HUMAN PERFORMANCE, 1(4), 205–235

Visual Search in Sport and Ergonomics: Its Relationship to Selective Attention and Performer Expertise

Bruce Abernethy
Department of Human Movement Studies
University of Queensland

Visual search data has been frequently used to make direct implications about aspects of selective attention. In the first part of this article, the relationship between visual search and selective attention is examined to see what assumptions and limitations exist in making these implications. It is revealed that although much of the existing visual search research can be interpreted from within the selective attention notions of pertinence and context, measures of visual orientation alone, as provided by eye-movement recording, are inadequate solitary indicators of the allocation of attention. The capacity to make attentional shifts without eye movements, the distinction between "looking" and "seeing," and the unknown role of information processed from the periphery of the retina in dynamic information pick-up emerge as essential limitations in the eye-movement recording approach to assessing selective attention. In the second part of the article, the extent to which visual search strategy, like selective attention, is mediated by the subject's level of task proficiency is examined by reviewing evidence from visual search analyses conducted within the applied settings of ergonomics and sport. It is revealed that experts and novices often systematically fixate upon different areas of a given display (implying differences in cue usage), although the evidence concerning differences in search rate (as indicative of processing load) is equivocal. Persistent failure to consider the assumptions and limitations within the methods used in applied visual research is highlighted, and some suggestions for future research direction are advanced.

Skilled action requires the human performer to continually interact with and adapt to the visually rich environment in which he or she lives. In order

---

Requests for reprints should be sent to Bruce Abernethy, Department of Human Movement Studies, University of Queensland, St. Lucia 4067, Australia.

to be successful in a wide range of perceptual-motor tasks, the performer must not only be capable of detecting the complexities of the surrounding visual display, but must also be capable of selecting out from this visual display only the most pertinent of information for detailed processing. It is currently uncertain as to what extent this selection process is reflected in the way the performer visually searches the display, continually moving his or her eyes to direct foveal vision to only selected areas of the display. It is the purpose of this article, therefore, to consider the nature of this relationship between selective attention and the visual search process, specifically as it applies to skilled performance in the "real world" domains of ergonomics and sport.

This article is broken down into two parts. In the first section, some fundamental notions about the visual search process are reviewed and the compatibility of data on visual orientation to predictions from selective attention theory is assessed. In the second section, the available evidence from visual search analyses in ergonomics and sport settings is evaluated in an attempt to determine the extent to which the visual search strategies used in these applied settings are influenced by the performer's level of expertise. The applied settings of ergonomics and sports are chosen to examine expert-novice differences in visual search because they provide a natural environment where expert performers are exposed to high degrees of task-specific practice—practice to the extent which cannot realistically be obtained within the laboratory.

THE VISUAL SEARCH PROCESS

Stages of the Visual Search Process

Visual search is usually conceived of as a two-stage process involving an initial capacity-free, preattentive stage, in which all visual information available from the receptors is held very briefly in literal representation in a rapidly decaying visual sensory store (termed *the icon*), and a subsequent attention-demanding focal stage of performance, in which selected items from the iconic store are subjected to detailed analysis (Neisser, 1967; see Figure 1). Although alternative terminology is often utilized, as exemplified in the acquisition process–identification process distinction used by L. G. Williams (1967) or, more recently, in the automatic search-controlled search distinction drawn by Schneider (1976) and Shiffrin and Schneider (1977), similar two-stage conceptions of the visual search process have dominated the literature (see also Swensson, 1980). Within these conceptions, selective attention is typically considered as just one of the components of the visual search process, specifically concerned with continuously and selectively

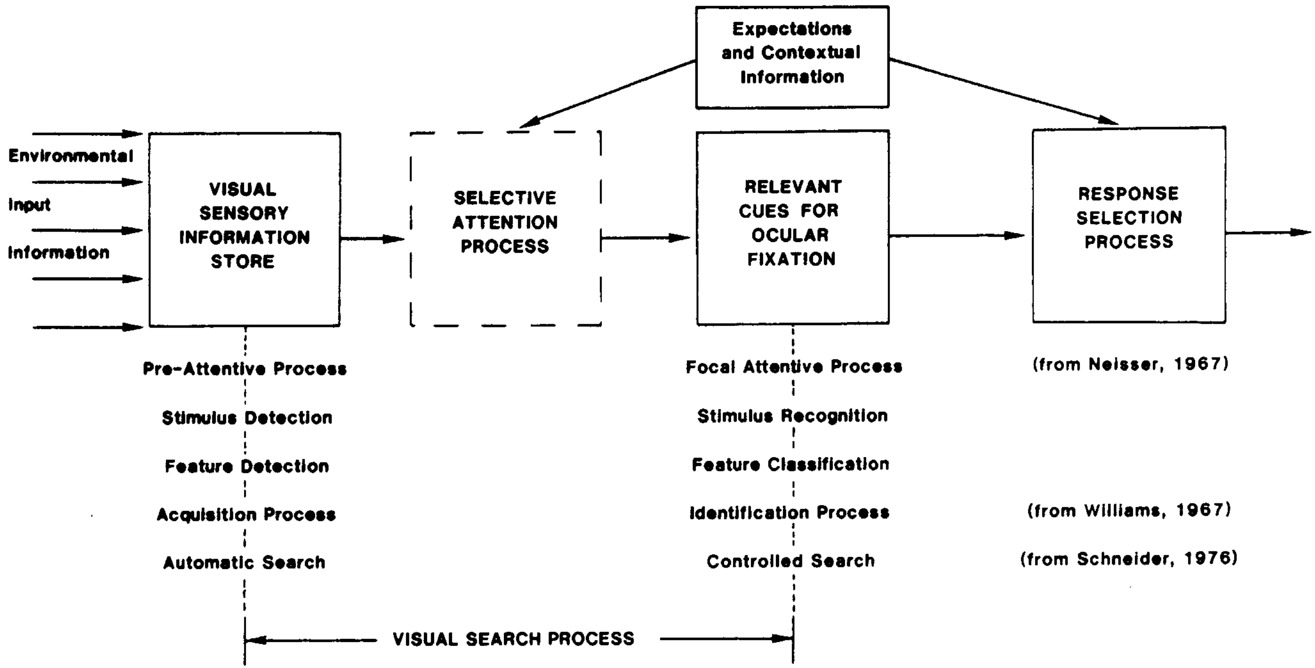

FIGURE 1. A typical two-stage model of visual search with selective attention as the mediating process between preattention and focal attention. Alternative classifications of this two-stage process are also shown.

guiding the passage of information from preattention to focal attention (Duncan, 1984). Because of this relationship, factors that influence selective attention, such as expectational and contextual information (Norman, 1968, 1969), are also hypothesized to exert some influence on the visual search process. The specific structural locus of selective attention, however, appears to vary somewhat from situation to situation, and the actual selection process may occur at one or more stages of the information processing chain (Acosta & Simon, 1976; Thomas, 1980) depending on specific task requirements.

Preattentive search. The first or preattentive stage of analysis is usually considered to be an automatic one (La Berge, 1981; Neumann, 1984; Schneider, 1976), because it allows the parallel processing of all concurrent input signals in a nonattention demanding manner (Salmoni, 1975). These concurrent input signals are believed to be held in a literal representation in the visual sensory store, but are available to the performer for only a very brief period of time. The information held in this store is subject to very rapid decay in the absence of attention (Sperling, 1960). In this brief period of time, very crude feature analysis is presumed to take place (Neisser, 1967); the results of this analysis are used to determine those aspects of the display worthy of more detailed focal attention. Both retinal (Long & Sakitt, 1980; Sakitt, 1975) and visual cortical (Di Lollo, Lowe, & Scott, 1974; Taylor & Brown, 1972) loci have been proposed for this visual sensory store (or icon; Neisser, 1967), but considerable uncertainty now exists as to whether the icon is real or is merely an artifact of the experimental paradigms used to study it (Dick, 1974; Haber, 1983). In any case, application of current knowledge regarding iconic memory directly to the consideration of visual search within applied settings is extremely difficult, given the severe absence of ecologically valid investigations of the phenomenon. As Sharp (1978) noted:

> . . . the value of sensory storage as a general theoretical concept is limited for its investigation has been delimited almost totally to the experimental situation where a stationary subject views a static field as in letter or form recognition. There is little evidence available which allows us to extrapolate from the static case to the dynamic one where there is relative movement between the visual field and the individual. . . . (pp. 5–6)

Although the preattentive analysis of visual information may well be an essential stage in skilled performance, in "real-world" skills a more critical current concern is with determining what information performers of different skill levels regard as sufficiently pertinent to commit to detailed focal attention. Examination of the cues reaching focal attention may provide insight into the perceptual strategies that characterize the expert performer of motor skills.

Focal attentive search. In contrast to the difficulties encountered in finding an appropriate paradigm for the study of preattentive aspects of visual search, focal attentive aspects of the search process lend themselves more readily to direct examination, especially through procedures such as eye-movement recording. (For a review of these eye-movement recording procedures see, e.g., Tursky, 1974, or Young & Sheena, 1975). As the high acuity region of the retina (the fovea) extends for only 2° of vision around the line of central fixation (Rayner, 1978), the position of the eye must constantly be moved in order to extract high-resolution information from those display areas of greatest current interest (Gaarder, 1975). By allowing measurement of the location of ocular fixations relative to different display features, eye-movement recording has provided a method from which implications can be drawn regarding the subject's allocation of focal attention.[1] The assumption made in the use of eye-movement recording in this way (which I return to in a moment) is that visual orientation to the display, as assessed from the location of ocular fixations on different display features, accurately reflects the subject's selective allocation of his or her limited processing capacity.

Cognitive and Applied Visual Research

From those studies that have used eye-movement recording, an important distinction can be drawn between cognitive and applied visual search research (Monk, 1976). In cognitive visual search research, the specific search task is of minimal interest to the researcher and serves merely as a vehicle for studying the underlying cognitive processes. The search material used is generally alphanumeric, because of its standard nature and ease of generation, and is usually presented in a form that is conducive to a single, specifiable order of search. To date, this cognitive form of research has focused principally on the issues of developing models of search time (e.g., Card, 1984; Drury, 1975) and identifying the factors influencing search speed (e.g., Drury & Clement, 1978; Mocharnuk, 1978). (Reviews of this research may be found in Barber, 1981; Kerr, 1982, pp. 153–157; Teichner & Krebs, 1974; or Wickens, 1984, pp. 259–261.)

Applied studies of visual search, on the other hand, place greater

[1]The frequently coined term *eye movement research* is a little paradoxical when one considers the importance assigned to ocular fixations rather than eye movements (Cohen, 1978a). Indeed, as Mackworth (1976, p. 174) noted, the "pause is mightier than the move" in most visual search research.

emphasis on the use of situation-specific tasks, because the task performance is the central concern in this case. The tasks and procedures used do not place restrictions on the order of search that can be used by the subject, as do the cognitive paradigms, and individual variability in the search strategies adopted is of principal interest. Although some bridging studies have emerged, which attempt to examine cognitive questions through the use of more realistic stimuli (e.g., Scanlan, 1977; Silbernagel, 1982), in order to examine issues of relevance to this article, it is necessary to consider primarily the specific research that has adopted the applied perspective.

To date, the majority of applied visual search studies available in the literature have been concerned primarily with the application of visual search to ergonomics, often with the objective of modifying task requirements or equipment layout. Eye-movement recording has been conducted both during the performance of relatively static tasks, such as radar operation (White & Ford, 1960), radiological examination (Kundel, 1974; Kundel & La Follette, 1972), and industrial inspection (Megaw & Richardson, 1979; Schoonard, Gould, & Miller, 1973; Wentworth & Buck, 1982), and during tasks where the performer moves at high speeds through the environment, such as in driving (e.g., Cohen, 1978a; Cohen & Studach, 1977; Mourant & Rockwell, 1970, 1972) or flying (Llewellyn & Thomas, 1963; Milton, 1952; Stager & Angus, 1978; Stern & Bynum, 1970). Obviously, the latter tasks provide situations that are more likely to reflect human performance limitations in information processing and which, in turn, are more akin to the kinds of temporal and attentional demands that exist in many competitive sports. Knowledge accrued from the more static tasks is nevertheless very useful in assessing the validity of eye-movement recording as a means of examining selective attention.

Applied Visual Search and Selective Attention Notions

It has been noted previously that the basic assumption underlying the assessment of selective attention from eye-movement recording procedures is that the characteristics of the fixations evident in the search pattern reflect, in a direct manner, the underlying perceptual strategies used by the performers. Fixation location characteristics are assumed to reflect information about the specific cues performers selectively attend to in order to extract task-relevant information, and fixation duration (or search rate) characteristics are assumed to reflect detail about the information-processing loads faced by the performers.

Many of the general findings regarding visual search, in ergonomics tasks especially, are, indeed, highly compatible with predictions that can be generated from theories of selective attention such as Norman's (1968, 1969) pertinence-based theory. It appears, for example, that the initial fixations of subjects in tasks, such as radiographic inspection (Kundel & La Follette, 1972; Kundel & Wright, 1969), closely reflect the subjects' a priori expectations regarding the probable location of the most pertinent information in the display and that subsequent fixations appear to be determined primarily by the flow of current information reaching the retina (Gale, Johnson, & Worthington, 1979). These observable search strategies are very much in keeping with the contentions from behavioral evidence (e.g., see Alain & Proteau, 1980) regarding the order in which "data-driven" sensory inputs and "conceptually driven" expectancy inputs exert their greatest influences on the selective attention process. Similarly, because the visual search of "real world" displays appears to proceed largely on the basis of the subject's predictions of event probabilities, some large sections of the display are very rarely sampled foveally (e.g., see Megaw & Richardson, 1979, or Papin, 1984), and search is largely restricted to those areas of the display with the highest perceived probability of containing pertinent information. Ambiguous and novel areas of the display appear to attract fixations (e.g., Kundel & Wright, 1969; Mackworth & Morandi, 1967), and there appears to be a relationship between fixation density and the rated informativeness of the display (Friedman & Liebelt, 1981). Search patterns appear to follow closely the subject's verbal estimates of the location of important information (Mackworth & Morandi, 1967; Pollack & Spence, 1968; Schissler, 1969), and the assignment of pertinence to display features appears to be, at least partially, cognitively mediated. The cognitive knowledge of the subject consequently appears as an important factor guiding search performance (Kundel & La Follette, 1972).

In keeping with many selective attention notions, the context in which the stimulus occurs also appears to influence scanning activity (Antes & Penland, 1981; Goillau, 1984; Rayner, 1984; Shinar, McDowell, & Rockwell, 1977), and a number of changes in critical search parameters occur with the induction of stress in a manner which reflects the corresponding decrements in selective attention performance (e.g., Kalunger & Smith, 1970; Mortimer & Jorgenson, 1972). Furthermore, visual search appears to reflect a number of the known limitations of short-term memory—some locations in static displays, for example, are searched a number of times in order to extract pertinent information (Card, 1984; Wickens, 1984, p. 252).[2] If one assumes an intimate link between selective attention and short-term memory, as many theorists have (e.g., Broadbent, 1958; Norman, 1968), then this observation, like the others, is compatible

[2]Because many theorists suggest that the selective attention process may be located in short-term memory, it should, therefore, acquire and reflect the functional limitations of short-term memory.

with the notion of visual search behavior reflecting the selective attention process.

There are, nevertheless, a number of limitations in eye-movement recording that make it a less than perfect indicator of selective attention. First, note that visual orientation to a display area in the form of a fixation does not necessarily ensure that actual perception or information extraction takes place, and this distinction between "looking" and "seeing" (Adams, 1966; Mackworth, Kaplan, & Metlay, 1964) has important implications for visual search research. There are frequent documentations in the applied research of target objects (e.g., crash sites in air-to-ground searches, Stager & Angus, 1978; red lights in traffic research, Thomas, 1968; or anomalies in chest radiographs, Kundel, Nodine, & Toto, 1984) that are fixated without being subsequently reported or responded to. This obviously highlights the necessity in attempts to imply cue usage from visual search data to also collect concomitant data on task performance and actual information extraction.

A second related limitation in assessing selective attention directly from eye-movement records is that it is possible to shift attention around the visual field without making any eye movements or without, consequently, altering the point of fixation (e.g., Gippenreiter & Romanov, 1974; Posner, 1980; Remington, 1980; Sanders & Houtmans, 1985; Shulman, Remington, & Mclean, 1979; Sperling & Reeves, 1980). These internal attentional shifts make it possible, for example, for information extracted from the visual periphery to be given processing priority, yet this aspect of focal attention cannot be gleaned from simple inspection of the eye-movement recording data. The current limitation in eye-movement recording procedures of only securing information about the directional orientation of the fovea, without reference to the potential visual acquisition capabilities of the parafovea and periphery, is obviously a substantial one given the apparently powerful role of the peripheral or ambient system in the detection and control of movement (Bonnet, 1975; Dichgans & Brandt, 1972; Paillard, 1980, 1982).

Third, the eye-movement recording approach also has substantial problems in terms of the absence of both inter- and intrasubject consistency in the use of search patterns (e.g., see Buchsbaum, Pfefferbaum, & Stillman, 1972) and in terms of technical limitations in the recording process. Technically, accurate long-term calibration of the eye-movement recording devices presents the major hurdle to reliable data extraction. Calibration of the recording devices is made difficult by nonlinearity in the response of the subject's eye mark for saccades made across the total range of the visual field and by baseline drifts that accompany any extended recording of the subject's visual search activity. All these limitations with eye-movement recording clearly need to be fully recognized and acknowledged before conclusions about selective attention strategies can be drawn. (For a more detailed consideration of these limitations see Abernethy, 1985.)

Given these methodological limitations, what then can be gained from studies of visual search activity in terms of understanding the role of perception in skilled motor performance?

EXPERT-NOVICE DIFFERENCES IN VISUAL SEARCH

It is known from behavioral studies that some differences in selective attention exist, both in ergonomics and particularly sport, between expert and novice performers. Expert-novice differences have been clearly demonstrated in the recognition of display structure (e.g., Allard, Graham, & Paarsalu, 1980) and in the pick-up and utilization of advance sources of information from the performance environment (e.g., Abernethy & Russell, 1987a; Jones & Miles, 1978), and some parallel evidence suggesting that changes in cue usage necessarily accompany gains in experience and competency exists (e.g., Fuchs, 1962). (Reviews of this literature may be found in Starkes & Deakin, 1984, or Abernethy, 1987.) In the following section, the question considered is to what extent visual search in ergonomics and sport, as assessed from eye-movement recording analyses, is influenced by the subjects' level of task proficiency. In reviewing the available literature on this issue, considerable emphasis is placed on the extent to which the procedural assumptions and limitations associated with the use of eye-movement recording are recognized and acknowledged.

Ergonomic Task Literature

As a consequence of the relationships between inexperience and accidents (Kay, 1978) and perceptual errors and accidents (Lawrence, 1974), a number of studies in ergonomics have dealt with the perceptual performance of experienced and novice workers. In studies of mine workers, for example, it has been shown that perceptual differences exist between experienced and inexperienced workers in their ability to discriminate safe from dangerous rock formations (Blignaut, 1979a, 1979b), and some evidence is now available suggesting that at least some of these perceptual performance differences may be due to differences in visual search strategy. In particular, some differences in terms of the specific cues foveated (i.e., differences in fixation location) and in the search rates adopted (i.e., differences in fixation duration) by experienced and novice workers are evident from the available research.

Differences in specific cues fixated. In static tasks, where both the display and the viewer remain stationary, the clearest examples of expert-novice differences in the distribution of fixation locations are in the studies of radiology (Carmody, 1980; Kundel, 1974; Kundel & La Follette, 1972; Kundel & Nodine, 1978). Skilled radiologists viewing a chest x-ray employ a search pattern which results in fixations being spread somewhat evenly around the circumferences of both lungs—a fixation distribution that is very similar to an estimate of the probability distribution of abnormalities for the chest (Kundel, 1974; Kundel & La Follette, 1972). Laymen, on the other hand, have the greatest proportion of their fixations located at the areas of sharpest visual contour, they are the areas surrounding the heart and mediasternum—areas that are attractive pictorially (e.g., see Mackworth & Morandi, 1967) but which are of relatively low pertinence for the isolation of chest pathologies. Optimal search strategies also appear to emerge with practice in other static tasks such as searching numerical arrays for target items (Sperandio & Bouju, 1983).

Differences in the qualitative aspects of visual search are also available from comparison of experienced and novice performers in dynamic tasks such as driving where there is relative movement between the human operator and the display. In the oft-cited works of Zell (1969) and Mourant and Rockwell (1972), novice drivers were reported to have fixations over a narrower horizontal range than experienced drivers and, in addition, were found to make forward fixations over a shorter distance than those used by the experienced. Such search patterns effectively prevented the novice drivers from having a broad awareness of potential vehicles or hazards approaching laterally and prevented them "looking ahead" to anticipate the future tasks demands. Furthermore, novices were reported to make fewer fixations near the focus of expansion[3] than did the experts, thus impeding their efficient extraction of information regarding the forward motion of the vehicle. Conversely, novice drivers made more fixations on the edge of the roadway, and these fixations presumably assisted in steering and positional control of the vehicle—functions that appear to be adequately controlled in experienced drivers through the use of peripheral vision (Bhise & Rockwell, 1971).

Finally, novice drivers were observed making more fixations on the speedometer but fewer on the rear vision mirror than did experts (Mourant & Rockwell, 1972). This observation suggests that the workload provided by vehicular control is such that the novice driver has little spare visual

[3]The focus of expansion is that point in the visual environment to which movement is directed and is, hence, the stationary point from which all optic flow radiates. It is believed by many (e.g., Fry, 1968) to provide the most specific environmental information available to the performer regarding the rate of forward motion and the onset of any directional changes.

capacity to allocate to other components of the driving task such as monitoring the position, direction, and relative velocity of other vehicles. The high foveal workload experienced by the novice driver also apparently impairs the novice's capacity to concurrently use peripheral vision for information acquisition, thus effectively resulting in a reduced functional visual field size (Sanders, 1970). This perceptual narrowing, which accompanies stress, appears to be a quite general characteristic of the visual system (Easterbrook, 1959), having been demonstrated under a range of different environmental conditions and resulting as a consequence of a wide range of stressors (e.g., Kobrick, 1972; Landers, Wang, & Courtet, 1985; Moskowitz, Sharma, & McGlothlin, 1972; Reynolds, 1976; Weltman & Egstrom, 1966; Weltman, Smith, & Egstrom, 1971).

Considerable task-specific experience appears necessary before the learner driver develops search strategies indistinguishable from those of the experienced driver (Cohen & Studach, 1977). With task-specific practice in ergonomic tasks the use of peripheral vision increases, attention is directed more automatically to pertinent features of the display, and the quality of information extraction is enhanced by use of a lesser number of environmental cues, each of greater pertinence (Neboit, 1983).

Differences in search rate used. Aside from differences in the quality of the information selected for processing, theories of selective attention also predict differences in the respective amounts of information that need to be processed by experts and novices. Specifically, experts are predicted to process less information because of their greater ability to recognize redundancy within the display. As the information-processing load appears to be the principal factor influencing search rate in cognitive tasks (Teichner & Krebs, 1974; Teichner & Mocharnuk, 1979) and as search rate also appears to increase whenever task complexity or temporal stress is added in applied tasks (e.g., see Bard, Guezennec, & Papin, 1981; McDowell & Rockwell, 1978), it is to be expected that expert performers may be able to use a lower visual search rate than novices in processing the information contained within a given perceptual display. This is in essence the *variable processing rate hypothesis* of Teichner and Krebs (1974). If experts also have a greater capability than novices to extract crucial information from peripheral vision, without the necessity to make eye movements (Davids, 1984), then this would similarly contribute to experts using fewer and more lengthy fixations than novices. Furthermore, the use of a search strategy in which the number of fixations is reduced is also in line with the expected reduction in the number of cues needed by the experts to perceptually construct the familiar display of their specific sport (the *perceptual automatizing hypothesis* of Furst, 1971) and is an efficient one in terms of maximizing the possible time for information extraction (during fixations) and minimizing the inactive processing time associated with saccadic movements.

The search rate of a subject can be potentially altered in one of two ways—either by altering the mean fixation duration ($\overline{FD}$) or perhaps by altering the time spent in making saccadic movements. Although there is some evidence derived from simple tachistoscopic studies indicating greater saccadic eye-movement speed for successful performers in sports tasks (Williams & Helfrich, 1977), by far the greatest potential for modulating overall search rate comes through alteration of the $\overline{FD}$.

In ergonomic tasks, in which strict time constraints are not imposed on the performer, such as in the radiological examination tasks, experts appear to need fewer fixations in order to locate an anomaly, although their search rates (as determined from $\overline{FD}$s)[4] are roughly the same (Kundel & La Follette, 1972) or even slower (Papin, Metges, & Hernandez, 1983) than those of the untrained observer. In these cases, the more rapid orientation to relevant information by the experienced viewers is in all probabillity due to their use of more pertinent cues and/or their superior expectancies regarding the potential location of anomaly information.

When temporal stress is added to ergonomic tasks, however, conflicting evidence regarding the search rate differences between expert and novice performers appears to emerge. In keeping with the predictions of Boynton (1960), superior performers in inspection tasks appear to need not only fewer fixations in order to detect item flaws (Schoonard et al., 1973) but also use a search strategy which is characterized by higher fixation rates, and hence shorter $\overline{FD}$s, than are used by less competent inspectors (Krebs, 1975; Megaw & Richardson, 1979; Schoonard et al., 1973). Comparable evidence of shorter $\overline{FD}$s for expert pilots (Senders, 1976; Stern & Bynum, 1970) and compatible findings of decreased $\overline{FD}$ with task-specific practice on a numerical searching task (Sperandio & Bouju, 1983) also support the somewhat unexpected conclusion of faster search rates for expert performers. On the other hand, there is conflicting evidence from flying (Neboit, 1983; Neboit, Papin, Pottier, Puimean-Chieze, & Viard, 1978) to indicate longer $\overline{FD}$s for experienced performers—findings supported in part by the increased $\overline{FD}$s, which are observed when extended practice is provided on either static tachistoscopic tasks (e.g., Furst, 1971; Schaffer & Gould, 1964; Schroeder, 1969a, 1969b, 1970; Schroeder & Holland, 1968) or "real-world" flying tasks (Papin, 1984). Similar trends for increased $\overline{FD}$ with practice have been reported in car drivers by Allen, Schroeder, and Ball, (1978), but, in this particular study, no concomitant expert-novice differences in search rates were observed.

Obviously then, despite the expectation of longer $\overline{FD}$s for experts, to date

[4]$\overline{FD}$ is actually the inverse of the search rate, that is, search rate = fixations/second averaged over the task duration whereas $\overline{FD}$ = the task duration/the number of fixations.

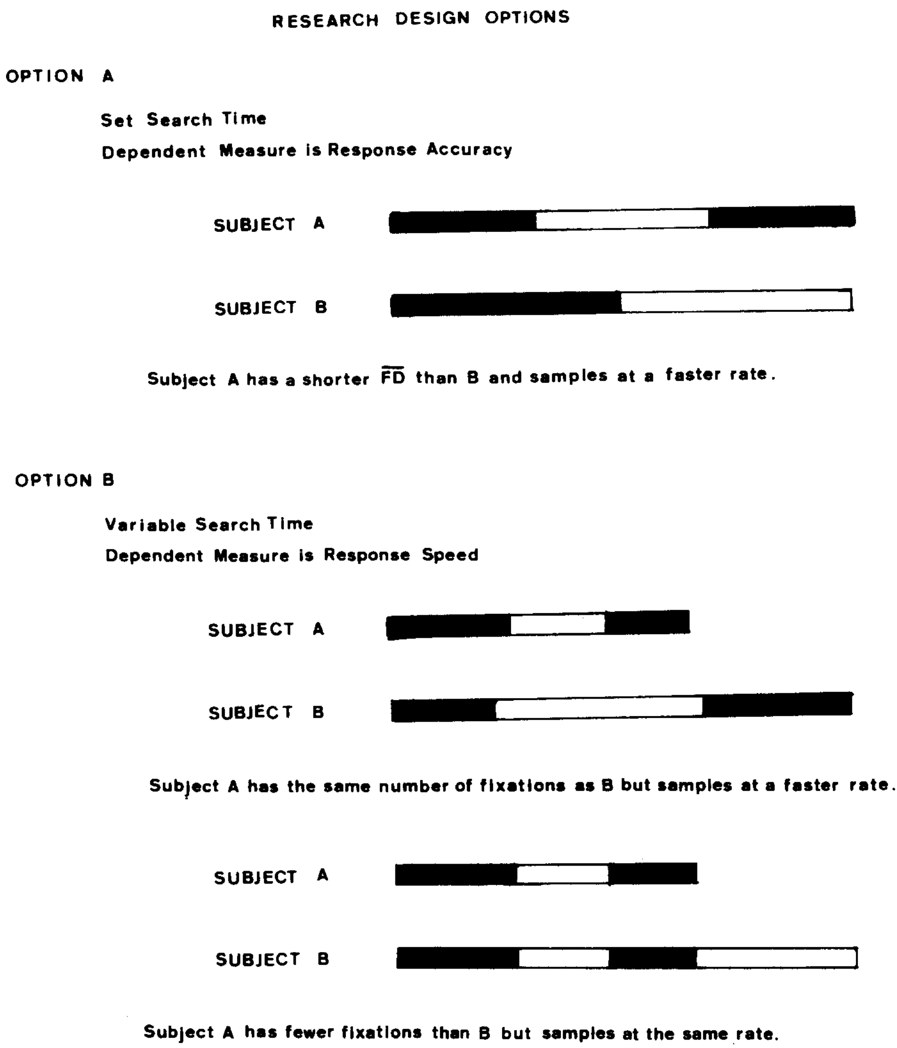

FIGURE 2. Dependence and independence of the measures of number of fixations (NF) and *M* fixation duration ($\overline{FD}$), under conditions where subjects are given a constant time course of display information and are required to respond for accuracy (Option A) or are given the task of responding as rapidly as possible, resulting in variable search times (Option B). In the first case, the two measures are inversely dependent and provide comparable estimates of search rate. In the second case, only $\overline{FD}$ provides a reliable measure of search rate that can be used to compare between subjects or between tasks.

no clear systematic differences in search rate in ergonomic tasks have been isolated which can be directly attributed to differences in subject proficiency. The existing studies are, however, fraught with methodological and paradigmatic limitations. There appears to be confusion in the literature regarding the use of the number of fixations as opposed to fixation duration as indicants of search rate (see Blanchard, 1985, or Premack & Collier, 1966), and there is generally little consideration made of the interdependence and independence of these measures in the design of the search tasks (see Figure 2). In cases where all subjects are presented with a constant duration display and a dependent measure of response accuracy is used for the task, the visual search measures of the number of fixations and $\overline{FD}$ are inversely proportional with either measure providing a reliable comparative indication of search rate. However, when subjects are required to make a visual judgment as rapidly as possible and the overall search time consequently varies between subjects, these two measures are no longer identical. In these instances of variable search time, the number of fixations, although providing an indication of the number of different locations that need to be sampled in order to make a judgment, no longer provides a reliable measure of search rate for comparing between subjects or between tasks. Unfortunately, many of the ergonomic studies of visual search employ designs that result in variable search times between subjects but report only measures of the number of fixations and not $\overline{FD}$ in assessing search rate.

Comparison of findings across the different ergonomic studies of visual search is made difficult not only because of differences in the search rate parameters reported but also because of differences between studies in the instructional sets imposed (in terms of speed or accuracy requirements), differences in the criteria used to define a fixation (Moffitt, 1980), and differences in the nature of the specific display information provided, be it static or dynamic.[5]

Sport Task Literature

Despite the great hope for eye-movement recording as an approach to understanding perceptual processes in sport (Rothstein, 1977; Terauds, 1976), applications of eye-movement recording to motor behavior and sports problem situations specifically did not emerge until the mid-1970s (e.g., Bard, Fleury, & Carrière, 1975; Haywood, 1977; Williams & Helfrich, 1977), some 20 to 30 years after these techniques had been first used in ergonomic settings (e.g., Milton, 1952; Tiffin & Bromer, 1943). A growing number of studies in the 1980s have, however, addressed the role of visual search in sport performance, with the majority of these studies arising from non-English sources, especially from the French-Canadian works of Bard and Fleury (1976, 1981), Bard, Fleury, Carrière, and Hallé (1980), the French work of Ripoll (1984, 1988), Ripoll, Papin, Guezennec, Verdy,

[5]It is well known that dynamic displays provide different information to perceivers than do static displays. Objects that may be indistinguishable while stationary become instantly recognizable once in motion (Johansson, 1973).

and Philip (1985), and Ripoll, Papin, and Simonet (1983), and the German works of Haase and Mayer (1978), Neumaier (1982, 1983) and Ritzdorf (1983). With recent advances in eye-movement recording technology, there has been a move toward the use of more ecologically valid field settings for data collection, but a number of methodological and interpretative problems persist which weaken current understanding of visual search in sport.

The earliest work on the application of eye-movement recording to sport perception problems appears to have been Bard and Fleury's (1976) work based on the examination of the search patterns of five expert and five novice basketballers. Bard and Fleury presented their subjects with a series of schematic slides depicting offensive positions in basketball to which the subjects were required to make, as rapidly as possible, a verbal response selection (from the four choices of *shoot, dribble, pass,* or *stay*). The subjects' visual search patterns were recorded while performing the task, and data regarding the frequency and location of fixations were used in conjunction with the decision time data as the dependent measures. No significant differences in decision time were obtained despite the faster mean vocal reaction time for the expert group, but differences in a number of visual search parameters were obtained. Specifically, experts were found to fixate more on significant empty space and the positioning of their teammate's opponent than did novices, indicating differences in pertinence assigned to different sections of the display. Moreover, in line with the earlier observations from inspection tasks by Schoonard et al. (1973), experts were seen to require fewer fixations in order to reach response selection decisions and, in the absence of decision time differences, this was interpreted as evidence for slower, more selective sampling of the environment by the experts. Similar conclusions regarding expert-novice differences in search rate have also been reported in more recent studies, which have taken the paradigm established in this study and applied it directly to other sport tasks (e.g., Helsen, Buekers, & Pauwels, 1986).

A number of obvious ecological validity problems evident in this early study by Bard and Fleury (1976) have been alleviated in subsequent studies through the development of dynamic film tasks to replace the static presentation of stimuli via slides. In the first instance, Bard et al. (1980) recorded the search patterns of four experienced and three inexperienced gymnastics judges as they observed a videotape of a series of gymnastic routines. As with the earlier study, it was demonstrated that experts and novices fixate on different display areas and, hence, utilize different cues in arriving at their response selections (in this case, routine scores). This was evident mainly in a greater upper body focus by the expert judges. As previously demonstrated, the expert judges also used fewer mean fixations than did the less experienced judges, but the differences failed to reach statistical significance, presumably because of the small sample size, the high individual variability (especially within the less experienced group), and the absence of a control group who were true task novices. In this case, if a constant viewing time is presumed for all subjects (see Figure 2), the differences in the number of fixations observed should also be truly indicative of a lower search rate for the experts.

Subsequent work by Vickers (1985), using slides of World Class gymnasts and a large sample size ($N = 30$), has also revealed differences in the specific cue usage of expert and novice gymnasts, although parameters relating to search rate were not examined. Similarly, Neumaier (1982), although also not examining search rate, revealed differences in the manner in which proficient gymnasts and nongymnasts observe a gymnastic routine (a floor exercise). In this study, experts were found to make most fixations around the middle of the gymnast's body close to the axis of rotation (a point of high biomechanical pertinence) whereas novices' attention was attracted more frequently to peripheral sectors of the moving body. With practice, this development of a search strategy which concentrates fixations on key kinematic features within the observed motion is a persistent phenomenon also occurring when observing and evaluating other athletic activities such as shot-putting (Möckel & Heemsworth, 1984).

More recent visual search analyses by Bard and her associates (Bard & Fleury, 1981; Bard et al., 1981) have continued the evolution of more ecologically valid experimentation by pursuing the recording of eye-movement behavior within field rather than laboratory settings. Although the restrictions in eye-movement technology limit field recording to tasks in which the performer is relatively stationary, this progression to field testing is desirable in view of the possible alterations in search strategy which may occur from the laboratory to the "real-world" setting (e.g., see Cohen, 1978a).

Bard and Fleury (1981) reported data drawn from recording the eye movements of ice hockey goalkeepers faced with the task of blocking either slap shots or sweep shots executed by an opponent. Although search rate differences were again not examined, differences in the visual cues used by expert and novice goalkeepers were apparent from the analysis of fixation locations. Expert performers maintained consistent fixation location distributions (approx. 65% of fixations on the stick and 35% on the puck) regardless of the shot type, whereas the fixations of the novices varied considerably dependent on the shot type being used by the offensive player. These alterations in fixation location by the novices may be objective evidence of their selective attention being drawn by their opponent to irrelevant or less relevant cue sources.

Examination of a comparable goal-keeping task, goal-keeping in soccer, was conducted by Tyldesley, Bootsma, and Bomhoff (1982) through the use of slide presentations of the actions of an opponent taking a penalty kick.

Although the group sizes ($N = 8$) were considered too small to draw comparison between experts and novices,[6] some systematic effects on the search patterns were noted according to the task instructions. When the subjects were required to pass judgment on both the height and lateral direction of the forthcoming shot, at least two fixations on the slide material were required—the first directed usually to the hip region and the second primarily to the opponent's shoulder or head. If subjects were required to anticipate the lateral direction only, often only one fixation was necessary, and this was most frequently directed to the lower leg or striking foot implying that this distal segment was the most pertinent source of directional information.

Bard et al. (1981) also examined, through a small sample of two masters, four experts, and four novices, the visual search patterns of competitive fencers, both in lessons and in duelling situations. For all skill groups, the most important source of information appeared to be the opponent's hand guard, and the majority of fixation location changes were seen to involve saccades shifting the focal attention between the hand guard and its neighboring elements (the forearm and the upper arm). Higher search rates were evident for all fencers as they moved from the training situation to the temporal stress of the competitive situation. Lower $\overline{\text{FD}}$s and, hence, higher search rates were apparent for the superior performers in this competitive situation. Despite the conclusions drawn in this article, these data appear to be contrary to the earlier data of Bard and Fleury (1976) and Bard et al. (1980) regarding the contention of lower search rates for experts.

Earlier comparative work on fencing is also available in the research of Haase and Mayer (1978) who used a much larger sample (12 experts and 13 novices) but a less ecologically valid task than that reported by Bard, Guezennec, and Papin. Using a visual reaction time task with stimuli either relevant or irrelevant to fencing, Haase and Mayer observed significantly longer $\overline{\text{FD}}$s for expert fencers, but on the fencing-relevant stimuli only. The results obtained, therefore, confirm the sport-specific influence of expertise on visual search strategy as observed previously in behavioral measures such as decision time (e.g., Ryan & Lakie, cited in Ryan, 1969; Tyldesley et al., 1982) and structure recognition (e.g., Allard et al., 1980). Differences in search strategy between experts and novices, therefore, appear to reflect not general visual-perceptual differences but rather differences that are due to sport-specific experience and expertise. Moreover, in contrast to Bard et al. (1981), the observation of longer $\overline{\text{FD}}$s for experts by Haase and Mayer is in keeping with the expectation of lower search rates for experts and is compatible with the earlier findings of Bard and Fleury (1976) and Bard et al. (1980).

[6]Interestingly, this is a much larger size than many of the studies in the Bard and Fleury (e.g., Bard & Fleury, 1976, 1981; Bard et al., 1980, 1981) series that draw expert-novice comparisons.

Recent studies are also now available concerning visual search activity in volleyball (Neumaier, 1983; Ripoll, 1988) and in some racquet sports (Ripoll & Fkeurance, 1985; Ritzdorf, 1983). Neumaier (1983), for example, in monitoring the search patterns of defensive players in volleyball, observed a preponderance of fixations on the striking arm and shoulder joint of the opposing spiker rather than on the ball at contact, and his data like Bard and Fleury's (1981), demonstrates almost a total absence of lower body fixations for tasks with an upper body emphasis. Given the converse relationship of limited upper body fixations in the kicking task examined by Tyldesley et al. (1982), fixation to display features exhibiting greatest kinematic change often appears to be an important feature of visual search activity in sport. Whether visual attention is automatically directed to the fastest moving features of the display or is directed there as a consequence of some more overt cognitive strategy is yet to be clearly ascertained.

Ritzdorf (1983), in examining the racquet sport of tennis, drawing from a large sample of 112 players from 4 different proficiency levels, reported a wide scattering of ocular fixations by the players across the display presented by their opponent. At least three different search order strategies were apparent for the various subjects used in this study: continuing eye movements following the ball, fixations in the order shoulder–ball–shoulder, and fixations in the order shoulder–shoulder–ball, but in this case, as in many other studies (e.g., Petrakis, 1987), high degrees of individual difference were observed.

Some persistent problems in the sport visual search literature. Although the utilization of eye-movement recording methods with sport tasks is still clearly in its infancy, a number of critical methodological and interpretative problems pervade the existing literature. These problems, many of which are shared with the ergonomics literature, warrant elucidation at this point as a means of not only drawing attention retrospectively to limitations in the current knowledge base, but also as a means of providing some prescriptive direction for future work in this area.

An obvious problem in many of the sport studies to date concerns the use of very small sample sizes and the associated problems this creates in terms of the representativeness of the results and in terms of justifying the generalized inferences drawn from them. These small sample sizes used in the visual search studies weaken their statistical power and this, in turn, brings into question the appropriateness of a number of the conclusions made thus far. A case in point here is the conclusions reached from the original Bard and Fleury (1976) study. No significant differences in decision time were obtained between the five expert and five novice basketball players used as subjects despite quite marked differences in the mean decision time values for the two groups. By contrast, decision time differences were observed on a similar decision-making task by Carrière (1978), when a larger sample size ($N = 10$) was utilized. Had a larger sample size been used in the earlier study and reliable expert–novice differences in decision time been achieved, the interpretation of both the decision time and ocular sampling rate data would have been quite different.

A second general problem relates to the question of ecological validity and the concern that experimentation be focussed on settings and tasks that are naturalistic and on the evoking of responses from subjects that are representative of their "real-world" behaviors (Gibbs, 1979; Neisser, 1976). Although considerable progress has been made in terms of a progression from the use of static, schematic slides as stimuli to recordings within field settings, considerable technological advances still seem necessary before eye-movement recording can be applied easily and unobtrusively to intact sport skills. To this end, the question must be raised as to what extent the current utilization of eye-movement recording devices may impede the subject's task performance or perhaps cause subtle changes in their normal visual search behavior. There is, to date, a glaring absence from the sport literature of studies which clearly demonstrate that the eye-movement recording apparatus used does not induce any concurrent decrements in primary task performance.[7]

A third problem which limits the utility of the existing sport visual search literature relates to the selection of the instructional sets delivered to the subject. Because the instructional set is known to exert a powerful influence on search strategy (Yarbus, 1967) and as the type of instruction has varied considerably from study to study, it is difficult to ascertain from the literature thus far whether differences observed between different sport tasks are a function of the specific sport environment or a function of the task descriptions presented to the subjects.

The instructional set selected in any given study can, moreover, severely constrain the conclusions that can eventually be drawn from a study. A case in point here is, again, the early work on basketball players (Bard & Fleury, 1976) designed to distinguish expert and novice subjects by using a task which required them to respond both as rapidly and accurately as possible to schematic problems. The conclusion that was ultimately drawn implicated fundamental differences in visual search rate between experts and novices, although it can be demonstrated that this may well have been an artifact of using a task in which both response speed and accuracy were allowed to co-vary. Observations that experts need fewer fixations than novices in order to make a response selection decision in such a task setting may be of little empirical significance if the willingness of the two groups to

[7]For an example from the ergonomics literature showing comparable subject performance with and without eye-movement recording, see Megaw and Richardson (1979).

TABLE 1
Comparison of Visual Search Rates Using the Number of Fixations (NF) and Mean Fixation Duration ($\overline{FD}$) Parameters

Search Rate Measure	Solution Complexity: One Possible Solution	Two Possible Solutions	Three Possible Solutions
M Number of Fixations			
Experts	4.33	3.52	3.24
Novices	5.09	4.59	4.18
M Fixation Duration[a]			
Experts	217.1	230.4	241.7
Novices	267.4	235.3	239.2

Notes. Data are adapted from *Vision and Sport* (p. 34) edited by I. M. Cockerill and W. W. MacGillivary, 1981, Cheltenham, England, Thornes (see Bard & Fleury, 1981), copyright 1981, and "La Strategie Perceptive et la Performance Motrice," by C. Bard et al., 1975, *Mouvement, 10,* p. 167, copyright 1975. Adapted by permission. The interpretation of the effect of solution complexity on search rate depends on what measure of search rate is used. From the NF parameter, it appears that experts sample at a slower rate than novices, irrespective of the situation complexity. However when $\overline{FD}$ is calculated, the slower search rate for experts appears under the one-solution condition only. Reporting search rate from the number of fixations parameter can, therefore, be potentially misleading.
[a]$\overline{FD}$s (in ms) were estimated by dividing the published decision times by the NF.

tradeoff speed for accuracy is different. Again, as was observed with the ergonomics literature, inappropriate use of the number of fixations rather than $\overline{FD}$ as the measure of search rate in such a case can also contribute to inappropriate conclusions regarding expert–novice differences (Table 1).

An additional and major interpretative problem common to almost all the visual search studies of sport relates to the popular assumption that differences in fixation locations between expert and novices imply differences in cue usage. This assumption is questionable on at least two grounds. The first is that the studies reported to date do not discount the possibility that differences in foveal activity may be attributable to differences in peripheral visual capability. Clearly, there are needs for better methods for investigating the functional role of peripheral vision (cf. Graybiel, Jokl, & Trapp, 1955) and for the systematic collection, in all studies, of details on the functional visual field sizes of the subject populations under investigation (Williams & Thirer, 1975). The second cause for concern is that many studies do not ensure that information available around the point of fixation is actually being picked up and utilized. The existing literature fails, almost without exception, to make the direct and essential link between search strategy and task performance and, therefore, does not discount the possibilities of either subjects with different search strategies producing comparable task performance or, the converse case, subjects with similar search patterns producing quite different levels of task performance. Clearly, measures of information pick-up should always accompany eye-movement recording if the functional importance of different search strategies are to be pin-pointed. A recent example of an approach using both behavioral measures of cue usage and concurrent eye-movement recording to tease out the visual search-information pick-up relationship is provided by Abernethy and Russell (1987b).

As a final point, it should also be noted that to date the majority of studies of visual search in sport have been concerned with the manner in which the performer perceptually analyzes the environment in order to select an appropriate course of action (what Ripoll et al., 1983, have termed *psycho-semantic operations*). Such a focus implicitly treats perception as if it were a stage of processing largely independent and precursive of action, thereby ignoring consideration of the important reciprocal links between perception and action (Turvey & Carello, 1986; von Hofsten & Lee, 1983). An interesting exception to this is a recent series of studies by Ripoll (1984), Ripoll, Bard, and Paillard (1986), and Ripoll et al. (1983) which have focused on the role that visual input plays in the control and organization of the selected motor action (what Ripoll et al., 1983, termed the *psycho-sensory motor operations*). Observations made thus far concerning the presence of more rapid head/eye alignment by expert subjects (Ripoll et al., 1986) and concerning the extent of individual differences in visual activity of even an apparently homogeneous group of expert subjects during motor performance (Ripoll, 1984; Ripoll et al., 1983, 1985) serve as timely reminders of the need to consider a large range of factors in assessing visual search activity. In considering group differences in visual search strategy, for instance, consideration must also be clearly given to other factors as influential as concomitant head movement and the degree of intragroup variability.

CONCLUSIONS AND FUTURE DIRECTIONS

In summary, the available visual search literature in sport, much like the ergonomic literature, contains numerous methodological and paradigmatic difficulties which limit its utility as a base from which to examine selective attention and information-processing notions related to expertise. Many of the more influential studies from both of these "real-world" environments use small sample sizes and are of questionable ecological validity and, almost without exception, alternatives to the data explanations advanced are possible. In particular, the role of potential expert-novice differences in the ability to use peripheral inputs has not been considered in assessing visual search performance, and there has been a general neglect, in all the studies cited, to consider the limitations and assumptions inherent in the use of the eye-movement recording method. There is, nevertheless, some evidence from the existing eye-movement recording studies to demonstrate qualitative differences in the specific environmental cues focally attended to by experts and novices. These differences in cue usage may reflect differences in pertinence and, in turn, in the quality of information being processed, although a clearer relationship between the specific visual cues used and corresponding anticipatory performance still needs to be established.

The evidence for expert-novice differences in search rate is less clear-cut. From the limited research available using the $\overline{FD}$ measure, there is little indication of experts being characterized by lower search rate as would be expected if search rate is an accurate indicator of information-processing load. Although some anecdotal evidence exists supporting expert-novice differences in search rate (e.g., Sandu, 1982, reported skilled volleyball players "zooming" to cues whereas novices rather "scan" to locate important information), the empirical evidence for such differences is equivocal (e.g., cf. the findings of the studies by Haase & Mayer, 1978, on fencing with those of Bard et al., 1981).

Clearly, to date, the influence of performer expertise on search rate and, to a lesser extent, on search orientation has been inadequately examined in "real-world" settings. Future research in all aspects of applied visual search obviously needs to address more directly the concerns of ecological validity and especially the concerns regarding the limitations and assumptions inherent in eye-movement recording, if substantive gains in the understanding of the perceptual aspects of skilled motor performance are to be made. The combination of existing eye-movement recording methodology with parallel measures of information pick-up and the development of more appropriate means of assessing the dynamic role of the peripheral system in visual search would, therefore, appear to be essential directions for this emerging area of visual-perceptual enquiry to take.

In this latter respect the recent emergence, for simple display tasks at least, of systems for eye-movement contingent stimulus control (e.g., McConkie, Wolverton, & Zola, 1984) offers a promising lead. These systems, now in use primarily with reading (McConkie & Rayner, 1975; Rayner, 1975) and simple picture viewing tasks (Gould, 1976, p. 333), utilize a procedure whereby stimulus presentation to either the fovea, parafovea, or periphery can be continuously and dynamically manipulated. Within this approach, early saccadic characteristics (primarily direction and angular acceleration) are first sampled using a sensitive eye-movement recording device and then the location of the forthcoming fixation is predicted, using sophisticated software run on a high-speed computer. With the endpoint known, the display characteristics arounds the 2° of foveal vision at this fixation point can be then either occluded (to examine information pick-up from peripheral visual input alone) or "windowed" (to examine information pick-up in the absence of peripheral input). Thus far, it has been shown from this approach that the quality of the information extracted by the subject depends on the size of the provided foveal "window," indicating that peripheral vision plays a role not only in guiding subsequent eye movements (Gould & Dill, 1969), but also in the integration of information across eye movements (Rayner, 1978; Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981; Rayner, McConkie, & Ehrlich, 1978; Rayner, McConkie, & Zola, 1980). Technical refinement of this particular approach to allow dynamic "real-world" stimuli to be presented to subjects may well open a new and fruitful avenue for research on the role of peripheral vision in expert sport and ergonomic performance.

ACKNOWLEDGMENTS

This article was prepared while I was on a special study program at the Department of Physical Education and Sports Science at the University of Birmingham. Appreciation is extended to the University of Queensland for sponsoring the program and to the University of Birmingham for clerical assistance in the manuscript preparation.

REFERENCES

Abernethy, B. (1985). Cue usage in 'open' motor skills: A review of the available procedures. In D. G. Russell & B. Abernethy (Eds.), *Motor memory and control: The Otago symposium* (pp. 110–122). Dunedin, New Zealand: Human Performance Associates.

Abernethy, B. (1987). Selective attention in fast ball sports. II: Expert-novice differences. *Australian Journal of Science and Medicine in Sport, 19*(4), 7–16.

Abernethy, B., & Russell, D. G. (1987a). Expert-novice differences in an applied selective attention task. *Journal of Sport Psychology, 9,* 326–345.

Abernethy, B., & Russell, D. G. (1987b). The relationship between expertise and visual search strategy in a racquet sport. *Human Movement Science, 6,* 283–319.

Acosta, E., Jr., & Simon, R. J. (1976). The effect of irrelevant information on the stages of processing. *Journal of Motor Behavior, 8,* 181–187.

Adams, J. A. (1966). Some mechanisms of motor responding: An examination of attention. In E. A. Bilodeau (Ed.), *Acquisition of skill* (pp. 169–200). New York: Academic.

Alain, C., & Proteau, L. (1980). Decision making in sport. In C. H. Nadeau, W. R. Halliwell, K. M. Newell, & G. C. Roberts (Eds.), *Psychology of motor behavior and sport, 1979* (pp. 465–477). Champaign, IL: Human Kinetics.

Allard, F., Graham, S., & Paarsalu, M. E. (1980). Perception in sport: Basketball. *Journal of Sport Psychology, 2,* 14–21.

Allen, J. A., Schroeder, S. R., & Ball, P. G. (1978). Effects of experience and short-term practice on driver's eye movements and errors in simulated dangerous situations. *Perceptual*

and Motor Skills, 47, 767–776.
Antes, J. R., & Penland, J. G. (1981). Picture context effects on eye movement patterns. In D. F. Fisher, R. A. Monty, & J. W. Senders (Eds.), *Eye movements: Cognition and visual perception* (pp. 157–170). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
Barber, P. (1981). Visual search and number of stimuli reexamined. *Psychological Bulletin, 89,* 176–182.
Bard, C., & Fleury, M. (1976). Analysis of visual search activity during sport problem situations. *Journal of Human Movement Studies, 3,* 214–222.
Bard, C., & Fleury, M. (1981). Considering eye movement as a predictor of attainment. In I. M. Cockerill & W. W. MacGillivary (Eds.), *Vision and sport* (pp. 28–41). Cheltenham, England: Thornes.
Bard, C., Fleury, M., & Carrière, L. (1975). La strategie perceptive et la performance motrice [Perceptual strategy and motor performance]. *Mouvement, 10,* 163–183.
Bard, C., Fleury, M., Carrière, L., & Hallé, M. (1980). Analysis of gymnastics judges' visual search. *Research Quarterly for Exercise and Sport, 51,* 267–273.
Bard, C., Guezennec, Y., & Papin, J-P. (1981). Escrime: Analyse de l'exploration visuelle [Fencing: Analysis of visual search]. *Medecine du Sport, 55*(4), 22–29.
Bhise, V. C., & Rockwell, T. H. (1971). The role of peripheral vision and time sharing in driving. *Proceedings 1971 Annual Meeting of the American Association for Automative Medicine.* New York: SAE, Inc.
Blanchard, H. E. (1985). A comparison of some processing time measures based on eye movements. *Acta Psychologica, 58,* 1–15.
Blignaut, C. J. H. (1979a). The perception of hazard. Hazard analysis and the contribution of visual search to hazard perception. *Ergonomics, 22,* 991–1000.
Blignaut, C. J. H. (1979b). The perception of hazard. II. The contribution of signal detection to hazard perception. *Ergonomics, 22,* 1177–1185.
Bonnet, C. (1975). A tentative model for visual-motion detection. *Psychologica, 18,* 35–50.
Boynton, R. M. (1960). Summary and discussion. In A. Morris & E. P. Horne (Eds.), *Visual search techniques* (pp. 231–250). Washington, DC: National Academy of Sciences, National Research Council.
Broadbent, D. E. (1958). *Decision and stress.* London: Academic.
Buchsbaum, M., Pfferbaum, A., & Stillman, R. (1972). Individual differences in eye movement patterns. *Perceptual and Motor Skills, 35,* 895–901.
Card, S. K. (1984). Visual search of computer command menus. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and performance X: Control of language processes* (pp. 97–108). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
Carmody, D. P. (1980). Visual search for modular abnormalities in chest x-ray films under normal and segmented viewing (Doctoral dissertation, Temple University, 1979). *Dissertation Abstracts International, 41,* 385-B.
Carrière, L. (1978). Les effets de la competition des résponses et du contexte sur la prise de décision dans des situations problèmes [The effects of response competition and context on the speed of responding in problem situations]. In F. Landry & W. A. R. Orban (Eds.), *Motor learning, sport psychology, pedagogy and didactics* (pp. 77–84). Quebec: Symposia Specialists, Inc.
Cohen, A. S. (1978a). *Eye movement behavior while driving a car: A review* (ARI Tech. Rep. No. TR-78-TH4). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.
Cohen, A. S. (1978b). *Car driver's pattern of eye fixations on the road and in the laboratory* (ARI Tech. Rep. No. TR-78-TH5). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.
Cohen, A. S., & Studach, H. (1977). Eye movements while driving cars around curves. *Perceptual and Motor Skills, 44,* 683–689.

Davids, K. W. (1984). The role of peripheral vision in ball games: Some practical and theoretical notions. *Physical Education Review, 7,* 26–40.

Dichgans, J., & Brandt, T. (1972). Visual-vestibular interaction and motion perception. *Bibliotheca Opthalmologica, 82,* 327-338.

Dick, A. O. (1974). Iconic memory and its relation to perceptual processing and memory mechanisms. *Perception and Psychophysics, 16,* 575–596.

Di Lollo, V., Lowe, D. G., & Scott, J. P., Jr. (1974). Backward masking and interference with the processing of brief visual displays. *Journal of Experimental Psychology, 103,* 934–940.

Drury, G. C. (1975). Inspection of sheet materials—Model and data. *Human Factors, 20,* 597–602.

Drury, G. C., & Clement, M. R. (1978). The effect of area, density, and number of background characters on visual search. *Human Factors, 20,* 597–602.

Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology: General, 113,* 501-517.

Easterbrook, J. A. (1959). The effect of emotion on cue utilization and the organization of behavior. *Psychological Review, 66,* 183–201.

Freidman, A., & Liebelt, L. S. (1981). On the time course of viewing pictures with a view toward remembering. In D. F. Fisher, R. A. Monty, & J. W. Senders (Eds.), *Eye movements: Cognition and visual perception* (pp. 137–155). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Fry, G. A. (1968). The use of the eyes in steering a car on straight and curved roads. *American Journal of Optometry and Archives of the American Academy of Optometry, 45,* 374–391.

Fuchs, A. H. (1962). The progression-regression hypothesis in perceptual-motor skill learning. *Journal of Experimental Psychology, 63,* 177–182.

Furst, C. J. (1971). Automatizing of visual attention. *Perception and Psychophysics, 10,* 65–70.

Gaarder, K. R. (1975). *Eye movements, vision and behavior.* New York: Wiley.

Gale, A. G., Johnson, F., & Worthington, B. S. (1979). Psychology and radiology. In D. J. Osborne, M. M. Gruneberg, & J. R. Eiser (Eds.), *Research in psychology and medicine* (Vol. 1). London: Academic.

Gibbs, J. C. (1979). The meaning of ecologically oriented inquiry in contemporary psychology. *American Psychologist, 34,* 127–140.

Gippenreiter, Y. B., & Romanov, V. Y. (1974). A method of investigation of the internal form of visual activity. In R. B. MacLeod & H. L. Pick, Jr. (Eds.), *Perception: Essays in honour of James J. Gibson* (pp. 227-249). London: Cornell University Press.

Goillau, P. J. (1984). Effect of display subtense on eye movement search. In A. G. Gale & F. Johnson (Eds.), *Theoretical and applied aspects of eye movement research* (pp. 281–291). Amsterdam: North-Holland.

Gould, J. D. (1976). Looking at pictures. In R. A. Monty & J. W. Senders (Eds.), *Eye movements and psychological processes* (pp. 323–345). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Gould, J. D., & Dill, A. (1969). Eye movement parameters and pattern recognition. *Perception and Psychophysics, 6,* 311-320.

Graybiel, A., Jokl, E., & Trapp, C. (1955). Russian studies of vision in relation to physical activity and sports. *Research Quarterly, 26,* 480–485.

Haase, H., & Mayer, H. (1978). Optische orientierungsstrategien von fechtern [Strategies of visual orientation of fencers]. *Leistungssport, 8,* 191–200.

Haber, R. N. (1983). The impending demise of the icon—A critique of the concept of iconic storage in visual information processing. *Behavioral and Brain Sciences, 6,* 1–10.

Haywood, K. M. (1977). Eye movements during coincidence-anticipation. Journal of Motor Behavior, 9, 313-318.

Helsen, W., Buekers, M., & Pauwels, J. (1986). The registration of eye-movements in sportgames. In L-E. Unestahl (Ed.), *Contemporary sport psychology* (pp. 94–102). Orebro, Sweden: VEJE Publishing.

Johansson, G. (1973). Visual perception of biological motion and a model for its analysis. *Perception and Psychophysics, 14,* 201–211.

Jones, C. M., & Miles, T. R. (1978). Use of advance cues in predicting the flight of a lawn tennis ball. *Journal of Human Movement Studies, 4, 231–235.*

Kalunger, N. A., & Smith, G. L., Jr. (1970). *Driver eye movement patterns under conditions of prolonged driving and sleep deprivation.* Unpublished manuscript, Ohio State University, Columbus, OH.

Kay, H. (1978). Accidents: Some facts and theories. In P. B. Warr (Ed.), *Psychology at work* (2nd ed., pp. 97–117). Harmondsworth, Middlesex: Penguin Books.

Kerr, R. (1982). *Psychomotor learning.* Philadelphia: Saunders.

Kobrick, J. L. (1972). Effects of hypoxia on voluntary response time to peripheral stimuli during central target monitoring. *Ergonomics, 15,* 147–156.

Krebs, M. J. (1975). Scanning patterns in real-time FLIR displays. *Proceedings of the 19th annual meeting of the Human Factors Society* (pp. 418–422).

Kundel, H. L. (1974). Visual sampling and estimates of location of information on chest films. *Investigative Radiology, 9,* 87–93.

Kundel, H. L., & La Follette, P. S. (1972). Visual search patterns and experience with radiological images. *Radiology, 103,* 523–528.

Kundel, H. L., & Nodine, C. F. (1978). Studies of eye movements and visual search in radiology. In J. W. Senders, D. F. Fisher, & R. A. Monty (Eds.), *Eye movements and the higher psychological functions* (pp. 317–328). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Kundel, H. L., Nodine, C. F., & Toto, L. (1984). Eye movements and the detection of lung tumors in chest images. In A. G. Gale & F. Johnson (Eds.), *Theoretical and applied aspects of eye movement research* (pp. 297–304). Amsterdam: North-Holland.

Kundel, H. L., & Wright, D. J. (1969). The influence of prior knowledge on visual search during the viewing of chest radiographs. *Radiology, 93,* 315–320.

La Berge, D. (1981). Automatic information processing – A review. In J. Long & A. Baddeley (Eds.), *Attention and performance IX* (pp. 173–186). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Landers, D. M., Wang, Q. M., & Courtet, P. (1985). Peripheral narrowing among experienced and inexperienced rifle shooters under low- and high-stress conditions. *Research Quarterly for Exercise and Sport, 56,* 122–130.

Lawrence, J. D. (1974). Human error and accidents in gold mining. *Journal of Safety Research, 6,* 78–88.

Llewellyn, E., & Thomas, P. E. (1963). The eye movements of a pilot during aircraft landing. *Aerospace Medicine, 34, 424–426.*

Long, G. M., & Sakitt, B. (1980). The retinal basis of iconic memory: Eriksen and Collins revisited. *American Journal of Psychology, 93,* 195–206.

Mackworth, N. H. (1976). Ways of recording line of sight. In R. A. Monty & J. W. Senders (Eds.), *Eye movements and psychological processes* (pp. 173–178). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Mackworth, N. H., Kaplan, I. T., & Metlay, W. (1964). Eye movements during vigilance. *Perceptual and Motor Skills, 18,* 397–402.

Mackworth, N. H., & Morandi, A. J. (1967). The gaze selects informative details within pictures. *Perception and Psychophysics, 2,* 547–551.

McConkie, G. W., & Rayner, K. (1975). The span of the effective stimulus during a fixation in reading. *Perception and Psychophysics, 17,* 578–586.

McConkie, G. W., Wolverton, G. S., & Zola, D. (1984). Instrumentation considerations in research involve eye-movement contingent stimulus control. In A. G. Gale & F. Johnson

(Eds.), *Theoretical and applied aspects of eye movement research* (pp. 39–47). Amsterdam: North-Holland.

McDowell, E. D., & Rockwell, T. H. (1978). An exploratory investigation of the stochastic nature of the driver's eye movements and their relationship to the roadway geometry. In J. W. Senders, D. F. Fisher, & R. A. Monty (Eds.), *Eye movements and the higher psychological functions* (pp. 329–345). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Megaw, E. D., & Richardson, J. (1979). Eye movements and industrial inspection. *Applied Ergonomics, 10*(3), 145–154.

Milton, Y. L. (1952). Analysis of pilot's eye movements in flight. *Journal of Aviational Medicine, 23,* 67–76.

Mocharnuk, J. B. (1978). Visual target acquisition and ocular scanning performance. *Human Factors, 20,* 611–631.

Möckel, W., & Heemsworth, C. (1984). Maximizing information as a strategy in visual search: the role of knowledge about stimulus structure. In A. G. Gale & F. Johnson (Eds.), *Theoretical and applied aspects of eye movement research* (pp. 335–342). Amsterdam: North-Holland.

Moffitt, K. (1980). Evaluation of the fixation duration in visual search. *Perception and Psychophysics, 27,* 370–372.

Monk, T. H. (1976). Target uncertainty in applied visual search. *Human Factors, 18,* 607–612.

Mortimer, R. G., & Jorgenson, C. M. (1972). Eye fixations of drivers as affected by highway and traffic characteristics and moderate doses of alcohol. *Proceedings of the 16th annual meeting of the Human Factors Society* (pp. 86–92).

Moskowitz, H., Sharma, S., & McGlothlin, W. (1972). Effect of marijuana upon peripheral vision as a function of the information processing demands in central vision. *Perceptual and Motor Skills, 35,* 875–882.

Mourant, R. R., & Rockwell, T. H. (1970). Mapping eye-movement patterns to the visual scene in driving: An exploratory study. *Human Factors, 12,* 81–87.

Mourant, R. R., & Rockwell, T. H. (1972). Strategies of visual search by novice and experienced drivers. *Human Factors, 14,* 325–335.

Neboit, M. (1983). Evolution de l'exploration visuelle avec l'apprentissage et avec l'experience professionelle [The evolution of visual scanning patterns with training and professional experience]. *Le Travail Humain, 46,* 33–48.

Neboit, M., Papin, J-P., Pottier, A., Puimean-Chieze, J-P., & Viard, D. (1978). Choix et techniques d'analyse d'indices de la prise d'informations visuelles [Selection and analysis techniques to indicate the acquisition of visual information]. *Médecine Aéronautique et Spatiale, Médecine Subaquatique et Hyperbare, 67,* 251–254.

Neisser, U. (1967). *Cognitive psychology.* New York: Appleton-Century-Crofts.

Neisser, U. (1976). *Cognition and reality: Principles and implications of cognitive psychology.* San Francisco: Freeman.

Neumaier, A. (1982). Untersuchung zur funktion des blickverhaltens bei visuellen wahrnehmungsprozessen im sport [An investigation of the function of looking in visual perception processes in sport]. *Sportswissenschaft, 12,* 78–91.

Neumaier, A. (1983). Beobachtungsstrategien und antizipation bei der abwehr von volleyball angriffen [Observation strategies and anticipation of defensive actions in volleyball]. *Leistungssport, 13*(4), 5–10.

Neumann, O. (1984). Automatic processing: A review of recent findings and a plea for an old theory. In W. Prinz & A. F. Sanders (Eds.), *Cognition and motor processes* (pp. 255–293). Berlin: Springer-Verlag.

Norman, D. A. (1968). Toward a theory of memory and attention. *Psychological Review, 75,* 522–536.

Norman, D. A. (1969). *Memory and attention.* New York: Wiley.

Paillard, J. (1980). The multi-channelling of visual cues and the organisation of a visually guided response. In G. E. Stelmach & J. Requin (Eds.), *Tutorials in motor behavior* (pp. 259-279). Amsterdam: North-Holland.

Paillard, J. (1982). The contribution of peripheral and central vision to visually guided reaching. In D. J. Ingle, M. A. Goodale, & R. J. W. Mansfield (Eds.), *Analysis of visual behavior* (pp. 367-385). Cambridge, MA: MIT Press.

Papin, J-P. (1984). Use of the NAC Eye Mark Recorder to study visual strategies of military aircraft pilots. In A. G. Gale & F. Johnson (Eds.), *Theoretical and applied aspects of eye movement research* (pp. 367-371). Amsterdam: North-Holland.

Papin, J-P., Metges, P-J., & Hernandez, C. (1983). L'exploration visuelle en radiologie pulmonaire [Visual search of chest radiographs]. *Le Travail Humain, 46,* 155-162.

Petrakis, E. (1987). Analysis of visual search patterns of dance teachers. *Journal of Teaching in Physical Education, 6,* 149-156.

Pollack, I., & Spence, D. (1968). Subjective pictorial information and visual search. *Perception and Psychophysics, 3,* 41-44.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32,* 3-27.

Premack, D., & Collier, G. (1966). Duration of looking and number of looks as dependent variables. *Psychonomic Science, 4,* 81-82.

Rayner, K. (1975). The perceptual span and peripheral cues in reading. *Cognitive Psychology, 7,* 65-81.

Rayner, K. (1978). Foveal and parafoveal cues in reading. In J. Requin (Ed.), *Attention and performance VII* (pp. 149-161). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Rayner, K. (1984). Visual selection in reading, picture perception and visual search – A tutorial review. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and performance X: Control of language processes* (pp. 67-96). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Rayner, K., Inhoff, A. W., Morrison, R. E., Slowiaczek, M. L., & Bertera, J. H. (1981). Masking of foveal and parafoveal vision during eye fixations in reading. *Journal of Experimental Psychology: Human Perception and Performance, 7,* 167-179.

Rayner, K., McConkie, G. W., & Ehrlich, S. (1978). Eye movements and integrating information across fixations. *Journal of Experimental Psychology: Human Perception and Performance, 4,* 529-544.

Rayner, K., McConkie, G. W., & Zola, D. (1980). Integrating information across eye movements. *Cognitive Psychology, 12,* 206-226.

Remington, R. W. (1980). Attention and saccadic eye movements. *Journal of Experimental Psychology: Human Perception and Performance, 6,* 726-744.

Reynolds, H. L. (1976). The effects of augmented levels of stress on reaction time in the peripheral visual field. *Research Quarterly, 47,* 768-775.

Ripoll, H. (1984). The study of visuo-motor co-ordination in rapid fire pistol. In D. Landers (Ed.), *Sport and elite performers* (pp. 153-162). Champaign, IL: Human Kinetics.

Ripoll, H. (1988). Analysis of visual scanning patterns of volleyball players in a problem solving task. *International Journal of Sport Psychology, 19,* 9-25.

Ripoll, H., Bard, C., & Paillard, J. (1986). Stabilization of head and eyes on target as a factor in successful basketball shooting. *Human Movement Science, 5,* 47-58.

Ripoll, H., & Fleurance, P. (1985, June). *Analysis of visual scanning patterns of table tennis players.* Paper presented at the VI World Congress in Sport Psychology, Copenhagen, Denmark.

Ripoll, H., Papin, J-P., Guezennec, J-Y., Verdy, J-P., & Philip, M. (1985). Analysis of visual scanning patterns of pistol shooters. *Journal of Sport Sciences, 3,* 93-101.

Ripoll, H., Papin, J-P., & Simonet, P. (1983). Approache de la fonction visuelle en sport [Visual function in sport]. *Le Travail Humain, 46,* 163-174.

Ritzdorf, V. (1983). Antizipation in sportspiel – dargestelt am beispiel des tennisgrundschlangs [Anticipation in sport: Investigation of the tennis ground stroke]. *Leistungssport, 13,* 5-9.

Rothstein, A. L. (1977). Prediction in sport: visual factors. In R. E. Stadulis (Ed.), *Research practice in physical education* (pp. 217–230). Champaign, IL: Human Kinetics.

Ryan, E. D. (1969). Perceptual characteristics of vigorous people. In R. C. Brown & B. J. Cratty (Eds.), *New perspectives of man in action* (pp. 88–101). Englewood Cliffs, NJ: Prentice-Hall.

Sakitt, B. (1975). Focus on short-term visual storage. *Science, 190,* 1318–1319.

Salmoni, A. W. (1975). The attention demands of input monitoring. *Journal of Human Movement Studies, 1,* 143–148.

Sanders, A. F. (1970). Some aspects of the selective process in the functional visual field. *Ergonomics, 13,* 101–117.

Sanders, A. F., & Houtmans, M. J. M. (1985). Perceptual processing modes in the functional visual field. *Acta Psychologica, 58,* 251–261.

Sandu, G. S. (1982). Selective attention in competitive volleyball. In J. H. Salmela, J. T. Partington, & T. Orlick (Eds.), *New paths of sport learning and excellence* (pp. 30–32). Ottawa, Ontario: Sport in Perspective, Inc.

Scanlan, L. A. (1977). Target acquisition in realistic terrain. In A. S. Neal & R. Palasek (Eds.), *Proceedings of the 21st annual meeting of the Human Factors Society.* Santa Monica, CA: Human Factors.

Schaffer, A., & Gould, J. D. (1964). Eye movement patterns as a function of previous tachistoscopic practice. *Perceptual and Motor Skills, 19,* 701–702.

Schissler, D. R. (1969). Analysis of pictures by subjective ratings and by eye fixations. *Journal of General Psychology, 81,* 83–94.

Schneider, W. (1976). Selective attention, memory scanning and visual search: Three components of one process (Doctoral dissertation, Indiana University, 1976). *Dissertation Abstracts International, 36,* 5841-B.

Schoonard, J. W., Gould, J. D., & Miller, L. A. (1973). Studies of visual inspection. *Ergonomics, 16,* 365–379.

Schroeder, S. (1969a). Effects of cue factors on selective eye movements and choices during successive discriminations. *Perceptual and Motor Skills, 29,* 991–998.

Schroeder, S. (1969b). Fixation and choice selectivity during discrimination transfer. *Psychonomic Science, 17,* 324–325.

Schroeder, S. (1970). Selective eye movements to simultaneously presented stimuli during discrimination. *Perception and Psychophysics, 7,* 121–124.

Schroeder, S., & Holland, J. G. (1968). Operant control of eye movement during human vigilance. *Science, 161,* 292–293.

Senders, J. W. (1976). Speculations and notions. In R. A. Monty & J. W. Senders (Eds.), *Eye movements and psychological processes* (pp. 355–365). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Sharp, R. H. (1978). Visual information-processing in ball games: Some input considerations. In F. Landry & W. A. R. Orban (Eds.), *Motor learning, sport psychology, pedagogy and didactics of physical education* (pp. 3–12). Quebec: Symposia Specialists.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychological Review, 84,* 127–190.

Shinar, D., McDowell, E. D., & Rockwell, T. H. (1977). Eye movements in curve negotiation. *Human Factors, 19,* 63–71.

Shulman, G. L., Remington, R. W., & Mclean, J. P. (1979). Moving attention through visual space. *Journal of Experimental Psychology: Human Perception and Performance, 5,* 522–526.

Silbernagel, B. L. (1982). Using realistic sensor, target, and scene characteristics to develop a target acquisition model. *Human Factors, 24,* 321–328.

Sperandio, J-C., & Bouju, F. (1983). L'exploration visuelle de données numériques présentées sur écran cathodique [Visual search of numerical arrays displayed on a cathode ray tube display terminal]. *Le Travail Humain, 46,* 49–63.

Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs, 74* (Serial No. 498).

Sperling, G., & Reeves, A. (1980). Measuring the reaction time of a shift of visual attention. In R. S. Nickerson (Ed.), *Attention and performance VIII* (pp. 347–360). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Stager, P., & Angus, R. (1978). Locating crash sites in simulated air-to-ground visual search. *Human Factors, 20,* 453–466.

Starkes, J. L., & Deakin, J. (1984). Perception in sport: A cognitive approach to skilled performance. In W. F. Straub & J. M. Williams (Eds.), *Cognitive sport psychology* (pp. 115–128). Lansing, NY: Sport Science Associates.

Stern, J. A., & Bynum, J. A. (1970). Analysis of visual search activity in skilled and novice helicopter pilots. *Aerospace Medicine, 41,* 300–305.

Swensson, R. G. (1980). A two-stage detection model applied to skilled visual search by radiologists. *Perception and Psychophysics, 27,* 11–16.

Taylor, S. G., & Brown, D. R. (1972). Lateral visual masking: Supraretinal effects when viewing linear arrays with unlimited viewing time. *Perception and Psychophysics, 12,* 97–99.

Teichner, W. H., & Krebs, M. J. (1974). Visual search for simple targets. *Psychological Bulletin, 81,* 15–28.

Teichner, W. H., & Mocharnuk, J. B. (1979). Visual search for complex targets. *Human Factors, 21,* 259–276.

Terauds, J. (1976). Cinematographical approach to eye movement analysis during perceptual skill tasks. In P. V. Komi (Ed.), *Biomechanics V-B* (pp. 497–501). Baltimore: University Park Press.

Thomas, E. L. (1968, August). Movements of the eye. *Scientific American,* pp. 88–95.

Thomas, J. R. (1980). Acquisition of motor skills: Information processing differences between children and adults. *Research Quarterly for Exercise and Sport, 51,* 158–173.

Tiffin, J., & Bromer, J. (1943). *Analysis of eye fixations and patterns of eye movements in landing a Piper Cub J-3 airplane* (Report No. 10). Washington, DC: Division of Research, Civil Aeronautics Administration.

Tursky, B. T. (1974). Recording of human eye movement. In R. F. Thompson & M. M. Patterson (Eds.), *Bioelectric recording techniques* (Vol. 1-C, pp. 100–135). New York: Academic.

Turvey, M. T., & Carello, C. (1986). The ecological approach to perceiving-acting: A pictorial essay. *Acta Psychologica, 63,* 133–155.

Tyldesley, D. A., Bootsma, R. J., & Bomhoff, G. T. (1982). Skill level and eye-movement patterns in a sport-orientated reaction time task. In H. Rieder, K. Bos, H. Mechling, & K. Reischle (Eds.), *Motor learning and movement behavior: Contribution to learning in sports* (pp. 290–296). Cologne: Hofmann.

Vickers, J. N. (1985). Expert-novice differences in knowledge structures of action (Doctoral dissertation, University of British Columbia, 1984). *Dissertation Abstracts International, 46,* 384-A.

Von Hofsten, C., & Lee, D. N. (1983). Dialogue on perception and action. *Human Movement Science, 1,* 125–138.

Weltman, R. G., & Egstrom, G. H. (1966). Perceptual narrowing in novice divers. *Human Factors, 8,* 499–505.

Weltman, G., Smith, J. E., & Egstrom, G. H. (1971). Perceptual narrowing during simulated pressure-chamber exposure. *Human Factors, 13,* 99–107.

Wentworth, R. N., & Buck, J. R. (1982). Presentation effects and eye-motion behaviors in dynamic visual inspection. *Human Factors, 24,* 643-658.

White, C. T., & Ford, A. (1960). Eye movements during simulated radar search. *Journal of the Optical Society of America, 50,* 909-913.

Wickens, C. D. (1984). *Engineering psychology and human performance.* Columbus, OH: Merrill.

Williams, H. G., & Helfrich, J. (1977). Saccadic eye movement speed and motor response execution. *Research Quarterly, 48,* 598-605.

Williams, J. M., & Thirer, J. (1975). Vertical and horizontal peripheral vision in male and female athletes and non-athletes. *Research Quarterly, 46,* 200-205.

Williams, L. G. (1967). The effects of target specification on objects fixated during visual search. *Acta Psychologica, 27,* 355-360.

Yarbus, A. L. (1967). *Eye movements and vision.* New York: Plenum.

Young, L. R., & Sheena, D. (1975). Survey of eye movement recording methods. *Behavior Research Methods and Instrumentation, 7,* 397-429.

Zell, J. K. (1969). *Driver eye-movements as a function of driving experience* (Tech. Rep. No. IE-16). Columbus, OH: Engineering Experiment Station, Ohio State University.