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Eye Movements and Hazard Perception in Police Pursuit and Emergency Response Driving

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How do police cope with the visual demands placed on them during pursuit driving? This study compared the hazard ratings, eye movements, and physiological responses of police drivers with novice and with age-matched control drivers while viewing video clips of driving taken from police vehicles. The clips included pursuits, emergency responses, and control drives. Although police drivers did not report more hazards than the other participants reported, they had an increased frequency of electrodermal responses while viewing dangerous clips and a greater visual sampling rate and spread of search. However, despite an overall police advantage in oculomotor and physiological measures, all drivers had a reduced spread of search in nighttime pursuits because of the focusing of overt attention.

Police pursuit driving has previously been defined as "an active attempt by a law enforcement officer operating a motor vehicle with emergency equipment to apprehend a suspected law violator in a motor vehicle, when the driver of the vehicle in question attempts to avoid apprehension" (Alpert, 1987, p. 299). This activity can be extremely dangerous to both parties involved in the pursuit and the general public. Recent statistics and some high-profile incidents in the United Kingdom have highlighted a rise in police-driver accidents. Sir Alistair Graham, chairman of the U.K. Police Complaints Authority, recently commented on a 178% increase in fatalities involving police pursuits, which he described as "totally unacceptable. . . . Police forces must take urgent steps to meet the rising tide of public concern" (Police Complaints Authority, 2001, p. 3). In the following year the U.K. Police Complaints Authority published a report investigating road traffic accidents involving police vehicles. They reported that in the 9 months preceding the publication of the study there were 30 fatalities resulting from police pursuits. Compared with the nine deaths that occurred in the 12-month period covering 1997–1998, this represents an increase of 344% in police pursuit fatalities over a period of time during which road usage only increased by 4.7% (an increase of 21.2 billion vehicle kilometers from 1997 to 2001, Department for Transport, UK, 2003).

Although absolute figures are not available for the United States, the number of police-driver accidents has been identified as a considerable problem. Several studies have reported that approximately 40% of all police pursuits in the United States results in an accident, half of which result in an injury, and 1% of all police pursuits result in a fatality (Alpert & Fridell, 1992; Crew, Fridell, & Pursell, 1995; Falcone, Wells, & Charles, 1992; Hill, 2002).

Although the number of police-driver accidents forms a very small part of the overall accident statistics of any country, the high-profile nature of such incidents serves to undermine public faith in the police force and can lead to litigation and compensation claims for considerable sums (Smith & Alpert, 1992). Despite these concerns there has been relatively little research undertaken on the behavioral factors that impinge on police driving with a view to reducing the number of accidents. The few studies that have looked at police-pursuit driving have been primarily concerned with collating pursuit outcome statistics (e.g., Alpert & Fridell, 1992; Falcone et al., 1992), attitudes toward pursuits (Alpert, 1998; Dunham, Alpert, Kenny, & Cromwell, 1998; Homant & Kennedy, 1994; MacDonald & Alpert, 1998), and correlations of personality factors with the likelihood to pursue (e.g., Homant, Kennedy, & Howton, 1994).

The lack of research into skills and behavior in these areas is surprising, considering the proliferation of general driving research that has occurred over the last decade. Driving psychologists have approached almost every aspect of driving that relates skills and experience to accident liability, yet little attempt has been made to apply these general findings to police driving. The present study is an attempt to form such a link between findings from general driving studies and the particular types of experience and task demands that are involved in police driving. The following sections first review some of the findings relating driving behavior to both normal driving situations and hazardous driving situations, before describing an experiment in which these findings are extended and applied to both emergency response situations and pursuit situations.

Hazardous Situations Influence Driver Behavior

Gregersen and Bjurulf's (1996) model of accident liability acknowledges two direct inputs into the calculation of *accident*

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liability, or the propensity of a driver to be involved in an accident. These inputs include the current on-road context and the skills and knowledge that the driver brings to bear on any problem within that context.

One of the key processes that link both of these factors is the visual extraction of information from the driving scene. Whatever situation a driver may encounter, it will be predominantly mediated by vision. Acquisition of visual information is influenced by experience and training. Perceiving a potentially dangerous situation is therefore dependent on the skills and knowledge of that driver. This section considers how drivers in general perceive and respond to hazardous events, primarily in terms of their oculomotor behavior, whereas the following section details the influences of skill and experience on the same measures.

It is often reported that 90% of all driving information is visual, and although the precise quantitative nature of these claims is somewhat spurious, the importance of vision is accepted (Sivak, 1996). Certainly errors of perception have been reported as a major cause of road accidents (Cairney & Catchpole, 1991; Nagayama, 1978; Quenault, 1967; Staughton & Storie, 1977). If a hazardous situation occurs that may lead to an accident, the hazard must first be perceived by the driver before remedial action can be taken. On this basis, the skill of *hazard perception*, or the ability to quickly perceive and respond to a potentially dangerous driving event, has attracted a considerable level of research interest.

The ability to perceive driving hazards has been investigated using a wide range of methodologies and stimuli (see Groeger & Chapman, 1996, for an overview of hazard perception tests), though the common form of the modern test requires participants to make discrete motor responses to potential hazards while viewing a series of video clips taken from the driver's perspective, traveling along a variety of roadways. The mean latency between the occurrence of a hazard, such as a pedestrian stepping into the road, and the participant's response is considered a measure of hazard perception ability. Unlike tests of static visual acuity, hazard perception scores, according to some researchers, appear to be related to accident liability (Pelz & Krupat, 1974; Quimby, Maycock, Carter, Dixon, & Wall, 1986). Several attentional and oculomotor measurements have been found to vary systematically with increases in the hazardous nature of a particular drive, seemingly independent of other increases in visual workload, and it is suggested that these visual search strategies are at least in part responsible for the low accident liability of certain drivers. For instance, experienced drivers tend to monitor the focus of expansion closely during an undemanding rural drive with no other vehicles present. When the roadway becomes more demanding, such as when driving through a suburban area or monitoring other lanes of traffic on a dual carriageway, visual search tends to spread wider, producing shorter fixation durations to deal with the increased amount of visual information (Crundall & Underwood, 1998; Underwood, Chapman, Bowden, & Crundall, 2002). However, the appearance of a hazard, such as the emergence of a bicycle from a side road, has the exact opposite effect, reducing the spread of search and increasing fixation durations as attention is focused on the hazard (Chapman & Underwood, 1998; Crundall, Underwood, & Chapman, 1999, 2002). Although this is an understandable response to dangerous stimuli, it results in temporary inattentional blindness to other stimuli in the driving scene. If a pedestrian were to step into the road while the driver's attention was diverted elsewhere, this could result in a collision.

One limitation of the findings that have been published so far is that they only deal with abrupt hazards over short time courses. Although the result of attentional capture by an abrupt hazard can be potentially dangerous, how much worse might the situation be when confronted with a prolonged hazard? In Hoyos's (1988) attempt to apply the transactional model of stress to hazardous driving situations, he pointed out that undesirable strain is not solely dependent on the intensity of the demands that are placed on the driver but also the duration of those demands. The longer a stressor is present, the greater is the strain placed upon drivers. One obvious example of such a situation is the typical police pursuit. In these situations the driver is exposed to a prolonged hazard, which may include high speeds, close following behavior, unconventional road maneuvers, and the additional mental load of communication and decision making concerning the pursuit. All of these factors may influence the driver's attention and oculomotor strategies for extracting visual information from the scene. For instance, the rate of change of the visual scene increases as driving speed increases. This may lead to shorter but more prevalent fixations in an effort to compensate for the more rapidly changing visual scene, or alternatively, drivers may try to view further down the road. In regard to car following, Hella, Laya, and Neboit (1996) found that close following of a vehicle ahead can lead to shorter fixation durations on the car in front and a wider spread of search. Many researchers have also shown that an increase in the difficulty of road maneuvers leads to an increase in the sampling rate, even when just comparing simple curves with straight roads (Shinar, McDowell, & Rockwell, 1977; Zwahlen, 1993). The effect of increased workload on eye movements due to a secondary task is more complex and is dependent on the nature of the task (Verwey & Veltman, 1996). Verbal tasks tend to decrease fixation durations and to encourage an increased sampling rate, whereas imagery tasks focus attention with longer fixations and a smaller spread of search (Recarte & Nunes, 2000).

The effects of these factors on oculomotor and attention measures are quite different from the effects predicted by the presence of a potential hazard. In regard to increases in speed, complex maneuvers, car following, and verbal communication with others these factors may all require the driver to increase his or her visual search, yet the appearance of a dangerous hazard tends to concentrate attention at one locus. How is this resolved? Does the prolonged hazard of a fleeing vehicle capture attention in the same way that an abrupt hazard does, or do trained police officers respond to the increased danger with a wider spread of search? One of the priorities of this research is to identify what happens to visual search strategies under these conditions. Specifically, compared with control clips, we predicted that police pursuits would lead either to a reduction in visual search, consistent with previous findings on abrupt hazards, or to an increase in visual search, as found in studies on general road complexity and car following. As emergency response drives do not have a particular hazard locus, we predicted that they would produce only increased visual search.

Experience and Training Improve Hazard Detection

McKenna and Crick (1994) reported that hazard perception skill improves with driver experience, such that response latencies to the onset of hazards are reduced. Although several studies have failed to replicate this basic effect (Chapman & Underwood, 1998; Crundall et al., 1999, 2002; Groeger, Field, & Hammond, 1998), McKenna and Crick's findings are supported by several previous studies that showed increased sensitivity to hazards with increased driving experience (Ahopalo, 1987; Pelz & Krupat, 1974; Quimby & Watts, 1981). These results may help explain the overrepresentation of young, novice drivers in the accident statistics (Cooper, Pinili, & Chen, 1995; Maycock, Lockwood, & Lester, 1991). Even when factors such as age, attitudes, and social norms are partialed out, driving experience remains a key factor in predicting accident liability (Gregersen & Bjurulf, 1996; Maycock et al., 1991).

Kowler (1989) reported that cognitive expectations, borne of experience, can influence anticipatory eye movements. Specifically, several studies have shown that the level of driving experience can influence the visual search strategies that are employed in scanning the scene while driving. Thirty years ago, Mourant and Rockwell (1970, 1972) published evidence suggesting that novice drivers lack the visual skills of their more experienced counterparts. Novices were found to have a smaller spread of search, to fixate closer to the car, to make more fixations on lane markers, and to make more pursuit fixations. A more recent study by Crundall and Underwood (1998) demonstrated that experienced drivers could adapt their visual search according to the particular demands of the roadway, though novice drivers tended to maintain the same, inflexible strategy across all road types.

The flexible strategies of experienced drivers may explain why they perform better at hazard-perception tests. If these drivers know the optimum focal points for spotting potential hazards on a particular road, then they should be able to spot the hazard faster than novice drivers, and thus have longer to respond to the situation.

In addition, novice drivers tended to have longer fixation durations in many situations than more experienced drivers (Crundall & Underwood, 1998). This is usually seen as an indication that it takes them longer to process objects and events, perhaps because of the novelty of the driving situation, similar to low-frequency words attracting longer fixations while reading (e.g., Rayner & Polletsek, 1989). The increase in fixation durations interacts with the presence of a hazard such that novices' fixation durations increase by a greater amount than experienced drivers' fixations increase when confronted with a dangerous event (Chapman & Underwood, 1998). It seems that experienced drivers are able to engage and disengage attention to hazards in a more efficient manner (Crundall et al., 1999, 2002).

On the basis of these data it is suggested that driving experience and training may improve both the ability to find potential hazards and the ability to process them once they have been located. Chapman, Underwood, and Roberts (2002) have reported an initial training intervention that has had limited success in developing these skills. It is unclear, however, how experience and training can prepare one for a prolonged hazard, such as pursuing a fleeing vehicle. We hope that the present study will provide information on how visual search develops to deal with such exceptional circumstances. Specifically, we predicted that large differences (Cohen's $f \geq 0.4$) would be found in comparisons of novice participants' oculomotor measures with those of police and matched-control participants and that similar, though possibly smaller, effects would also be noted between the police and the matched controls. Similar patterns of effects were predicted for measures of hazard perception, though because of the inconsistent nature of hazard perception findings, we expected that any effects would be smaller than those noted for the eye movements (Cohen's $f < 0.4$).

An Overview of the Current Study

Previous research has demonstrated the effects of abrupt hazards on oculomotor behavior and how experience and training can mitigate the attentional capture that is caused by a hazard onset. The study of police-pursuit driving should extend these results by investigating the extremes of both hazardous situations and levels of experience and training. Although the pursuit of another vehicle may be one of the most dangerous driving events that one can engage in, police-pursuit drivers number among the most highly trained individuals on the road. Research into this area should therefore both benefit our understanding of how drivers process prolonged hazards and, through a comparison of police drivers with age-matched controls and a group of novice drivers, provide further insight into the separate roles of training and experience.

The study required participants to view video clips of drives taken from police vehicles during pursuits and responses to emergency calls. The primary difference between these two types of clip was the presence or absence of a fleeing vehicle. Control clips were also shown to participants. These were clips of normal driving along roads similar to those used in the pursuit and response clips. The participants' primary task was to rate how hazardous they thought each drive was. These ratings were made continuously throughout the duration of the clips, using a sliding scale. During the clips, eye movements and electrodermal responses (EDRs) were monitored. We predicted that these measures would be sensitive to the hazardous events shown in the driving clips.

Specifically, we predicted that police drivers would be more sensitive to the level of hazard in the driving clips because of their greater experience with pursuit and response events and may therefore produce higher hazard ratings compared with the two control groups. Similarly, we predicted that eye movements and EDRs would also differ. In more hazardous clips, we believed that EDRs would increase in all participants, though police drivers might again show differing sensitivities because of their experience with similar drives. Previous research suggests that eye movements are affected by increased demand, though it is possible that the different demands that pursuit driving and response driving engender will produce different effects. Of particular interest is whether the fleeing vehicle acts as a trap for attention or whether the increased visual complexity, speed, and demand of these clips produces a greater spread of search, as some previous research would suggest. We predicted that the pursuit clips would either restrict visual search relative to control clips or increase visual search as drivers attempt to look beyond the vehicle ahead. Response clips should merely increase visual search compared with control clips, as they have no specific locus of demand to capture attention. The clips were also separated into those filmed during the daytime and those filmed during the nighttime. We predicted that the reduced salience of surroundings during nighttime clips would increase any focusing effect noted in pursuit drives.

We also predicted that whatever the effect of a prolonged stressor in the pursuit clips, police drivers would be less susceptible to the detrimental influences of increased demand on eye movement strategies. Specifically, if focusing were found to occur in pursuit clips, the police drivers would still maintain a relatively large spread of search compared with the other drivers.

Method

Participants

The participants were 48 drivers split into three groups. The first group consisted of 16 young, novice drivers with a mean age of 20.4 years, a mean annual mileage of less than 2,000 miles, or 3,218 km (primarily personal use, with little or no work-related use), and a mean of 2.9 years' driving experience since passing the driving test (with all drivers having less than 5 years' driving experience). The second group was composed of 16 police drivers with a mean age of 39.2 years, a mean annual mileage of approximately 20,500 miles, or 32,991 km (of which roughly half is work related), and a mean of 21.8 years' driving experience. All police drivers were trained to pursuit standard, and all had previously been engaged in real-life pursuits. The final group was made up of 16 experienced drivers who were matched with the police cohort in terms of age and number of years' exposure since passing the driving test. Their mean age was 37.1 years with an annual mileage of 10,500 miles, or 16,898 km (one third being work related), and a mean of 18.9 years' driving experience. The additional mileage of the police drivers compared with the matched-control drivers was primarily due to their jobs, and this was therefore considered to reflect the additional experience gained as a police driver within roughly the same number of years since passing the driving test.

All police drivers who volunteered for the study were men; therefore only male drivers were recruited for the control groups in order to maintain compatibility.

Stimuli

The stimuli were a set of 48 videos of driving situations recorded from the point of view of the driver. Each video lasted approximately 60 s. Sixteen of the videos were recorded from police vehicles engaged in pursuit of other vehicles in and around the city of Nottingham in the United Kingdom. Such pursuits typically involved following another vehicle at a high speed, with the fleeing vehicle, the police vehicle, or both contravening traffic laws (the average speed for pursuits was 47 mph during daytime clips and 39 mph during nighttime clips). A further 16 videos were recorded from police vehicles engaged in emergency-response driving in and around Nottingham. In these situations there was no particular vehicle being followed, but the driver's vehicle proceeded at high speeds, often passing through red lights and frequently overtaking other vehicles that had stopped to let it pass (the average speed for responses was 60 mph during daytime clips and 44 mph during nighttime clips). The final 16 videos were standard control drives from similar environments in and around Nottingham but with the driver remaining within the prevailing speed limit and abiding by the highway code (with average speeds of 29 and 27 mph for daytime and nighttime clips, respectively). For each group of 16 videos, half were recorded in the daytime and the remaining half recorded at nighttime.

Apparatus

The stimuli were played on a video recorder through an Epson EMP-50 digital projector onto a large white screen. The visual image subtended 60° × 38° of visual angle, with participants seated 100 cm from the screen. Participants' eye movements were monitored using a head-mounted SMI Eyelink eye tracker sampling at 250 Hz. Monocular measures were taken from each participant's dominant eye.

Hazard-perception ratings were recorded through a response box with a sliding scale of 0–10. The slider was always placed at the midpoint before testing, and the box provided tactile feedback when the slider passed through the center of the scale, providing the participant with relative awareness of the position of the slider on the scale without having to look at it during the video clips. Hazard level and skin conductance were recorded online using a Biopac MP30 biopotential amplifier, sampling at 100 Hz, connected to a Macintosh computer.

Design

A 3 × 3 × 2 mixed design was used. The between-groups factor was driving experience (novice, police, and matched controls). The two within-group factors were the type of drive presented (pursuit, emergency response, and control drives) and the time at which the drive was conducted (daytime or nighttime). Several different measures were recorded. For eye movements, fixation durations and spread of search in the horizontal and vertical meridians were noted. Mean hazard rating and EDR were calculated for each clip, along with the number of sudden increases in EDR and hazard rating.

The stimuli were presented in two blocks of 24 clips. The order of clips to be presented within a block was randomly determined and then transferred to videotape for presentation. A second videotape was also recorded with the clips in reverse order. The order of the clips and the order of the blocks were counterbalanced across participants.

Procedure

Each participant was asked to complete a questionnaire that assessed his level of driving experience, the number of bumps and accidents that he had been involved in (in which an accident was defined as an incident that resulted in damage of over £500 [around $809]; incidents producing less damage were termed bumps). Participants were informed that they did not have to complete any of the questions if they did not want to. The questionnaire also asked participants to rate their own driving ability relative to others on scale ranging from 1 (*much worse*) to 9 (*much better*), in which the average driver would score 5. The participant was then seated approximately 1 m from the projector screen, and the hazard-monitoring task was explained. Participants were told that the lowest position of the slider represented "low or no hazard, e.g., clear visibility and no other road users present" and that the highest point of the slider represented "high hazard: extreme likelihood of an accident occurring to yourself or another road user—a situation that may require immediate evasive action." They started each clip with the slider placed at the midpoint of the scale and were asked to adjust its position constantly in response to changing road conditions.

The participant was then shown a series of example clips that were not subsequently used in the experiment. These clips allowed the participants to become familiar with the type of stimuli that they would see during the experiment and also allowed them to practice using the sliding-hazard scale.

After the practice trials the participant was calibrated on the eye tracker, and electrodes were attached to measure EDR.

After a successful calibration the experiment began with a 10-s fixation cross displayed at the center of the screen. After each clip the fixation cross reappeared. The participant was instructed to keep his eyes on the cross whenever it appeared. This gap between clips allowed the experimenter to correct any drift of calibration that may have occurred during the clip. After 24 clips, the participant was given a break, before the process was repeated for the second block of clips.

Results

All analyses were investigated with planned comparisons. Weighted contrasts for the between-groups factor were made between the novice drivers and the mean of the two experienced-driver groups and also between the police drivers and the matched controls. Contrasts for the within-group factors were made for control clips versus the mean of pursuit and response clips, and pursuit versus response clips, across the levels of nighttime and daytime.

The results are divided into four sections. The first section reports participants' self-rated driving ability and compares this with their driving history. The second section details their reports of the level of hazard contained within the driving clips. The third section reports the analyses conducted on the oculomotor measures, and the fourth section is concerned with the physiological measures.

Self-Rating of Driving Ability and Accident History

Although this study was not designed to explicitly measure self-perceived driving ability or to produce an accurate rating of accident liability for individual drivers, participants were asked to provide coarse measures for subsequent analyses. Self-ratings and self-reported accident histories should therefore not be viewed as exact measures taken for individuals. They are included at the start of the Results section, however, as an aid to delineate between the driver groups and to provide the reader with a general description of the nature of the average driver who falls within each group.

Participants were asked to rate their driving ability relative to other drivers on a scale ranging from 1 (*much worse*) to 9 (*much better*), where the population mean was considered to be 5. The data from one participant were not available. The accident history of drivers covered the period from passing the driving test to the present. Two drivers did not provide an accident history.

In regard to self-rated driving ability, novice drivers averaged a score of 6, matched-control drivers averaged a score of 6.2, and police drivers averaged a score of 7.9. Weighted contrasts revealed that police drivers produced higher ratings than the matched controls, with novices producing lower ratings than the other groups (Cohen's $f = 0.44$ and 0.65 for both comparisons, respectively; see Table 1). Only one participant, a novice driver, gave a rating of 4. The remaining drivers believed themselves to be at or above average in terms of their driving ability.

In regard to accident history, novices reported an average of only 0.5 accidents and 0.1 bumps per participant. Matched controls reported 1.2 accidents and 0.6 bumps on average, and police drivers reported 3.4 accidents and 2.1 bumps on average. The number of accidents involving police drivers was inflated by one outlier who reported 30 accidents. When questioned further about the high number of reported accidents, the participant revealed that the majority of accidents were intentional attempts to halt fleeing vehicles using car contact. If this participant is removed, the number of police accidents and police bumps drops to 1.5 and 1.9, respectively.

Table 1
Weighted Contrast Table for Self-Rated Driving Ability

Source and contrast	*df*	*F*	*f*
Self-rated ability			
Novice vs. matched controls and police	1	8.41**	0.44
Matched controls vs. police	1	18.49**	0.65
Within-group error	44	(1.35)	

Note. Value enclosed in parentheses represents mean square error. Effect size is represented by Cohen's *f*.
** $p < .01$.

If driving ability is viewed as a ratio of the number of accidents to number of years driving (with the outlier removed from the group of police drivers), a definite superiority for the police drivers and matched-control drivers can be seen compared with the novices (see Table 2), though it should be noted that any ratio calculated over several years will tend to decrease as the time period increases because of memory loss (e.g., Chapman & Underwood, 2000).

Analysis of Perceived Hazard

Weighted contrasts revealed that control clips were rated as less hazardous than all other clips, though pursuit clips and response clips did not differ. Contrasts also revealed an interaction between the type of clip and the time of day (see Figure 1). The interaction is due to a reduction in the difference between control clips and other clips during nighttime drives (Cohen's $f = 1.53$). Although pursuit clips and response clips were considered more hazardous than control clips, only control clips were considered more dangerous during the nighttime. There was no evidence of a significant effect of driving experience on the hazard ratings (see Table 3).

A similar series of contrasts was conducted on the number of hazards detected (see Table 3). A discrete hazard response was defined as a sudden increase in the continuous measure of hazard level, calculated as a *z* score with the difference between the score at any one point and the average of the preceding 50 samples divided by the standard deviation of the preceding 50 samples. A *z* score of 1.96 was set as the criterion. Contrasts confirmed that control clips had the lowest number of reported hazards compared with all other clips (Cohen's $f = 0.59$), though this was primarily due to the large increase in the number of hazards reported in the response clips, as revealed by the extreme effect size of the contrast of pursuit clips and response clips (Cohen's $f = 0.75$).

As with the analysis of the mean hazard rating, an interaction was found between the type of clip and the time of day (see Figure 2), which was again due to an increase in the number of hazards reported during nighttime control clips (Cohen's $f = 0.52$). There was no evidence of a significant effect of driving experience on the number of hazards reported.

Analysis of Eye Movements

As a precursor to the eye movement analysis, all fixations below 100 ms in duration were removed from the data. Weighted contrasts were conducted on three parameters of the visual search strategy: mean fixation durations and spread of search in the vertical and horizontal meridians (see Tables 3 and 4). The last two measures were calculated as the standard deviations of fixation locations in the *x* and *y* axes for each clip, the mean of which was taken for each clip type for every participant.

Table 2
Average Ratios of Accidents and Bumps per Year of Driving Experience for the Three Driver Groups

Group	Accidents	Bumps
Novice	0.16	0.04
Matched controls	0.05	0.02
Police	0.06	0.09

Note. One outlier was removed from the police group.

In regard to mean fixation durations, weighted contrasts produced main effects for clip type, time of day, and driver. A two-way interaction between the type of driving clip and the time of day and a three-way interaction between all three factors was also found. Novices had longer fixation durations compared with other drivers (Cohen's $f = 0.45$), though the tendency of police drivers to produce longer fixation durations than the matched controls was not significant (Cohen's $f = 0.20$). Similar comparisons of the clips revealed that control clips produced shorter fixation durations than other clips (Cohen's $f = 0.75$), with pursuits producing the longest fixations when compared with response clips (Cohen's $f = 0.45$). The interaction between clip and time of day was primarily due to an increase in fixation durations in the nighttime pursuits when compared with the response clips (Cohen's $f = 1.28$). Interaction contrasts of the three- way interaction (Cohen's $f = 0.44$) reveal that this was due to the novices' producing the longest fixation durations during nighttime pursuits compared with response clips (see Figure 3).

The results suggest that novice drivers had the longest fixation durations on all clips. Furthermore, though the three groups of drivers showed an increase in fixation durations during the nighttime pursuits relative to the other clips, the novices appeared to be the most susceptible to this effect. While nighttime pursuit drives attract longer fixation durations, no such effect was evident during the daytime clips. Instead, fixation durations in daytime response clips were longer than fixation durations in daytime pursuits.

Analysis of the spread of search in the horizontal meridian revealed novices to have a smaller spread of search compared with all other drivers (Cohen's $f = 0.43$), though this was primarily due to the large increase in scanning by the police drivers, as noted in the contrast between police and matched controls (Cohen's $f = 0.75$). The interaction contrasts revealed a difference in the comparisons of novice drivers with the other drivers, across the factor of time (Cohen's $f = 0.50$). This was due to a small increase in horizontal scanning by novices during daytime clips (see Figure 4). A second interaction, between clip and time of day, was primarily due to a crossover interaction between the comparison of pursuit clips and response clips across daytime and nighttime (Cohen's $f = 4.01$), with measures for control clips falling in between. It appears that although police drivers have the greatest overall horizontal spread of search, high horizontal scanning tends to occur during daytime pursuits and nighttime response drives, whereas scanning is reduced for nighttime pursuits and daytime responses (see Figure 5).

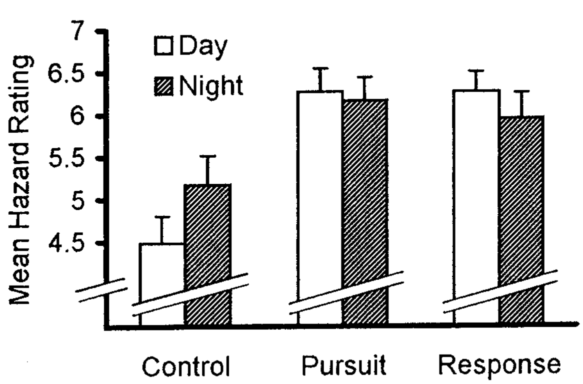

Figure 1. Mean hazard ratings for the three types of driving clip across day and night, measured on a continuous scale of 0–10 (with standard error bars added).

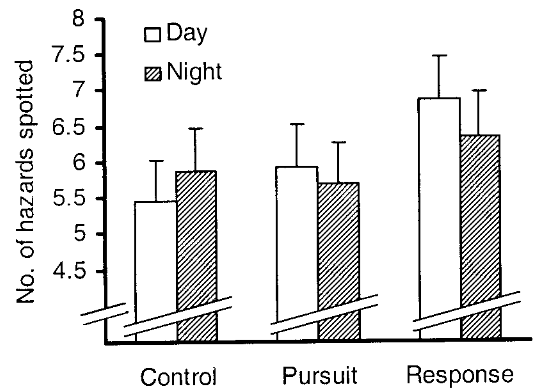

Figure 2. The frequency of discrete responses to hazards in a particular clip, reported for the three types of driving across day and night (with standard error bars added).

Data for the spread of search in the vertical meridian were found to deviate from normality and were therefore subjected to a reciprocal transform. Analysis of the spread of search in the vertical meridian found that novice drivers had a greater vertical spread of search than police drivers and matched-control drivers (Cohen's $f = 0.49$) though there was no evidence of a significant difference between police and matched controls. Differences between means were also noted for clip type and time of day, although both effects were accounted for by an interaction between the two factors that was due to a large increase in vertical scanning during daytime pursuits (as noted in the comparison of pursuit clips with response clips across the factor of time of day, Cohen's $f = 1.61$; see Figure 6).

Analysis of Physiological Measures

Planned contrasts were conducted on the mean levels of EDR across the types of clips (with one policeman removed from the analysis as equipment failure had resulted in a loss of data). The only significant result was an effect of the time of day (see Table 3 for contrast results), with daytime clips producing a higher mean EDR than nighttime clips. This is unremarkable considering the greater amount of visual information that impinges on the driver in

Table 3
Weighted Contrast Table for Mean Hazard Ratings, Frequency of Reported Hazards, and Mean Fixation Durations

Source	Contrast	*df*	Mean hazard ratings *F*	Mean hazard ratings *f*	Frequency of hazards reported *F*	Frequency of hazards reported *f*	Mean fixation durations *F*	Mean fixation durations *f*
Between subjects								
Driver (D)								
	Novice vs. matched controls and police	1	0.15	0.06	1.90	0.21	9.15**	0.45
	Matched controls vs. Police	1	0.48	0.10	0.01	0.01	1.83	0.20
Within-group error		45	(1.18)		(4.84)		(2,792.58)	
Within subject								
Type of driving clip (CL)								
	Control (C) vs. Pursuit (P) and Response (R)	1	205.30**	2.14	15.68**	0.59	25.20**	0.75
	P vs. R	1	2.67	0.24	25.38**	0.75	9.00**	0.45
D × CL								
	C vs. P and R	2	0.54	0.15	0.33	0.12	2.50	0.33
	P vs. R	2	0.19	0.09	1.49	0.26	2.55	0.34
CL within-group error								
	C vs. P and R	45	(0.42)		(0.89)		(356.05)	
	P vs. R	45	(0.22)		(1.18)		(528.52)	
Time of day								
	Day (DT) vs. Night (N)	1	2.51	0.24	1.26	0.17	12.29**	0.52
T × D								
	DT vs. N	2	0.24	0.10	0.89	0.20	0.73	0.18
T within-group error								
	DT vs. N	45	(0.16)		(0.47)		(0.48)	
T × CL								
	C vs. P and R	1	105.70**	1.53	12.26**	0.52	0.41	0.10
	P vs. R	1	2.45	0.23	0.52	0.11	74.16**	1.28
T × CL × D								
	C vs. P and R	2	0.12	0.07	0.05	0.05	0.01	0.02
	P vs. R	2	0.11	0.07	0.13	0.08	4.40*	0.44
T × CL within-group error								
	C vs. P and R	45	(0.37)		(2.46)		(710.89)	
	P vs. R	45	(0.84)		(5.73)		(1,262.51)	

Note. Values in parentheses represent mean square errors. Effect size is represented by Cohen's *f*.
$^*p < .05$. $^{**}p < .01$.

the daytime clips. No evidence of significant effects of the type of driving clip or the level of driver experience was found.

In addition to an analysis of the mean EDR across clips, the frequency of EDRs was calculated in the same manner as the calculation of the number of hazards. These discrete EDRs, considered indicative of sudden increases in hazard awareness, were subjected to similar planned contrasts. Daytime clips were found to produce the higher number of EDRs, which was again attributed to increased visual stimulation during the daytime. An effect of driver was also found (with means of 3.9, 4.1, and 6.7 for the novices, matched controls, and police, respectively), with police drivers producing a greater frequency of EDRs than the matched controls (Cohen's $f = 0.38$), although the comparison of novice drivers to the mean of the matched controls and police drivers was not significant.

Discussion

The analyses demonstrate that both the police drivers and the matched controls had shorter fixation durations than the novice drivers. The police drivers had the greatest horizontal scanning, whereas novices had increased vertical scanning. Pursuit drives appear to focus overt attention, especially in the novice drivers, though this is mostly during nighttime clips. Daytime pursuit clips actually appeared to increase the scanning relative to control clips. Emergency response clips appeared to show the reverse effect, with decreased spread of search and an increase in fixation durations during the daytime, and a decrease in relative fixation durations and an increase in horizontal scanning during the nighttime. In addition, although no evidence of significant driver group differences was noted for hazard-perception ratings, the frequency of EDRs suggests that the police drivers were aware of a greater number of arousing stimuli.

The large experiential effects found in eye movements fit with previously published findings (Chapman & Underwood, 1998; Crundall & Underwood, 1998; Mourant & Rockwell, 1972; Underwood, Crundall & Chapman, 2002; Underwood, Chapman, et al., 2002). Shorter fixation durations, noted for both the police drivers and the matched-control drivers, are considered indicative

Table 4
Weighted Contrast Table for Horizontal and Vertical Spread of Search, Mean EDRs, and Frequency of EDRs

			Horizontal spread of search		Vertical spread of search[a]		Mean EDR		Frequency of EDRs	
Source	Contrast	*df*	*F*	*f*	*F*	*f*	*F*	*f*	*F*	*f*
			Between subjects							
Driver (D)										
	Novice vs. Matched controls and police	1	8.19**	0.43	10.88**	0.49	1.72	0.20	3.08	0.26
	Matched Controls vs. Police	1	25.14**	0.75	1.89^{-3}	>0.01	0.79	0.13	6.14*	0.38
Within-group error		45	(203.25)		(1.41^{-5})		(55.13)[b]		(8.40)[b]	
			Within subject							
Type of driving clip (CL)										
	Control (C) vs. Pursuit (P) and Response (R)	1	5.24*	0.34	33.07**	0.86	4.06*	0.30	2.05	0.22
	P vs. R	1	26.22**	0.76	90.42**	1.42	0.32	0.09	0.01	0.02
D × CL										
	C vs. P and R	2	0.36	0.13	2.26	0.32	0.49	0.15	1.71	0.28
	P vs. R	2	0.31	0.12	2.66	0.35	0.90	0.20	2.77	0.35
CL within-group error										
	C vs. P and R	45	(133.18)		(5.46^{-6})		(0.52)[b]		(1.09)[b]	
	P vs. R	45	(103.98)		(5.59^{-6})		(0.51)[b]		(1.44)[b]	
Time of day										
	Day (DT) vs. Night (N)	1	0.05	0.03	40.08**	0.94	8.51*	0.44	4.28*	0.31
T × D										
	DT vs. N	2	5.54**	0.50	2.95	0.36	1.26	0.24	1.62	0.27
T within-group error										
	DT vs. N	45	(56.00)		(2.74^{-6})		(0.20)[b]		(0.90)[b]	
T × CL										
	C vs. P and R	1	11.04**	0.50	5.52*	0.35	1.74	0.20	3.79	0.29
	P vs. R	1	722.68**	4.01	134.44**	1.72	1.81	0.20	0.39	0.09
T × CL × D										
	C vs. P and R	2	0.66	0.17	0.53	0.15	0.01	0.02	1.15	0.23
	P vs. R	2	0.11	0.07	0.96	0.21	2.57	0.34	0.20	0.10
T × CL within-group error										
	C vs. P and R	45	(108.11)		(1.92^{-5})		(1.59)[b]		(2.30)[b]	
	P vs. R	45	(432.83)		(2.06^{-5})		(1.91)[b]		(4.09)[b]	

Note. Values enclosed in parentheses represent mean square errors. Effect size is represented by Cohen's *f*. EDR = electrodermal response.
[a] These contrasts were based on data subjected to a reciprocal transform to correct for nonnormality. [b] Degrees of freedom were reduced to 44 because of missing data.
* $p < .05$. ** $p < .01$.

of the reduced processing time required at any particular point of fixation, resulting in a corresponding increase in the sampling strategy of the visual scene. We predicted that a reduced effect would be noticed between police drivers and matched controls, but this difference did not reach significance (Cohen's $f = 0.20$).

There was a similar experiential effect in the horizontal scanning, in which police drivers had a greater mean standard deviation of fixation locations compared with matched-control drivers. It appears that the police drivers were processing more elements from a wider area of the visual scene than the other groups. This again fits with previous research on the influence of experience on oculomotor measures, which suggests that as experience increases, so does horizontal search. However, the main source of this effect is from the contrast between police drivers and matched controls (Cohen's $f = 0.75$), and although the novices had lower horizontal scanning when compared with all drivers (Cohen's $f = 0.43$), this large effect seems primarily due to the police drivers.

In addition to the limited overall scanning of the novices, their spread of horizontal search appeared to be further restricted during the nighttime clips. Neither the matched controls nor the police drivers were significantly influenced by the time of day. This large interaction (Cohen's $f = 0.50$) suggests that novice drivers may suffer from overt focusing during the nighttime, regardless of clip type. The strength of this effect argues for further study, independent of hypotheses relating to police driving.

The pattern of results changed with the analysis of the vertical search. A between-groups effect was noted, but this was due to greater vertical search in the novice drivers. This again partially replicates previous claims (e.g., Evans, 1991; Renge, 1980) that novice drivers tend to search predominantly in the vertical meridian, although search patterns tend to flatten and widen with increased experience.

In addition to the between-groups effects, eye movements were also found to differ across clip type and according to whether the

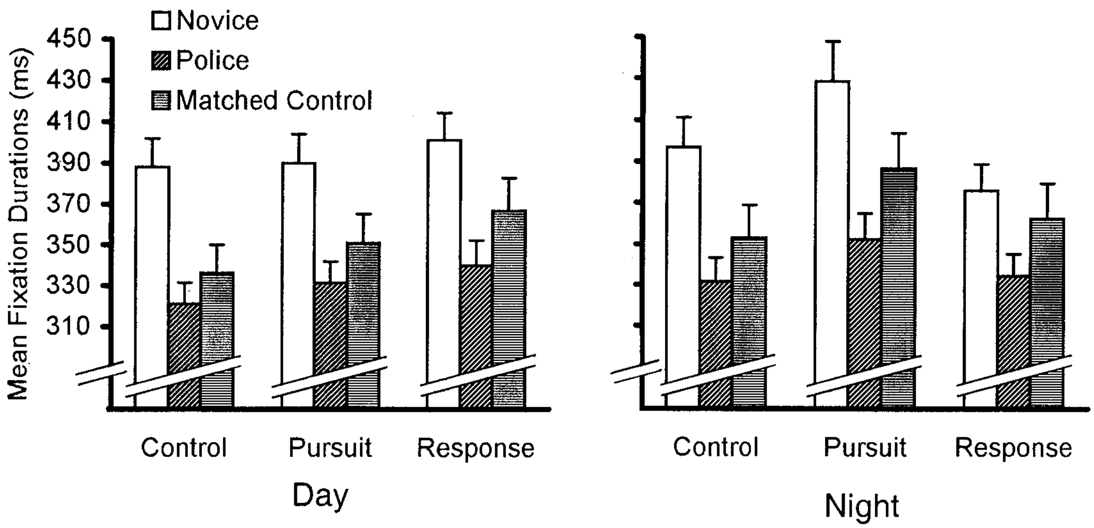

Figure 3. Mean fixation durations for the novices, matched controls, and police drivers across the three types of driving clip (with standard error bars added).

clip was filmed during the daytime or the nighttime. It was initially predicted that the pursuit drives would produce the longest fixation durations on the basis that prolonged hazards should lead to an even greater increase in attentional capture than abrupt hazards (Chapman & Underwood, 1998). This prediction has been upheld only for nighttime clips and, then, predominantly for the novice drivers.

During the night, extrafoveal objects are less salient and fewer in number, which in turn increases the salience of the central fleeing vehicle, resulting in longer fixation durations. This is supported by the analysis of the horizontal spread of search, which is greatly reduced in the nighttime pursuit clips as the drivers focus on the fleeing vehicle. During daytime pursuits, however, it seems as if all of the drivers are more aware of their surroundings, and they do their best to sample as much of the scene as possible with reduced fixation durations and a greater spread of horizontal search. This occurs even when compared with response drives, which one would normally predict would require a higher sampling rate.

The results suggest that the participants may have been aware that the fleeing vehicle could attract too much of their attention, and may have therefore adopted a compensatory strategy. It should be noted that it is also possible, however, that the fleeing vehicle may move more in the horizontal axis during the daytime clips, thus producing a wider spread of search while retaining the focus of attention.

Both U.S. and U.K. publications have reported that pursuit accidents are most likely to occur during the hours of darkness (Payne & Fenske, 1997; Police Complaints Authority, 2002). Although these results are confounded to a certain extent by the

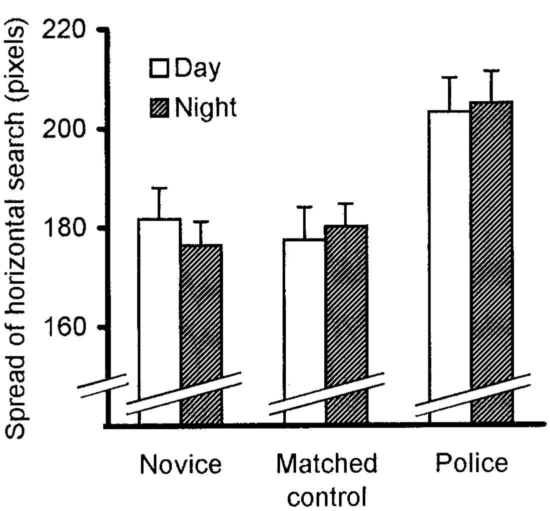

Figure 4. Horizontal spread of search for the three groups of drivers across day and night (with standard error bars added).

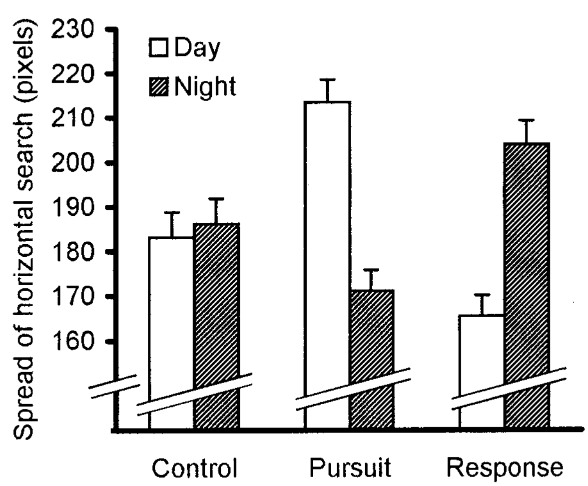

Figure 5. Horizontal spread of search for the three types of driving clip, across day and night (with standard error bars added).

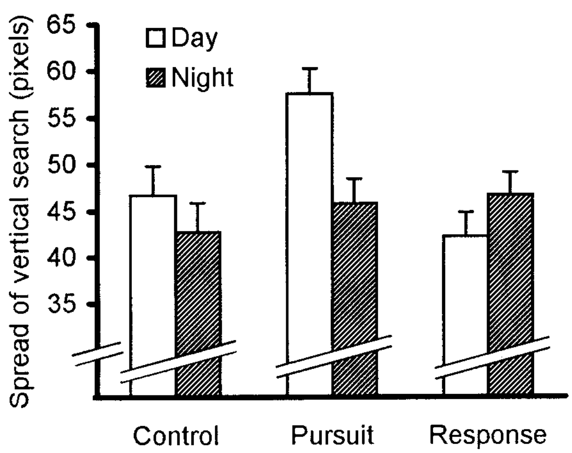

Figure 6. Vertical spread of search for the three types of driving clip, across day and night (with standard error bars added).

larger amount of illicit activity that occurs at night, it should be of some concern that police drivers may pay less attention to their surroundings when pursuing a vehicle at night, as this may reduce awareness of other potential hazards such as pedestrians. Although it is possible that police drivers rely more on the increased sensitivity of peripheral vision in darkness (e.g., Leibowitz, Post, Brandt, & Dichgans, 1982), it appears that the increased salience of the fleeing vehicle at night captures their attention.

Aside from the predicted differences found in the oculomotor measures, should we be concerned that police drivers produce the same hazard ratings as novice drivers produce? Previous research on accident liability suggests that the development of visual skills is vital to promote safer driving, and researchers using similar methodologies have successfully discriminated between driver groups (Ahopalo, 1987; McKenna & Crick, 1994; Pelz & Krupat, 1974; Renge, 1980), yet no evidence was found in the present study to support this hypothesis.

The inability of hazard-perception tests to discriminate among driver groups is not unprecedented, however (Chapman & Underwood, 1998; Crundall et al., 1999, 2002; Groeger et al., 1998). One suggestion for these discrepancies across the research literature is that hazard-perception differences arise only from preselected stimuli that have previously been found to show a difference. Even those researchers who have published literature about this effect acknowledge that the selection of certain clips is crucial in the link between hazard-perception ability and driving performance (Quimby & Watts, 1981). It is possible that the stimuli used in the present study were too realistic. If the hazardous events were exaggerated or staged to provide clearly defined onsets, then perhaps a difference would be forthcoming. However, selecting and editing stimuli would have to be undertaken by designers who are themselves experienced drivers. If the designers of a hazard-perception test used their driving experience to create hazards, then it would be unsurprising to find that experienced drivers performed better at spotting these hazards.

We expected EDRs to increase during faster and more dangerous drives (e.g., Hashimoto, 1970). No evidence was found for differences between the type of clips, though police drivers were found on average to produce a greater number of EDRs in response to all clips. This suggests that the police drivers were responding to a greater number of hazardous events, at least at a physiological level, than the novice drivers or the matched-control group. It appears that the police drivers were most sensitive to the number of potentially hazardous events, at least at a physiological level, yet there is no evidence that this resulted in changes in the number of hazards reported. This suggests that there are differences between the police drivers and the two other groups in what they perceive, but it is possible that they also differ on the criterion of what needs to be reported as a hazard. Combined with the self-ratings of driving ability, this makes perfect sense. As the police drivers regard themselves as better able to deal with hazardous driving, they may view many events seen on the tape as not hazardous enough to warrant a response. Although this would not necessarily affect initial increases in physiological arousal due to perceiving a hazardous event, it could influence the cognitive appraisal of the event and the decision to report it (Hoyos, 1988).

Although the hazard-perception measure may be flawed as a method of distinguishing among driver groups, it still demonstrated a difference among the types of driving clip, which may provide insight into the nature of the perceived hazards police drivers face when engaged in similar situations. The three participant groups agreed that both pursuit clips and response clips were more hazardous than control clips in regard to the mean rating level, although response clips had the greatest frequency of discrete hazard responses. The primary difference between the response clips and the pursuit clips was the presence of a fleeing vehicle (though it should also be noted that there is a 9 mph average difference between the two clips). It appears that when the fleeing vehicle is present, the participants either are less aware of other hazards or do not judge other hazards to be as important. Response driving, however, produces a high frequency of discrete hazards because any response to a brief increase in danger is not overshadowed by the prolonged hazard of the fleeing car.

In conclusion, the police drivers' higher ratings of self-perceived driving ability were reflected in shorter fixation durations and a greater spread of horizontal search. Their increase in EDRs compared with other drivers fits with the hypothesis that police drivers are generally more aware of their surroundings. There is evidence, however, of overt attention focusing in nighttime pursuits, though the magnitude of this focusing is much greater for the novice drivers. Paradoxically, focusing also seems to occur in daytime response drives. As the daytime response drives were the fastest and contained the greatest frequency of hazards according to the hazard ratings of all participants, one would predict the opposite effect: that these clips would produce the widest sampling strategy. If this surprising result is upheld in future research, it may represent a greater safety issue than focusing during pursuits, as it extends to the wider emergency response community.

Future research should also extend the methodology to overcome any potential confounds. Although several studies have demonstrated that video-based driving experiments can elicit eye movements similar to those noted in the real world (e.g., Hughes & Cole, 1986; Underwood et al., 2002), some specific eye movements may occur only when individuals are actually driving (e.g., tangent point fixations; Land & Lee, 1994). Replication of these results in the real world (despite the difficulties involved) would allow generalization of these conclusions beyond the laboratory. In addition, potential problems with the self-selection of participants into driver groups and their subsequent motivation should be addressed.

Aside from these methodological issues, the present research has identified areas of concern regarding visual attention in prolonged hazardous situations, and future research must assess the implications of these findings for the safety of police drivers, the general public, and anywhere else it is possible to attempt to reduce any related risk.

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- *Journal of Consulting and Clinical Psychology:* **Annette M. La Greca,** PhD, ABPP, Professor of Psychology and Pediatrics, Department of Psychology, P.O. Box 249229, University of Miami, Coral Gables, FL 33124-0751.
- *Developmental Psychology:* **Cynthia García Coll,** PhD, Brown University, 21 Manning Walk, Providence, RI 02912.

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- For *Journal of Consulting and Clinical Psychology,* submit via www.apa.org/journals/ccp.html.
- For *Developmental Psychology,* submit via www.apa.org/journals/dev.html.

Manuscript submission patterns make the precise date of completion of the 2004 volumes uncertain. Current editors, Mark B. Sobell, PhD, and James L. Dannemiller, PhD, respectively, will receive and consider manuscripts through December 31, 2003. Should 2004 volumes be completed before that date, manuscripts will be redirected to the new editors for consideration in 2005 volumes.