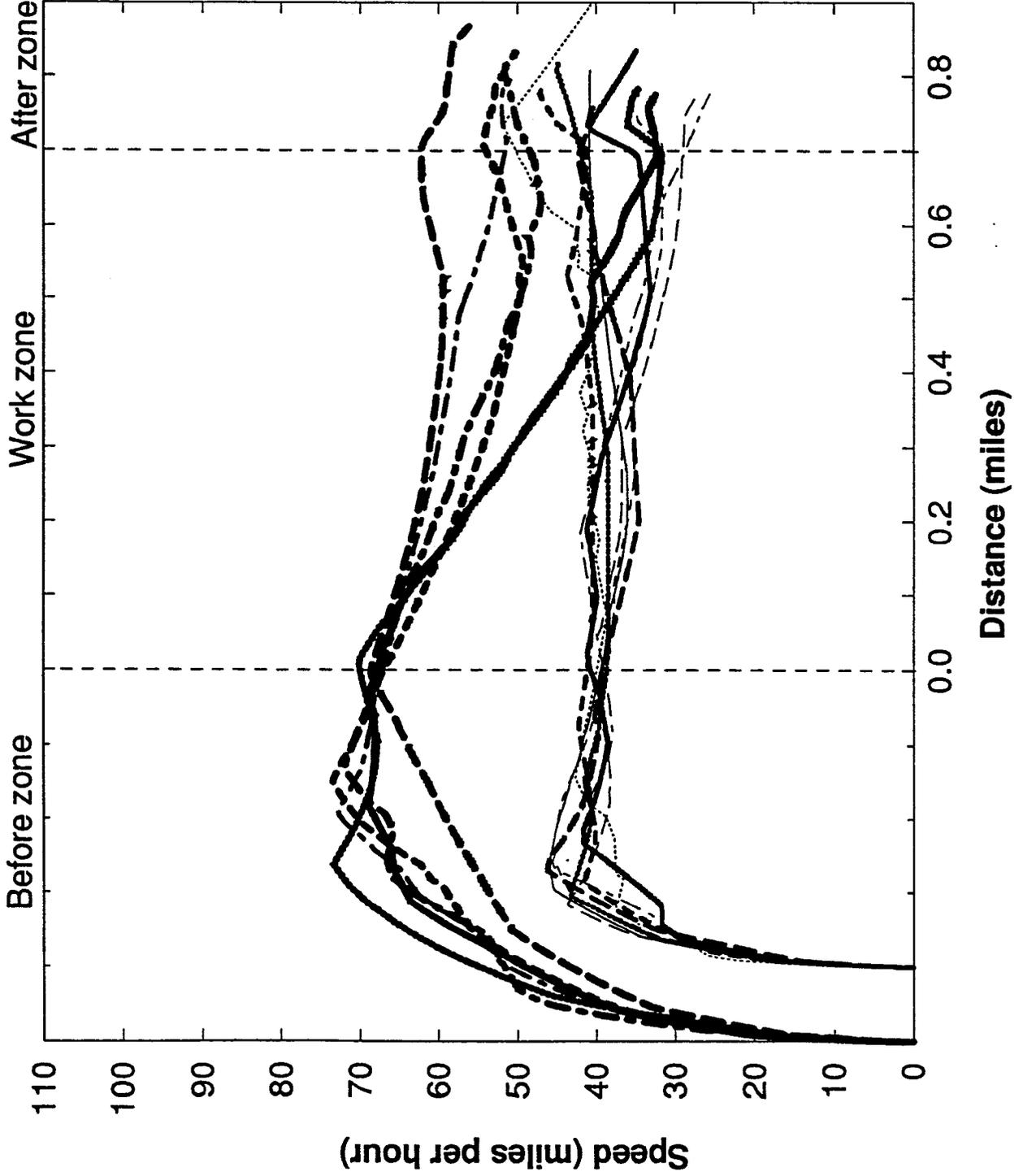
LGD Experiment 3 Subject: 17

- 40; No lights (1)
- 40; No lights (15)
- - - 40; Green; Lt. stat (10)
- - - 40; Green; Lt. fwd (5)
- - - 40; Green; Lt. bwd (14)
- 40; Red; Lt. stat (7)
- 40; Red; Lt. fwd (3)
- - - 40; Red; Lt. bwd (11)
- - - 40; White; Lt. stat (8)
- - - 70; Green; Lt. stat (12)
- 70; Green; Lt. fwd (6)
- 70; Green; Lt. bwd (2)
- - - 70; Red; Lt. stat (9)
- 70; Red; Lt. fwd (13)
- - - 70; Red; Lt. bwd (4)



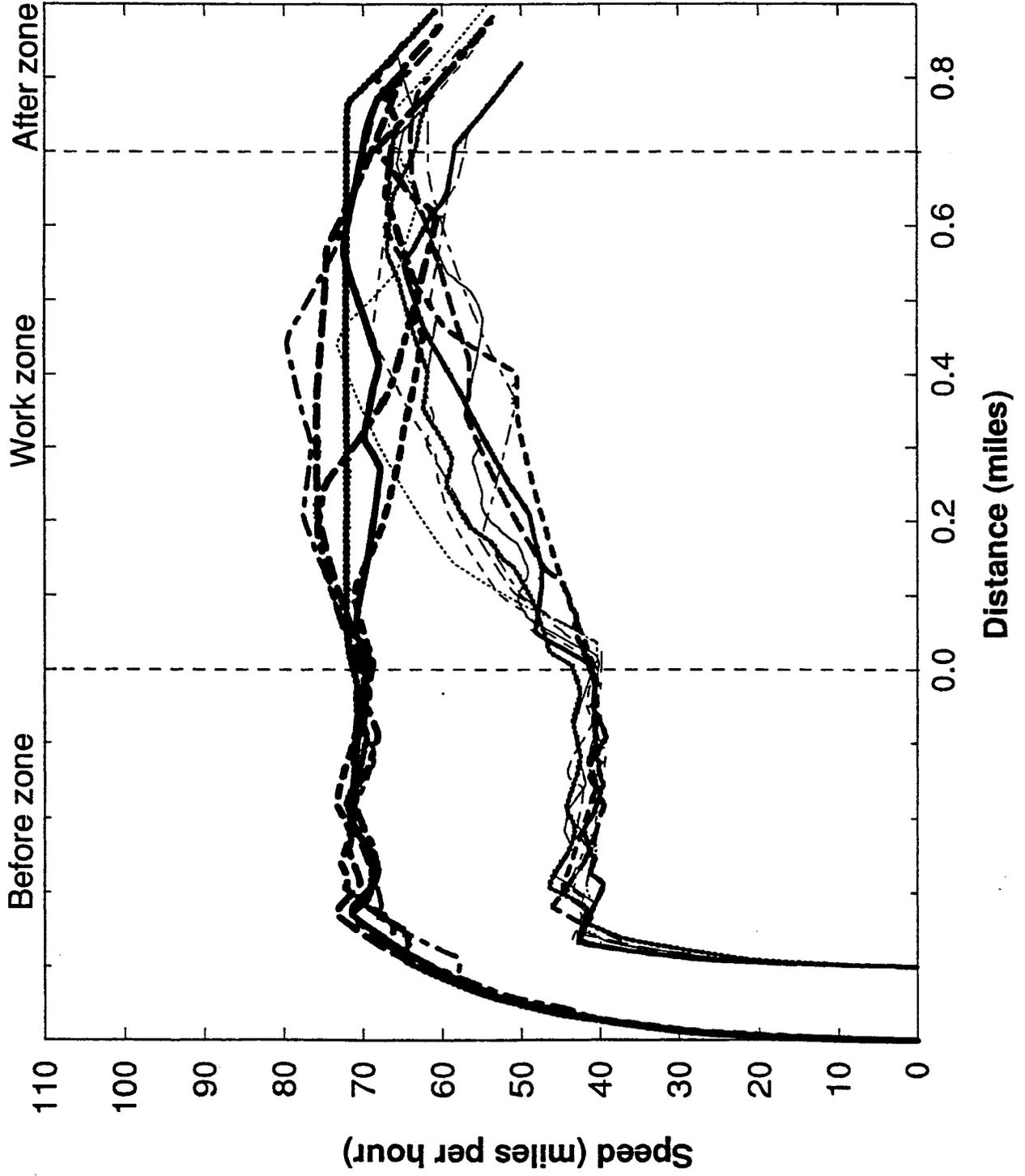
LGD Experiment 3 Subject: 18

- 40; No lights (1)
- 40; No lights (15)
- - - 40; Green; Lt. stat (6)
- · - 40; Green; Lt. fwd (11)
- · · 40; Green; Lt. bwd (2)
- 40; Red; Lt. stat (9)
- 40; Red; Lt. fwd (13)
- - - 40; Red; Lt. bwd (5)
- · - 40; White; Lt. stat (8)
- · · 70; Green; Lt. stat (4)
- 70; Green; Lt. fwd (10)
- 70; Green; Lt. bwd (14)
- · - 70; Red; Lt. stat (7)
- · · 70; Red; Lt. fwd (3)
- · · 70; Red; Lt. bwd (12)



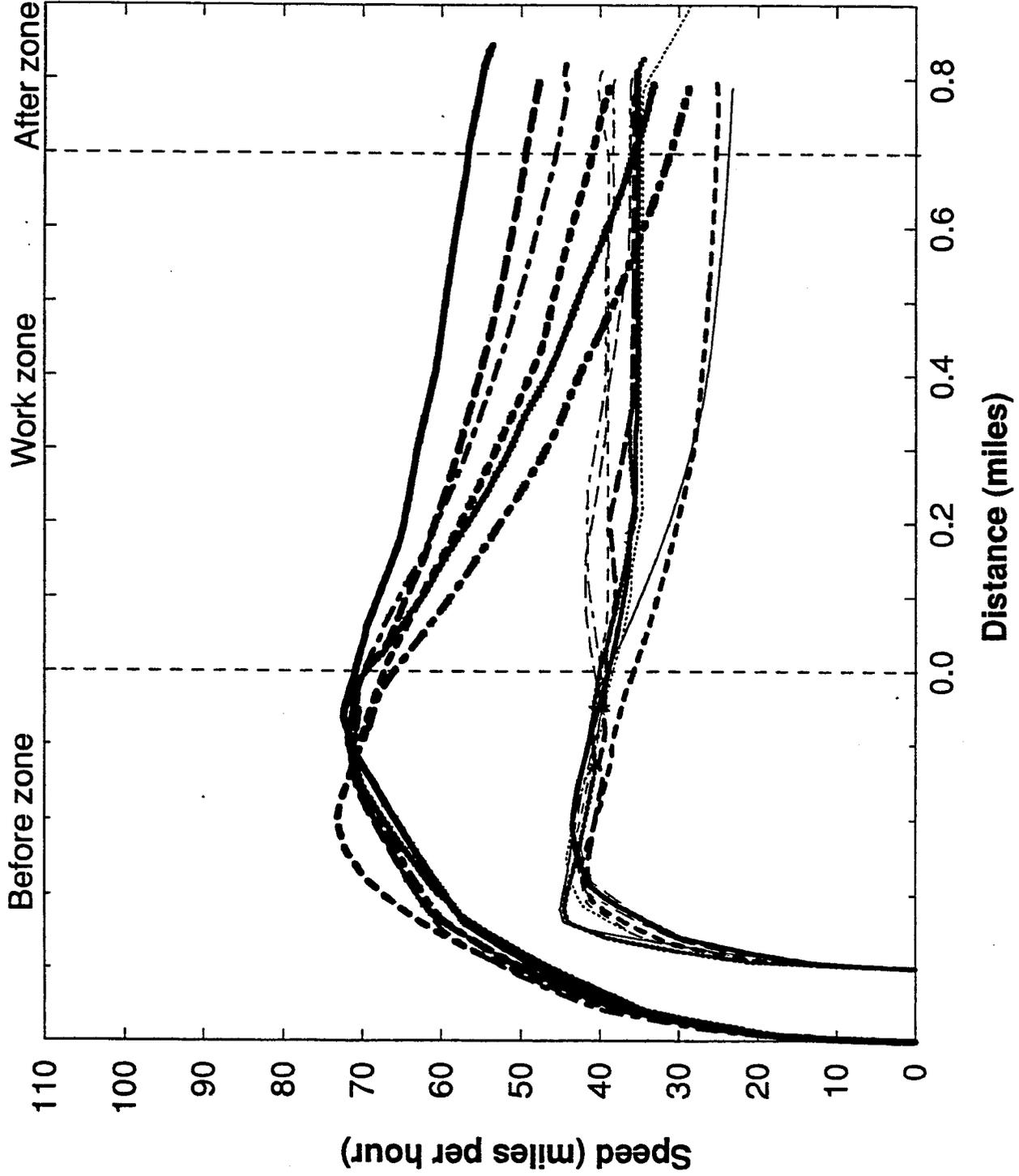
LGD Experiment 3 Subject: 19

- 40; No lights (1)
- 40; No lights (15)
- - - 40; Green; Lt. stat (13)
- - - 40; Green; Lt. fwd (4)
- - - 40; Green; Lt. bwd (7)
- 40; Red; Lt. stat (9)
- 40; Red; Lt. fwd (2)
- - - 40; Red; Lt. bwd (14)
- - - 40; White; Lt. stat (8)
- - - 70; Green; Lt. stat (11)
- 70; Green; Lt. fwd (5)
- 70; Green; Lt. bwd (12)
- - - 70; Red; Lt. stat (3)
- 70; Red; Lt. fwd (6)
- - - 70; Red; Lt. bwd (10)



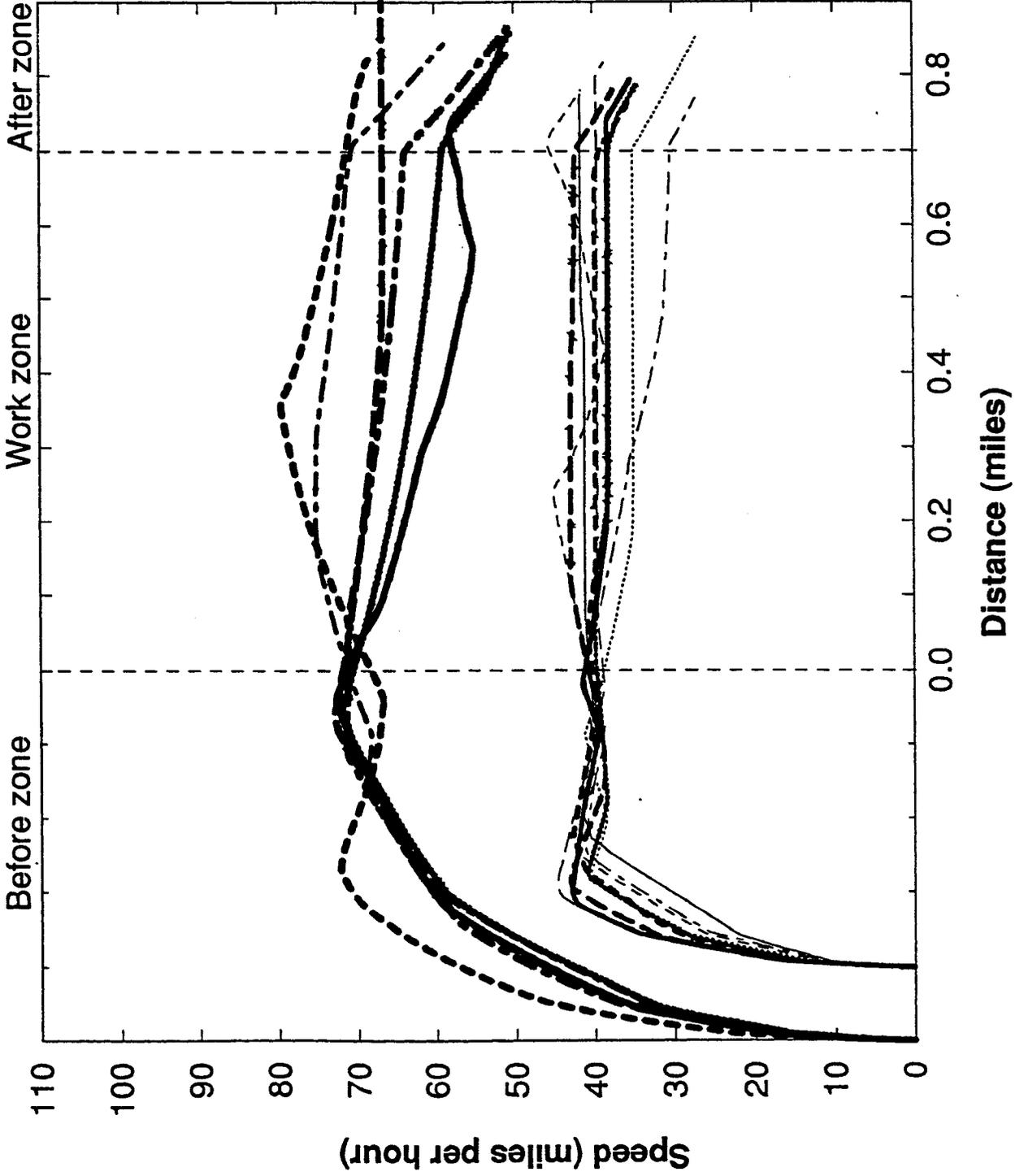
LGD Experiment 3 Subject: 20

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - - 40; Green; Lt. stat (3)
- · - 40; Green; Lt. fwd (12)
- · · 40; Green; Lt. bwd (9)
- 40; Red; Lt. stat (7)
- ⋯ 40; Red; Lt. fwd (14)
- - - 40; Red; Lt. bwd (2)
- · - 40; White; Lt. stat (8)
- · · 70; Green; Lt. stat (5)
- 70; Green; Lt. fwd (11)
- 70; Green; Lt. bwd (4)
- - - 70; Red; Lt. stat (13)
- · - 70; Red; Lt. fwd (10)
- · · 70; Red; Lt. bwd (6)



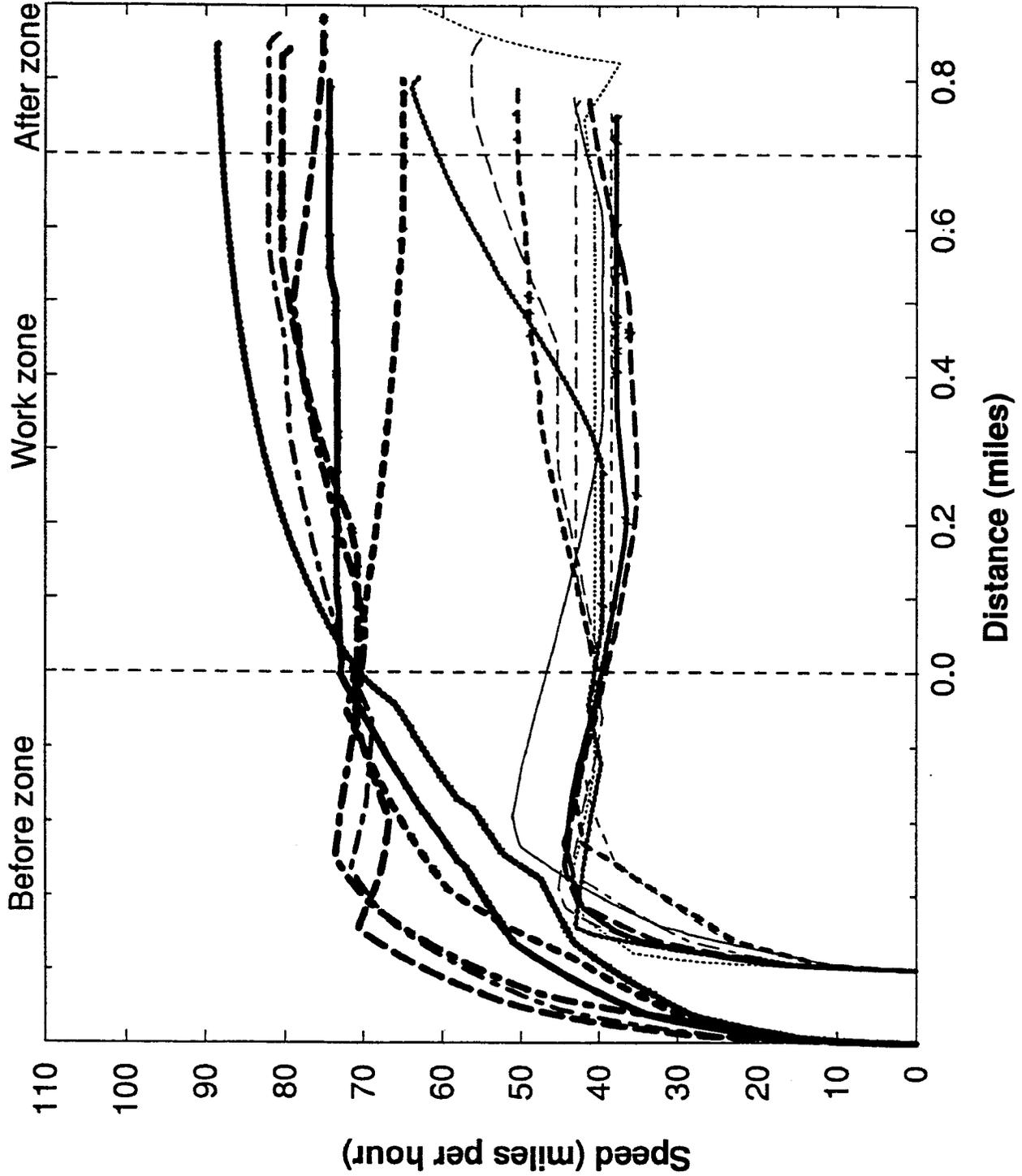
LGD Experiment 3 Subject: 21

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - 40; Green; Lt. stat (6)
- · 40; Green; Lt. fwd (3)
- · 40; Green; Lt. bwd (9)
- 40; Red; Lt. stat (14)
- 40; Red; Lt. fwd (10)
- - 40; Red; Lt. bwd (5)
- · 40; White; Lt. stat (8)
- · 70; Green; Lt. stat (12)
- 70; Green; Lt. fwd (11)
- 70; Green; Lt. bwd (4)
- · 70; Red; Lt. stat (13)
- · 70; Red; Lt. fwd (2)
- · 70; Red; Lt. bwd (7)



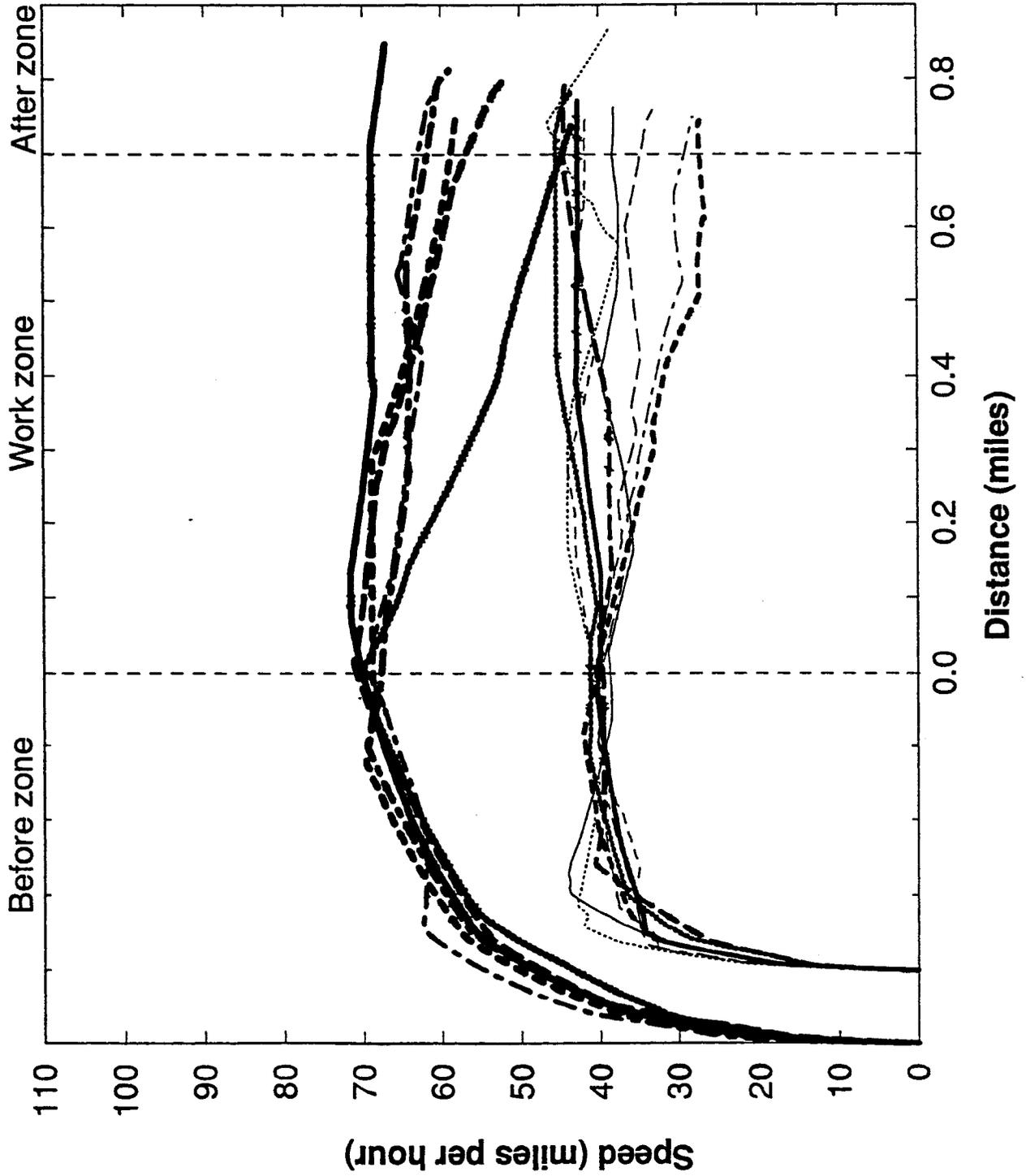
LGD Experiment 3 Subject: 23

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - 40; Green; Lt. stat (6)
- · - 40; Green; Lt. fwd (3)
- · · - 40; Green; Lt. bwd (12)
- 40; Red; Lt. stat (5)
- · - 40; Red; Lt. fwd (14)
- · · - 40; Red; Lt. bwd (9)
- - 40; White; Lt. stat (8)
- · - 70; Green; Lt. stat (4)
- · · - 70; Green; Lt. fwd (11)
- 70; Green; Lt. bwd (7)
- · - 70; Red; Lt. stat (10)
- · · - 70; Red; Lt. fwd (13)
- · · - 70; Red; Lt. bwd (2)



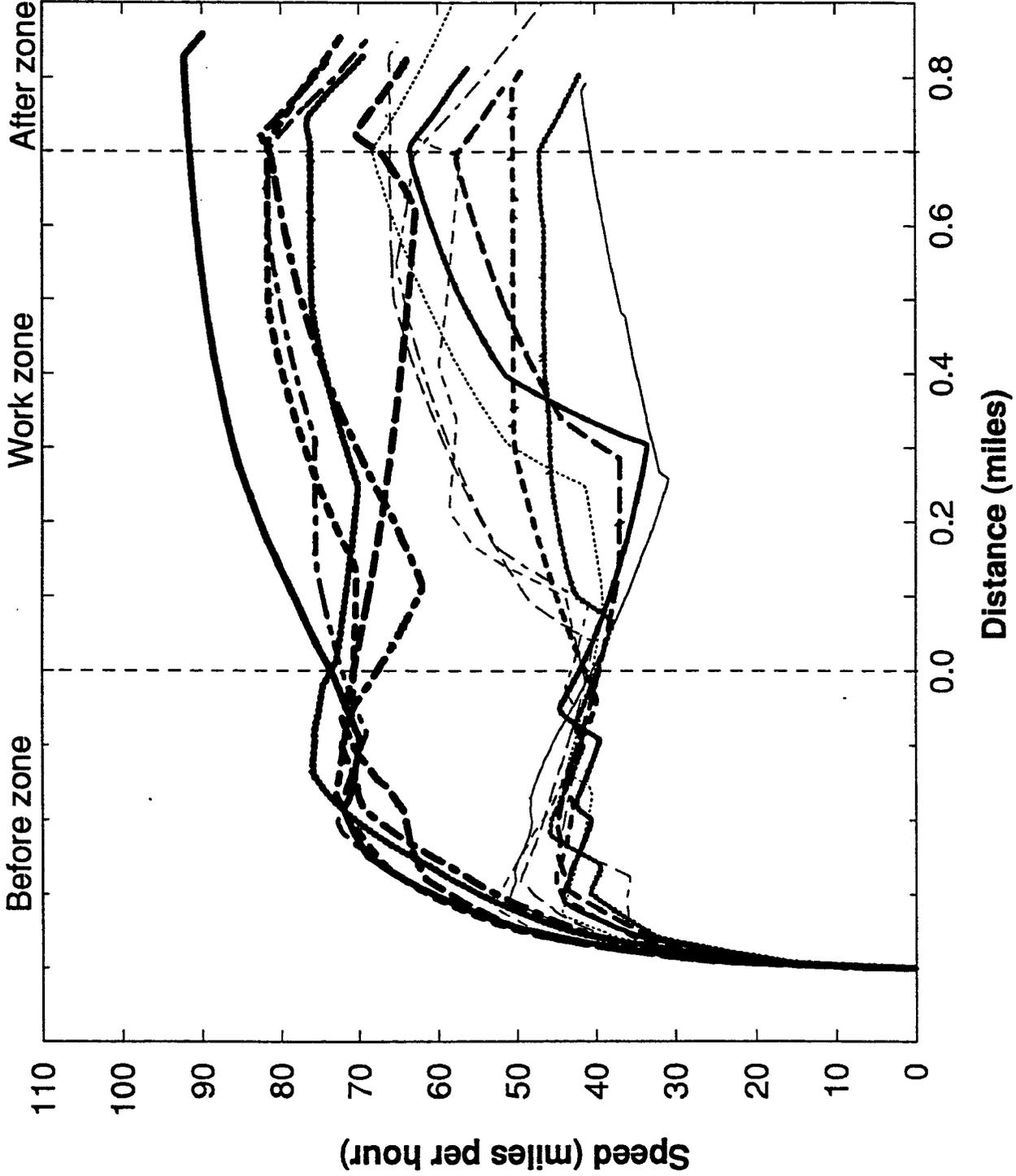
LGD Experiment 3 Subject: 24

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - 40; Green; Lt. stat (10)
- · - 40; Green; Lt. fwd (13)
- · · 40; Green; Lt. bwd (4)
- 40; Red; Lt. stat (11)
- ⋯ 40; Red; Lt. fwd (2)
- - 40; Red; Lt. bwd (7)
- · - 40; White; Lt. stat (8)
- · · 70; Green; Lt. stat (12)
- 70; Green; Lt. fwd (5)
- 70; Green; Lt. bwd (9)
- · - 70; Red; Lt. stat (6)
- 70; Red; Lt. fwd (3)
- · · 70; Red; Lt. bwd (14)



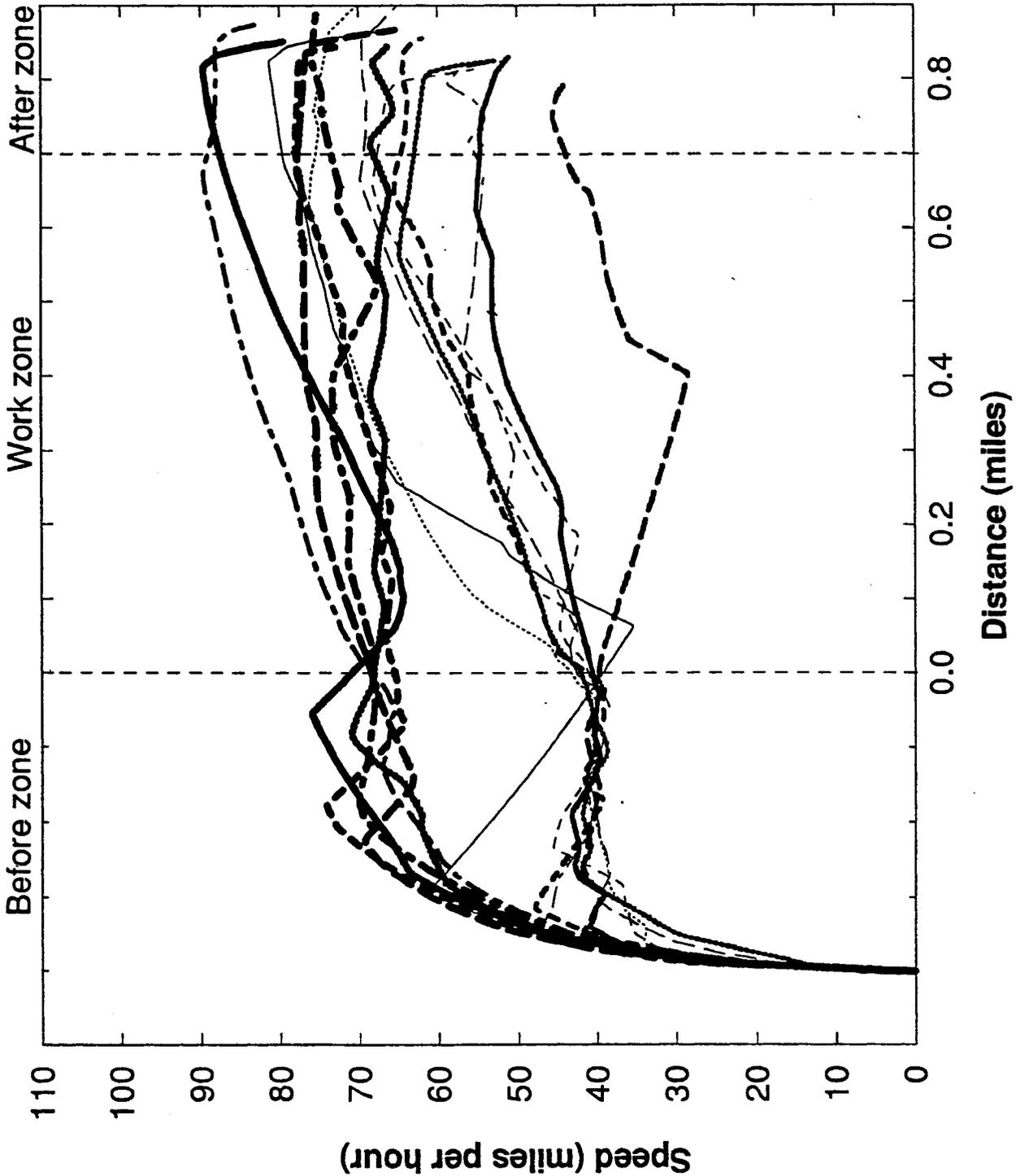
LGD Experiment 3 Subject: 25

- 40; No lights (1)
- 40; No lights (15)
- - - 40; Green; Lt. stat (6)
- - - 40; Green; Lt. fwd (14)
- - - 40; Green; Lt. bwd (2)
- 40; Red; Lt. stat (10)
- 40; Red; Lt. fwd (7)
- - - 40; Red; Lt. bwd (4)
- - - 40; White; Lt. stat (8)
- - - 70; Green; Lt. stat (9)
- 70; Green; Lt. fwd (12)
- 70; Green; Lt. bwd (3)
- - - 70; Red; Lt. stat (13)
- - - 70; Red; Lt. fwd (11)
- - - 70; Red; Lt. bwd (5)



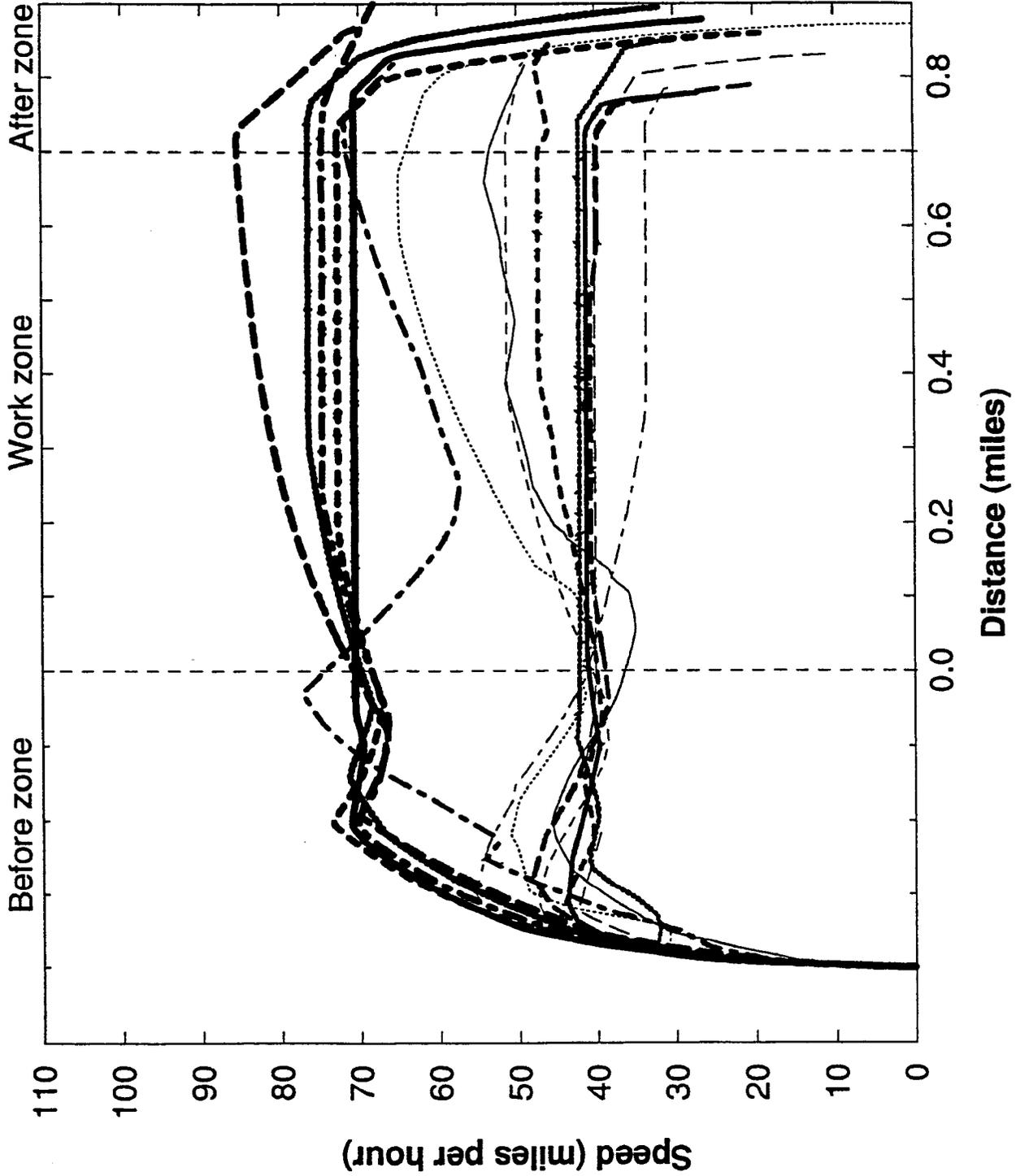
LGD Experiment 3 Subject: 26

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - 40; Green; Lt. stat (10)
- · 40; Green; Lt. fwd (2)
- · 40; Green; Lt. bwd (14)
- 40; Red; Lt. stat (6)
- ⋯ 40; Red; Lt. fwd (9)
- - 40; Red; Lt. bwd (12)
- · 40; White; Lt. stat (8)
- · 70; Green; Lt. stat (7)
- 70; Green; Lt. fwd (4)
- 70; Green; Lt. bwd (13)
- - 70; Red; Lt. stat (3)
- · 70; Red; Lt. fwd (5)
- · 70; Red; Lt. bwd (11)



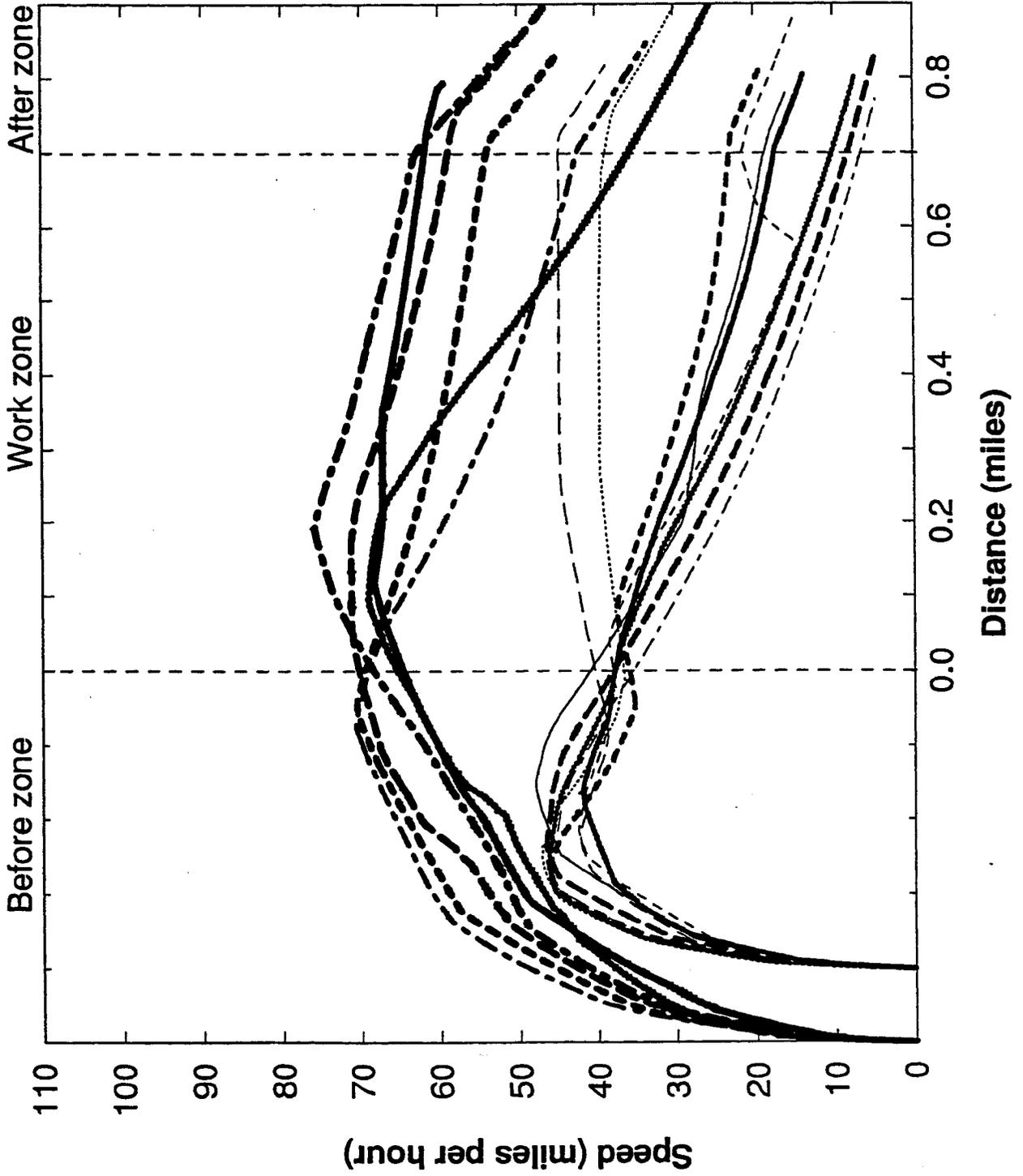
LGD Experiment 3 Subject: 27

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - - 40; Green; Lt. stat (12)
- · - 40; Green; Lt. fwd (9)
- · · 40; Green; Lt. bwd (5)
- 40; Red; Lt. stat (13)
- ⋯ 40; Red; Lt. fwd (6)
- - - 40; Red; Lt. bwd (3)
- · - 40; White; Lt. stat (8)
- · · 70; Green; Lt. stat (2)
- 70; Green; Lt. fwd (11)
- 70; Green; Lt. bwd (10)
- - - 70; Red; Lt. stat (14)
- · - 70; Red; Lt. fwd (7)
- · · 70; Red; Lt. bwd (4)



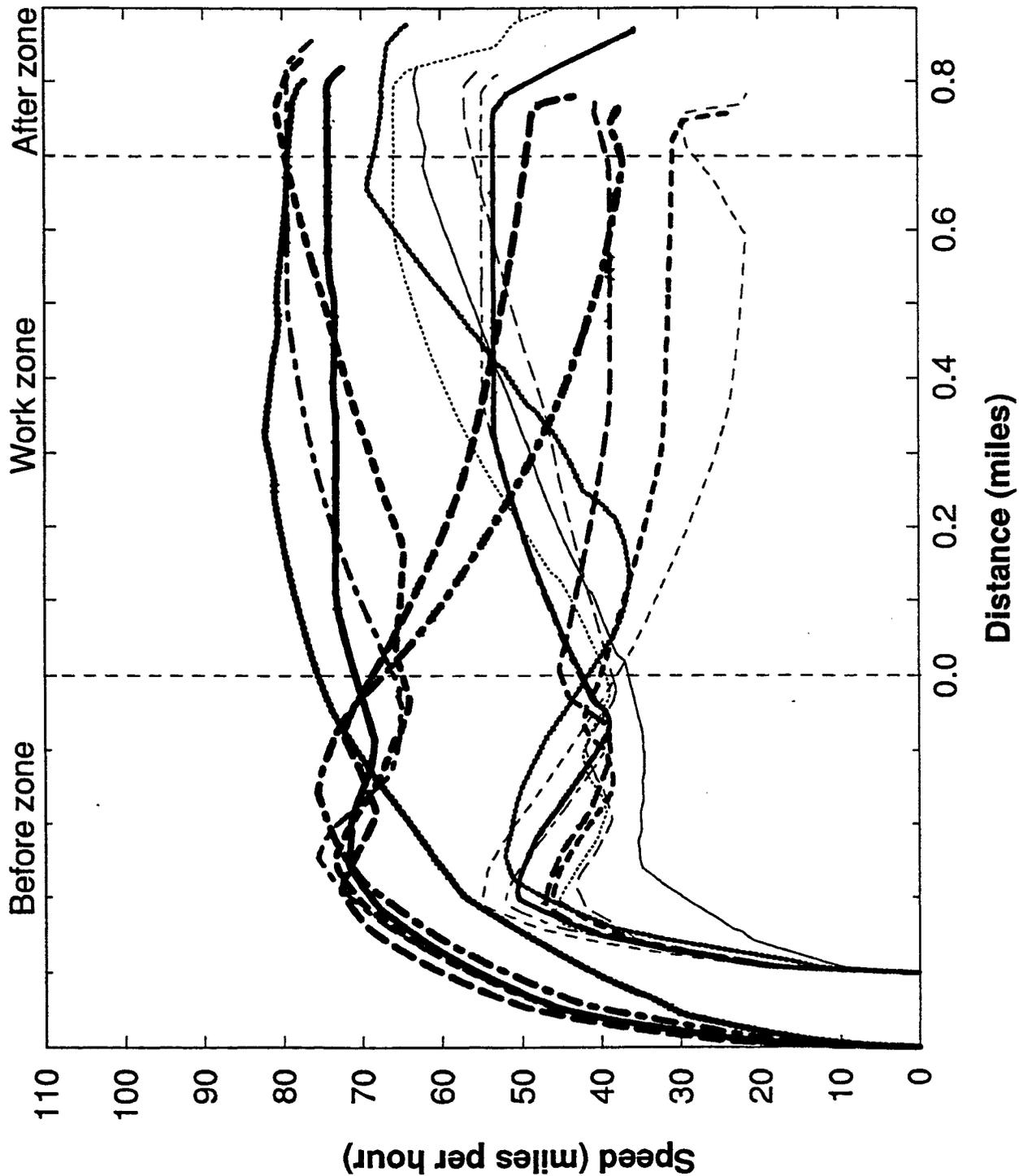
LGD Experiment 3 Subject: 28

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - 40; Green; Lt. stat (4)
- · - 40; Green; Lt. fwd (7)
- · · - 40; Green; Lt. bwd (11)
- 40; Red; Lt. stat (3)
- · — 40; Red; Lt. fwd (10)
- - - 40; Red; Lt. bwd (13)
- · - - 40; White; Lt. stat (8)
- · · - - 70; Green; Lt. stat (14)
- 70; Green; Lt. fwd (5)
- · — 70; Green; Lt. bwd (6)
- - - 70; Red; Lt. stat (2)
- · - - 70; Red; Lt. fwd (9)
- · · - - 70; Red; Lt. bwd (12)



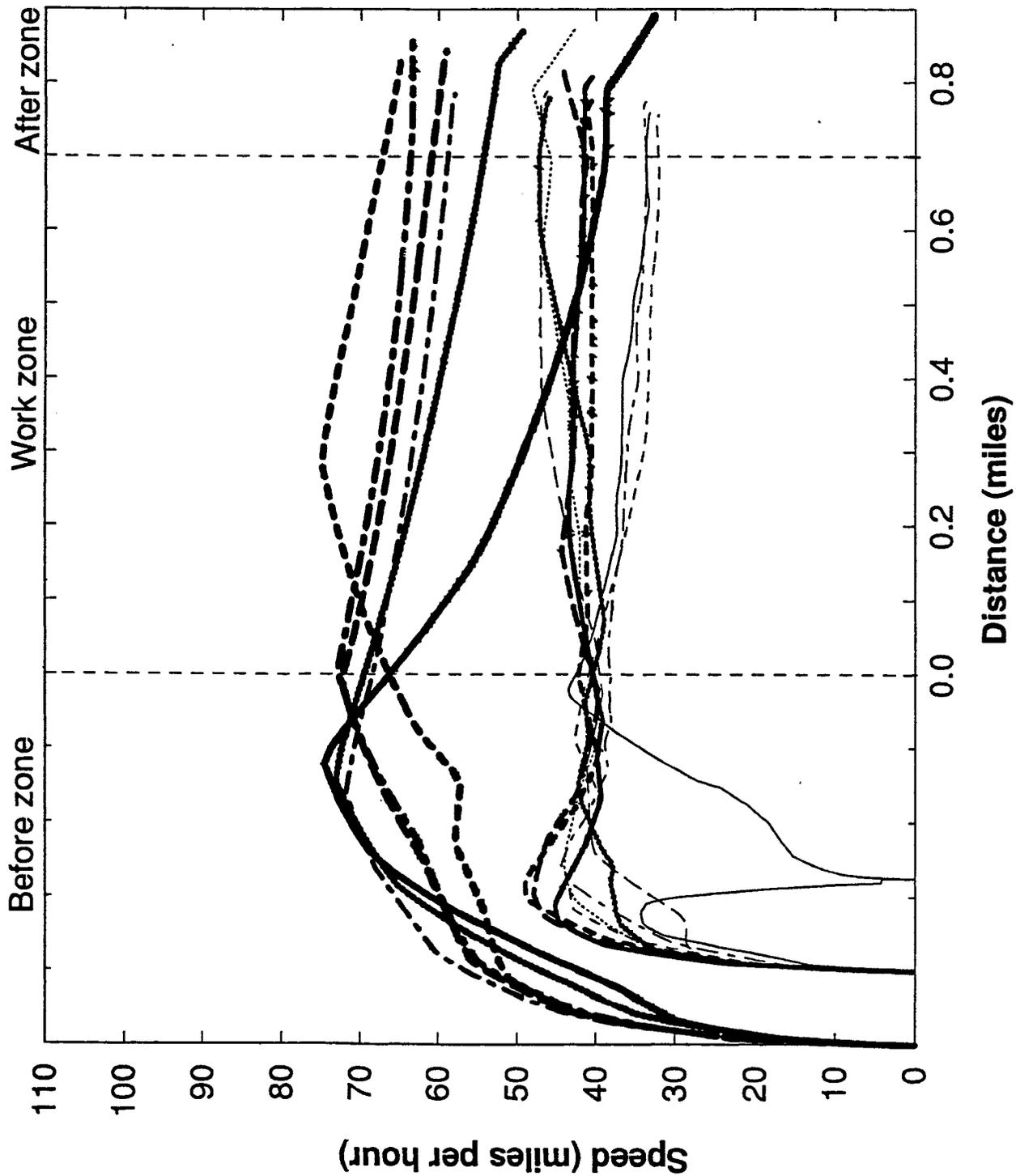
LGD Experiment 3 Subject: 29

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - 40; Green; Lt. stat (10)
- · - 40; Green; Lt. fwd (5)
- · · - 40; Green; Lt. bwd (14)
- 40; Red; Lt. stat (7)
- ⋯ 40; Red; Lt. fwd (3)
- - 40; Red; Lt. bwd (11)
- · - 40; White; Lt. stat (8)
- · · - 70; Green; Lt. stat (12)
- 70; Green; Lt. fwd (6)
- 70; Green; Lt. bwd (2)
- · - 70; Red; Lt. stat (9)
- ⋯ 70; Red; Lt. fwd (13)
- · · - 70; Red; Lt. bwd (4)



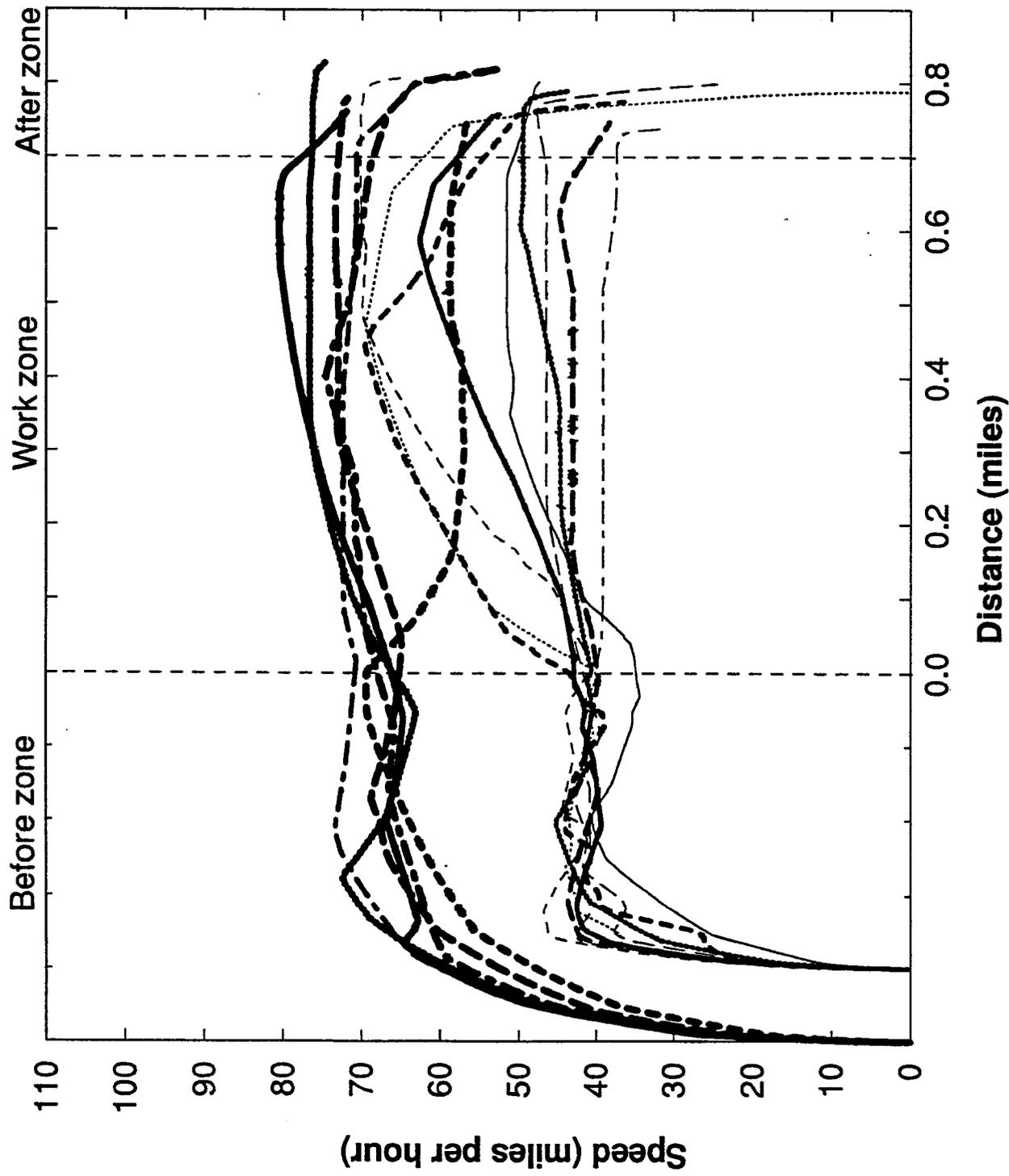
LGD Experiment 3 Subject: 30

- 40; No lights (1)
- 40; No lights (15)
- - - 40; Green; Lt. stat (6)
- - - 40; Green; Lt. fwd (11)
- - - 40; Green; Lt. bwd (2)
- 40; Red; Lt. stat (9)
- 40; Red; Lt. fwd (13)
- - - 40; Red; Lt. bwd (5)
- - - 40; White; Lt. stat (8)
- - - 70; Green; Lt. stat (4)
- 70; Green; Lt. fwd (10)
- 70; Green; Lt. bwd (14)
- - - 70; Red; Lt. stat (7)
- - - 70; Red; Lt. fwd (3)
- - - 70; Red; Lt. bwd (12)



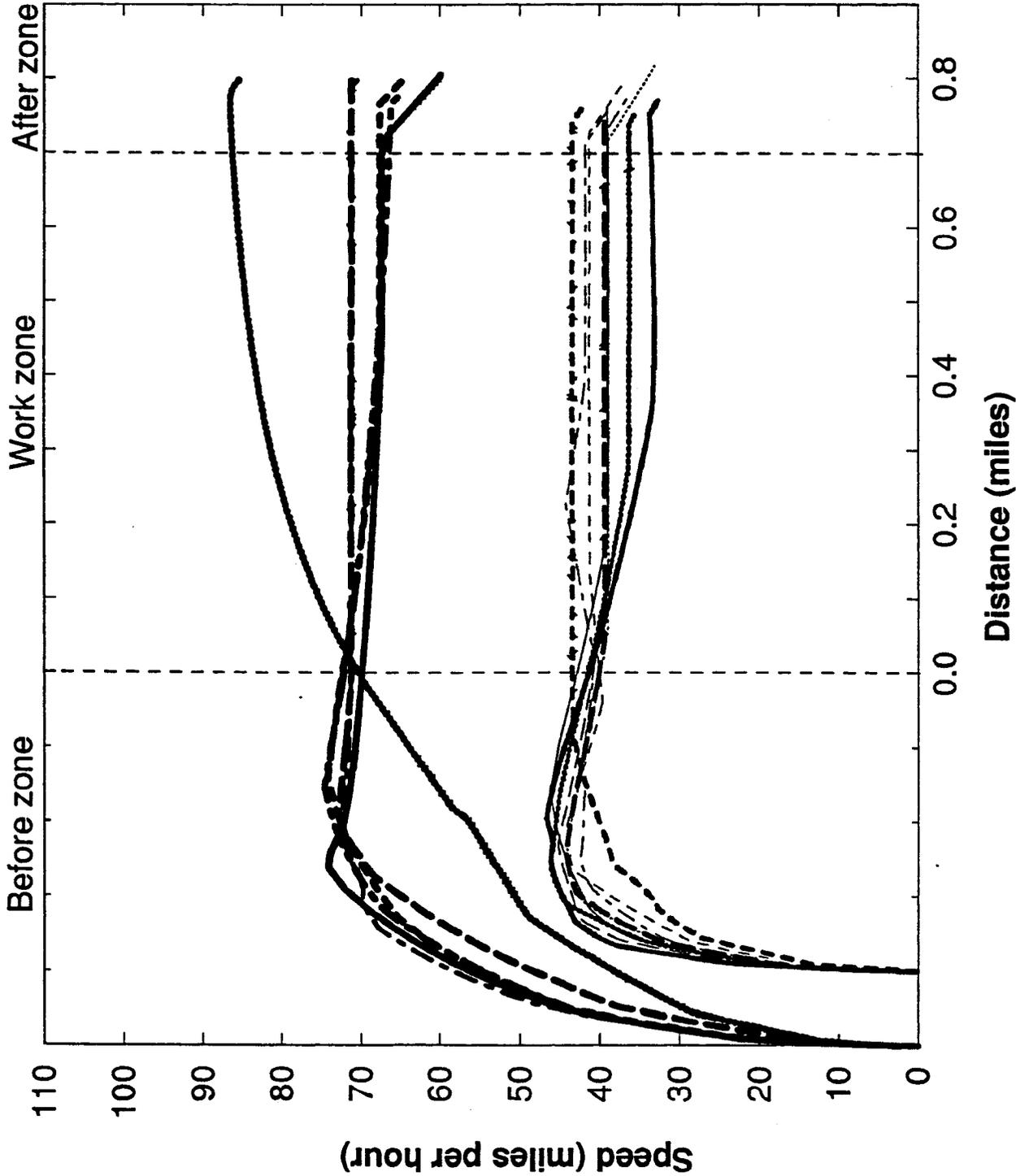
LGD Experiment 3 Subject: 31

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - 40; Green; Lt. stat (13)
- · - 40; Green; Lt. fwd (4)
- · - 40; Green; Lt. bwd (7)
- 40; Red; Lt. stat (9)
- ⋯ 40; Red; Lt. fwd (2)
- - 40; Red; Lt. bwd (14)
- · - 40; White; Lt. stat (8)
- · - 70; Green; Lt. stat (11)
- 70; Green; Lt. fwd (5)
- 70; Green; Lt. bwd (12)
- - 70; Red; Lt. stat (3)
- · - 70; Red; Lt. fwd (6)
- · - 70; Red; Lt. bwd (10)



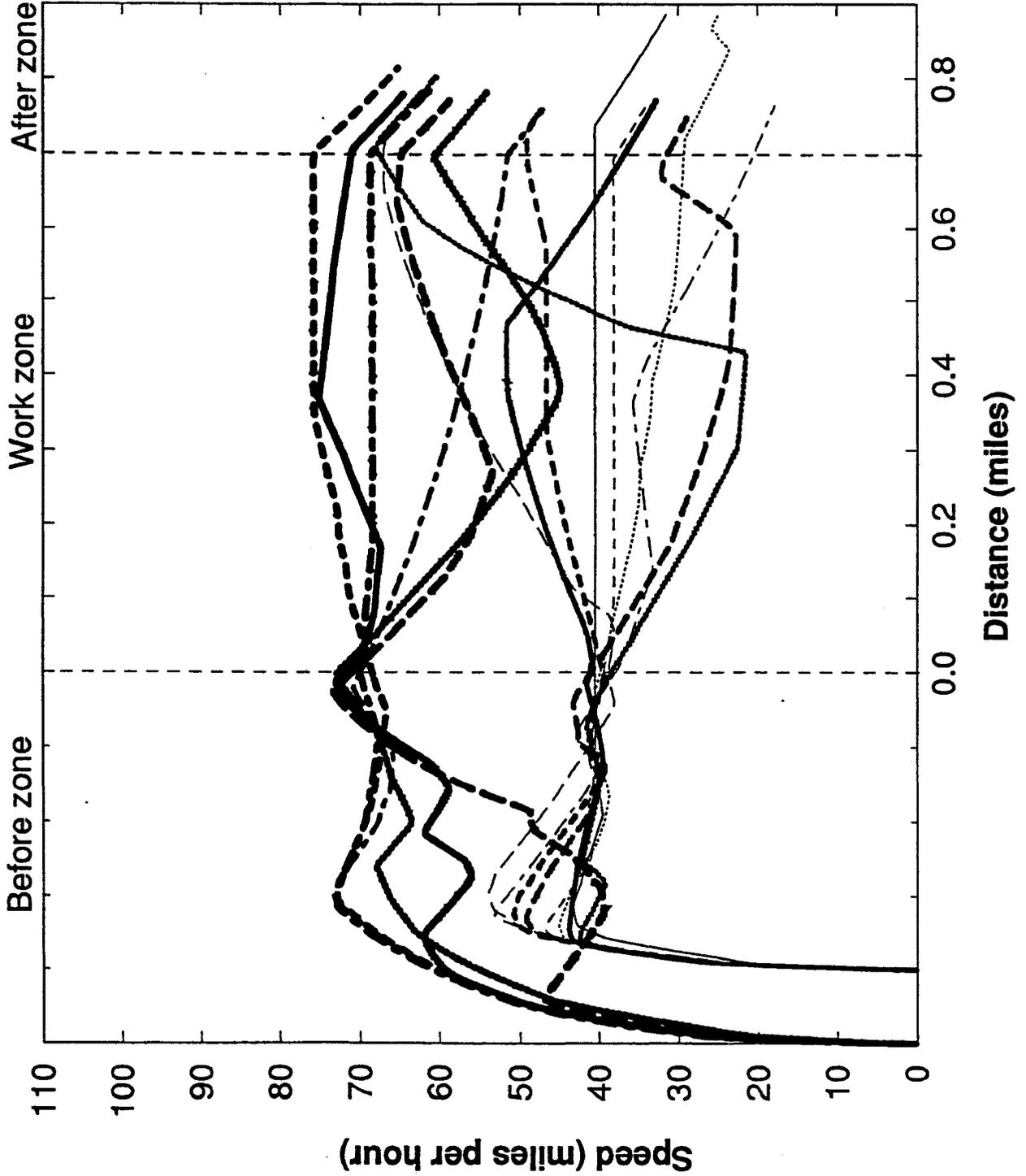
LGD Experiment 3 Subject: 32

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - 40; Green; Lt. stat (3)
- · - 40; Green; Lt. fwd (12)
- · · 40; Green; Lt. bwd (9)
- 40; Red; Lt. stat (7)
- 40; Red; Lt. fwd (14)
- - 40; Red; Lt. bwd (2)
- · - 40; White; Lt. stat (8)
- · · 70; Green; Lt. stat (5)
- 70; Green; Lt. fwd (11)
- 70; Green; Lt. bwd (4)
- - 70; Red; Lt. stat (13)
- · - 70; Red; Lt. fwd (10)
- · · 70; Red; Lt. bwd (6)



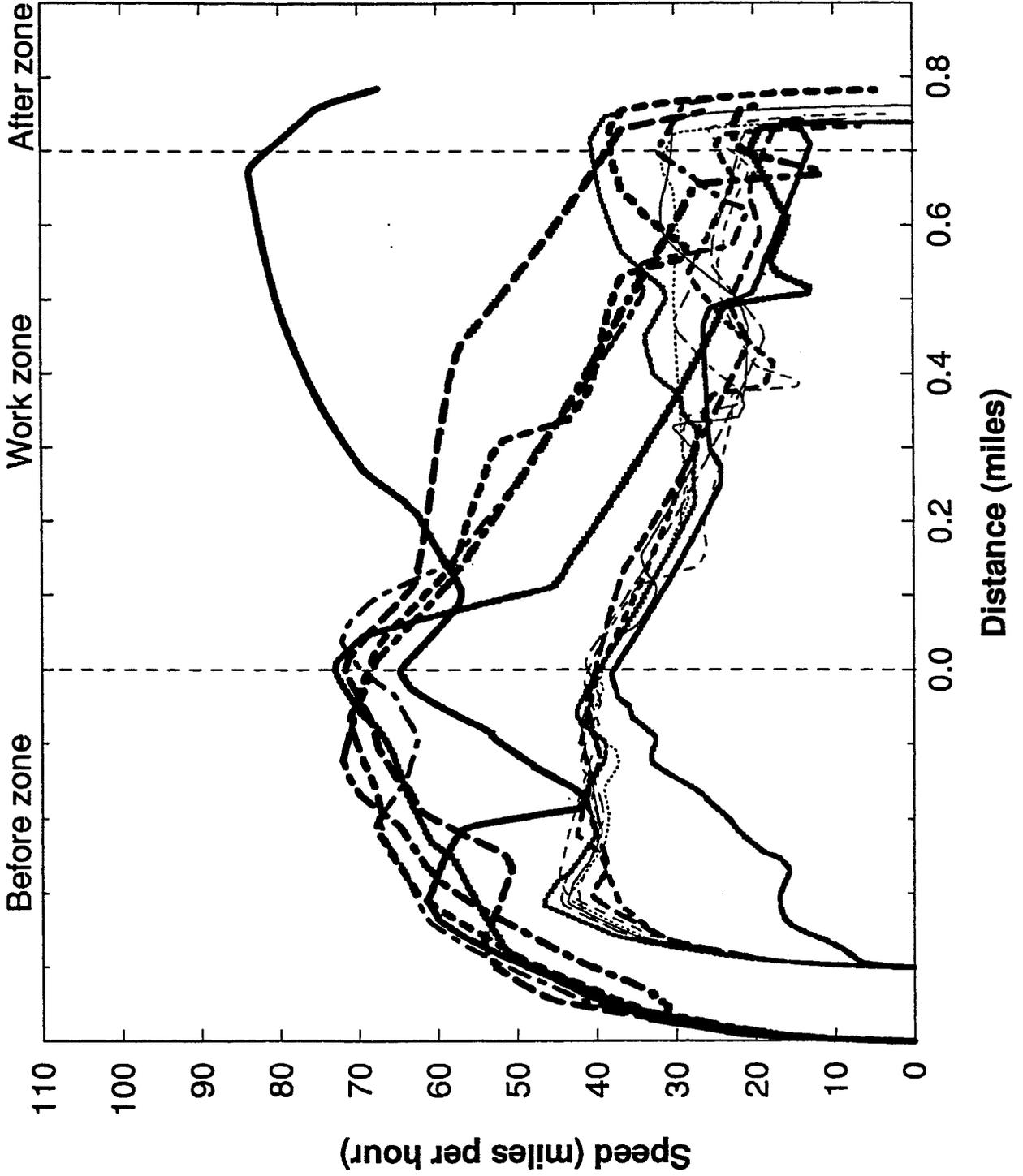
LGD Experiment 3 Subject: 33

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - 40; Green; Lt. stat (6)
- · 40; Green; Lt. fwd (3)
- · - 40; Green; Lt. bwd (9)
- 40; Red; Lt. stat (14)
- 40; Red; Lt. fwd (10)
- - 40; Red; Lt. bwd (5)
- · 40; White; Lt. stat (8)
- · - 70; Green; Lt. stat (12)
- 70; Green; Lt. fwd (11)
- 70; Green; Lt. bwd (4)
- - 70; Red; Lt. stat (13)
- · 70; Red; Lt. fwd (2)
- · - 70; Red; Lt. bwd (7)



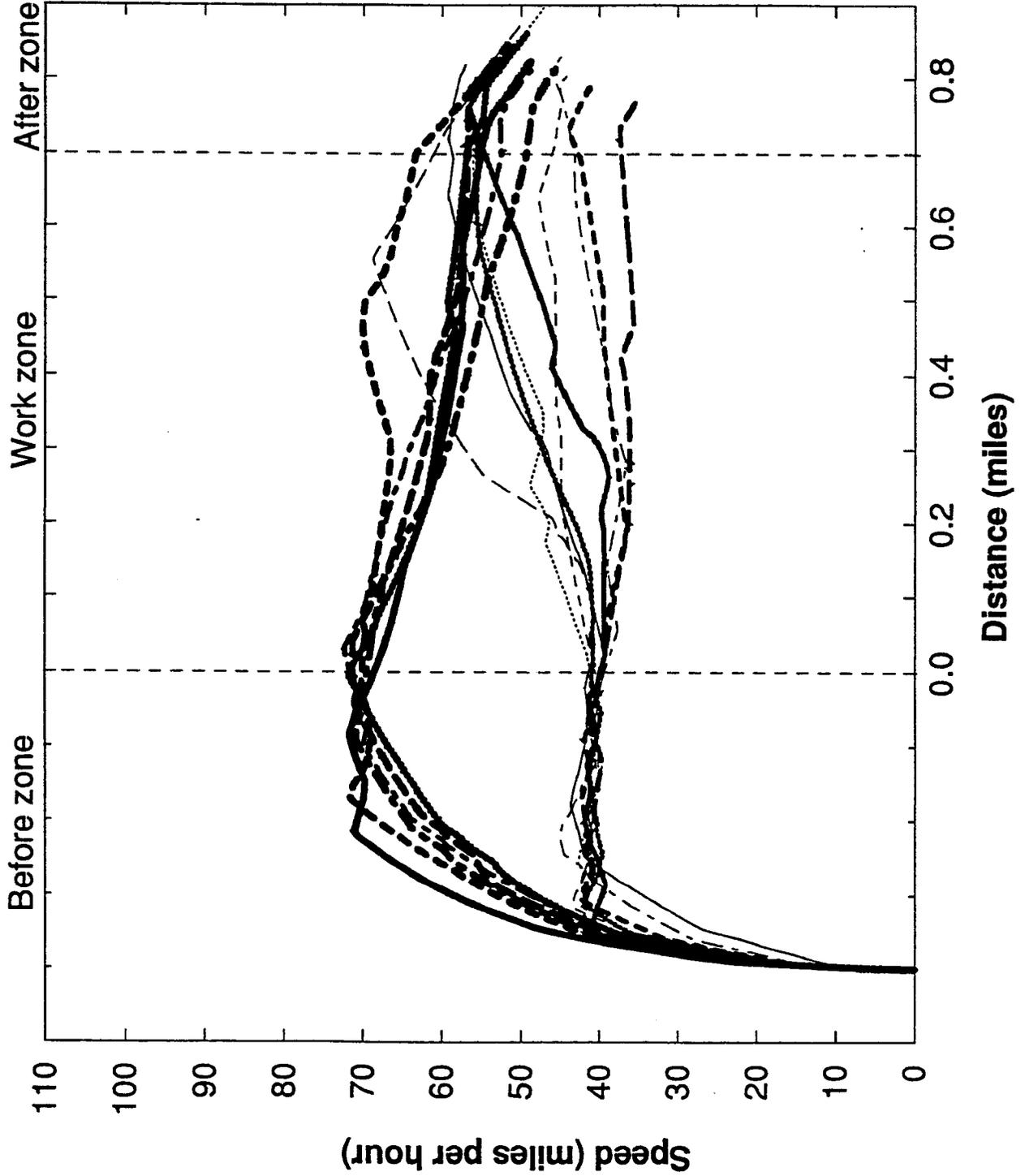
LGD Experiment 3 Subject: 34

- 40; No lights (1)
- 40; No lights (15)
- - - 40; Green; Lt. stat (10)
- · - 40; Green; Lt. fwd (13)
- · · 40; Green; Lt. bwd (7)
- 40; Red; Lt. stat (2)
- 40; Red; Lt. fwd (6)
- - - 40; Red; Lt. bwd (11)
- · - 40; White; Lt. stat (8)
- · · 70; Green; Lt. stat (4)
- 70; Green; Lt. fwd (5)
- 70; Green; Lt. bwd (12)
- - - 70; Red; Lt. stat (3)
- · - 70; Red; Lt. fwd (14)
- · · 70; Red; Lt. bwd (9)



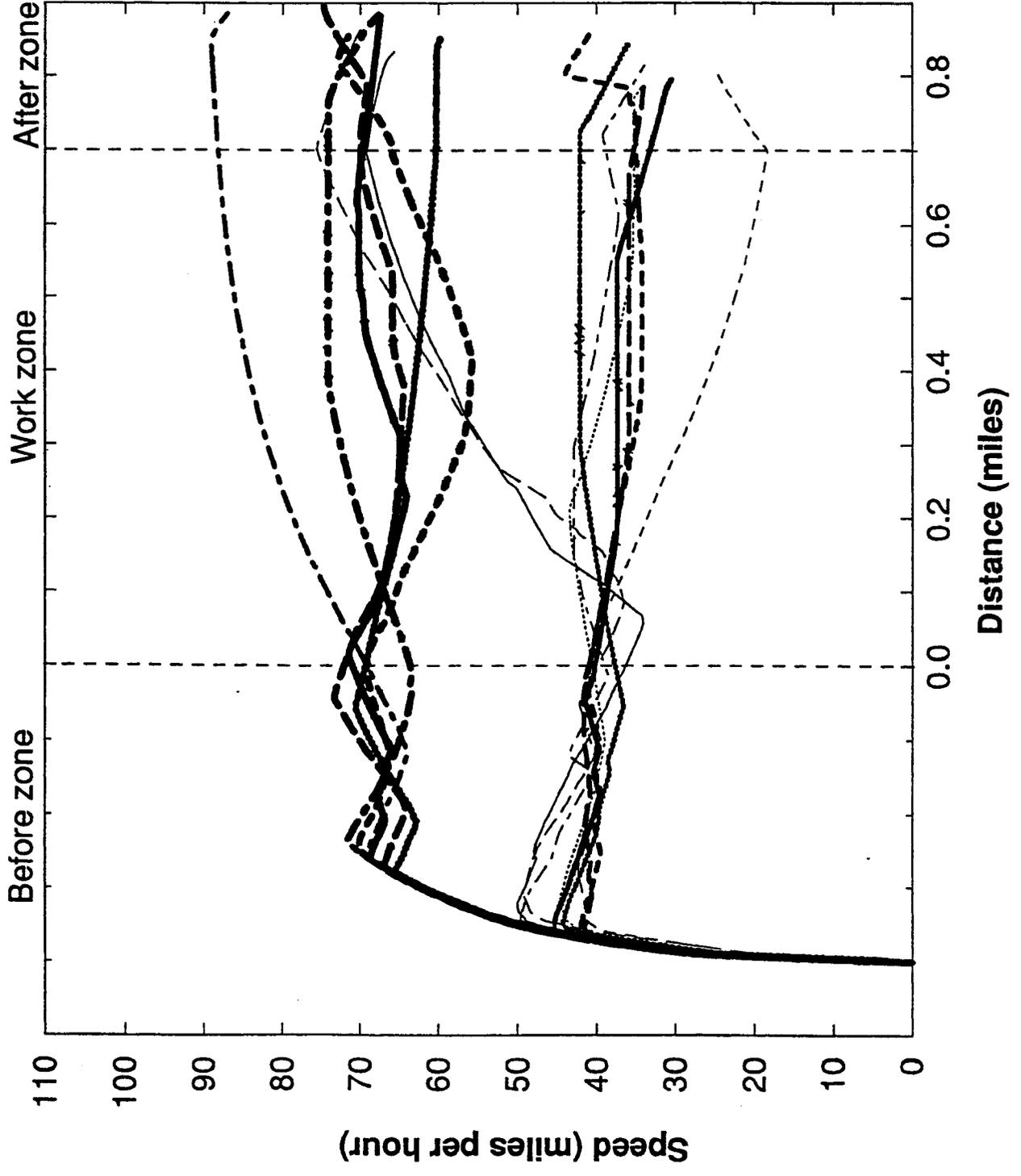
LGD Experiment 3 Subject: 37

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - 40; Green; Lt. stat (6)
- · - 40; Green; Lt. fwd (14)
- · · - 40; Green; Lt. bwd (2)
- 40; Red; Lt. stat (10)
- · — 40; Red; Lt. fwd (7)
- - - 40; Red; Lt. bwd (4)
- · - 40; White; Lt. stat (8)
- · · - 70; Green; Lt. stat (9)
- 70; Green; Lt. fwd (12)
- · — 70; Green; Lt. bwd (3)
- - - 70; Red; Lt. stat (13)
- · · - 70; Red; Lt. fwd (11)
- · · - 70; Red; Lt. bwd (5)



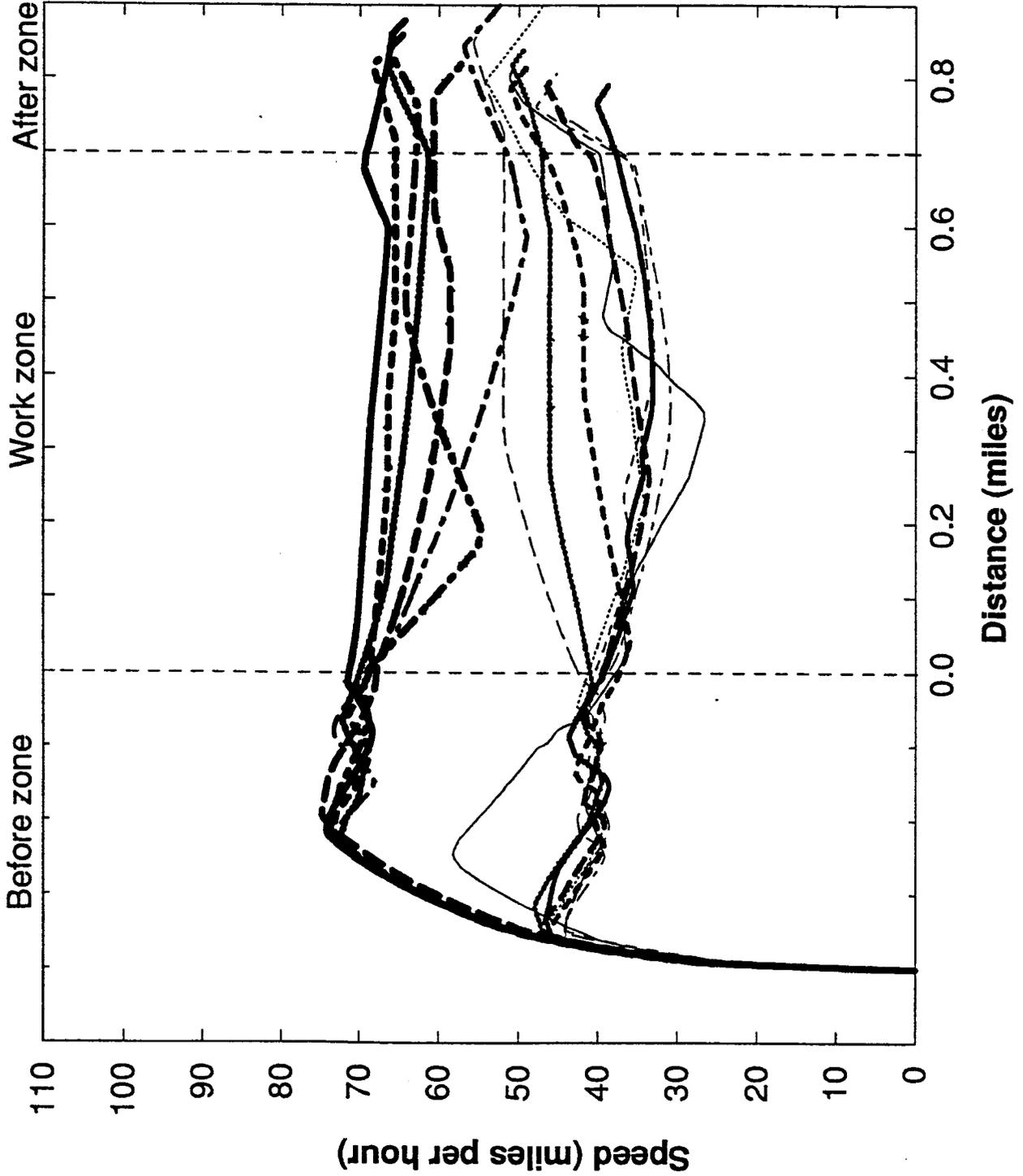
LGD Experiment 3 Subject: 38

- 40; No lights (1)
- 40; No lights (15)
- - - 40; Green; Lt. stat (10)
- - - 40; Green; Lt. fwd (2)
- - - 40; Green; Lt. bwd (14)
- 40; Red; Lt. stat (6)
- 40; Red; Lt. fwd (9)
- - - 40; Red; Lt. bwd (12)
- - - 40; White; Lt. stat (8)
- - - 70; Green; Lt. stat (7)
- 70; Green; Lt. fwd (4)
- 70; Green; Lt. bwd (13)
- - - 70; Red; Lt. stat (3)
- 70; Red; Lt. fwd (5)
- - - 70; Red; Lt. bwd (11)



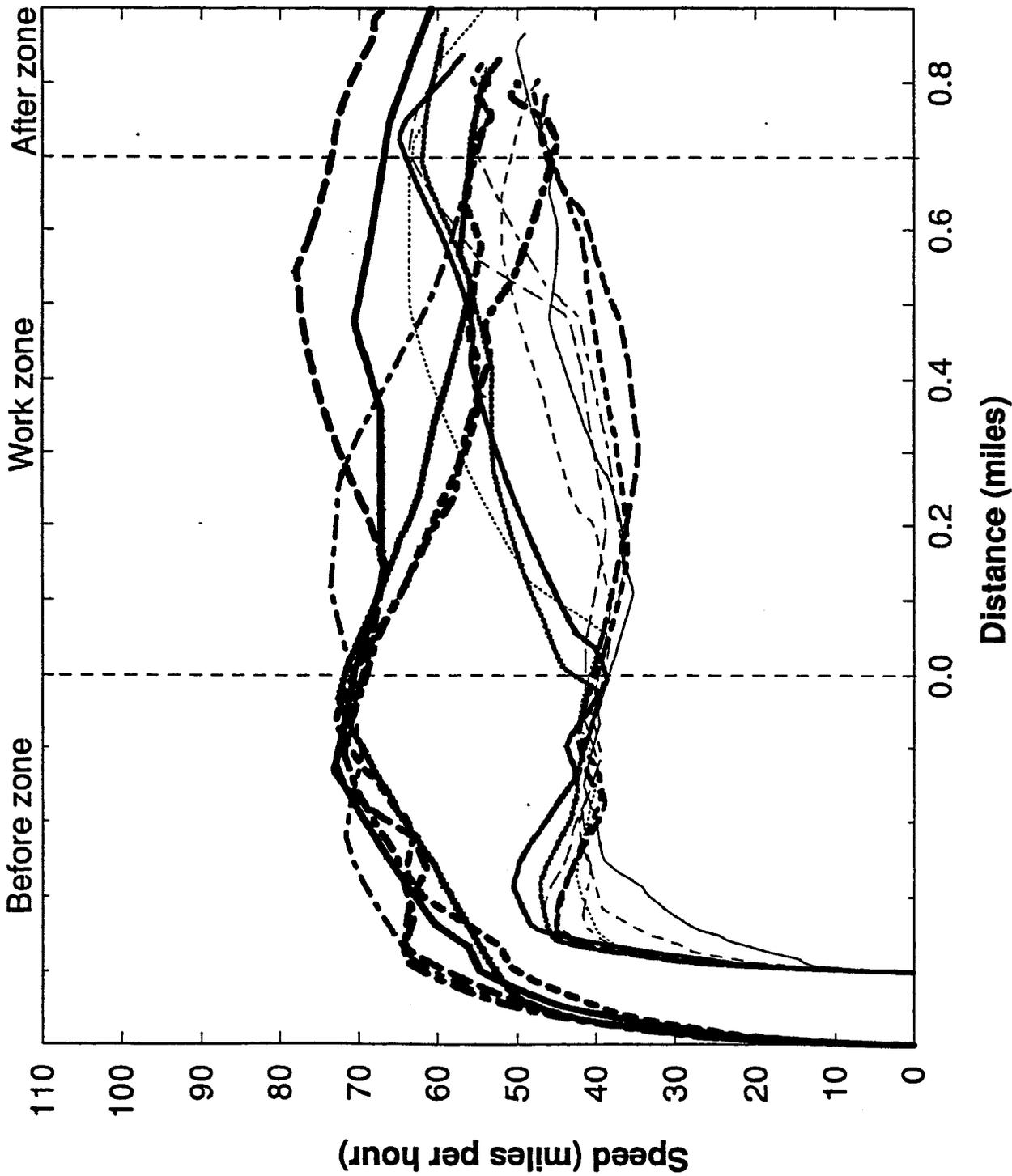
LGD Experiment 3 Subject: 39

- 40; No lights (1)
- 40; No lights (15)
- - - 40; Green; Lt. stat (12)
- - - 40; Green; Lt. fwd (9)
- - - 40; Green; Lt. bwd (5)
- 40; Red; Lt. stat (13)
- 40; Red; Lt. fwd (6)
- - - 40; Red; Lt. bwd (3)
- - - 40; White; Lt. stat (8)
- - - 70; Green; Lt. stat (2)
- 70; Green; Lt. fwd (11)
- 70; Green; Lt. bwd (10)
- - - 70; Red; Lt. stat (14)
- - - 70; Red; Lt. fwd (7)
- 70; Red; Lt. bwd (4)



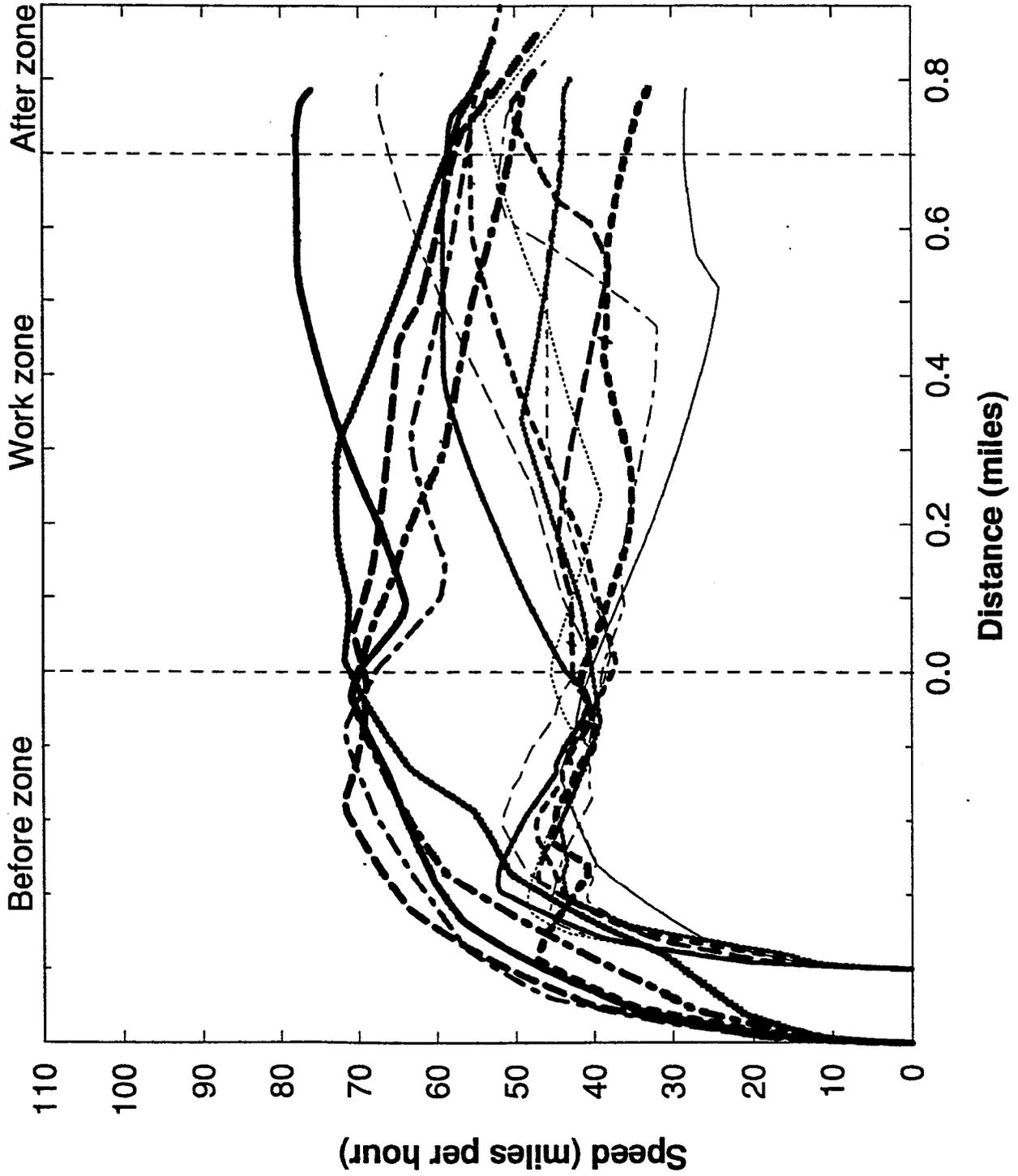
LGD Experiment 3 Subject: 40

- 40; No lights (1)
- 40; No lights (15)
- - - 40; Green; Lt. stat (4)
- · - 40; Green; Lt. fwd (7)
- · · - 40; Green; Lt. bwd (11)
- 40; Red; Lt. stat (3)
- 40; Red; Lt. fwd (10)
- - - 40; Red; Lt. bwd (13)
- · - 40; White; Lt. stat (8)
- · · - 70; Green; Lt. stat (14)
- 70; Green; Lt. fwd (5)
- 70; Green; Lt. bwd (6)
- - - 70; Red; Lt. stat (2)
- · - 70; Red; Lt. fwd (9)
- · · 70; Red; Lt. bwd (12)



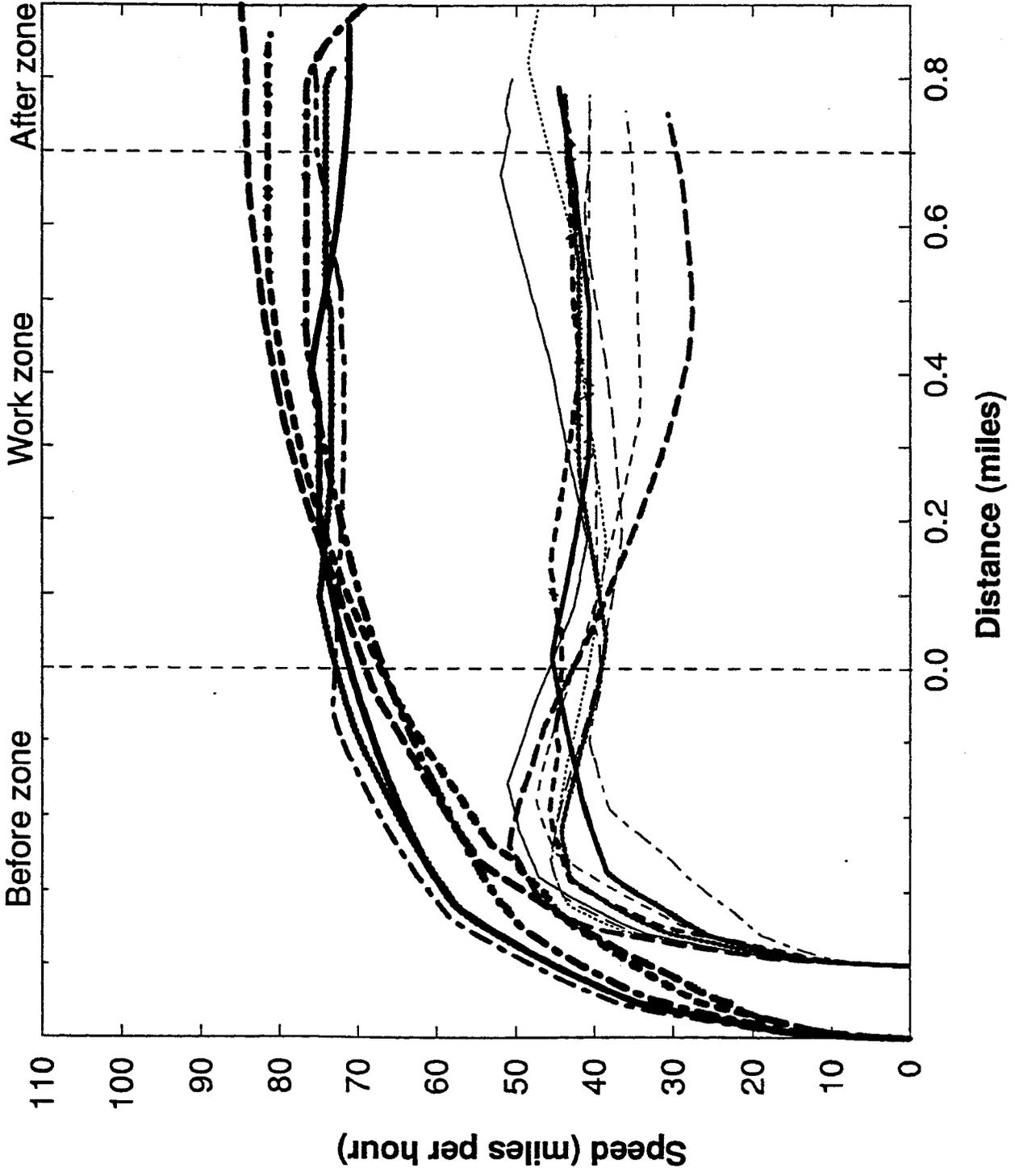
LGD Experiment 3 Subject: 41

- 40; No lights (1)
- 40; No lights (15)
- - - 40; Green; Lt. stat (10)
- - - 40; Green; Lt. fwd (5)
- - - 40; Green; Lt. bwd (14)
- 40; Red; Lt. stat (7)
- 40; Red; Lt. fwd (3)
- - - 40; Red; Lt. bwd (11)
- - - 40; White; Lt. stat (8)
- - - 70; Green; Lt. stat (12)
- 70; Green; Lt. fwd (6)
- 70; Green; Lt. bwd (2)
- - - 70; Red; Lt. stat (9)
- - - 70; Red; Lt. fwd (13)
- - - 70; Red; Lt. bwd (4)



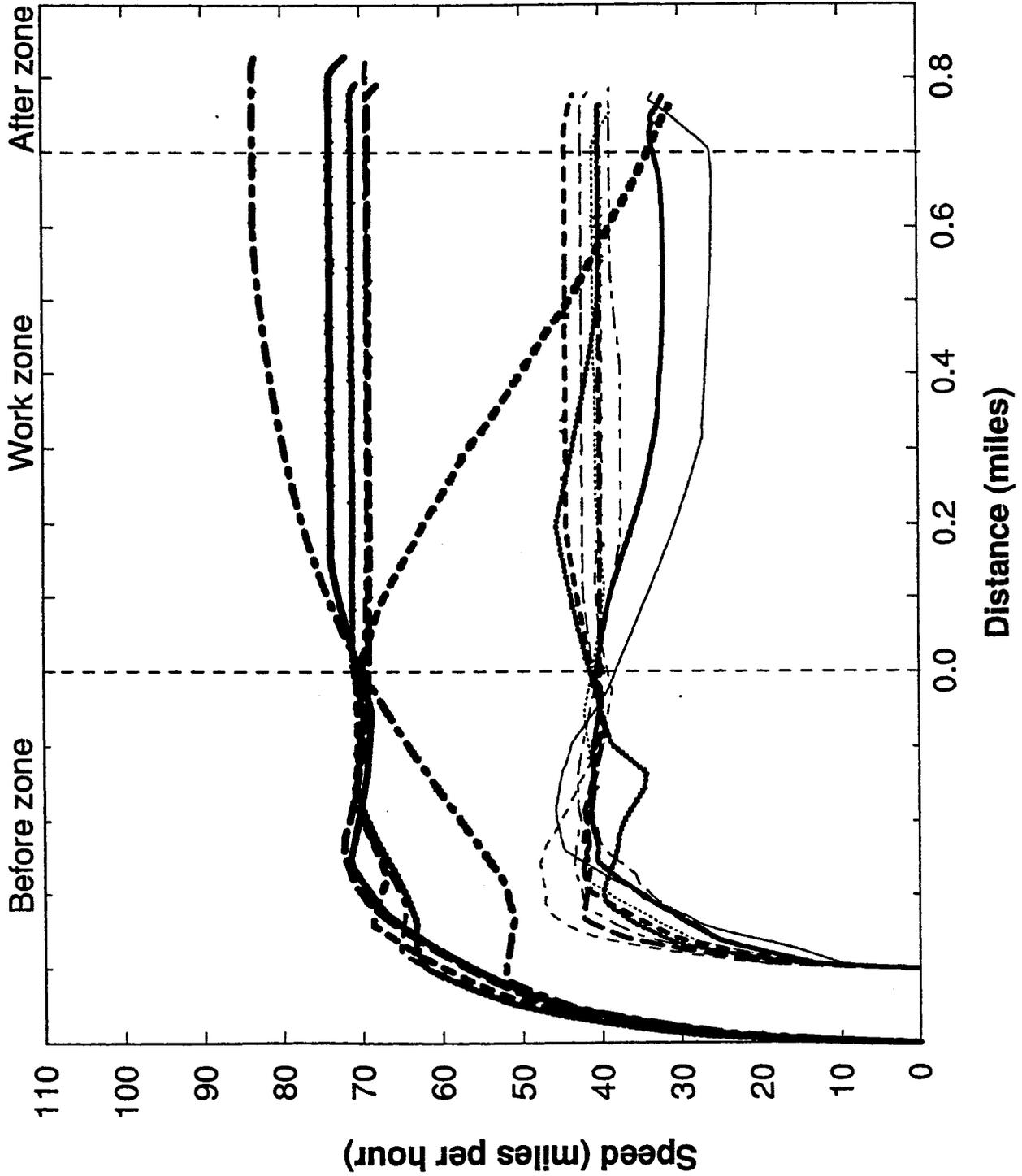
LGD Experiment 3 Subject: 42

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - - 40; Green; Lt. stat (6)
- · - 40; Green; Lt. fwd (11)
- · · 40; Green; Lt. bwd (2)
- 40; Red; Lt. stat (9)
- 40; Red; Lt. fwd (13)
- - - 40; Red; Lt. bwd (5)
- · - 40; White; Lt. stat (8)
- · · 70; Green; Lt. stat (4)
- 70; Green; Lt. fwd (10)
- 70; Green; Lt. bwd (14)
- - - 70; Red; Lt. stat (7)
- · - 70; Red; Lt. fwd (3)
- · · 70; Red; Lt. bwd (12)



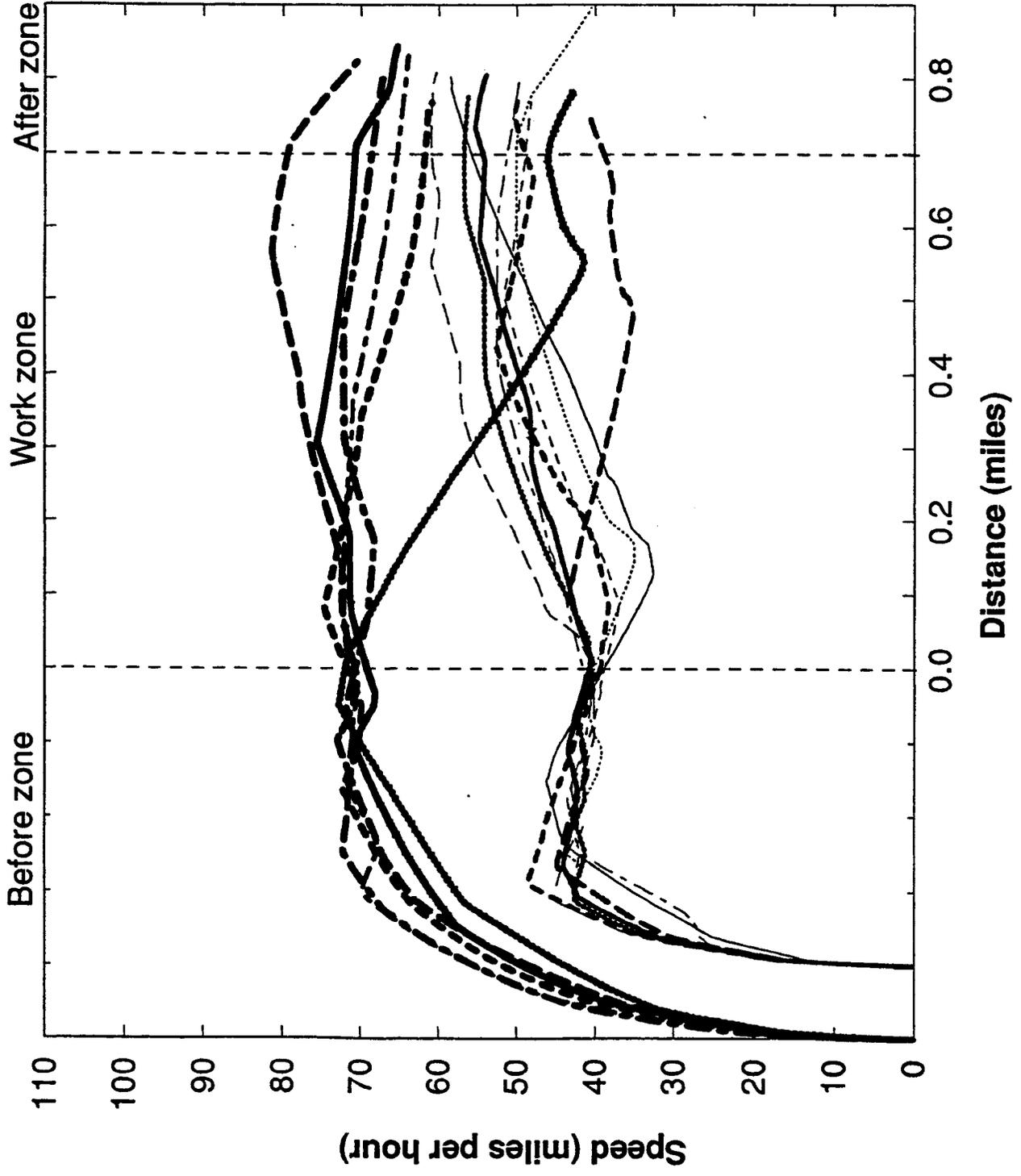
LGD Experiment 3 Subject: 43

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - 40; Green; Lt. stat (13)
- · - 40; Green; Lt. fwd (4)
- · · - 40; Green; Lt. bwd (7)
- 40; Red; Lt. stat (9)
- ⋯ 40; Red; Lt. fwd (2)
- - 40; Red; Lt. bwd (14)
- · - 40; White; Lt. stat (8)
- · · - 70; Green; Lt. stat (11)
- 70; Green; Lt. fwd (5)
- 70; Green; Lt. bwd (12)
- - 70; Red; Lt. stat (3)
- · - 70; Red; Lt. fwd (6)
- · · - 70; Red; Lt. bwd (10)



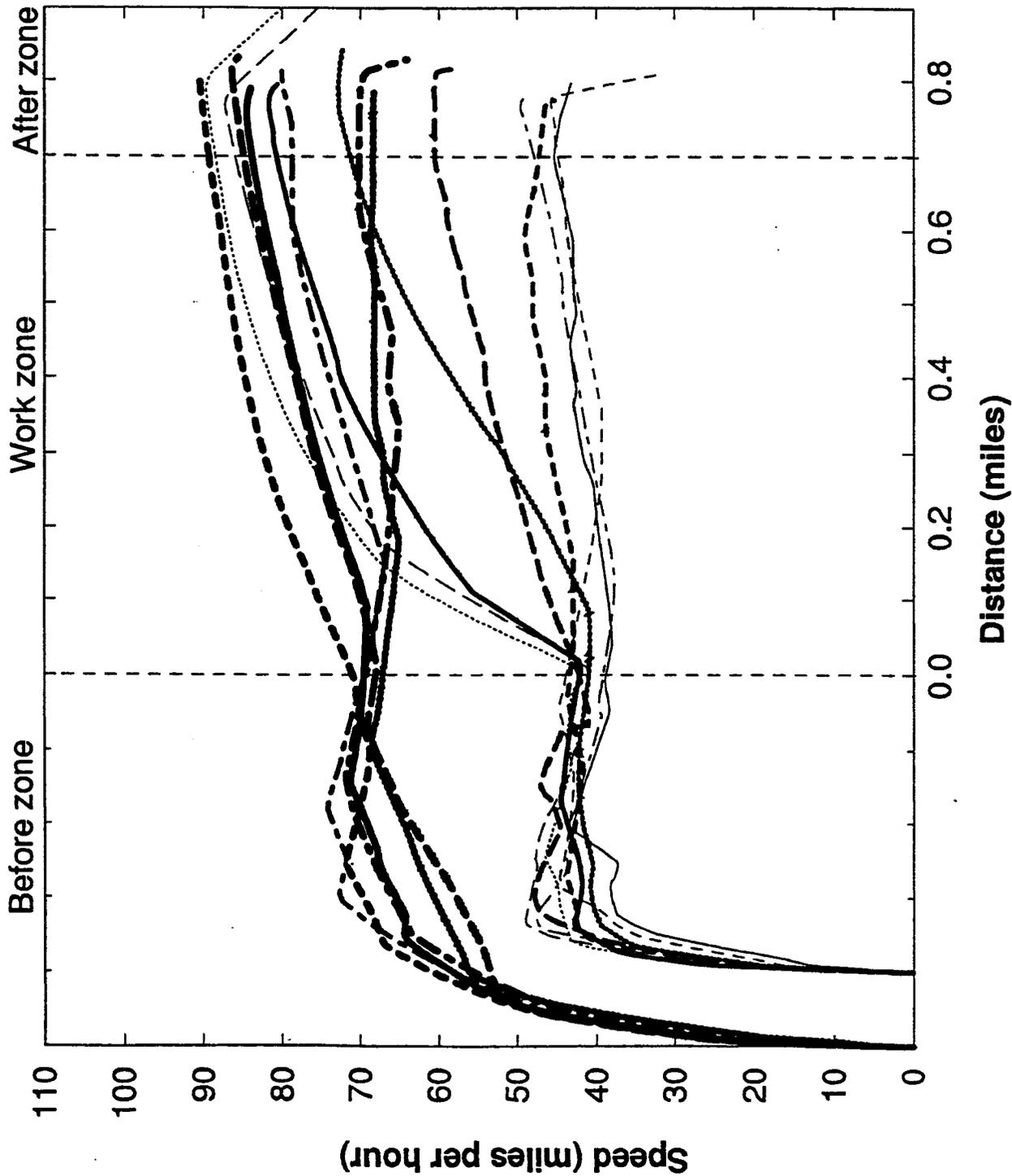
LGD Experiment 3 Subject: 44

- 40; No lights (1)
- 40; No lights (15)
- - - 40; Green; Lt. stat (3)
- · - 40; Green; Lt. fwd (12)
- · · 40; Green; Lt. bwd (9)
- 40; Red; Lt. stat (7)
- 40; Red; Lt. fwd (14)
- - - 40; Red; Lt. bwd (2)
- · - 40; White; Lt. stat (8)
- · · 70; Green; Lt. stat (5)
- 70; Green; Lt. fwd (11)
- 70; Green; Lt. bwd (4)
- - - 70; Red; Lt. stat (13)
- · - 70; Red; Lt. fwd (10)
- · · 70; Red; Lt. bwd (6)



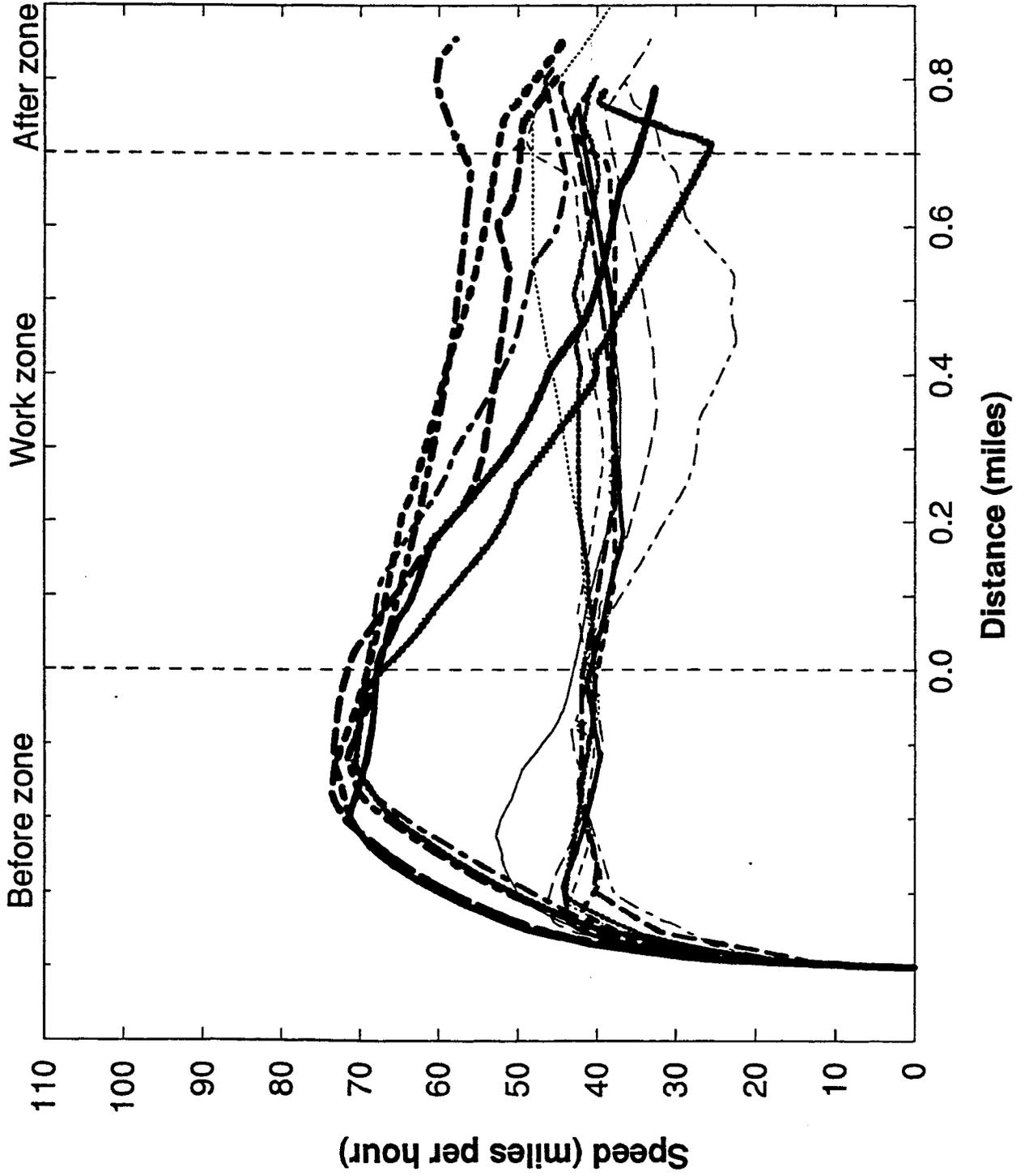
LGD Experiment 3 Subject: 45

- 40; No lights (1)
- ⋯ 40; No lights (15)
- - - 40; Green; Lt. stat (6)
- · - 40; Green; Lt. fwd (3)
- · · 40; Green; Lt. bwd (9)
- 40; Red; Lt. stat (14)
- 40; Red; Lt. fwd (10)
- - - 40; Red; Lt. bwd (5)
- · - 40; White; Lt. stat (8)
- · · 70; Green; Lt. stat (12)
- 70; Green; Lt. fwd (11)
- - - 70; Green; Lt. bwd (4)
- · - 70; Red; Lt. stat (13)
- · · 70; Red; Lt. fwd (2)
- · · 70; Red; Lt. bwd (7)



LGD Experiment 3 Subject: 46

- 40; No lights (1)
- 40; No lights (15)
- - - 40; Green; Lt. stat (6)
- - - 40; Green; Lt. fwd (14)
- - - 40; Green; Lt. bwd (2)
- 40; Red; Lt. stat (10)
- 40; Red; Lt. fwd (7)
- - - 40; Red; Lt. bwd (4)
- - - 40; White; Lt. stat (8)
- - - 70; Green; Lt. stat (9)
- 70; Green; Lt. fwd (12)
- 70; Green; Lt. bwd (3)
- - - 70; Red; Lt. stat (13)
- - - 70; Red; Lt. fwd (11)
- - - 70; Red; Lt. bwd (5)



APPENDIX L.

LGD1&2 (Proceedings of the 2nd ITS World Congress)

Lighted Guidance Devices^{#1&2}: Environmental Modulation of Driving Behavior THROUGH WORK ZONES

Max Vercruyssen^{1,2,3,4}, P.A. Hancock², William Knecht², Olukayode Olofinboba², Sue Chrysler⁵, Gayna Williams², Dave May⁵, and Rich Newell⁵

¹ Intelligent Transportation Systems Institute, CTS, University of Minnesota, Minneapolis, MN, USA

² Human Factors Research Laboratory, University of Minnesota, Minneapolis, MN, USA

³ Instituut voor Gerontechnologie, Technische Universiteit Eindhoven, Eindhoven, NL

⁴ Pacific Islands Geriatric Education Center, Univ of Hawai'i School of Medicine, Honolulu, HI, USA

⁵ Traffic Control Materials Division, 3M Company, St. Paul, MN USA

ABSTRACT

This research investigated the effectiveness of prototype lighted guidance devices (LGDs) in a virtual environment that manipulated optical flow and environmental cues to influence covertly drivers' perception of velocity and thereby indirectly modulate vehicle speed.

Experiment 1 examined the effects of driver age, driver sex, light pulse characteristics (all on; all off; 50mph forward, 5on:5off, & 50mph forward, 7on:3off); speedometer feedback; and vehicle location within the work zone. Despite age and sex differences, 24 drivers showed vehicle acceleration throughout the work zone associated with forward pulsing lights compared to control conditions.

Experiment 2 investigated the effects of driver sex, light pulse direction (forward 25mph, backward 50mph, & stationary), light color (red & green), zone entry speed (40 & 70mph), and location within the zone on vehicle speed and lane tracking for 24 drivers (12 male & 12 female). Results replicated those of Experiment 1 showing vehicle acceleration to forward pulses and also slowing to backward pulses plus a slight advantage of green lights compared to red and white lights.

Without explicit instructions or signage, LGDs modulated actual vehicle speed: green lights atop jersey barriers pulsed in a forward direction at ≥ 25 mph increased the speed of vehicles entering the zone at ≤ 40 mph and backward pulsing lights at ≥ 50 mph decreased the speed of vehicles entering the zone at 70mph.

1. GENERAL INTRODUCTION

Many accidents occur each year in highway work (construction) zones where workers are at risk of injury due to drivers traveling too fast through the work area. Traveling too slowly through the zone can also cause problems of traffic congestion, bottlenecks, and the increased risk of injury to workers by having drivers in the zone who are upset about increased transit time and

are thus willing to accept higher levels of risk when driving in an attempt to "make up for lost time." Because conventional signage has not been successful in optimizing traffic flow and safety, this problem has become a topic for intelligent transportation systems researchers and those interested in developing intelligent work zones.

This research project evaluated the efficacy of lighted guidance devices (LGDs) in work zones for providing control of vehicle speed as part of a total Intelligent Work Zone system with sensors informing a central processor unit (CPU) of current traffic conditions. The CPU in turn calculates the optimal pacing of vehicles and instructs the variable message signs and the LGDs to present drivers with information that would modulate their driving behavior. Thus, needed are the specific algorithms that permit the calculation of signal characteristics for LGDs based on such input information as zone entry speeds, traffic density, road repair conditions, worker density, weather and road surface conditions, visibility, etc. The success of LGDs depends on the modeling of driver responses to a variety of LGD variables making the human factors research herein described essential to development of LGDs.

This research was initiated to determine whether LGDs would influence driving behavior through a simulated work zone. Of particular interest were the effects of such factors as driver characteristics (e.g., age and sex), work zone characteristics (e.g., entry speed and length of zone), and characteristics of pulsing lights (e.g., pattern, direction, speed, color). Following pilot studies and prototype testing two experiments were conducted.

2. EXPERIMENT 1

2.1. Introduction

While testing prototype LGD hardware and software it became obvious that individual differences could be expected in the way drivers respond to driving through

work zones with experimental LGDs. Driver age and sex differences might influence generalizations made about LGD effects. For instance, age difference in divided attention might reveal themselves in lane tracking [1,2]. However, since motion perception and driving skill are influenced by age [3,4], it was uncertain how age differences might emerge. Age differences in vehicle velocity have been repeatedly demonstrated [5,6].

According to optical flow theory, participants should accelerate in the presence of pulsing lights when the pulse direction is in the same direction as the direction of travel on the road. In the control conditions involving either no lights or constantly-lit lights, there should be no tendency to change speed in the work zone. It was uncertain what pattern of lights on to off would produce the strongest LGD effect. For instance, with lights spaced eight feet apart, for a section of 10 lights, which would produce the strongest sense of apparent motion, 5on:5off or 7on:3off?

Another variable of interest was the influence of a actual vehicle velocity as displayed visually via a digital head-up display (HUD) [7].

Finally, the distance traveled through the zone might influence LGD effect so it is important to examine such effects relative to zone position.

Therefore, the purpose of this experiment was to examine the effects of driver age, driver sex, pulse pattern, feedback of actual velocity (HUD), and zone location through a one-mile zone.

2.2. Method

Participants. Twenty-four U.S. licensed drivers volunteered to be participants in this experiment: 12 young adults (< 55 yrs) and 12 older adults (> 55 yrs) with each group evenly divided into males and females. All were in good general health with 20/20 vision naturally or with corrective lenses. The young were undergraduate students and the old were community volunteers. All received US\$10 for their participation.

Task. Participants were asked to drive on a flat, straight, two-lane roadway with all traffic traveling in one direction (like a work zone), at night with LGDs along each shoulder. The LGDs were either all off, all on, or partially on and off in a way which gave the impression of movement at 50 mph forward.

The Driving Simulator. This research was conducted on a fixed-based front display driving simulator which modeled a 1990 Honda Accord. Essentially, driver behaviors like accelerator, brake, and steering movements were converted from analog to digital signals through a VMIVME-3118 64-channel A/D board and made input information into a model which approximated the vehicle. Outputs from this model were then used to adjust the eyepoint of the driver in the environment according to the inputs provided. Changes in the virtual visual

environment were made at a rate of at least 15 Hz (usually > 30 Hz) making the perception of the driver one of actual driving. Generation of virtual environments was controlled by a Silicon Graphics IRIS 4D/310 VGXT graphics mini-computer with a 4-channel video splitter using custom software developed on VAPS, Multigen, and Designer's Workbench.

The front flat screen was 116.5 x 86.25 inches (26.5" from bottom of screen to ground) at a distance of approximately 104" from the eyes of the average height seated participant. An Electrohome ECP 3100 projector, mounted approximately 79" from lens center to ground and located 146" from the screen was used to generate all virtual environments. The projected image dimensions were 91.5" x 71.5". The field of view height was 63" from the bottom of the projected image and the width included all of the projected screen (> 116.5").

Virtual Environment. Objects were texture-wrapped polygons in convenient formats (e.g., rgb or tiff) to store pixel and color information. The maximum road width at the bottom of the image was 35"; the minimum road width at the horizon was 1.75" at 11.5" above the bottom of the projected image frame. The simulated LGDs were round flashing lights (4" in diameter) characteristic of conventional roadway flashers, but synchronized for sequential flashing. The lights were spaced eight feet apart on each side of a flat, straight roadway, four feet outward from the edge of the pavement (i.e., on the shoulders), at an elevation of 40 inches (4" light atop of a 36" lane dividing barrier) above the roadway, and at a sufficient intensity to be visible at 2000 feet. The actual largest diameter of the light (at full looming) was 0.56 inches and its minimum diameter (at the horizon) was indistinguishable from the background. The roadway simulated was straight and flat 24' lane with about 1/3 of a left lane visible. Also, evening lighting conditions (moderate darkness) were simulated (approximately 20:00h).

Haptic noise was added to the steering to simulate uneven road surface and crosswind effect thereby making the simulator "feel" more like an actual car being driven on a typical roadway. The steering torque motor patterns of noise were designed to be completely random and nonintrusive to vehicle tracking within the lane.

Yellow skip line cues (4" x 10' with 40' spaces between lines) were provided on the pavement as a left-side lane divider and simulated "farmers' fields" of approximately 1/4-mile wide were presented on each side of the roadway to facilitate speed estimation. The right edge line was white, continuous, and 4" wide.

Independent Variables. Between group organismic variables were age (<55 yrs vs. >55 yrs) and sex (male vs. female). Repeated measures were light type (all lights off, all lights on, 5on:5off, and 7on:3off), head up display (HUD) speedometer (on vs. off), and location within the

zone (0.1 mi before the zone and at each 0.1 mi throughout zone).

Fixed Variables. For Experiment 1 no instructions were given regarding vehicle speed upon entering the zone. Letting drivers enter at whatever speed was comfortable to them helped establish baseline behavioral patterns and increased ecological validity of the task. Although vertical height of the light source determines visual angle of the stimulus which may influence the perception of apparent motion, no additional benefit was observed from raising or lowering the LGDs from their typical placement of 36" above the roadway. Similarly, the investigators subjectively evaluated the relationship of the number of lights on and off in a series and arrived at 5on:5off and 7on:3off as the best patterns for producing the apparent motion effects. Contrast with surrounding environment was made relatively constant by simulating night driving in ideal weather conditions.

Dependent Measures. Accelerator pedal movement, steering wheel movements, lane position, and zone position were sampled approximately every 50 ms and converted into driver speed (mph) and lane tracking deviation.

Procedure. Participants were instructed to drive as they normally would in a real car under normal driving conditions through a construction zone at night. No instructions were given regarding the maintenance of vehicle speed through the simulated work zone.

2.2. Results

Speed and lane deviation data were analyzed according to age2 x sex2 x pulse4 x zone11 x HUD2 mixed ANOVA designs with repeated measures on the last three factors.

Speed (mph). Typically, participants accelerated in approaching the zone and then drove as they normally would at night through a work zone.

Figure 1 illustrates average speed at each tenth of a mile through the zone for all 24 participants as a function of pulse separation and presence of the head-up-display of a digital speedometer. Collapsing data across all treatments and conditions, vehicle speed gradually increased throughout the zone ($F(10,200)=11.046$; $p<.0005$; $\text{Eta}^2=.003$). With the heads-up-display on, drivers entered and traveled through the zone slower than when the HUD was off ($F(1,20)=6.347$; $p=.020$; $\text{Eta}^2=.020$). Regarding pulse features, drivers entered and traveled through the zone slightly faster with the experimental pulses (7on:3off & 5on:5off) than with the control conditions (all lights on and all lights off) ($F(3,60)=4.184$; $p=.009$; $\text{Eta}^2=.054$). The interaction of pulse features and zone location zone was significant ($F(30,600)=1.839$; $p=.005$; $\text{Eta}^2=.190$), as was pulse type

by location by HUD status ($F(30,600)=3.618$; $p<.0005$; $\text{Eta}^2=.072$).

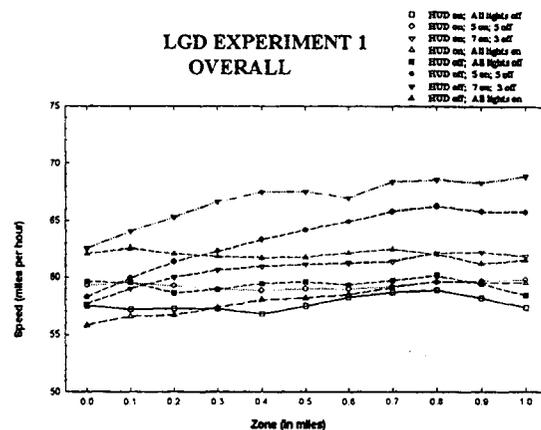


Figure 1. Speed through zone by speedometer feedback, light characteristics, and zone location across participants.

There were significant age differences in speed at each of the tenth mile segments ($F(10,200)=1.984$; $p=.037$, $\text{Eta}^2=.174$). Most pronounced was the influence of the HUD on driving speed in the young ($F(30,600)=1.671$; $p=.015$, $\text{Eta}^2=.211$). The young entered slower and drove consistently through the zone compared to the old when the HUD was on, regardless of light pulses; however, with the HUD off young drivers showed a significant increase in speed with each tenth mile segment compared to the control conditions.

There were significant sex differences in speed at each of the tenth mile segments ($F(10,200)=2.606$; $p=.005$, $\text{Eta}^2=.122$). The separation of conditions is more obvious in the speed plot for males but an impressive effect of the 5on:5off pulsing lights is shown in the female data where they entered the zone slow and left the zone fast. The interaction of sex by zone location by HUD was also significant ($F(10,200)=4.739$; $p<.0005$, $\text{Eta}^2=.042$).

Young male drivers entered the zone faster for the LGD conditions without HUD than for all other conditions and then accelerated gradually for the 7on:3off pulse pattern with no change in speed for the 5on:5off pattern. Young female drivers were more varied in zone entry speeds but showed a strong LGD pattern for HUD off conditions -- control passes were constant throughout the zone, with lights on faster than lights off, compared with LGD pulsing lights which both caused an increase in speed with each 1/10 mile in the zone. Older male drivers showed distinct slower entry speeds for HUD on conditions with little change throughout the zone compared with HUD off conditions which showed no changes in the control passes but speed increases in the LGD passes, especially in the case of the 5on:5off pattern

to which these participants entered the zone at nearly the slowest speed (55 mph) and left the zone at the fastest (69 mph). Older females entered and drove through the zone faster than other groups but showed the same pattern of LGD effects for the HUD off conditions -- no change in controls and an increase in velocity associated with LGD flashing lights and distance traveled in the zone.

Lane Deviation (Swerve). Differences by age, sex, and age by sex were not significant. However, differences were significant for HUD but small in absolute value (.0000776 + .0001292, .0000559, + .0001137 miles; $F(1,20)=4.726$; $p=.042$, $\eta^2=.042$) and sex by pulse by mile ($F(30,600)=1.617$; $p=.021$, $\eta^2=.218$).

2.4. Discussion

Both for the "pure" control (no HUD, all lights off) and the alternative control (no HUD, all lights on) conditions there were relatively uniform travel speeds through the work zone -- i.e., whether the work zone lighting was all on or all off, as long as it was uniform, there was no evidence of spontaneous tendency to change speed in the work zone. In contrast, LGD conditions caused a tendency to accelerate through the zone.

The results of this simulation experiment indicate that pulsing lights traveling in the same direction as a moving vehicle have the potential to increase vehicle speed by altering the driver's perception of velocity. When drivers had uniform optical flow cues, their tendency was to travel at uniform speed. When the optical flow cues were manipulated by causing the lights to pulse in the same direction as the driver, the net result was a tendency to accelerate. Although there appears to be a suppression effect of the HUD, wherein drivers suppress the spontaneous tendency to accelerate by referencing their speedometer, the data support the trend that this acceleration tendency "leaks through" the suppression effect anyhow. This suggests the lane deviations might have been greater if the standard speedometer display were used and that potential benefits of LGDs may be removed by HUDs. This is a non trivial issue since HUDs are being implemented on many new cars [8].

While it was expected that the greatest change would occur in the first 1/10th mile, when drivers had their initial reaction to the abrupt change in optical flow (e.g., an alerting or orienting response), this did not happen. LGD effects appear to be associated with exposure duration or distance in the zone.

Unanswered by Experiment 1 was the effect of pulse direction (pulses went forward but not backward), color of the pulses (only white was tested), and zone entry speed (participants entered at speeds of their own choosing). Experiment 2 was designed to address these issues.

3. EXPERIMENT 2

3.1. Introduction

Experiment 1 identified sex differences that required further investigation. Since other studies have identified sex/gender differences in time perception in driving tasks [9], it seemed prudent to investigators to increase statistical power by foregoing the age variable in order to double the sample size of the sex/gender variable.

Because of prior experience with certain colors of lights in traffic situations, drivers may have preconceived expectations or stereotypes for the meaning of specific colors (e.g., red means stop) making color a potentially powerful stimulus code.

Experiment 1 permitted participants to enter the work zone at speeds of their choosing so needed in Experiment 2 was systematic manipulation of vehicle entry speed into the zone, at least testing fast and slow entry speeds. Few previous studies have investigated the relationship of initial speed and speed through work zones [10].

Thus, the purpose of Experiment 2 was to investigate the effects of driver sex, pulse color, pulse direction, and zone entry speed through a 0.7-mile zone.

3.2. Method

The method used in Experiment 2 was nearly the same as that used in Experiment 1 with a few exceptions as noted.

Participants. Twenty-four healthy licensed drivers from the University of Minnesota and surrounding community volunteered to serve as paid (\$10) participants in this experiment: 12 males and 12 females of similar age and driving experience.

Color of Lights. The limited amount of time in the simulator before symptoms of simulator sickness appeared permitted only two colors to be investigated: red/amber and green of equal luminance. These colors were selected to maximize distance between the two colors perceptually and conceptually -- amber for caution, red for stop, and green for go.

Pulse Pattern. A single pulse pattern of 7on:3off was used because it caused a greater acceleration effect than 5on:5off in Experiment 1. The two control conditions used in Experiment 1 showed nearly identical results but subjective responses from the participants indicated that having any lights in the zone was more distracting than none. Therefore, all lights on was used as the control for this experiment.

Pulse Speed and Direction. Twenty-five mph forward was used to determine if drivers continue to drive 8-12 mph faster than the pulse as seen in Experiment 1;

50 mph backward was chosen to match Experiment 1 pulse speed but in the reverse direction; 0 mph was selected as a control condition.

Zone Entry Speed. Entry speeds of 40 and 70 mph were arbitrarily selected as slow and fast speeds.

As part of the search for optimal lane delineation and traffic flow a jersey barrier was inserted beneath the flashing lights. The actual barrier height emerged from the horizon and increased to seven inches at full loom (relative height in the virtual environment was 36").

3.3. Results

Speed and lane deviation data were analyzed according to sex2 x color2 x pulse direction3 x zone8 mixed ANOVA designs with repeated measures on the last three factors.

Speed (mph). Figure 2 illustrates the overall pattern when all data for all participants across all conditions are presented as a function of zone entry speed and zone location.

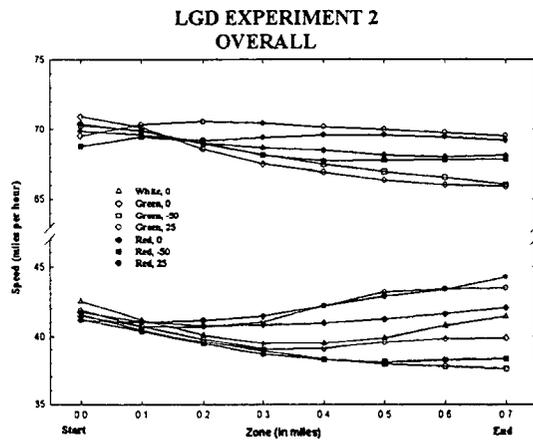


Figure 2. Speed through zone as a function of entry speed, light color, pulse direction, and zone location across all 24 participants.

Zone Entry at 40 mph. Analyses of data with zone entry speeds of 40 mph revealed that travel through the zone was fastest (42.1 + 5.8 mph) with forward LGD pulses and slowest (39.0 + 5.0 mph) with backward pulses compared with stationary lights (40.6 + 5.0 mph; $F(2,48)=10.200$; $p<.0005$; $Eta^2=.004$) (see Figures 2 and 3). Pulse direction by zone location was also significant ($F(14,336)=10.558$; $p<.0005$; $Eta^2=.003$) with little difference at the beginning of the zone and increasing LGD effects appearing toward the end of the zone.

Zone Entry at 70 mph. Analyses of data with zone entry speeds of 70 mph revealed LGD effects but only in

the latter portion of the zone as shown in the pulse direction by zone location interaction ($F(14, 336)=2.428$; $p=.003$; $Eta^2=.132$) shown in Figures 2 and 3 – travel through the zone was fastest with forward LGD pulses and slowest with backward and stationary pulses. Overall there was a decline in speed while progressing through the zone ($F(7,168)=3.118$; $p=.004$; $Eta^2=.090$). There was also a color by zone location interaction ($F(7,168)=3.130$; $p=.004$; $Eta^2=.090$) where green lights caused the greater slowing through the zone than red. However, the effects of pulse direction and color of lights must be interpreted relative to the interactions each of these factors had with sex of the driver. There was a sex by pulse direction by zone location was not as pronounced at a zone entry speed of 70 mph compared with a zone entry speed of 40 mph. The sex by color interaction ($mg=69.3 + 6.6$, $mr=68.5 + 7.0$, $fg=67.9 + 4.9$, $fr=69.3 + 5.5$ mph; $F(1,24)=4.982$; $p=.035$; $Eta^2=.035$) is especially pronounced in females causing the sex by color by zone location interaction ($F(7,168)=2.914$; $p=.007$; $Eta^2=.101$).

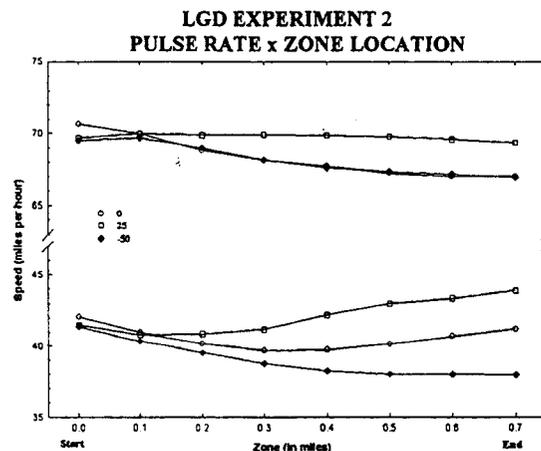


Figure 3. Pulse rate/direction by zone location by zone entry speed across all participants.

Lane Deviation (Swerve). Analyses of lane deviation data in a sex2 x color2 x speed3 x mile8 mixed ANOVA design with repeated measures on the last three factors was conducted after partitioning the data by zone entry speed. For zone entry at 40 mph, only one contrast was significant -- across conditions there was an increase in lane deviation with increasing distance in the zone ($F(7,168)=2.722$; $p=.011$; $Eta^2=.112$). For zone entry at 70 mph, no contrasts were significant.

3.4. Discussion

The effects of pulsing lights on vehicle speed through work zones depends on sex of the driver, zone entry speed, direction of the pulsing lights, color of the lights, and location within the zone. Forward pulses compared with controls cause vehicle acceleration but only for those entering the zone slowly and only after about 1/2 of a mile in the zone. However, as seen in Experiment 1, the forward pulsing lights may produce greater effects at 50 mph than at 25 mph. Backward pulses slow vehicles in the zone, regardless of entry speed, almost immediately upon entering the zone, especially if the lights are green and more so for males at slow entry speeds and females at fast entry speeds.

4. GENERAL DISCUSSION

Although the validity of driving simulators in evaluating speed reducing measures is known [11, 12], the true effect of LGDs in actual traffic conditions remains to be seen. This information helps development of algorithms for servo-regulation of LGDs via monitoring of information coming from road sensors.

Controlling the speed of vehicles traveling through work zones is an important safety as well as traffic management goal. Often drivers' are unfamiliar with the work zone and may become confused and lose control of their vehicle thus making lane delineation also important. The smooth flow of traffic through work zones would reduce rear-end and other collisions, increase construction worker safety, and improve traffic management in areas surrounding the work zone.

5. ACKNOWLEDGMENTS

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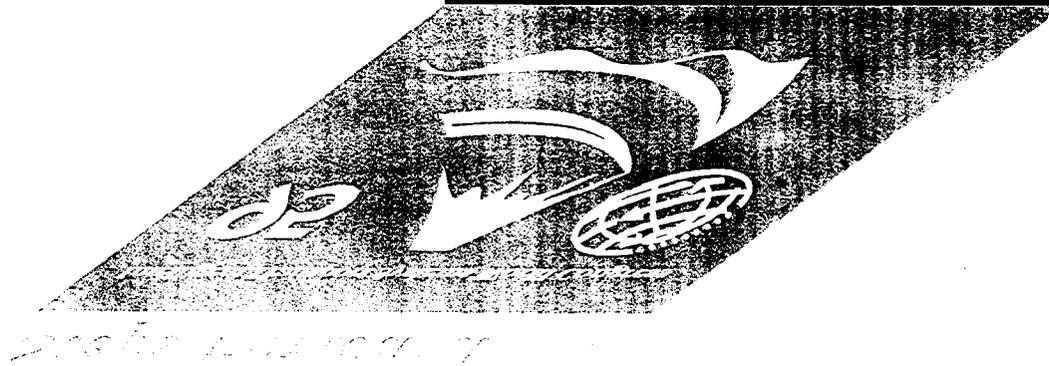
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PROCEEDINGS

“Steps Forward”

VOLUME III



**The Second World Congress
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'95 YOKOHAMA**

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APPENDIX M.
LGD3 (Proceedings of the 2nd ITS World Congress)
***Lighted Guidance Devices*^{#3}: Environmental Modulation of
Drivers' Perception of Vehicle Speed Through Work Zones**

Max Vercauysen^{1,2,3,4}, P.A. Hancock², Gayna Williams²,
Olukayode Olofinboba², Marthand Nookala⁵, and Dennis Foderberg¹

¹ Intelligent Transportation Systems Institute, CTS, University of Minnesota, Minneapolis, MN, USA

² Human Factors Research Laboratory, University of Minnesota, Minneapolis, MN, USA

³ Instituut voor Gerontechnologie, Technische Universiteit Eindhoven, Eindhoven, NL

⁴ Pacific Islands Geriatric Education Center, Univ of Hawai'i School of Medicine, Honolulu, HI, USA

⁵ Minnesota Guidestar Program, Minnesota Department of Transportation, St. Paul, MN, USA

ABSTRACT

This experiment (#3 in a series) investigated the effects of pulsing lights, which gave the illusion of movement (Phi phenomenon), on drivers' perception of motion and vehicle speed through work zones.

Forty drivers participated: 20 young (10 female, 10 male; 21-42 yrs) and 20 older adults (10 female, 10 male; 55-87 yrs). Each participant made 15 passes through a work zone in the virtual world of a driving simulator: a control pass with stationary white lights, two control passes with no lights, and 12 passes of test conditions -- 2 colors (red & green) x 3 apparent pulse speeds (-80, 0, & +80mph) x 2 zone entry speeds (40 & 70mph).

Age, sex, and zone entry speed differences were found, but overall, (1) backward moving lights (-80mph) caused drivers to reduce their vehicle speed, (2) forward moving lights (+80mph) caused drivers to increase their vehicle speed, (3) stationary light and control lights had little or no effect, and (4) green produced stronger effects than red.

1. INTRODUCTION

With respect to safety, this report examines an approach to control traffic flow through work zones. Work zones prove particularly dangerous to drivers since they present uncertain conditions with multiple cues of a novel and sometimes ambiguous nature. Work zones are even more troublesome for workers who may be required to perform functions mere feet from passing vehicles with little or no protection. Little wonder incursions into work zones are frequent and most destructive events. The present work concerns a lighted guidance device (LGD) to promote safe and efficient passage through the work zone. While lighted guidance may provide cues to directional control, the present research focuses on the perceptual field for vehicle velocity control.

This experiment investigated the hypothesis that pulsing lights alongside the roadway could modulate traffic flow causing regression to a criterion speed, i.e., slowing vehicles entering the zone faster than a criterion speed and raising the speed of vehicles entering the zone slower than the criterion speed. The pulsing lights, which gave the illusion of movement (the Phi phenomenon), were positioned parallel and lateral to the roadway of a simulated work zone in the virtual world of a driving simulator. By sending pulses of lights moving alongside the driver it was hoped that drivers would spontaneously and unconsciously modulate their speed to synchronize with that of the light pulses.

LGD Experiment 1 examined the effects of driver age, driver sex, light pulse characteristics (all lights on; all lights off; 50 mph forward pulses, 5 on / 5 off; 50 mph forward pulses, 7 on / 3 off), speedometer feedback, and vehicle location within the zone. Despite age and sex differences, 24 drivers showed vehicle acceleration throughout the zone associated with forward pulsing lights compared to control conditions.

LGD Experiment 2 investigated the effects of driver sex, light pulse direction (25 mph forward, stationary, & 50 mph backward), light color (red & green), zone entry speed (40 & 70 mph), and location within the zone on vehicle speed and lane tracking for 24 drivers. Results replicated those of Experiment 1 showing vehicle acceleration to forward pulses and slowing to backward pulses plus a slight advantage of green lights compared to red and white lights. Based on the results of Experiments 1 and 2, LGDs appear to affect drivers' perception of velocity and vehicle speed: green lights atop jersey barriers pulsed in a forward direction at 25 mph or faster increases the speed of vehicles entering the zone at 40 mph or less and backward pulsing lights at 50 mph or faster decrease the speed of vehicles entering the zone at 70 mph.

Experiments 1 and 2 provided initial evidence that apparent motion and one's perception of velocity could be systematically manipulated to influence the speed at

which volunteers drove through work zones in the virtual environment of a driving simulator. However, the magnitude of this effect was small and varied according to a number of variables. Experiment 3 was designed to manipulate the variables from Experiments 1 and 2 which most influenced LGD effects in order to increase the power of LGDs in modulating vehicle speed. Specifically, the purpose of this experiment was to investigate the effects of driver age, driver sex, pulse direction, pulse color, zone entry speed, and location within the zone on vehicle speed and lane deviation.

2. METHOD

2.1 Participants

Forty healthy drivers volunteered to be participants in this experiment (see Table 2.1). Twenty young participants were recruited from the University of Minnesota population, including both students and employees. The twenty senior participants were predominantly recruited from the University Retirees Volunteers Association, or their friends. Each participant received ten dollars upon completion of the experiment.

Table 2.1. Participant Demographic Characteristics

<i>Item</i>	<i>Younger Female</i>	<i>Younger Male</i>	<i>Older Female</i>	<i>Older Male</i>
Volunteers/group	10	10	10	10
Mean age (yrs)	26.5	30	71.7	71.1
Age range (yrs)	21 - 36	22 - 42	66 - 78	55 - 87
Years driving	10.8	13.5	52	54.7
Hours driving/week	8	11.9	8.1	10.5
Yearly mileage	10111	11570	5812	9,500
Weekly mileage	216.7	165	67	161.7

2.2. Experimental Task

Each participant completed a driving simulator session which lasted approximately 30 minutes during which they drove 15 times down a straight road in the simulator's virtual environment. Each participant was requested to reach one of two specified speeds before entering the work construction zone: 40 or 70 mph. After entering the work zone, the participant was to drive in a comfortable manner, similar to how (s)he would in his/her own car at night through a construction zone. In the experimental conditions lights appeared on top of a 36" high wall on each side of the roadway. The lights were manipulated in three ways: they were on all the time, they gave the

appearance of moving at 80 mph towards the driver, and they gave the appearance of moving away from the driver at 80 mph. The color of the lights was either green or red.

2.3. The Automobile Simulator

This experiment was conducted on a fixed-based front-display driving simulator using a 1990 Honda Accord and equations of motion which modeled this vehicle. Essentially, driver behaviors like accelerator, brake, and steering movements were converted from analog to digital signals through a VMIC 3100 64-channel A/D board (using voltage divider circuits) and made input information into a model which approximated the vehicle. Outputs from this model were then used to adjust the eyepoint of the driver in the environment according to the inputs provided. Changes in the virtual visual environment were made in near real-time at least 15 times per second (in most experimental situations the cycle times are 30Hz or better) making the perception of the driver one of actual driving. Generation of virtual environments was controlled by a Silicon Graphics IRIS 4D/310 VGXT graphics mini-computer with a 4-channel video splitter using custom software developed on VAPS, Multigen, and Designer's Workbench.

The front flat screen was 116.5 x 86.25 inches (26.5 inches from bottom of screen to ground) at a distance of approximately 104 inches from the eyes of the average height seated participant (eyes approximately 48 inches above the ground). An Electrohome ECP 3100 projector, mounted approximately 79 inches from lens center to ground was used to generate all virtual environments. The projected image dimensions were 91.5 x 71.5 inches. The field of view height was 63 inches from the bottom of the projected image and the width included all of the projected screen (> 116.5 inches).

2.4. Virtual Environment

Objects were texture-wrapped polygons in convenient formats (e.g., rgb or tiff) to store pixel and color information. The maximum road width at the bottom of the image was 35 inches; the minimum road width at the horizon was 1.75 inches at 11.5 inches above the bottom of the projected image frame. The simulated LGDs were round flashing lights (4 inches in diameter) characteristic of conventional roadway flashers, but synchronized for sequential flashing. The lights were spaced eight feet apart on each side of a flat, straight roadway, four feet outward from the edge of the pavement (i.e., on the shoulders), at an elevation of 40 inches (4" light atop of a 36" lane dividing barrier) above the roadway, and at a sufficient intensity to be visible at 2000 feet. The actual largest diameter of the light (at full looming) was 0.56

inches and its minimum diameter (at the horizon) was indistinguishable from the background. The roadway simulated was straight and flat 24 ft lane with about 1/3 of a left lane visible.

Based on findings from piloting and Experiments 1 and 2, the pulse width (i.e., distance between unlighted sections of the device) was set at 7 on / 3 off with motion simulated at 80 mph forward and backwards. Data collection began with no lights present for 0.15-mile before the 0.7-mile zone in which LGDs were tested and continued for 0.15-mile after with no lights present. Also, evening lighting conditions (moderate darkness) were simulated (approximately 20:00h).

Haptic noise was added to the steering to simulate uneven road surface and crosswind effect thereby making the simulator "feel" more like an actual car being driven on a typical roadway. The steering torque motor patterns of noise were designed to be completely random and nonintrusive to vehicle tracking within the lane.

Yellow skip line cues (4" x 10' with 40' spaces between lines) were provided on the pavement as a left-side lane divider and simulated "farmers' fields" of approximately 0.25-mile wide were presented on each side of the roadway to facilitate speed estimation. The right edgeline was white, continuous, and 4" wide.

2.5. Design and Independent Variables

There were three directions of lights: towards the driver (-80 mph), stationary (0 mph), and with the driver (+80 mph). There were two color of lights: red or green. Two zone entry speeds were used: 40 and 70 mph, ± 5 mph. Two organismic factors of interest were age (young vs. old) and sex (male vs. female). The final design was a 2 (age) x 2 (sex) x 3 (direction of lights) x 2 (color of lights) x 2 (entry velocity into construction zone) with repeats on the last three factors.

The first and last conditions were control conditions. The participant entered the construction zone at 40 mph, and no lights were given on top of the concrete wall. A catch trial was included in the middle of the trials in which the driver entered the construction zone at 40 mph to see stationary white lights.

2.6. Dependent Measures

Continuous velocity (mph) and steering data (decimal miles) were collected throughout each trial at a sampling rate of at least 10 Hz, from the initiation of the trial, until the trial was terminated by the experimenter.

2.7. Procedure

After the participants had signed a consent form they were taken to the driving simulator where each

participant was made to feel comfortable in the vehicle by being instructed on how to adjust the seat in order to easily reach the pedals and view the projection screen. Instructions were given on how to drive the car in the simulated environment. Before the experimenter left the simulator room, each participant was informed that there was a microphone and speaker in the car in order for two way communication to take place during the session.

The volume of the communication between the experimenter and the participant was adjusted in order for instructions to be heard clearly. The experimenter read a text of instructions to the participant. If the participant interrupted while the instructions were being read, the experimenter would answer questions. It was important that the instructions were read in their entirety so that each participant received a minimum number of instructions to complete the task, however it was also important for the participant to feel comfortable in the driving simulator environment. After the task had been explained to the participant, a request for questions from the participant was encouraged. The task was reiterated once more in a formal way.

The experimenter decided whether to provide extra instructions on how to drive in the simulator dependent upon the apparent comfort level of the participant. Extra instructions, usually only related to use of the accelerator, were very brief.

The task required participants to enter a lighted construction zone at two speeds, 40 and 70 mph, ± 5 mph. The participant had use of the gas, brake, and steering wheel. The driver did not have access to the speedometer as it was distracting from the driving task, and therefore an awareness of speed was achieved by having the experimenter read aloud the speed of the driver's vehicle as it was displayed only on the experimenter's console. The experimenter was well practiced in helping participants accelerate or decelerate as needed to enter the zone at the specified speed. It was the intent of any such advice to assist the driver to reach the target speed prior to reaching the construction zone. If zone entrance speed was not ± 5 mph of the required speed, the condition was repeated at the end of the session.

2.8. Treatment of Data

The work zone was divided into seven 0.1-mile sections and an additional 0.1-mile section was included prior to entering the zone. For each of the eight sections the mean velocity lane deviation was calculated by using all the values recorded over that section.

For both velocity and steering performance, data were analyzed according to a 2 (age) x 2 (sex) x 2 (color of lights) x 3 (direction of lights) x 2 (entry velocity into work zone) x 8 (location in work zone) mixed analysis of variance (ANOVA) design where the last four factors

were repeated measures. For each entry velocity, for both velocity and steering performance, a 2 (age) x 2 (sex) x 2 (color of lights) x 3 (direction of lights) x 8 (location in work zone) mixed ANOVA with repeated measures on the last three factors was used.

The first and last trials were analyzed separately using a 2 (age) x 2 (sex) x 2 (trial) mixed ANOVA design. An ANOVA was also completed on all the trials at 40 mph, this included the controls, the white light condition, and the other six, 40 mph experimental conditions using a 2 (age) x 2 (sex) x 9 (conditions) design.

3. RESULTS

Analyses were conducted on 12 data sets with results of five here reported: (1) vehicle velocity data using combined zone entry speeds, (2) vehicle velocity data for zone entry at 40 mph, (3) vehicle velocity data for zone entry at 70 mph, (4) distance to synchrony data, and (5) lane deviation data.

3.1. Velocity Change for Combined Entry Speeds

Analyses of vehicle speed through the work zone revealed thirteen significant contrasts: two main effects and eleven interactions. The direction of the light pulse was reported in nine of the effects and entry speed in six. Thus, separate ANOVAs are reported for the 40 and 70 mph entry speed conditions. Figure 1 shows the entry speed into the work zone to be 55 mph, which is a result of forcing drivers to enter the zone half of the passes at 40 mph and half of the passes at 70 mph.

After separating the data by entry speed, two four-way interactions were significant: age by direction of light pulse by light color by zone location ($F(14,504) = 1.74$; $p = 0.0452$), and age by sex by direction by zone location ($F(14,504) = 2.43$; $p = 0.0026$). The two most extreme curves were both for green lights: forward pulses cause an increase in vehicle speed through the zone, especially for older driver, and backward pulses cause a slowing of vehicles, especially for young drivers.

There appears to be very little change in velocity throughout the work zone for the stationary pulse lighting condition. The effect of direction of pulse and color of lights can be seen clearly in Figure 1, which illustrates a three-way interaction of pulse direction by light color by zone location ($F(14,504) = 3.5$; $p = 0.0001$). The age by pulse direction interaction was also significant ($F(14,504) = 2.02$; $p = 0.015$), such that the older adult drivers appear to be more affected by the lights traveling in the same direction as they are driving, and less influenced by the lights moving against them (mean speed on zone exit: fwd = 59.82, stat = 53.88, bkwd = 51.89), both the

directions of the pulse influence the behavior of younger drivers, unlike the stationary light condition (fwd = 58.71 stat = 56.10, bkwd = 48.39).

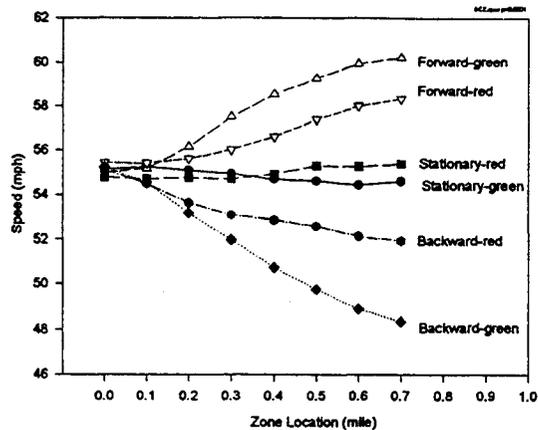


Figure 1. Mean vehicle velocity as a function of direction of light pulse, color of light, and location in zone ($p = 0.0001$).

In the second four-way interaction, the results relating the change in speed through the work zone with respect to the direction of the light pulse is the same (main effect: $F(2,72) = 26.98$; $p = 0.0001$ (forward > stationary > backward). Large changes through the work zone were found for the young females -- they appeared to drive fast when the lights were forwards (mean = 60.63) and slowly when the lights were pulsing backwards (mean = 47.90). In contrast the older females behavior was moderately effected by the direction of the lights (fwd = 61.10, bkwd = 52.44). The males appeared to show almost opposing behavior with regards age groups. The older males exited the zone in the forward condition the fastest, and yet in the backward light condition were the slowest (fwd = 61.10, bkwd = 52.44), and the opposite is virtually true for the younger males, who were the slowest in the forward light condition, and just ahead in speed of the young females in the backward pulsing condition (fwd = 56.79, bkwd = 51.34). Clearly the effects of LGDs varies as a function of age and sex. The effect of pulsating lights may be less prominent in older than in younger adults ($F(2,72) = 3.22$; $p = 0.0459$).

3.2. Velocity Data for Zone Entry at 40 mph

Participants were requested to enter the construction zone at 40 mph in this condition, having been primed (biased) with instructions to enter zone while driving in a manner that felt comfortable. The ANOVA results compared well with those of vehicle velocities through the zone when collapsed over the two entry speeds.

The significant three-way interaction illustrated in Figure 2 is for direction by color by location ($F(14,504) =$

3.44; $p = 0.0001$). The relationship between the color of the lights and the exit speeds suggests that the red lights do not have as strong an effect in the pulsating light conditions as the green lights (fwd-green = 52.24, fwd-red = 49.18, bkwd-green = 43.57, bkwd-red = 43.57). The relationship between the absolute velocities on exiting the work zone and the direction of pulse of the light still presents the format of forwards lights producing higher speeds than the stationary than the backward condition as in the ANOVA results collapsed across entry speed (main effect: $F(2,72) = 17.34$; $p = 0.0001$). However in considering the relative velocity to which the driver entered the zone a new picture is presented. The forward pulsating lights produced a dramatic increase in speed from the entry speed of 40.78 mph to 50.71 mph, and even an increase for the stationary condition, compared with stationary lights which produced the customary "slow entry acceleration" of 6 mph from the beginning to the end of the zone. The red light in the backward condition followed a similar increase to the green stationary condition but not as great. The condition that showed very little change, 1 mph increase across the zone, was exposure to the green backward pulsating lights.

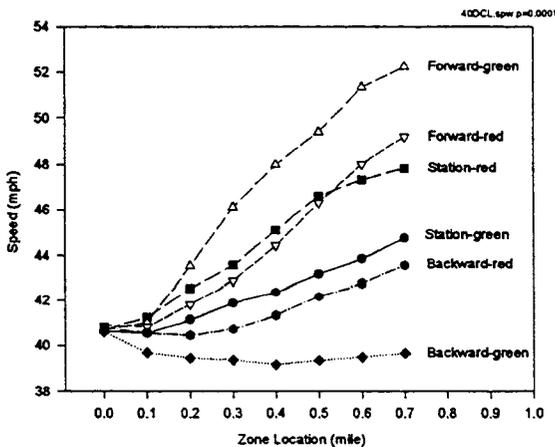


Figure 2. Mean vehicle velocity through the work zone following entry at 40 mph as a function of direction of light pulse, color of lights, and zone location ($p = 0.0001$).

The four-way interaction, illustrates a similar trend to the previous figure. Whenever vehicles enter at slow or fast speeds, relative to approximately 55 mph, there is a tendency to accelerate or decelerate, respectively, toward a middle speed. This is evident in these data by observing the pattern of acceleration from 40 mph seen in the stationary lighting. Regarding LGD effects a slow entry speeds, four of the five lowest exit speeds are for the backward pulsating light condition and approximately equal the entry speed indicating that backward pulse here thwarted the tendency to accelerate through the zone.

Apparently a "floor effect" is acting here to prevent further slowing of slow entering vehicles. The forward pulsating lights cause considerable acceleration, especially for young female and older male drivers. Of the four age by sex groups, young male drivers are the only group to violate the direction of the pulsating light effect as performance for the stationary condition provided a slightly faster time than for the forward condition (stat = 48.03, fwd = 45.84).

The five-way interaction basically illustrates that LGD effects vary as a function of all of the factors investigated. When entering work zones at 40 mph, backward pulses cause drivers to maintain their speed throughout the zone with little effect of driver age, driver sex, and color of lights. However, forward pulsating lights cause drivers entering the zone at slow speeds to accelerate and this effect is especially pronounced in young females when using green lights.

3.3. Velocity Data for Zone Entry at 70 mph

Only one, three-way interaction was significant: direction by color by zone ($F(14,504) = 1.85$; $p = 0.03$) (see Figure 3). When the entry speed is 70 mph there is some decrease in speed in all the conditions, as expected by the regression to the mean phenomenon. However, the decrease is negligible in the forward pulsating light (exit speeds of 68.16 mph for the green lights and 67.49 mph for the red lights) suggesting that the tendency to slow for fast entry vehicles was counteracted by the forward pulses to maintain a constant high speed at the ceiling of driver comfort through the zone. A larger decrease is found in the stationary condition, again with green being faster than red (64.44 and 62.94 mph, respectively). There is a reversal in the slowing order of the color of lights for the backward pulsating condition such that the exiting speeds are 60.29 mph for red and 57.03 mph for green. The decrease in speed caused by forward pulsating greens is dramatic (70 mph at entry to 57.03 mph at exit). Unlike individual responses for slow entering vehicles, age and sex of the driver were not significant factors affecting LGD effects for vehicles entering the zone at 70 mph.

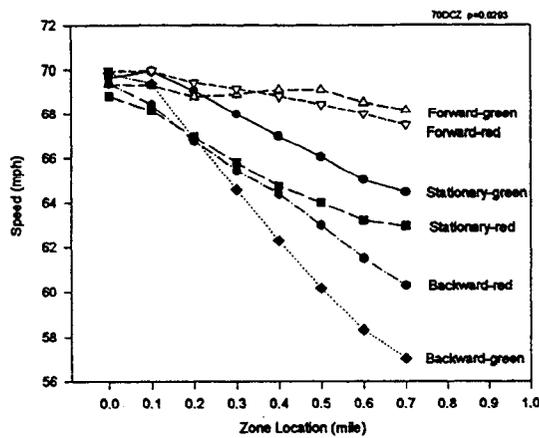


Figure 3. Significant interaction for direction of light pulses by color of light by zone location, for the 70 mph entry speed ($p = 0.0293$).

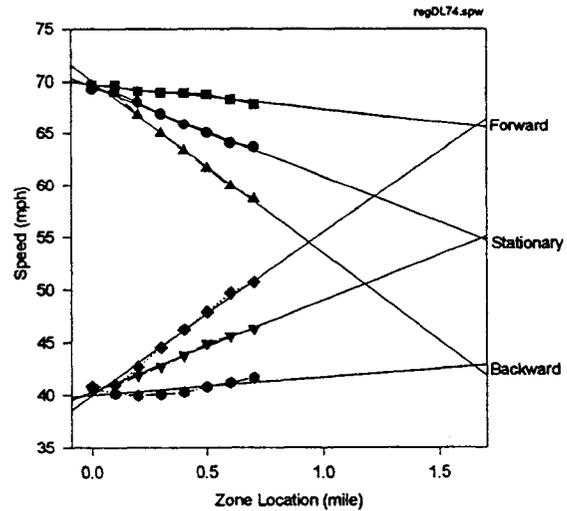


Figure 4. At 1.7 miles into the zone vehicle velocity is predicted to stabilize regardless of entering the zone at 40 or 70 mph, when displayed as a function of pulse direction.

3.4. Extrapolation to Predict Synchrony

This experiment was designed to investigate the interaction of factors affecting the effectiveness of LGDs in modulating driving behavior through work zones. Given that vehicle velocity covaries with the direction, velocity, and color of pulsing lights, it became intuitively interesting to assess the point at which the drivers' perception of self-movement in relation to the optical flow of LGDs in the environment were comfortable or synchronous, i.e., the point at which, regardless of entry speed, the driver is comfortable with their speed in relation to the objects passing in their immediate environment. Assuming linear regression extrapolations are remotely appropriate here, it is possible to illustrate the distance into the zone at which drivers might find LGD effects disappear, i.e., where the vehicle speed stabilizes regardless of whether entering the zone at 40 or 70 mph based on pulse direction and color of the lights. Taking these same data and collapsing over color, Figure 4 illustrates a simplified version of the logic of predicting driver comfort for perceptual monitoring of self-motion, environmental motion, and artificial devices producing apparent motion cues to synchronize events or to reduce mental effort.

3.5. Lane Deviation (Steering Swerve)

Lane deviation was carefully monitored as a measure of steering or tracking accuracy. However, despite finding significant changes in this measure the magnitude of these effects (mere inches of swerve on a highway) seems relatively unimportant. In other words, LGDs affect vehicle speed much more than they do steering behavior.

4. DISCUSSION

The data are unequivocal in their recognition of the velocity control factor in the manipulation of the environmental display. Founded in perceptual psychology, the present conception illustrates the interactional properties of color, direction, and speed in influencing driver velocity control. If this interactive 'field' of factors is more fully specified, it argues strongly that an effective control device can be instituted such that work zone speed may be changed according to the display presented. How such a manipulation will directly influence safety has yet to be theoretically and empirically articulated to its fullest extent. However, the present findings are most encouraging that this effect should be real. If successful, it might represent a true ITS technology to promote both driver and worker safety.

It appears that LGD Experiments 1-3 are the first attempts at systematically manipulating LGD parameters to determine their effects on perception of self motion and thereby influencing vehicle velocity through work zones. Much needed now are field applications which validate findings from the simulator.

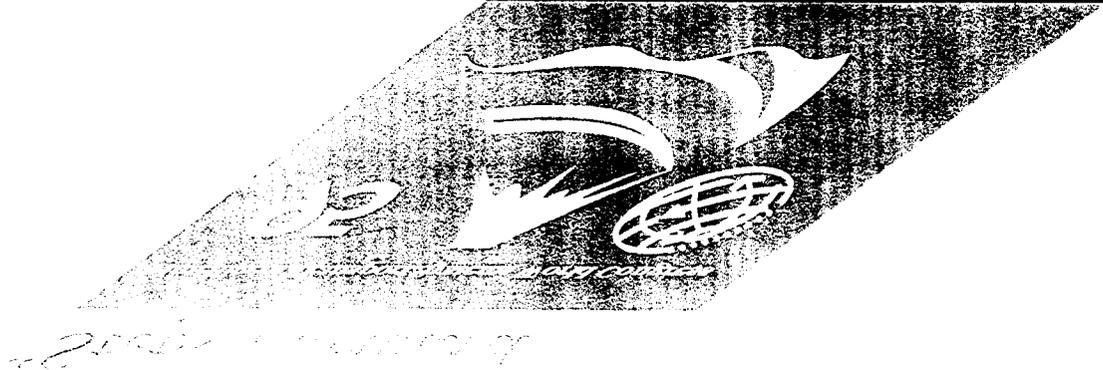
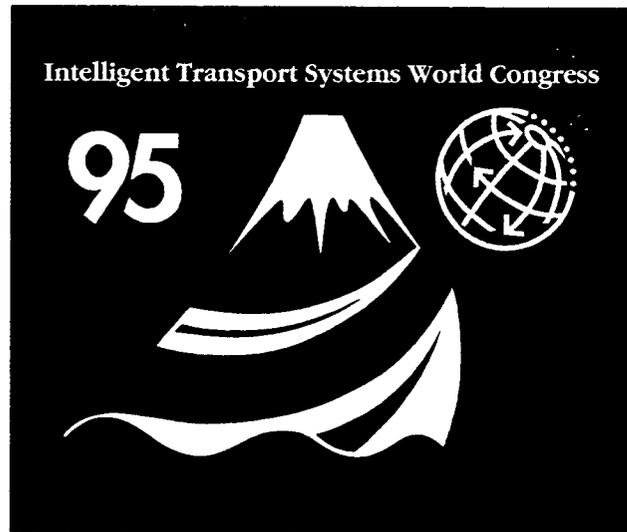
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PROCEEDINGS

“Steps Forward”

VOLUME IV



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VERTIS: Vehicle, Road and Traffic Intelligence Society
2-3-18, Kudan-Minami, Chiyoda-ku, Tokyo 120, JAPAN

