PERGAMON

Accident Analysis and Prevention 34 (2002) 763–772

ACCIDENT ANALYSIS & PREVENTION

www.elsevier.com/locate/aap

Signal detection in conditions of everyday life traffic dilemmas

Tova Rosenbloom *, Yuval Wolf *

Department of Criminology, Bar-Ilan University, Ramat Gan 52900, Israel

Received 8 November 2000; received in revised form 4 April 2001; accepted 10 June 2001

Abstract

This paper shows how the *paradigm of signal detection* could serve as a viable means for the analysis of drivers' choices in conditions of everyday life traffic dilemmas. The participants were 28 drivers, most of them professional, who spend at least 6 h a day on the road. All agreed to have a note-taking silent passenger for the entire journey, every day during a period of 3–4 weeks. All completed the sensation-seeking questionnaire. Their 'to do or not to do' choices in conditions of four (out of a total of six) traffic dilemmas (amber light, distance keeping, stopping in road-crossing and merging in routes) were analyzable in terms of a modification of the paradigm of signal detection. In accord with the basics of the paradigm of signal detection, the rate of success of the drivers to detect signals of danger on the road (perceptual sensitivity) fell into the range of partial uncertainty (more than 50% and not too much above this level)! The choices made by thrill-and-adventure-seeking drivers were more lenient than the choices of the drivers who scored lower on this dimension.

Keywords: Signal detection; Traffic dilemmas; Sensation seeking

1. Introduction

1.1. Detection of road signals

The psychology of driving, though being field oriented, is well developed in terms of theoretical thinking aimed to account for safety issues (e.g. Rothengatter and Vaya, 1997). There is, however, a shortage in efforts to account for related issues by means of substantive paradigms aimed to elucidate a variety of psychological phenomena. This paper presents an attempt to exemplify how a framework, such as *the paradigm of signal detection*, could serve as a viable means for the analysis of drivers' choices in conditions of everyday life driving dilemmas.

S*ignal detection* as a scientific construct relates to a cognitive process where an individual observer attempts to detect a familiar signal that is expected to appear on the background of a compound of internal and external noise. The observer participates in a series of such guessing attempts in conditions of partial uncertainty. In each trial s/he has to decide whether or not a stimulus is present (Green and Swets, 1966; Macmillen and Creelman, 1991; Swets, 1996).

The paradigm of signal detection postulates that the observer's response may derive from two independent sources. One source, *perceptual sensitivity*, relates to the observer's ability (relative success) to discriminate between *noise + signal* and *noise alone* in a given series of detection trials. Expectedly, this sensitivity is resistant to situational effects, especially those affecting the other source, *decision criterion*. The criterion is expected to change as a function of two sorts of factors: (1) prior exposure to the relative emergence of noise + signals (a-priori probability), and (2) positive or negative rewards (payoff matrix). The paradigm merges a psychophysical conception of signal and noise with statistical decision theory.

The history of the paradigm of signal detection is multidisciplinary. More than half a century ago, studies in the fields of engineering (marine and aviation), physics and psychology were already conducted within this framework. Since then, the paradigm has been applied to a wide range of areas, such as polygraph machines, X-raying, radarscope and air traffic, and functioning of nuclear plants. Psychological applica-

* Corresponding authors. Tel.: +972-3-531-8983; fax: +972-3-574-1959.

E-mail addresses: rosenbt1@mail.biu.ac.il (T. Rosenbloom), wolfyu@mail.biu.ac.il (Y. Wolf).

0001-4575/02/$ - see front matter
PII: S0001-4575(01)00076-8

tions of the paradigm have focused on perceptual processes, vigilance, recognition and reaction time (Egan, 1975; Lappin and Uttal, 1976).

In the last decades, the range of substantive problems to which the paradigm has been applied has greatly broadened. It includes medical, paramedical and non-medical diagnosis, cognition and memory (Ackerman et al., 1996; Battaglia and Perna, 1995; Hanley and McNeil, 1982; McFall and Treat, 1999; Thelen et al., 1996).

The paradigm is being applied to 'softer' issues as well, such as child–mother interaction (Contole and Over, 1979) and diagnosis of personality dispositions and predispositions (Danzinger and Larsen, 1989; Hastrup, 1979; Harkins and Green, 1975; Stelmach et al., 1984) Recently, unconscious influences on memory were researched too (Jacoby et al., 1993). The paradigm is even applied to sales (Knowles et al., 1994), algebra learning (Rehdler, 1999) and psycholinguistics (Sobin and Alpert, 1999).

The *experimental session* of signal detection includes two classes of events, *noise alone* and *noise + signal*, which vary on a single dimension and have a fixed priority of occurrence. The observer makes a choice whether or not each event includes a signal. The entire set of trials generates a 2×2 stimulus–response matrix (Table 1).

No single matrix of this type provides an adequate description of the observer's performance since an estimate of the variation in the observer's criterion must also be obtained. At least two sets of trials facilitate a shift in decision criterion. Unconventionally, the present study examined the prospect of criterion differences between observers with two opposing predispositions — sensation seekers and sensation avoiders (see below).

The paradigm of signal detection provides a framework for analysis of choices made by road users. On-the-road danger signals, hard to predict, appear from time to time on the background of noise, i.e. a complex of irrelevant stimulation (e.g. Hoffmann, 1966; Hulthen, 1962; Newsome, 1974; Wolf et al., 1988).

In an illustrative study, conducted in the years 1958–1960, 42 army truck operators were observed on duty (Dobbins et al., 1961). The study was intended mainly to diagnose individual driver's levels of success in detecting signals of danger (i.e. perceptual sensitivity or vigilance) over a 7-h period of driving. In spite of distracting factors such as boredom and fatigue, the overall level of sensitivity was considerably high (83% of all critical signals were detected) and remained at that level throughout the driving period. Increased variability in the individuals' vigilance was observed in extra driving hours.

Table 1
Stimulus–response matrix of signal detection

Response	Stimulus event	
	Signal	Noise
Yes	Hit	False alarm
No	Miss	Correct rejection

Nearly three decades later, Wolf et al. (1988), following Newsome (1974), conducted a quasi-field study of signal detection, using the task of gap-acceptance in three levels of experimentally produced frustration. Each participant decided whether or not each of small spaced gaps was passable by his/her car. The findings point to the viability of the paradigm of signal detection as an appropriate means for the study of on-the-road choices.

Beyond these two studies, which involve a field examination of the paradigm of signal detection, laboratory applications of the paradigm to issues of road use are main stream (e.g. Haga, 1984; Lehto et al., 1998; Mihal and Barrett, 1976; Mongrain and Standing, 1989; Perchonok and Hurst, 1968).

The above mentioned quasi-field study of Wolf et al. (1988) was followed by a laboratory simulation. The authors indicate that this part of their study was not as informative as was their original study. In terms of mundane validity, however, even the former is a half-way progress, since it was conducted in a parking lot, not in everyday life conditions. This study is limited in terms of external validity as well, due to its focus on only one, marginally important, detection dilemma, i.e. gap acceptance.

A straightforward question emerges from this analysis: Does everyday life driving speak in terms of signal detection? This question is twofold. One puzzle is the researchers' ability to observe signal detection in a variety of meaningful road dilemmas, such as pedestrians' road crossing, amber light, distance keeping or merging in roundabouts. The other aspect of the question is whether or not the condition of partial uncertainty which typifies signal detection events (more than 50% success but not too much above this level) is an inherent component of choices made in conditions of everyday life driving dilemmas, recalling the pre experimental calibration in the study of Wolf et al. (1988). A positive empirical answer to this twofold question has a better prospect when drivers' choices in conditions of everyday life road dilemmas are observed, without any experimental interruption (see Hypothesis 1 in Section 1.3).

Such a study is in accord with the current trend of overarching between some aspects of psychological constructs (Staats, 1999). Here, an overarching between *state* and *trait* is needed (see also, anxiety-state and anxiety-trait, Seligman, 1971). A relevant such construct in the context of driving is *sensation seeking*, due to the apparent affinity between *risky choices* in conditions of road dilemmas and the motivation to *seek sensation*.

This affinity is evident, based on a variety of empirical examinations (see a review in Jonah, 1997). The findings, however, account for a relatively modest share of the relevant variance, i.e. road accidents and violations of road regulations. It is suggested here that an attempt to observe real-driving choices in terms of detection of risky signals by sensation seekers and sensation avoiders might advance the ability to account for inappropriate driver behavior.

1.2. Sensation seeking and on-the-road signal detection

Sensation Seeking means individuals' predisposed motivation to achieve an optimal level of arousal (Zuckerman et al., 1978; Zuckerman, 1994, 1999). The construct includes the following four factors: (1) *Thrill and Adventure Seeking* (TAS); (2) *Experience Seeking* (ES); (3) *Disinhibition* (Dis); (4) *Boredom Susceptibility* (BS). While s*ensation avoiders* need a minimal level of stimulation, *sensation seekers* are involved in various risky activities (Zuckerman, 1978) including risky driving (McMillen et al., 1989) were they are more daring and commit more violations (Jonah, 1997).

Zuckerman (1994) (pp. 368–369) found that high sensation seekers are faster and more accurate than low ones in response to most complicated stimulation. They also learn faster in settings of instrumental conditioning and when regarding a task as a great challenge, their performance is improved (Ball and Zuckerman, 1992). In terms of the present issue, sensation seeking is connected to reckless and risky driving (Arnett et al., 1997; Beirness, 1995; Burns and Wilde, 1995; Donovan, 1993; Elander et al., 1993; Furnham and Saipe, 1993; Hakamies, 1998; Heino et al., 1992; Horvath and Zuckerman, 1993; McMillen et al., 1989; West et al., 1992).

Specifically, sensation seekers over-speed, commit over-takings and tail-gatings, and drive while intoxicated more than sensation avoiders (Arnett, 1990; Beck, 1981; Donovan et al., 1983, 1985; Stacy et al., 1991; Stoduto et al., 1995; Wilson, 1992). They pass more cars, change lanes more often (McMillen et al., 1992) and avoid safety belts (Wilson and Jonah, 1988).

Sensation seekers perceive less risk than sensation avoiders in various driving situations and their perceived-risk and risky-driving are negatively correlated. They manifest better skills but poorer safety orientation (Heino et al., 1992; Horvath and Zuckerman, 1993; Jonah, 1997; McMillen et al., 1989; Yu and Williford, 1993). Generally, sensation seekers seem to over-trust their own driving skills, underestimate risk and are engaged in riskier driving compared to sensation avoiders.

Two of the four components of the construct of sensation seeking, i.e. thrill seeking and boredom susceptibility, are of special relevance to the psychology of road use. The relevance of the former element in the present context does not require any further elaboration for two reasons: firstly, it is almost synonymous with the original construct. Secondly, roads are dynamic and full of thrill and adventure stimulation. The latter element, boredom susceptibility, is defined by Zuckerman (1979) as the motivation to avoid monotonous, repetitious, expected and unvaried stimuli. Ball and Zuckerman (1992) (p. 830) suggest that sensation seekers might be able to avoid boredom by seeking challenging activities including risky ones (such as risky driving). Moreover, the traffic jams which typify modern urban roads, provide boredom avoiders an 'opportunity' to feel uncomfortable and restless, and thus to take more risk. Based on these findings, differences in detection responses in conditions of everyday life road dilemmas are expected. Sensation seekers are hypothesized to adopt a more lenient decision criterion than sensation avoiders (see Hypothesis 2, in Section 1.3).

1.3. Summary and hypotheses

Two hypotheses based on the distinction of the paradigm of signal detection between two sources of detection responses, i.e. perceptual sensitivity and decision criterion, are derived from the introduction.*Hypothesis 1* is related to the partially uncertain nature of driving dilemmas. If the notion of signal detection applies to on-the-road drivers' choices (not only to laboratory settings), where task difficulty is calibrated in advance to meet the required success ratio), then drivers' relative success in discriminating between 'noise + signal' and 'noise alone' (sensitivity) should be somewhat above 50% but not too much beyond that level. A rate of 50% or below, and a rate of 76% or above would violate the necessary requirement of partial uncertainty.

Hypothesis 2 is based on the nature of the mechanism behind the motivation to seek sensation or to avoid such an experience (see Section 1.2) and is related to the other component of detection responses, i.e. decision criterion. It is hypothesized that drivers whose TAS (thrill and adventure) and BS (boredom susceptibility) scores are in the upper part of the scale will adopt more lenient choices than drivers whose scores are in the lower part of the scale.

Table 2
Distribution of participants in the different conditions of TAS and driving speciality

Speciality	TAS score			
	Women		Men	
	Below MS	Above MS	Below MS	Above MS
Bus	3	1	4	1
Taxi	2	1	2	
Mini-bus		1	2	
Truck			1	1
Non-professional		1	1	7
Sum	**5**	**4**	**10**	**9**

2. Method

2.1. Participants

The participants were 28 drivers, nine females and 19 males, who are used to spending at least 6 h a day on the road (the range of monthly mileage is 2200–3500) over a period of 5–30 years. Their age range is 25–57 (mean = 36). These drivers were recruited by means of advertisements spread all over the state of Israel. All agreed to have a note-taking silent passenger for the entire journey every day during a period of 3–4 weeks. Each of the five taxi drivers was paid to compensate for a potential loss of income.

The participants' distribution of TAS scores by type of driving speciality is listed in Table 2. The table shows that even in such a relatively small self-selecting sample the participants are evenly located on the two banks of the TAS mid-score (5.5). This implies that the sample, beyond driving speciality, is viable in terms of sensation seeking. A reservation should be made regarding the men's sample, where most professionals are below the mid-score and most non-professional are above this score. The sample is too small to justify any speculation. Moreover, the detailed analysis below of the data indicates that this irregularity is not a source of any confounded effect.

Apparently, the type of driving speciality seems to be a greater jeopardy for the internal validity of the findings. This can be due to several well-known psychological sources. One possible source is the subjective extension of drivers' personal space as a function of the size of the car's internal volume (bus and truck drivers are assumed to feel more potent on the road than drivers of private cars do). Another source is de-individuation (such an effect is least likely in buses and most likely in trucks, private cars being in-between). Both sources have the potential of facilitating sensation seeking in drivers disposed to seek such an experience.

Nevertheless, from a conceptual perspective, these vectors and other potentially relevant vectors (such as professionals' experience, different operating characteristics of trucks and interaction between the type of vehicle driven and behavior), should expectedly be leveled by compensating forces, as implied from Wilde's conception of *Risk Homeostasis* (Wilde, 1982). Indeed, the below participant-by-participant analysis of the data (see especially Tables 4 and 6) does not reveal any such contamination. Moreover, if there was such a latent contaminating effect it should have leveled the predicted effect of decision criterion.

2.2. Design and procedure

Six major traffic dilemmas were selected for observation: amber light, distance keeping, stopping at a pedestrian cross-walk, merging in routes, keeping to the right, and yielding to police. The last two dilemmas were disregarded in the final statistical analysis. On an ad hoc basis keeping to the right came out irrelevant for taxi drivers, who enjoy the availability of many right side routes exclusive for public transportation. Yielding-to-police dilemmas were disregarded due to an insufficient relative frequency.Twenty-eight collaborators were recruited carefully to serve as note-taking passengers who record the driver's choices when facing road dilemmas. They were well-paid on a daily basis for their work. In order to minimize observer's bias, the note-takers were selected following a detailed questioning in a personal meeting deliberated to diagnose their approach to safe driving and their personal history as drivers and pedestrians was screened. Only those found to be safe and well-balanced decision-makers on the road were recruited. They were extensively trained (during a 6-h meeting) to sharpen and standardize their criteria for classifying the participant drivers' choices as reflecting either an acceptance of the situation as dangerous (noise + signal) or a rejection of the above assumption (noise alone).The note-takers were trained to use a simplified variation of the *rating procedure*, proposed by the paradigm of signal detection (Macmillen and Creelman, 1991), in order to sensitize their classifications. This procedure requires a confidence rating (on a five-point scale) following the yes–no choice. In the next phase, data analysis, only the dichotomous choices which were followed by a confidence rating of 3 and above were considered sufficient for the data analysis.

2.3. Data analysis

The drivers' choices in each of the four dilemmas were coded as follows:

Pedestrians' road-cross. In the pedestrians' dilemma, if the driver stopped once the pedestrian had stepped onto the road-cross his/her choice was recorded as a *hit*. A *miss* was insufficient distance to react and if the driver did not notice the pedestrian until too late. Braking when the pedestrian did not step in was considered a *false alarm*. Passing over when the pedestrian did not step in was considered a *correct rejection*.

Amber-light. If the driver stopped at a junction when the traffic light was yellow his choice was recorded as a *hit*. Crossing the junction in a similar condition was considered a *miss*. Braking at a junction though the light had just turned to yellow was considered *false alarm*. Crossing the junction in a similar condition was considered a *correct rejection* (Liu et al., 1996).

Merging in routes. Waiting in a turn to a main road until vehicle passed by was recorded as a *hit*. Breaking into a jammed road without waiting until it was safe to pass was considered a *miss*. Waiting in a turn when the road is free was considered a *false alarm*. Turning to a free road without waiting was recorded a *correct rejection*.

Distance keeping. Keeping an appropriate distance from the vehicle ahead was recorded as a *hit*. No standardization of distance between vehicles is made by traffic rules, due to dependence on velocity and road conditions. Alternatively, the observers were trained to weight velocity and road conditions to breaking time of 2–3 s for defining appropriate distance. Reducing the distance in such a condition was considered a *miss*. Keeping an unnecessary distance was considered a *false alarm*. Reducing distance in a similar condition was recorded as a *correct rejection*.

Each driver responded in his/her own free time, to the Hebrew version (Birenbaum and Montag, 1984) of Zuckerman's psychometric test of sensation seeking (e.g. Burns and Wilde, 1995). This test was separately administered to the drivers with a complete 'blindness' of the note-taker passengers to the scores of the driver s/he was observing.

The choices of each driver in the four dilemmas were summed up in terms of the relative frequency of *success* (Su) and *leniency* (Le, i.e. the willingness to overlook risk). The range of choices made by drivers in the four dilemmas was between 22 and 63. The beyond individual distribution (sums, means and standard deviations) of these choices is presented in Table 3.

The two respective exponential statistics, d' for perceptual sensitivity and β for decision criterion, were calculated for each participant on the basis of his/her values of Su and Le. Due to limitations involved in the attempt to observe signal detection in vivo, the present design should have been constructed non-metrically, i.e. fewer trials than required to enable parametric statistical analyses. Fortunately, the paradigm of signal detection tolerates such a loss in order to gain in terms of internal validity (e.g. Macmillen and Creelman, 1991; Swets, 1996). Accordingly, Su and Le served as raw estimates of the respective exponential statistics, β and d', that are traditionally used as estimates of perceptual sensitivity and decision criterion.

These statistics were subjected to conventional, mainly *descriptive*, statistical arrangements. More specifically, due to the quasi case study nature of the design, the focus was on a participant-by-participant analysis of the data. Two individual scores of sensation seeking, gathered from the responses to the test, were included in the analyses: *Thrill and adventure* and *boredom susceptibility*.

3. Results and discussion

The range of success values in Table 4 is in accord with Hypothesis 1. This hypothesis expected success values, which imply that the choices of the drivers were made in conditions of partial uncertainty (more than 50% and not too much beyond that level). The success values of all participants, except one, are above 50% and below 76%, 18 of them are in the range of 54–70%. This finding is worth noting, recalling that all choices of the participants in response to the relevant road dilemmas were recorded, without any interruption!

In agreement with Hypothesis 2, this table shows that on-the-road leniency of drivers with high scores of thrill and adventure seeking (TAS) in response to road dilemmas was higher than the leniency of those with low motivation to seek sensation. This trend is more detectable in Table 5, which presents grouped statistics. MANOVA (1, 23) supports this impression: F-values for leniency and β are 6.87 and 5.54, respectively,

Table 3
The drivers' choices in the four traffic dilemmas: descriptive statistics

Statistic	Dilemma			
	Amber light	Distance keeping	Road-cross	Merging in routes
Sum: (beyond individuals)	1350	1501	1090	1094
SIR[a]	32–55	30–63	23–44	22–43
Mean	48.50	55.40	40.37	40.50
S.D.	38.75	39.17	35.16	25.34

[a] Semi interquartile range.

Table 4
Signal detection statistics of the 28 drivers by level of TAS and BS[a]

	TAS	BS	Age	Statistics of signal detection			
				% Su	% Le	d'	β
High SS	10	5	29	70.99	70.78	1.23	2.10
	9	5	34	73.72	59.82	1.46	1.80
	9	4	**31**	**58.73**	75.34	1.23	3.44
	9	3	45	68.36	51.54	1.18	1.41
	9	1	29	71.00	55.30	1.33	1.77
	9	5	50	54.75	64.00	0.13	1.06
	8	1	30	59.67	**62.83**	**0.65**	**1.42**
	8	8	25	51.60	71.92	0.06	0.97
	8	1	35	52.07	81.30	0.51	1.45
	8	2	25	55.85	47.95	0.29	0.98
	7	**4**	27	49.57	58.26	0.05	1.00
	6	8	48	57.38	85.76	1.48	2.70
	6	4	54	60.50	52.43	2.31	1.04
	8.15	*3.90*	*35.53*	*60.32*	*64.44*	*0.92*	*1.63*
Low SS	5	2	35	61.11	35.48	1.10	0.80
	5	3	48	70.00	59.81	1.09	1.39
	5	2	55	**67.00**	37.03	0.72	0.85
	5	0	40	65.60	59.70	**0.81**	1.21
	4	3	**45**	71.27	49.73	0.10	**0.97**
	4	4	43	67.70	44.50	0.88	0.88
	4	**2**	52	57.82	**53.08**	0.40	1.05
	4	2	45	69.93	60.93	0.97	1.16
	3	0	57	59.23	59.80	0.86	0.87
	3	1	55	50.36	62.77	0.09	1.00
	3	3	40	66.66	59.50	0.28	0.92
	3	1	53	68.04	60.20	0.96	1.43
	2	1	45	65.37	31.24	0.33	0.86
	1	1	44	71.93	32.44	1.12	0.60
	0	1	30	75.20	48.79	0.73	1.00
	3.40	*1.74*	*45.80*	*65.82*	*50.33*	*0.70*	*1.00*

[a] Means are in italics; Medians are in bold; % Su, % of successful responses; % Le, % of lenient responses; d', the exponential value for Su; β, the exponential value for Le.

$P < 0.05$ (there is no difference in terms of % success and d').

The connection between sensation seeking (TAS and BS) and decision criterion (leniency and β) is also in accord with Hypothesis 1: For *TAS* with *leniency and* β, $r(1, 27) = 0.32$ and 0.49, respectively, $P < 0.05$; for *BS* with *leniency and* β, $r(1, 27) = 0.07$ ($P > 0.05$) and 0.40 ($P < 0.05$), respectively.

3.1. Signal detection and sensation seeking

Table 4 cross-tabulates individual values of success — 'sensitivity' and leniency — 'decision criterion' within level of sensation seeking. The table points to a possible connection between individuals' tendency to seek sensation and their adoption of lenient decision criterion. Mean leniency in driving is noticeably different for high and low sensation seekers, 60.5 and 46.2%, respectively. This impression is supported by MANOVA, which reveals two significant main effects for Le and β, $F(1, 24) = 6.87$, and $F(1, 22) = 5.54$, respectively, $P < 0.05$. The all-sample correlation of 0.32 between leniency and TAS ($P < 0.05$) can be conceived as another support for the above conclusion.

An inclusive presentation of individual values of sensitivity and leniency by age is presented in Table 6. Visual inspection of Le values in the table reveals a sort of U-shape function. The source of this trend is rooted in the middle 'group' (around age 40). These participants are more cautious in everyday life detection (re-

Table 5
Grouped signal detection statistics by TAS levels

TAS	Statistic	Success	Leniency	d'	β
High ($n = 13$)	Mean	66.46	60.50	0.92	1.63
	S.D.	8.35	14.72	0.70	0.75
	Median	58.73	62.83	0.65	1.42
Low ($n = 15$)	Mean	68.88	46.15	0.70	1.00
	S.D.	5.33	10.04	0.36	0.22
	Median	67.00	53.08	0.81	0.97

Table 6
Individual statistics of the 28 drivers nested in age[a]

Age	TAS	BS	Statistics of signal detection			
			% Su	% Le	d'	β
57	3	0	**59.23**	59.80	0.86	0.87
55	**5**	2	67.00	37.03	0.72	0.85
55	3	1	50.36	62.77	0.09	1.00
54	6	4	60.50	52.43	2.31	1.04
53	3	1	68.04	60.20	0.96	1.43
52	4	**2**	57.82	53.08	0.40	**1.05**
50	9	5	54.75	64.00	0.13	1.06
48	6	8	57.38	85.76	1.48	2.70
48	5	3	70.00	**59.80**	1.09	1.39
52.55	*4.89*	*2.80009*	*60.56*	*59.43*	**0.89**	*1.27*
45	**4**	**2**	69.93	60.93	0.97	1.16
45	9	**3**	**68.36**	**51.54**	1.18	1.41
45	2	1	65.37	31.24	0.33	0.86
45	4	3	71.27	**49.73**	0.10	0.97
44	1	1	71.93	32.44	1.12	0.60
43	4	4	**67.70**	44.52	**0.88**	**0.88**
40	5	0	65.60	59.70	**0.81**	1.21
40	3	3	66.66	59.50	0.28	**0.92**
43.38	*4.00*	*2.13*	*68.35*	*48.70*	*0.71*	*1.00*
35	**8**	1	52.07	81.83	0.51	1.45
35	5	**2**	61.11	35.48	1.10	0.80
34	9	5	73.72	**59.82**	1.46	1.80
31	9	4	58.73	75.34	1.23	3.44
30	0	1	75.20	51.21	**0.73**	1.00
30	8	1	**59.67**	62.83	0.65	**1.42**
29	9	1	71.00	55.30	1.33	1.77
29	10	5	70.99	70.78	1.23	2.10
27	7	4	49.57	58.26	0.05	1.00
25	8	8	51.60	71.92	0.06	0.97
25	8	2	55.85	47.95	0.29	0.98
30.00	*7.36*	*3.09*	*61.77*	*60.75*	*0.79*	*1.52*

[a] Means in italics; Medians in bold.

call that the table presents % of cautious responses). This impression, however, is not supported by one-way ANOVA. Thus, only follow ups with greater and more variable samples of drivers can decide whether or not there is an unusual age-dependent trend in terms of on-the-road leniency.

3.1.1. TAS and BS

Both TAS and BS scores in younger drivers (age range of 23–35) are higher than in the two older age groups — 40–45 and 48–57 (the respective means of TAS are 7.40 vs. 4.00 and 4.89, and 3.50 vs. 2.13 and 2.89, respectively, for BS). Inferentially, only TAS scores differentiated between younger and older drivers, $F(2, 23) = 5.17$, $P < 0.05$. This trend is in line with the agreement in the literature that the inclination to seek sensation peaks in early adulthood (Zuckerman, 1994, pp. 122–123).

A correlation analysis, separately for each age group, reveals a disposition-leniency connection. This connection is increased with age — $30 < 40 < 50$; the respective correlation coefficients are 0.20, 0.31, and 0.74. This trend might be associated with the decrease of TAS scores with age (means of the youngest [30] and oldest [50] participants are 7.4 and 4.9, respectively), while BS scores remained stable beyond age (the respective means are 2.8 and 3.0).

The indication that boredom susceptibility is age-resistant can be taken as a support for the speculative conclusion (Table 6) regarding the relative increase of importance of BS over the age of 45. This conclusion, however, should be subjected to further conceptual and empirical analysis, which focuses on mid-life developmental analysis.

Conceivably, both components of sensation seeking, TAS and BS, are related to age: Sensation seekers are more settled with age, presumably due to socializing processes, while boredom avoiding is, presumably, based on an age-resistant mechanism. Furthermore, the correlation between leniency in driving and each of these two measures of sensation seeking demonstrates opposite trends in terms of a shift from age 40 to 50: For TAS, this correlation decreases from 0.66 to 0.21 while for BS it increases from 0.23 to 0.62. The impact of TAS on risk-taking in driving is, apparently, much stronger until the age of 45. Later, after many years of intensive driving, drivers (at least in the present sample) seem to develop higher mastery of both vehicle and road use and therefore allow themselves to take more risk, independently of their personality inclinations. Boredom susceptibility, however, differentiates successfully between high and low risk-takers even among the professionals.

4. General discussion

The present findings seem to convey a promise for the prospect of using a non-metric version of the paradigm of signal detection (see Section 2.3) in the context of drivers' choices in conditions of on-the-road driving dilemmas. The present attempt to apply this method to real driving, without any a-priori calibration, was successful in two respects. One respect is related to the psychological nature of everyday life road dilemmas. The relative success of the drivers' choices (above 50% and not too much beyond this level) indicates that such dilemmas form an environment of *partial uncertainty*. The other respect is related to the varied and representative nature of the sample of road dilemmas in the present study. These dilemmas *suggested themselves* during the long trips made by the 28 participants.

This work and its results are in line with recent attempts to move the paradigm of signal detection out of the 'safe' environment of the laboratory. Such an environment has been a preferred location for signal detection studies (Ackerman et al., 1996; Battaglia and Perna, 1995; Contole and Over, 1979; Danzinger and Larsen, 1989; Egan, 1975; Hanley and McNeil, 1982; Harkins and Green, 1975; Hastrup, 1979; Jacoby et al., 1993; Knowles et al., 1994; Lappin and Uttal, 1976; McFall and Treat, 1999; Rehdler, 1999; Sobin and Alpert, 1999; Stelmach et al., 1984; Thelen et al., 1996).

Methodologically, the endless great amount of effort and money invested in this study was a risk in itself. A failure to reject the null hypotheses (one for each rationalized hypothesis) would have been an invitation for impossible-to-answer contents. For instance, in such a case one might have argued that erroneous scores might have been evenly distributed in the two alternative classes of observations (noise + signal and noise alone). If this was the case, however, no effect of leniency on the background of sensitivity invariance would have been found!

In terms of *internal validity*, the present procedure seems quite innovative, due to the valid solution for the paradigm's demand to observe a relatively long series of on-the-road dilemmas. One might be concerned, however, about using the signal detection paradigm to analyze driving behavior. Such a reservation might be based on the true assumption that while choices depend on detection, they also depend on the circumstances in which the choices are presented, e.g. time required to stop, presence of close following vehicles, pedestrian who has made eye contact, etc.

Practically, however, the present observation was able to isolate each such a dilemma in a way (see above a description of the procedure) which made the concrete stimulation in each such trial free of any other signal. Any other element is defined by the driver (assuming partial uncertainty) as irrelevant to the to-be-detected signal. To be more specific, when a driver is approaching a road crossing area s/he is looking for a relevant signal, i.e. pedestrians who are about to get into the road. In such a state of alert, any other stimulation is defined and perceived as a special case of noise.

External validity, however, needs further purification, i.e. follow-ups with other samples of drivers; recalling that the present sample included only 28 professional and quasi-professional drivers.

Another contribution of this work is related to the *decisional* element of signal detection. This source of response, unlike perceptual sensitivity which remained invariant, differentiated between drivers with high and low scores of sensation seeking (mainly thrill and adventure). The former tended to make more lenient choices than the latter.

This finding is in line with Ball and Zuckerman (1992) (pp. 829–830), who suggested to use the paradigm of signal detection to distinguish between response inhibition and attention of high and low sensation seekers. The connection to driving is implied, recalling that driving provides high sensation seekers with a handful of opportunities for exciting experiences (Arnett et al., 1997; Beirness, 1995; Burns and Wilde, 1995; Horvath and Zuckerman, 1993; Jonah, 1997).

From a broader theoretical perspective, based on the apparently valid findings, the present method can provide a stage for the examination of relevant issues. For example, according to the *risk homeostasis theory* (Wilde, 1976, 1982), drivers are aimed to reduce gaps between their *target risk* and *perceived risk*. Consequently, sensation seekers are assumed to commit more risky choices to maintain their *high target level* of risk, i.e. to detect relatively *more* risky signals than sensation avoiders.

A different mechanism is suggested by the *zero-risk theory* (Lajunen et al., 1998; Summala, 1997; Summala, and Naatanen, 1997). According to this conception, drivers' perception of road stimuli is modified by their expectancies. Thus, sensation seekers are expected to overestimate their driving capabilities. On this basis, their expectation to reveal risky signals on the road is *reduced*.

Two alternative predictions are derived: (1) high sensation seekers prefer risky signals (risk homeostasis), and (2) they avoid such signals (zero-risk). The present bridging (Staats, 1999) between signal detection and sensation seeking might enable an orderly confrontation between the two alternative hypotheses.

Another issue worth noting is the relatively weak informative value of the sub-scale of BS. This sub-scale's items may not reflect individuals' disposition of boredom susceptibility, especially due to cultural incompatibility and values contamination. The following statements from the questionnaire illustrate this problem: 'The worst social sin is to be a bore' or 'I prefer smart people even if they are insulting others'. These statements seem to carry heavy North American connotation. They might not facilitate sufficient variance in Israeli respondents.

Due to the promising potential of this sub-scale in the context of road use, further research is called for. Such work should be deliberated to produce cultural-free items, which are more related to specific object-stimuli or person-stimuli aspects. This recommendation is also in line with the report by Zuckerman (1994) (pp. 34–54) on this sub-scale's weakness in terms of reliability and reproducibility across populations with different cultural backgrounds.

It can be concluded that in accord with this work's expectation the method of signal detection provides a promising framework for future attempts to deepen the understanding of drivers' choices in conditions of real road dilemmas. Already three decades ago, Price (1966) had detailed the explicit advantages of this paradigm, such as the use of available information by the observer and an experimenter's, not observer's, control of relevant stimulation.

From a critical perspective, McFall and Treat (1999) (pp. 237–239) note that like all theories, the theory of signal detection is based on too generalized assumptions. For instance, the assumption of normal distribution of observers' responses and the distinction between (only) two possible choices. The paradigm has been developed, especially in the last three decades, and is currently considered a qualified tool for scientific study of behavioral and clinical issues (McFall and Treat, 1999). It is suggested here that the advantage, exemplified in the present study, involved in overarching between the detection of risky road signals and sensation seeking should compensate for the degraded ability to use traditional procedures of the paradigm of signal detection in everyday life. Future attempts to move the paradigm of signal detection closer to everyday life road use should thus compromise in terms of adherence to the traditional experimental procedure and statistical tools, as was done in the present study.

References

Ackerman, D.L., Greenland, S., Bytritsky, A., 1996. Use of receiver-operator characteristic (ROC) curve analysis to evaluate predictors of response to clomipramine therapy. Psychopharmacological Bulletin 32, 157–165.

Arnett, J., 1990. Drunk driving, sensation seeking and egocentrism among adolescents. Personality and Individual Differences 11, 541–546.

Arnett, J., Offer, D., Fine, M.A., 1997. Reckless driving in adolescence: 'state' and 'trait' factors. Accidental Analysis and Prevention 29, 57–63.

Ball, S.A., Zuckerman, M., 1992. Sensation seeking and selective attention: Focused and divided attention on a dichotic listening task. Journal of Personality and Social Psychology 63, 825–831.

Battaglia, M., Perna, G., 1995. The 35% CO_2 challenge in panic disorder: Optimization by receiver operator characteristics (ROC) analysis. Journal of Psychiatry Research 29, 111–119.

Beck, K., 1981. Driving while under the influence of alcohol: Relationship to attitude and beliefs in a college population. American Journal of Drugs and Alcohol Abuse 8, 377–388.

Beirness, D.J., 1995. Do we really drive as we live? The role of personality factors in road crashes. Alcohol, Drugs and Driving 9, 129–143.

Birenbaum, M., Montag, I., 1984. A cross-national comparison of the factorial invariance across sex of Sensation Seeking Scale. Research Report RM-4-84 Unit for Evaluation Research and Measurement, School of Education, Tel-Aviv University, Israel.

Burns, P.C., Wilde, G.J.S., 1995. Risk taking in male taxi drivers: Relationships among personality, observational data and driver records. Personality and Individual Differences 18, 267–278.

Contole, J., Over, R., 1979. Signal detection analysis of social infant behavior. Infant Behavior and Development 2, 189–199.

Danzinger, P.R., Larsen, J.D., 1989. Personality dimensions and memory as measured by signal detection. Personality and Individual Differences 10, 809–811.

Dobbins, D.A., Tiedman, J.G., Skordal, D.M., 1961. Field study of vigilance under highway driving conditions. U.S. Army Personnel Research Office, Office of Chief of Research and Development, Technical Research Note.

Donovan, D.M., 1993. Young adult drinking-driving: Behavioral and psychosocial correlates. Journal of Studies on Alcohol 54, 600–613.

Donovan, D.M., Marlat, G.A., Salzberg, P.M., 1983. Drinking behavior, personality factors and high-risk driving. Journal of Studies on Alcohol 44, 395–428.

Donovan, D.M., Queisser, H.R., Salzberg, P.M., Umlauf, R.L., 1985. Intoxicated and bad driver: subgroups within the same population of high-risk men drivers. Journal of Studies on Alcohol 46, 375–382.

Egan, J.P., 1975. Signal Detection and ROC Analysis. Academic Press, New York.

Elander, J., West, R., French, D., 1993. Behavioral correlates of individual differences in road-traffic crashes: An examination of methodology and findings. Psychological Bulletin 113, 279–294.

Furnham, A., Saipe, J., 1993. Personality correlates of convicted drivers. Personality and Individual Differences 14, 329–336.

Green, D.A., Swets, J.A., 1966. Signal Detection Theory and Psychophysics. Wiley, New York.

Haga, S., 1984. An experimental study of signal vigilance errors in train driving. Ergonomics 27, 755–765.

Hakamies, B.L., 1998. Older drivers' accident risk: Conceptual and methodological issues. Accidental Analysis and Prevention 30, 293–297.

Hanley, J.A., McNeil, B.J., 1982. The meaning and use of the area under a receiver operating characteristics (ROC) curve. Radiology 143, 29–36.

Harkins, S., Green, R., 1975. Discriminability and criterion differences between extraverts and introverts during vigilance. Journal of Research in Personality 9, 335–340.

Hastrup, J., 1979. Effects of electrodermal lability and introversion on vigilance decrement. Psychophysiology 6, 302–310.

Heino, A., Van der Molen, H., Wilde, G.J.S., 1992. Differences in risk experience between sensation avoiders and sensation seekers. Personality and Individual Differences 20, 71–79.

Hoffmann, E.R., 1966. Note on detection of vehicle velocity changes. Human Factor 8, 139–141.

Horvath, P., Zuckerman, M., 1993. Sensation seeking, risk appraisal, and risky behavior. Personality and Individual Differences 14, 41–52.

Hulthen, L., 1962. Note on detection probability and observance in road traffic. Bulletin Information, C.I.D.I.T.V.A. 9, 8.

Jacoby, L.L., Toth, J.P., Jonalinas, A.P., 1993. Separating conscious and unconscious influences of memory: Measuring recollection. Journal of Experimental Psychology: General 122, 139–154.

Jonah, B.A., 1997. Sensation seeking and risky driving: A review and synthesis of the literature. Accidental Analysis and Prevention 5, 651–665.

Knowles, P.A., Grove, S.J., Keck, K., 1994. Signal detection theory and sales effectiveness. Journal of Personal Selling and Sales Management 14, 1–14.

Lajunen, T., Corry, A., Summala, H., Hartley, L., 1998. Cross-cultural differences in drivers' self-assessments of their perceptual-motor and safety skills: Australians and Finns. Personality and Individual Differences 24, 539–550.

Lappin, J.S., Uttal, W.R., 1976. Does prior knowledge facilitate the decision of visual targets in random noise? Perception and Psychophysics 20, 367–374.

Lehto, M.R., Papastavrou, J.D., Giffen, W.J., 1998. An empirical study of adaptive warnings: Human versus computer-adjusted warning thresholds. International Journal of Cognitive Ergonomics 2, 19–33.

Liu, C., Herman, R., Gazis, D.C., 1996. A review of the yellow interval dilemma. Transportation Research Analysis 30, 333–348.

Macmillen, N.A., Creelman, C., 1991. Signal Detection Theory: A User Guide. Cambridge University Press, Cambridge.

McFall, R.M., Treat, T.A., 1999. Quantifying the information value of clinical assessments with signal detection theory. Annual Review of Psychology 50, 215–241.

McMillen, D.L., Smith, S.M., Wells-Parker, E., 1989. Brief report: The effects of alcohol, expectancy and sensation seeking on driving risk taking. Addictive Behavior 14, 477–483.

McMillen, D.L., Pang, M.G., Wells-Parker, E., Anderson, B.J., 1992. Alcohol, personality traits and high risk driving: A comparison of young, drinking driver groups. Addictive Behaviors 14, 477–483.

Mihal, W.L., Barrett, G.V., 1976. Individual differences in perceptual information processing and their relation to automobile accident involvement. Journal of Applied Psychology 61, 229–233.

Mongrain, S., Standing, L., 1989. Impairment of cognition, risk-taking, and self-perception by alcohol. Perceptual and Motor Skills 69, 199–210.

Newsome, L., 1974. Risk taking as a decision process in driving. Supplementary Report 81. Transport and Road Research Laboratory, Crowthorne, UK.

Perchonok, K.H., Hurst, P.M., 1968. Effect of lane-closure upon driver decision making and traffic flow. Journal of Applied Psychology 52, 410–413.

Price, R.H., 1966. Signal detection methods in personality and perception. Psychological Bulletin 66, 55–62.

Rehdler, B., 1999. Detecting unsolvable algebra word problems. Journal of Educational Psychology 91, 669–683.

Rothengatter, T., Vaya, E.C. (Eds.), 1997. Traffic and Transport Psychology: Theory and Application. Pergamon, New York.

Seligman, M.E.P., 1971. Phobias and preparedness. Behavior Therapy 2, 307–320.

Sobin, C., Alpert, M., 1999. Emotion in speech: The acoustic attributes of fear, anger, sadness and joy. Journal of Psycholinguistic Research 28, 347–356.

Staats, A.W., 1999. Unifying psychology requires new infrastructure, theory, method, and a research agenda. Review of General Psychology 3, 3–13.

Stacy, A.W., Newcomb, M.D., Bentler, P.M., 1991. Personality, problem drinking, and drunk driving: mediating, moderating, and direct-effect models. Journal of Personality and Social Psychology 60, 795–811.

Stelmach, R.M., Wieland, L.D., Wall, M.U., Plouffe, L., 1984. Personality and the effects of stress on recognition memory. Journal of Research in Personality 1, 164–178.

Stoduto, G., Mann, R.E., Anglin, L., Pavic, B., Fallon, F., Lauzon, R., 1995. Profile of adolescent drinking drivers. In: Kloeden, C.N., McLean, A.J., (Eds.), Alcohol, Drugs and Traffic Safety-T'95. Proceedings of the 13th International Conference on Alcohol, Drugs and Traffic Safety, ICADTS-T'95, International Council on Alcohol, Drugs and Traffic Safety, Adelaide, pp. 265–270.

Summala, H., 1997. Hierarchical model of behavioral adaptation and traffic accidents. In: Rothengatter, T., Vaya, E.C. (Eds.), Traffic and Transport Psychology, Theory and Application. Pergamon, New York.

Summala, H., Naatanen, R., 1997. The zero-risk theory and overtaking decisions. In: Rothengatter, T., Vaya, E.C. (Eds.), Traffic and Transport Psychology, Theory and Application. Pergamon, New York.

Swets, J.A., 1996. Signal Detection Theory and ROC Analysis in Psychological Diagnostics: Collected Papers. Erlbaum, Mahwah, NJ.

Thelen, M.H., Mintz, L.B., Van der Wal, J.S., 1996. The bulimia test — revised: validation with DSM-IV criteria for bulimia nervosa. Psychological Assessment 8, 219–221.

Yu, J., Williford, W.R., 1993. Alcohol and risk/sensation seeking. Specifying a causal model of high-risk driving. Journal of Addictive Disease 12, 79–96.

West, R., Elander, J., French, D., 1992. Mild social deviance, type A personality and decision making style as predictors of self-reported driving style and crash risk. In: Letter, J., Grecian, G. (Eds.), Behavioral Research in Road Safety. Transport and Road Research Laboratory, Crowthorne, UK, pp. 1–16.

Wilde, G.J.S., 1976. Social interaction patterns in driver behavior: An introductory review. Human Factors 18, 477–492.

Wilde, G.J.S., 1982. The theory of risk homeostasis: Implications for safety and health. Risk Analysis 2, 209–225.

Wilson, R.J., 1992. Convicted impaired drivers and high risk drivers: how similar they are? Journal of Studies on Alcohol 53, 335–344.

Wilson, R.J., Jonah, B.A., 1988. The application of problem behavior theory to the understanding of risky driving. Alcohol, Drugs and Driving 4, 173–191.

Wolf, Y., Algom, D., Lewin, I., 1988. A signal detection theory analysis of a driving decision task: Spatial gap acceptance. Perceptual and Motor Skills 66, 683–702.

Zuckerman, M., 1978. Sensation seeking. In: London, H., Exner, J. (Eds.), Dimensions of Personality. Wiley, New York, pp. 487–550.

Zuckerman, M., 1979. Sensation Seeking: Beyond the Optimal Level of Arousal. Erlbaum, Hillsdale, NJ.

Zuckerman, M., 1994. Behavioral Expressions and Biosocial Bases of Sensation Seeking. Cambridge University Press, Cambridge.

Zuckerman, M., 1999. Vulnerability to Psychopathology: A Biosocial Model. American Psychological Association, Washington, DC.

Zuckerman, M., Eysenck, S.B.G., Eysenck, H.J., 1978. Sensation seeking in England and America: Cross-cultural, age, and sex comparisons. Journal of Consulting and Clinical Psychology 46, 139–149.