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Research Report

Cognitive Ethology and exploring attention in real-world scenes

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ABSTRACT

We sought to understand what types of information people use when they infer the attentional states of others. In our study, two groups of participants viewed pictures of social interactions. One group was asked to report where the people in the pictures were directing their attention and how they (the group) knew it. The other group was simply asked to describe the pictures. We recorded participants' eye movements as they completed the different tasks and documented their subjective inferences and descriptions. The findings suggest that important cues for inferring attention of others include direction of eye gaze, head position, body orientation, and situational context. The study illustrates how attention research can benefit from (a) using more complex real-world tasks and stimuli, (b) measuring participants' subjective reports about their experiences and beliefs, and (c) observing and describing situational behavior rather than seeking to uncover some putative basic mechanism(s) of attention. Finally, we discuss how our research points to a new approach for studying human attention. This new approach, which we call Cognitive Ethology, focuses on understanding how attention operates in everyday situations and what people know and believe about attention.

1. Introduction

> "I learned that when a science does not usefully apply to practical problems there is something wrong with the theory of science."
>
> J. J. Gibson, 1982, p. 18 (original published 1967)

Attention has always been a topic of interest in cognitive neuroscience (Gazzaniga, 1995). Attention continues to be an interesting topic because it is something that we all experience, whether we are driving a car, listening to a conversation in a noisy room, or reading the morning paper. Everyone is, in some sense, an expert on what attention is and how it is used in everyday settings. Indeed, it is a truism to say that "everyone knows what attention is" (James, 1983/1890). Interestingly, however, studies of attention from the perspectives of cognitive psychology and cognitive neuroscience have neglected to articulate the knowledge that ordinary people have about attention and to study how attention operates in everyday situations (see Kingstone et al., 2003; Koch, 1999;

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Neisser, 1976). Surprisingly, we still do not know how attention operates when, for example, we merely cross a street, and we certainly do not have a complete understanding of what insights regular people have about attention. In this paper, we report our initial attempt to learn a little about what it is that "everyone knows" about attention and how attention might be operating in tasks that more closely match those that individuals conduct each day.

We begin by asking why attention research has largely neglected any systematic investigation of how attention operates in everyday settings and what people know about attention. We consider this question in the context of cognitive neuroscience's investigation of attention and find that there are several serious problems with the fundamental assumptions underlying this approach. Based on these considerations, we derive three alternative research principles, which we believe will lead to studies that will provide a more complete understanding of attention in everyday life. To illustrate the utility of these principles, we report an initial study focused on understanding what information people use when they infer the attentional states of others. Finally, using these principles, we suggest an alternative approach to studying attention that we refer to as *Cognitive Ethology* and describe how this approach differs from other approaches that have been used to study psychological phenomena in the past.

2. Principles of attention research

We find it striking that after decades of research on attention the scientific community still does not know what ordinary people think about attention. Nor do we know how attention operates in everyday situations such as driving a car or crossing the street. Even more striking is the simple fact that attention researchers rarely ever try to observe systematically human attention in real-world settings. Why is it that recent studies of attention have almost completely neglected naturalistic observation of attentional behavior and peoples' everyday knowledge about attention? We believe the answer to this question is revealed when one considers the *assumptions* that underlie contemporary investigations of attention.

Early formal investigations of attention, such as those conducted by Broadbent (1958), Cherry (1953), Neisser (1967), Posner (1978), and Treisman (1960), were firmly grounded in the *information processing framework* (see Neisser, 1967, 1976; Pashler, 1998). According to this framework, attention is construed as a process or a set of processes in a series of information processing stages. As noted by Pashler (1998), "the core idea of the information-processing approach is to analyze the mind in terms of different subsystems that form, retain, and transmit representations of the world" (p. 7). This approach continues to underpin attention research today and has laid the foundation for the *cognitive neuroscience approach* (Gazzaniga, 2004), which seeks to link the putative information processing stages to specific processes in the brain.

At the center of this research philosophy has been the belief that, in order to understand how attention operates in everyday settings, one must first uncover the basic mechanisms and processes of attention. Underlying this general belief are two critical assumptions (see Kingstone et al., 2005, submitted for publication): the first is that the basic mechanisms, or processes, of attention are *stable across situations*. And the second is that the stable mechanisms can best be revealed and isolated by imposing *rigorous control* over both stimuli and behavior. Together, these assumptions have justified and even necessitated studying attention in extremely controlled, simplified, and artificially contrived laboratory paradigms (Kingstone et al., 2003).

A consideration of the implications of these assumptions points to why investigations of attention have neglected naturalistic observation of behavior as well as peoples' everyday knowledge of attention. Within the context of these assumptions, observation of human behavior in everyday settings is thought to have little utility because, in the real world, stimuli and behavior are complex and inherently uncontrolled. Furthermore, people's everyday understanding of attention is considered to be uninformative because most people have little expertise regarding how they might behave in artificial laboratory tasks. In addition, it is believed that they do not have introspective access to the basic mechanisms of attention as revealed by these artificial laboratory tasks (e.g., Nisbett and Wilson, 1977).

The cognitive neuroscience approach to attention, characterized by the search for stable mechanisms of attention by imposing control over stimuli and behavior, is nicely illustrated by two of the most popular paradigms for studying attention: the Posner cueing paradigm (Posner, 1978) and the visual search paradigm (Treisman and Gelade, 1980). In the Posner cueing paradigm, participants view a computer screen containing a fixation cross at the center of the screen with a box on either side of the fixation cross. On a given trial, attention is cued to one of the two boxes either by flashing one of the boxes or by presenting an arrow at fixation which points to one of the boxes. A target square is then presented in one of the two boxes, and participants are required to press a button as fast as possible when the target square appears. Notice that, in this paradigm, the stimuli are reduced to flashes of light, squares, and arrows, and the response is simply the press of a button. Similar control is present in the visual search paradigm. Here, participants are shown a target among a varying number of distractors. The task is to detect, identify, or localize the target as fast as possible. The target and distractors are typically defined by a simple feature (e.g., color or orientation) or some combinations of these features. And, as with the Posner cueing paradigm, participants respond by simply pressing a key when they detect, identify, or localize the target. The ease of replicating these simple paradigms and their effects coupled with the rigorous control they afford over both stimuli and behavior has fostered a general faith that the paradigms tap into stable and fundamental mechanisms of attention.

This faith may be misguided. Consider for example the studies using the Posner cueing paradigm. For over two decades, theories of attention have been based on the idea that central non-predictive directional cues (e.g., a central arrow that points to the left and right boxes equally often) do not orient attention reflexively; only primitive stimulus features such as an abrupt flash of light can capture attention automatically. But, recent findings reported by Kingstone et al. (Friesen and Kingstone, 1998; Kingstone et al., 2000) and others (Driver et al., 1999; Langton and Bruce, 1999) have shown that faces presented centrally with eyes looking either left or right will orient attention reflexively even when they are non-predictive. These findings show clearly that the meaning of central cues is analyzed and can orient attention reflexively. Similar to research using the Posner paradigm, studies of visual search have led to models of attention in which attention is guided primarily on the basis of a preattentive analysis of basic stimulus features such as color and luminance (e.g., Wolfe, 1994, 1996; Wolfe and Horowitz, 2004; Treisman and Gelade, 1980). However, recent findings using faces expressing positive and negative emotion have shown that negative faces attract attention and lead to more efficient search than do positive faces (e.g., Eastwood et al., 2001; Hansen and Hansen, 1988; Õhman et al., 2001). Again, these findings suggest that the previous feature-centered view of attentional guidance is likely to be incorrect and that the meaning of stimuli plays an important role in directing attention.

These and other recent findings using ecologically valid stimuli in the standard attention paradigms (e.g., Handy et al., 2003; Riddoch et al., 2003) demonstrate that the constraints imposed by studying attention in such highly controlled paradigms have determined, and more importantly, have limited, what we have learned and can learn about attention (Kingstone et al., 2003). As a result of studying attention in these paradigms, theories have focused largely on understanding the role that basic features play in directing attention (Wolfe, 1994, 1996; Wolfe and Horowitz, 2004; Theeuwes, 1994; Treisman and Gelade, 1980). The central place of basic features in theories of attention is no doubt due to, and a reflection of, the kinds of stimuli used in studies of attention. That is, because most studies use only simple features as stimuli in order to ensure control over the stimuli, it is not surprising that simple features are at the center of current theories of attention. Thus, it seems that the existing theories of attention recapitulate, and are limited by, the constraints that have been imposed on stimuli and behavior by the controls of the experimental paradigms. Simply using more meaningful stimuli reveals a very different picture about attention: attention is not driven solely by basic stimulus features, but rather it is committed according to a rich and complex analysis of the meaning that a situation holds for an individual.

The main implication that we would like to draw from the studies mentioned above is the following: if meaning matters, then it is very likely that the principles of attention investigated with artificial paradigms are very different from the principles of attention that apply when individuals interact with their environment in more meaningful and ecologically valid ways. This is likely to be the case because the meanings and values of objects change across individuals and situations. For instance, being a few feet away from a tiger has a very different significance depending on whether you are at the zoo and the tiger is in a cage or you are at the zoo and the tiger has escaped out of a cage.

These ideas motivated us to reconsider the assumptions of stability and control underlying the typical cognitive neuroscience approach to studying attention. Our reconsideration of the approach led us to the conclusion that the limitations of the current cognitive neuroscience approach are deeply rooted in serious problems with the underlying assumptions themselves (Kingstone et al., 2005, submitted for publication). First, there appears to be a clear problem with assuming that processes and mechanisms are stable across situations. Indeed, there is a growing body of evidence suggesting that mechanisms are not stable across situations but that they change as situations change (Neisser, 1976; Monsell, 1996; Di Lollo et al., 2001). Second, there are considerable drawbacks to imposing rigorous control over stimuli and behavior. While imposing control over situations may reveal important characteristics of simple linear systems, complex systems theory (see Ward, 2002; Weinberg, 1975) has established that maximizing control does not reveal important characteristics of rich, dynamic, non-linear systems such as human cognition and attention in the real world.

These reasons led us to take seriously the possibility that existing investigations of attention in highly controlled settings are producing an incomplete, and perhaps even an incorrect, view of how attention operates in everyday settings (Ristic and Kingstone, in press). Moreover, it does not seem that simply using more complex and ecologically valid stimuli in the standard attentional paradigms will provide a complete solution to this problem. While such studies have been useful in pointing to the limitations of cognitive neuroscience research, given our concerns above, we do not think that they will provide a way in which one might systematically uncover important aspects of attention as it functions in the real world. In other words, the current state of affairs points to the possibility that, because the paradigms themselves create very controlled and impoverished situations (even when complex and meaningful stimuli are used), they might not be capturing important aspects of attention as it operates in the real world.

For instance, consider the finding that eye gaze appears to lead to reflexive attentional shifts of attention in the Posner cueing paradigm (Driver et al., 1999; Friesen and Kingstone, 1998; Langton and Bruce, 1999). One interpretation of these findings, and perhaps the most favored one, is that eye gaze orients attention because eye gaze direction is an important cue for inferring the attentional states of others (Ristic et al., 2005). Langton et al. (2000) support this interpretation by contrasting the attentional response to social cues such as eyes with non-social cues such as arrows. They note that non-social central cues such as arrows pointing left and right do not lead to reflexive shifts of attention, as originally found by Jonides (1981). Because non-social central cues do not lead to reflexive attentional shifts like eyes do, Langton et al. suggest that eye gaze is a special cue that "pushes" attention because it communicates where people are attending. But, recent findings strongly question this interpretation. Several laboratories have now shown that central arrow cues lead to cueing effects that are largely indistinguishable from those obtained with central eyes looking left or right (e.g., Ristic et al., 2002; Tipples, 2002; Friesen et al., 2004). These findings suggest that Jonides' original results reflect a Type II error and that central arrow cues do in fact lead to reflexive shifts of attention even when they are not predictive of the target location (see also Gibson and Bryant, in press). Clearly, it does not make much sense to suppose that arrow cues direct attention reflexively because people are inferring the attentional state of the arrow! These findings, therefore, call into question whether eye gaze "pushes" attention because it reveals where someone is attending.

We believe that similar concerns can be raised about other findings indicating that head, hand, and body position are used to infer the attentional states of others (e.g., Langton and Bruce, 2000). In all of these studies, participants are asked to make highly constrained responses to highly controlled stimuli. For instance, studies investigating whether hand pointing directs attention have used pictures of an isolated person pointing up and down (e.g., Langton and Bruce, 2000). When one of the only stimuli is a person pointing up and down, it is perhaps not surprising that pointing will have an influence on performance. From these data, it is also unclear if pointing influences responses because people are inferring the attentional state of the pointing person or for some other reasons (for example, the person looks like an arrow). And, even if people were inferring the attentional state of the pointing person, it is unclear whether and under what conditions this would occur in real-world situations when the person is not presented in isolation, cut out as it were from his or her natural surroundings. In general, it is our position that the connection/generalization between isolated stimuli and contextualized situations is not trivial nor is there compelling evidence to support its assumption. For these reasons, broad conclusions about brain mechanisms that function as direction-of-attention detectors (e.g., Perret et al., 1985) that are based on highly controlled laboratory studies might be misguided (Ristic and Kingstone, in press; Gibson and Kingstone, in press).

These general concerns, which are illustrated above with our specific consideration of how the results with directional stimuli have been misinterpreted in the past, bring to the forefront the following critically important question: given that studying attention in highly controlled, laboratory paradigms might not be shedding light on how attention is oriented in real life, how should one be studying attention?

In the present study, we sought to move towards a fundamentally different way of studying attention. Our investigation was motivated by three general principles. First, we rejected the assumptions of stability and control and instead assumed that brain processes, mental processes, and behavior change across situations. This meant that we were no longer tied to stock model tasks and paradigms normally thought to measure fundamental and basic mechanisms of attention. Our rejection of the assumption of stability also implies that in order for results to generalize to real-world scenarios we need to use tasks with greater ecological validity. Second, we acknowledged that important characteristics of attention will be revealed when participants are given more freedom and control over their task and when the emerging variability in behavior is observed and measured rather than stringently controlled. This allowed us to study attention in a task that used more complex and ecologically valid stimuli as well as to measure aspects of behavior as people engaged with the stimuli in an ongoing manner. Finally, we embraced the assumption that personal insights into one's performance (i.e., subjective reports) provide critical and informative data that must be accounted for and incorporated into theories and explanations. The advantage of accepting peoples' subjective reports as valid data meant that we could, at least partly, tap into what "everyone knows" about attention.

We believe that a combination of these three principles forms the beginning of a radically different approach to studying attention. For instance, consider the issue of inferring where other people are attending that we have used as an example thus far. The first step to address this issue from our three principles is to have people make inferences about people's attention in complex situations and to ask them to report which cues they are using to make such inferences. In addition, one might monitor participants' eye movements as they make such inferences and consider what they are looking at as they make their judgments. Ultimately, we believe it is the combination of the first-person subjective reports and the third-person behavioral observations in complex everyday situations that is likely to reveal important aspects about attention. In the study that follows, we illustrate how the three principles outlined above might be used to evaluate what cues people use to infer the attentional states of others.

3. The present study

3.1. *Overview*

In the present study, we were interested in applying the three principles described above to understand what types of information people use when they infer the attentional states of others. Accordingly, we sought to observe and describe participants' behavior as they freely explored pictures of real-world social scenes. Moreover, to tap into our participants' everyday understanding of attention, we asked them to provide us with detailed subjective reports about their performance.

Participants viewed pictures that depicted one or more individuals involved in everyday behaviors (e.g., listening to a speech, painting, playing basketball). Example of two pictures used in the study are shown in Fig. 1. Participants were required to view each picture and then answer the following question: "where are the people in the picture directing their attention, and how do you know?" To ensure that we would not

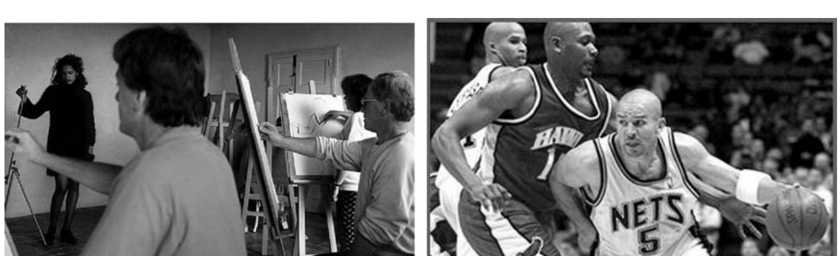

Fig. 1 – The art (left) and sport (right) images used in the experiment.

constrain participants' behavior with highly similar stimuli, we chose six very different pictures. To gain a baseline measure of how people explore and discuss these pictures, we asked another group of participants to simply "describe the picture". The gaze positions of the participants in both groups were monitored non-invasively with an EyeLink eye monitor. We reasoned that participants would naturally fixate the information that they considered to be important (e.g., Antes, 1974; Yarbus, 1967), and thus gaze position would provide a good first approximation of the cues that were being used by participants when making inferences about attention or describing a picture. In addition to observing the objective eye movement data, we also collected the first-person subjective reports that participants provided after they viewed each image. These uniquely human data are invaluable for several reasons. At a mundane level, they provide a validity check that the participants understood what they were supposed to be doing while performing a given task. More interestingly, they provide a rich collection of what participants perceive and recall about their own motivations and behavior as well as revealing their perceptual framework or response strategy that cannot be determined by objective measures alone.

In summary, by collecting subjective reports and measuring the eye fixations of the participants while they viewed scenes to infer the attentional states of the individuals in the scenes or to describe the scenes, we were able to address several important questions about attention: (1) what information do observers *report* using when they make inferences about the attentional states of others? (2) What information do observers *fixate* when they view a scene with the goal of inferring where people are attending? (3) Do the subjective reports and the eye fixations agree? (4) Do patterns of fixations depend on whether observers view pictures to infer attentional states or whether they view pictures in order to describe them?

4. Results and discussion

We discovered that pictures such as the art and sport images illustrated in Fig. 1, which depict a small group of people with each member occupying his or her relative spatial share of the picture, provide the best and most balanced combination of subjective and objective data measures. We chose to exclude at present the other images because they either contained too many people (e.g., a person giving a speech to a large crowd; many people gathered around a fountain), too few head and eye regions (e.g., an artist from the neck down who is painting the scene in front of him), or the nature of the image did not allow for parsing of the eye and head regions of different people (the reflection of a comrade in the soldier's sunglasses). In the analysis reported below, we consider first the subjective reports of participants and then the objective eye movement data for the art and sport pictures.

4.1. *Subjective reports*

The subjective reports for the describe group and infer group were quantified in the following manner. For the infer group, we made a list of all the objects or scene regions that participants mentioned in reporting where people in the picture were attending. We also listed the cues that participants mentioned to infer where people in the picture were attending. For the describe group, a comprehensive list was made containing the objects or areas in the scene that participants mentioned in their descriptions, as well as any schemas or concepts that participants mentioned (e.g., "art class"). For both the infer and describe groups, we first went through every participant's subjective report and constructed a master list of region, cue, and schema categories. After the composite list was created, we went back to each participant's report and gave one point for each cue that they mentioned at least once. Thus, each participant received up to a maximum of one point per category. We obtained the percentage of participants who mentioned a given category by summing up the points in that category and dividing by the number of participants. The subjective reports were scored by two independent coders. There was very good agreement among the coders with 88% agreement for the art image and 75% agreement for the sport image.

Some individual examples of the subjective reports given in the describe and infer groups are shown in Table 1. One can see that in the infer group there is frequent use of cues such as where the people in the picture are looking, as well as where their heads and bodies are facing. In addition, both Subjects 3 and 4 in the infer group make use of their conceptual

Table 1 – Individual subjective report data

	Art	Sport
Describe group		
Subject 1	"An art class. Female model is in the front for everyone to draw. People are looking at her and sketching her onto their paper."	"A basketball game against Hawaii and Nets. There are three players in the picture and the guy in the middle has the ball."
Subject 2	"In a drawing class, a woman is posing for two men and one woman. The drawers are looking carefully at the poser."	"Jason Kidd, a basketball player, tries to dribble past his defender. Another basketball player in the background is watching. There are also fans in the stands."
Infer group		
Subject 3	"The model is looking at the floor and is hunching over a bit, facing the floor. The artists are attending to the model and to their canvasses by looking and facing their bodies toward them."	"The guy on the left is attending to the middle guy (looking) who is looking and reaching for the ball. The guy with the ball is attending off-screen (basket?) by looking and shaping his body to that direction."
Subject 4	"The artists are looking at the girl wearing black holding the tripod. They are attending to the pictures they are drawing."	"The defenseman in the dark jersey is looking at the ball. The guy in the white jersey is looking at the defenseman's back. Jason Kidd has his eye on where he will dribble the ball. The audience in the back is watching these three players."

understanding of the scene. For example, Subject 4 infers that "Jason Kidd has his eye on where he will dribble the ball. The audience in the back is watching these three players." There is little visual evidence that either of these attentional states is occurring in the scene, and so one must assume that this subject was using his understanding of a typical basketball game to infer the attentional states of Jason Kidd and the audience. In the describe group, one can see that both subjects make less use of attentional cues such as eye gaze and head/body direction than do the subjects in the infer group, although it is clear that occasional use of these cues does occur (e.g., Subject 2: "the artists are looking carefully at the poser"). Furthermore, we see more use of overall schemas such as "art class" and "game" in the describe group than in the infer group, particularly for Subject 1.

The group data are shown in Figs. 2 and 3. Fig. 2 shows the frequencies with which participants reported a given region or cue for the art image in the describe (upper panel) and infer (lower panel) conditions. The corresponding frequencies for the sport image are shown in the same manner in Fig. 3. Each figure also shows the data from two independent coders. A comparison of the left (coder 1) and right (coder 2) sides of the figures shows considerable agreement between coders. Because we had such high agreement across coders, when discussing the results shown in Figs. 2 and 3, we report the mean percentages, averaged across the two coders.

Overall, the group data were consistent with the individual data. For the infer group, one finds that there are three main cues for inferring attention: where people are looking (as reflected in the "eye gaze" cue), head/body orientation, and, interestingly, cues that required an understanding of the overall meaning of the scene. For instance, consider the sport image. Averaging across the two coders, a large proportion (69%) of participants inferred attentional states from their knowledge of the plays and strategies that occur during a typical basketball game. This cue could not have been used without an overall understanding of the scene and an understanding of the game of basketball. This occurred, albeit to a lesser extent, in the art scene, in which 23% of participants mentioned that they knew the model was being attended to because she was the subject of the artists' paintings. The use of this cue requires an understanding that, in an art class situation, people generally attend to what they are attempting to paint. Note that, for the infer group, *where* the participants report people were attending was weighted unequally among the individuals in the scenes, with the model being considered the primary focus of attention in the art scene and the middle basketball player mentioned most frequently in the sport scene. Finally, attention was not only inferred as being directed to other

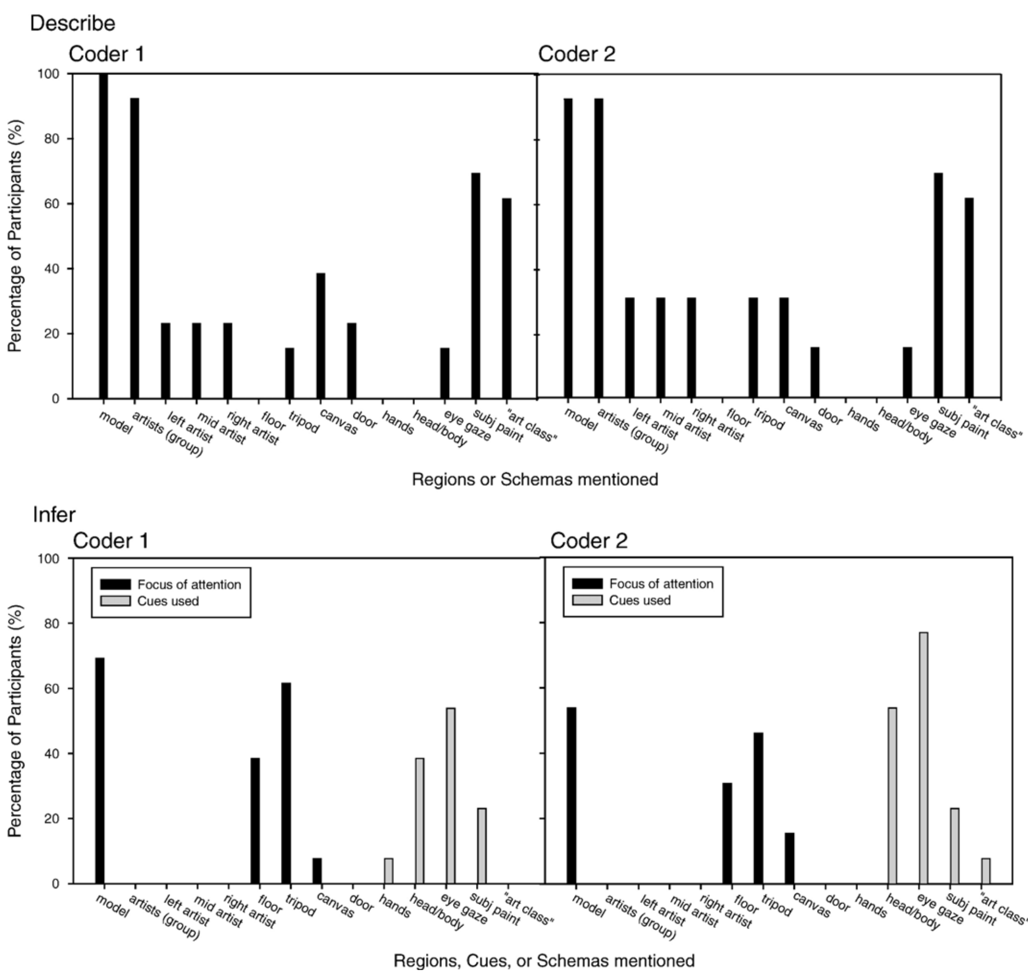

Fig. 2 – The frequencies with which regions in the art image were mentioned by participants in the describe group (upper panel) and the infer group (lower panel).

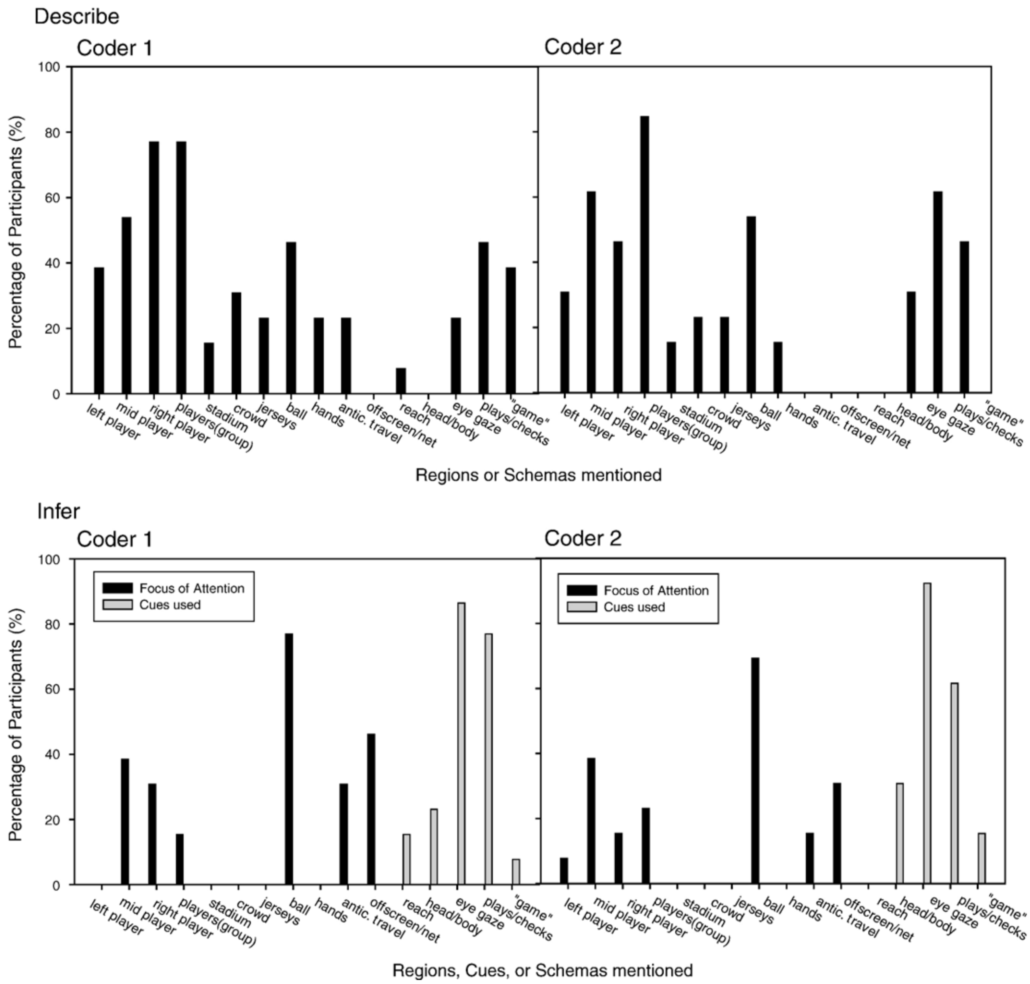

Fig. 3 – The frequencies with which regions in the sport image were mentioned by participants in the describe group (upper panel) and the infer group (lower panel).

people in each scene, but to nonliving objects as well, with the model being reported as attending to the floor (35%), the artists being reported as attending to the canvasses (54%), and the basketball players reported as attending to the ball (73%). Indeed, the object of attention need not be in the scene at all, with some participants (39%) reporting that the players in the sport scene were attending to something off-screen—such as to another player or to the basketball net—which was clearly not in the picture.

For the describe group, almost all participants mentioned the model in the art scene, and many of them mentioned the basketball players in the sport scene. In the sport scene, while many people mentioned the "players" as a group (81%), the individual players were mentioned quite frequently, with the middle and right (Jason Kidd) players mentioned the most. For the art scene, a different pattern emerged. Aside from the model, who was mentioned by virtually all participants, most of the descriptions of the art scene mentioned the artists as a group (92%), whereas the individual artists were each mentioned by only 26% of participants. Importantly, participants mentioned the *overall* theme of the scene when describing both the art scene ("art class": 62%) and the sport scene ("game": 46%) more often than when inferring attentional states ("art class": 8%; "game": 11%). In addition, it is important to note that, for the sport scene, the two cues that had been identified most frequently for inferring attention—the eyes and the plays/checks involved in a basketball game—were mentioned more frequently by the infer group (eyes: 88%; plays/checks: 69%) than by the describe group (eyes: 31%; plays/checks: 53%). Similarly, for the art scene, the two cues that had been identified most frequently for inferring attention—the eyes and head/body orientation– were mentioned more frequently by the infer group (eyes: 65%; head/body: 46%) than by the describe group (eyes: 15%; head/body: 0%).

Finally, the two objects that had been identified most frequently as the objects of people's attention—the canvasses and the basketball—were mentioned more frequently by the infer group (canvasses: 54%; basketball: 73%) than by the describe group (canvasses: 23%; basketball: 50%) Similarly, whereas 35% of participants said that the floor was the focus of the model's attention and 39% of participants said that the basketball players were attending to something off-screen, no one mentioned these regions in the describe group. On the other hand, objects that were not frequently mentioned as foci of attention were more frequently mentioned by the describe group. For example, the tripod was only considered an object

Fig. 4 – The regions of interest for the art (left) and sport (right) images used in the present analysis.

of attention by 15% of participants in the infer group but was mentioned by 35% of participants in the describe group. Similarly, whereas no one mentioned the crowd as an object of attention in the infer group, the crowd was mentioned by 27% of participants in the describe group.

In summary, we find from the subjective reports that gaze direction, scene meaning (e.g., plays/checks), and head/body position are the three key cues for inferring attention allocation. Together, these findings suggest that people do use gaze direction to infer the attentional states of others (see Friesen and Kingstone, 1998; Langton and Bruce, 1999; Langton et al., 2000) as well as other cues such as head orientation and body position (see Langton and Bruce, 2000; Langton et al., 2000). However, the findings also reveal that *situational context* is often considered to be an important cue for inferring the attentional states of the people in the picture. Indeed, so important is situational context that it can lead people to report that attention is being committed to items that are not even present in the scene. To our knowledge, the influential role of situation context for inferences of attention has heretofore not been reported, reflecting perhaps the fact that the standard context of an attention experiment in the laboratory is extraordinarily impoverished in nature. Our findings suggest that situational context will be an extremely rich variable for consideration in future studies of attention.

4.2. *Objective eye movements*

We considered how eye movements depended on specific regions of interest (e.g., Antes, 1974; Mackworth and Morandi, 1967). The regions of interest for the art and sport images that were used in the present analysis are shown in Fig. 4. The regions were identical across infer and describe groups so that it was possible to evaluate how fixation patterns *differed* depending on whether participants inferred the picture or described how attention was being allocated in the picture. Eye movements corresponding to each of the two scenes (art and sport) were analyzed with respect to (1) the characteristics of the eye fixations (e.g., fixation duration, fixation frequencies) in each region of the images and (2) the frequency of transitions between regions in each image.

4.2.1. *Region-based analyses of fixations*

Five regions were identified: eyes, heads, bodies, other objects, and background. To compensate for the fact that the regions were not equivalent in terms of area, we computed area-normalized fixation frequencies and duration percentages.[2]

We first highlight individual eye movement data from four participants (two in the describe group and two in the infer group). Fig. 5 shows the two subjects from the describe group, and Fig. 6 shows the two subjects from the infer group. One can see that, while there is some variability between individuals, two main eye movement patterns emerge. First, regardless of task, in the art scene, most fixations are committed to the eyes and faces of the model and the three artists, as well as to the canvasses and the tripod. Second, again regardless of task, in the sport scene, most fixations are committed to the eyes and faces of the three basketball players, as well as to their jerseys and to the basketball. Interestingly, although the crowd takes up almost half of the image, each subject only fixates the crowd on a few occasions.

There are also some group differences that are evident between Figs. 5 and 6. For the art scene, the two infer subjects seem to be considerably more interested in the eye regions of the model and artists than are the two describe subjects. Similarly, in the sport scene, the infer subjects make more fixations on the eye regions of the basketball players than do the describe subjects, as well as more transitions between the eye regions of the left-most and middle player. Finally, the two infer subjects commit more fixations to the basketball region than do the describe subjects, which was noted as an important object of attention in their subjective reports.

As for the group data, the area-normalized fixation frequency and duration percentages are shown in Tables 2 and 3, respectively. Inspection of the tables reveals that the pattern of fixation frequencies (Table 2) is similar to the pattern of fixation durations (Table 3). For both measures, eye movements were preferentially biased toward the eyes and

[2] To make the fixation and transition analyses manageable and meaningful, we chose to use a relatively small number of regions of interest (i.e., five). These regions were held constant across fixation and transition analyses. The regions were chosen partly based on the subjective report data, which suggested that eyes, heads, and bodies were important, as well as on an initial set of data-driven cluster analyses. The area-normalized fixation percentages were computed by dividing the percentage of fixations in each region by the area of the region (measured in square degrees of visual angle), separately for each participant. Similarly, we computed the area-normalized fixation duration percentages by dividing the total fixation duration percentages in each region by the area of the region.

Fig. 5 – Eye movement data from two participants in the describe group.

heads of individuals, particularly for the infer group. In the art scene, this was most apparent in the fixations committed to the eyes, and, in the sport scene, it was most apparent in the fixations committed to the heads of the people in the scene. In all other ways, the pattern of fixations was effectively the same for the describe and infer groups for both scenes.

These observations were supported by analyses of variance (ANOVA). The fixation frequency data are shown in Table 2. The data were analyzed using a mixed ANOVA with image (art vs. sport) and region (eyes, heads, bodies, objects, background) as within-participant factors and group (describe vs. infer) as a between-participant factor. There were main effects for region, $F(4,240) = 23.8$, $P < 0.001$, image, $F(1,240) = 5.18$, $P < 0.05$, and group, $F(1,240) = 3.90$, $P < 0.05$. The ANOVA also showed that there was a significant interaction between region and image, $F(4,240) = 11.9$, $P < 0.001$, reflecting the fact that fixation frequency was highest for the eye region in the art scene and the head region for the sport scene. The interaction between group and region was marginally significant ($F(4,240) = 2.19$, $P = 0.07$) consistent with the finding that the difference between infer and describe groups was largest in the head and eye regions. No other interaction was significant.

Fixation durations were analyzed in a similar manner. The means of the duration percentages, normalized by the region area, are shown in Table 3, separately for the two images and the two groups. As in the previous analysis, there was a significant main effect for region ($F(4,240) = 22.20$, $P < 0.001$),

Fig. 6 – Eye movement data from two participants in the infer group.

Table 2 – Area-normalized fixation percentages of five region categories, separated as a function of group (describe vs. infer) and image (art vs. sport)

	Art		Sport	
	Describe	Infer	Describe	Infer
Eyes	0.496	1.156	0.544	0.591
Heads	0.225	0.245	0.821	1.224
Bodies	0.153	0.137	0.036	0.042
Objects	0.293	0.250	0.349	0.329
Background	0.064	0.065	0.180	0.149

Note. Values are expressed as percent of the total number of fixations/area (%/degree^2).

and the main effects of group and image brushed significance ($P < 0.06$). There was again a significant interaction between region and image ($F(4,240) = 13.18$, $P < 0.001$), reflecting that eye duration was longer for the eye region in the art scene and the head region in the sport scene. The interaction between group and region was marginally significant ($F(4,240) = 2.081$, $P = 0.08$), agreeing again with the fact that the difference between infer and describe groups was largest in the head and eye regions. No other interaction reached significance.

4.2.2. *Transitions between region categories*

The analyses reported above were concerned with individual eye fixation behavior. In this second set of analyses, we concentrated on the fixation transition behavior between the regions of interest by fitting a first-order Markov model to the data, similar to the approach used by Liu (1998) and Henderson et al. (2000). The area-normalized transitions[3] are shown in Table 4, and they echo what we reported above for the individual eye fixation behavior. For both the describe and infer groups, eye movement transitions were observed primarily between the eye and head regions, especially so for the infer group. Transitions involving other regions were similar across groups indicating that the differences between groups were specific to transitions between eyes and heads. These patterns of results were similar across the art and sport images indicating that the findings generalized across images.

These conclusions were confirmed by ANOVA. To facilitate the description of the analyses, we refer to the region in which an eye movement originated as "region^T" and the region in which the eyes fixated after the eye movement (i.e., transition) as "region^{T+1}". The art and sport images were each analyzed using a 5 × 5 × 2 mixed ANOVA that included the within-participant factors of region^T (eyes, heads, bodies, objects, background) and region^{T+1} (eyes, heads, bodies, objects, background) and the between-participant factor of group (describe vs. infer). For the art image, the ANOVA revealed significant main effects of region^T ($F(3,384) = 4.83$, $P < 0.01$), region^{T+1} ($F(3,384) = 5.00$, $P < 0.01$), and of group ($F(1,384) = 5.66$, $P < 0.05$). Furthermore, the analyses revealed significant interactions between group and region^T ($F(3,384) = 3.35$, $P < 0.05$) and group and region^{T+1} ($F(3,384) = 3.41$, $P < 0.05$). A post hoc analysis of region^T using Tukey HSD revealed two homogenous subsets, one set containing the eyes and the other set containing the rest. A similar analysis of the sport image revealed significant main effects of region^T ($F(3,384) = 14.19$, $P < 0.001$), region^{T+1} ($F(3,384) = 14.83$, $P < 0.001$), and of group ($F(1,240) = 6.59$, $P < 0.05$). There was also a significant interaction between region^T and region^{T+1} ($F(9,384) = 5.37$, $P < 0.001$). A post hoc analysis of region^T using Tukey HSD revealed two homogenous subsets, one set containing the eyes and heads and the other set containing the rest.

4.3. *Summary: subjective reports vs. objective eye movements*

When the subjective reports and the objective eye movements are considered together, it becomes apparent that these two distinct measures converge on the same conclusion in many respects and provide unique insights in other respects. A strong convergence between measures was clearly evident with regard to the use of eye gaze and head orientation as cues for inferring the attentional states of others. The subjective reports indicate that the participants used eye gaze and head position as important cues for inferring the attentional states of people in the scenes. This agreed with the objective eye movement data showing that participants fixated eyes and heads more frequently and for a longer duration when inferring attention than when describing the scene. In addition, there was a greater amount of eye movements (i.e., transitions) between eye and head regions in the infer condition compared to the describe condition.

The overall patterns of eye movements were also very similar across infer and describe groups. This is surprising in light of the numerous studies that have shown that eye movements are highly sensitive to the nature of the viewing task and the instructions given to participants (see Yarbus, 1967; Henderson and Hollingworth, 1999). This is one way in which the subjective reports and objective eye movement data differed. Several interesting findings emerged in the subjective reports that were not readily apparent in the objective eye movement data. For instance, the subjective reports revealed that participants used body orientation cues to infer the

Table 3 – Area-normalized duration percentages of five region categories, separated as a function of group (describe vs. infer) and image (art vs. sport)

	Art		Sport	
	Describe	Infer	Describe	Infer
Eyes	0.735	1.345	0.564	0.633
Heads	0.218	0.251	0.871	1.561
Bodies	0.147	0.142	0.037	0.032
Objects	0.299	0.251	0.417	0.338
Background	0.063	0.056	0.169	0.140

Note. Values are expressed as percent of the total fixation time/area (%/degree^2).

[3] To compensate for the fact that regions corresponding to each of the states (eyes, heads, bodies, objects) varied substantially in area, we introduced an area compensation, similar to the area compensation used in the eye fixation analyses. We computed area-compensated transition matrices by dividing the number of transitions from category R_i to category R_j by the product of the areas of R_i and R_j.

Table 4 – Area-normalized fixation transitions between the eyes, heads, bodies, and objects, separated as a function of group (describe vs. infer) and image (art vs. sport)

		Describe				Infer			
		Eyes	Heads	Bodies	Objects	Eyes	Heads	Bodies	Objects
Art	Eyes	0	10.3	4.1	8.8	70.5	28.4	6.4	8.8
	Heads	10.3	3.8	1.9	2.3	29.7	4.5	1.7	2.4
	Bodies	5.9	1.8	1.2	2.3	5.9	1.6	1.0	2.7
	Objects	7.4	2.3	2.4	5.2	8.8	3.6	2.4	3.2
Sport	Eyes	31.6	30.9	5.2	0	85.9	63.5	9.9	9.9
	Heads	49.8	13.0	3.1	8.8	85.9	14.3	3.5	8.8
	Bodies	2.1	3.5	1.4	2.8	6.6	4.9	1.2	3.2
	Objects	3.3	3.8	2.3	0	3.3	7.5	3.4	0

Note. The cells represent the number of transitions (number of transitions/10^{-4} degree^2) from the previous region (rows) to the current region (columns). There are 0 transitions from object → object in the sport image because only 1 object existed (the ball).

attentional states of others. However, the eye movement analysis failed to reveal that eye fixations or movements differed in these regions between the infer and describe group. Similarly, the subjective reports indicated that participants used the meaning of the situations in the scenes to infer attention, and this again was not readily apparent in the eye movement data. Thus, our findings clearly suggest that the subjective reports provide information and suggest hypotheses that go substantially beyond those that emerge from the eye movement data alone.

5. General discussion

For decades, attention has been studied from the information processing viewpoint and most recently from a cognitive neuroscience perspective. Both of these perspectives construe attention as a mind/brain process (or a set of a finite number of processes) that can be revealed through carefully controlled laboratory studies. We (Kingstone et al., 2005, submitted for publication; see also Giesbrecht et al., in press) have noted recently, however, that the assumptions underlying these approaches are flawed and that they are unlikely to reveal important aspects of attention as it operates in everyday situations. Specifically, we have noted that attentional mechanisms might be much less stable than previously thought and controlled laboratory settings might in fact be a hindrance to uncovering important aspects of attention that occur in the real world.

In the present study, we have taken an alternative approach to the study of attention. Rather than seeking to find stable basic mechanisms of attention in controlled paradigms, we sought to observe and describe the sorts of information that people use when they complete an attentional task that they engage in every day—that of inferring the attentional states of others. Specifically, we monitored participants' eye movements and recorded their subjective impressions as they either described social scenes or inferred the attentional states of the participants in the scenes. The study led to a number of interesting findings:

(1) The subjective reports of participants revealed several important cues for inferring attentional states of others. These included direction of eye gaze, head position, body orientation, and, most importantly, situational context. Situational context was found to be so important that it led participants to report objects of attention that were not even in the image, such as an off-screen basketball net.

(2) Objective eye movements indicated that eye gaze and head position were critical factors for inferring attention. The eyes and heads were fixated more often and for a longer duration when participants were inferring attentional states than when they were describing a picture. In addition, making inferences of attention led to a greater number of transitions between eye and head regions than did describing scenes.

(3) Participants reported using cues when inferring attention, such as body position and situational context, that were not revealed in the analysis of the objective eye movements. These findings illustrate that subjective reports provide information that goes beyond what may be found from objective measures alone.

Taken together, these findings go substantially beyond previous studies of attention in controlled laboratory paradigms, and particularly studies that have investigated the cues that people use to infer attentional states of others. For instance, to date, the role of situational context has received little study in attention research. More importantly, demonstrating that situational context matters is critical because it brings into question the validity of previous studies which have sought to maximize experimental control by minimizing variability in situational context. That is, the data strongly suggest that laboratory findings and conclusions are specific to the contrived environment that was used to generate them.

The present findings also extend previous work on scene perception (Buswell, 1935; Yarbus, 1967; see Henderson and Hollingworth, 1999 for a review). While our study bares some similarity to previous scene viewing studies in that we monitored eye movements while participants viewed scenes, our study is unique in that it focused on using eye movements as an indicator of the cues that people use when they infer the attentional states of others. To our knowledge, inferring attention of people in scenes has not been explored previously in the scene perception literature.

On a more general note, we wish to highlight the unique direction in which our research on attention is heading. The present study constitutes our first step towards developing a new research approach that we call *Cognitive Ethology* (Kingstone et al., 2005, submitted for publication). In what follows, we briefly outline the assumptions and principles of this approach and then clarify how our approach is similar to and distinct from existing frameworks.

5.1. *Cognitive Ethology: a new approach to studying attention*

The primary goal of the Cognitive Ethology approach is to understand various cognitive concepts, such as attention, in the context of real-world situations. This approach rejects the assumptions of process stability and rigid laboratory control that typify the cognitive and cognitive neuroscience explorations of attention. Our approach replaces the assumptions of stability and control with two alternative assumptions. The first is that attentional behavior is not stable but varies across situations. Given that the ultimate goal is to understand how attention operates as individuals engage in everyday behaviors, the approach seeks to study attention not in laboratory settings, but in real-world situations. Indeed, the present findings support this assumption by demonstrating that a critical factor that influences attentional inferences is situational context. The second assumption is that attentional behavior is inherently complex and can only be understood by characterizing the naturally occurring complexity of human behavior in various situations. In other words, the goal is to understand naturally occurring variability rather than artificially created variability in controlled laboratory tasks.

In addition to these two assumptions, the approach is also based on several key principles. First, as the term "cognitive" in Cognitive Ethology suggests, the approach seeks to understand what have classically become "cognitive" concepts, such as attention and perception. Second, the approach seeks to ground concepts in people's everyday understanding of those concepts (see Koch, 1999). Third, the approach focuses primarily on *observing* and *describing* overt behavior in natural contexts, as well as people's subjective reports of their beliefs and experiences. Finally, the Cognitive Ethology approach holds that personal insights into one's performance (i.e., subjective reports) provide critical and informative data that must be accounted for and incorporated into theories and explanations. Combining objective data and subjective reports is at the heart of this approach.

Our even-handed treatment of objective and subjective data can easily be met with considerable skepticism. Indeed, subjective reports of personal experience and beliefs are often seen as suspect and are largely ignored in cognitive neuroscience studies of attention. Researchers often believe that subjective reports are not reliable and replicable across individuals and situations and that they are vulnerable to experimenter demands. And, it is generally agreed that people do not have introspective access to attentional mechanisms because they operate, for the most part, below conscious awareness. Moreover, on occasions, when peoples' subjective reports agree across individuals, they may be inconsistent with their behavior (Nisbett and Wilson, 1977; Hulbert and Heavy, 2001).

Though a complete treatment of each of these criticisms of subjective reports is beyond the scope of this paper, we note that many of the criticisms that have been made against the use of subjective reports apply equally to objective measures of performance (see Ericsson, 2003). In fact, it has even been argued that some form of introspective methodology is an integral part of all "objective" methods (Jack and Roepstorff, 2002, 2003). And, finally, over the past few decades, there have been considerable advances in the development of first-person methodologies that minimize the extent to which introspective reports bias conscious experience and the extent to which they are susceptible to experimenter demands (see Dennett, 2003; Ericsson, 2003; Ericsson and Simon, 1980; Luz and Thompson, 2003).

It is also worth noting the several ways in which subjective reports are extremely useful for studying human attention. Most importantly, subjective reports provide direct access to participants' explicit and perceived goals, intentions, and behavior in everyday situations. They also provide important insights into differences in behavior across individuals (Dixon et al., 2004; Smilek and Dixon, 2002) and the types of attentional strategies people are trying to implement in various situations. Subjective reports are extremely useful for revealing additional aspects of a situation not captured in behavioral measures. Finally, they are extremely valuable for generating hypotheses that can later be tested with objective measures.

5.2. *Cognitive Ethology and the present study*

Several of the principles of Cognitive Ethology motivated the present study. In line with the rejection of the assumption of control, we attempted to study attention using naturally complex real-world scenes. We also studied attention in a natural and complex task that people engage in every day (i.e., inferring attentional states of others). And, rather than restricting possible responses to a key press, we measured the complex set of eye movements that participants made as they observed the scenes. We also rejected the assumption that attentional mechanisms are stable across situations and sought to simply describe behavior rather than making inferences about some putative basic attentional mechanism. Consistent with Cognitive Ethology's emphasis on integrating objective and subjective data, we recorded peoples' reports of their subjective experiences and integrated them with our objective eye movement data.

Several benefits of measuring subjective reports are illustrated by the present study. When comparing our subjective and objective data, we noted that participants reported using head/body posture as a cue for inferring attention, though we did not find any specific use of this cue in our eye movement data. From a cynical perspective, one might conclude from these findings that the subjective reports are simply incorrect. However, we believe that subjective reports should not be dismissed so lightly. Indeed, it is possible that it was our measure of eye movements that was not sensitive enough to pick up peoples' use of head/body position as a cue. Clearly, this disagreement between the two measures is very interesting and warrants further study. It also shows how subjective reports can play an important role in directing future research. Another interesting finding revealed by subjective reports is that people used situational context as cue for inferring the attentional states of others. This was also not found with the eye movement data, which is not surprising, however, as it is difficult to conceive of a pattern of data that would support this conclusion. We find then that these data provide yet another example of how subjective reports can lead to findings over and above what can be found using objective measures.

It is also worth noting, however, that there are several ways in which our study failed to meet the goals of Cognitive Ethology. Though we used complex stimuli and gave participants a relatively naturalistic task, we did not observe how people infer attention in the real world, such as when they are driving or crossing the street. In addition, there were a number of factors in the study that were under experimental control. For instance, we gave the same stimuli to each individual, we systematically varied instructions (infer versus describe), and we seated all participants the same distance (roughly 57 cm) from the images. Such control is inconsistent with Cognitive Ethology because, as we noted above, a central facet of our approach is to observe freely varying and unconstrained behavior. Along these lines, another weakness of our study is that we did not allow participants to physically interact with their environment. There is now considerable evidence suggesting that action, and participants' potential for action, is critical to attention and perception (e.g., Grison et al., in press; Gibson, 1979; Handy et al., 2003; Harman et al., 1999; Tipper, in press). The fact that we constrained action (e.g., locomotion, hand movements, and body movements) in our study places constraints on what we can learn about attention. This being said, our study did consider overt eye movements which do constitute an overt behavior that is quintessential for attentional orienting (see Findlay and Gilchrist, 2003; Rizzolatti et al., 1987, 1994). It is important to emphasize that, ultimately, Cognitive Ethology is about unconstrained real-world behavior and not about controlled laboratory tasks. Future studies need to focus on real-world situations if we are to continue to gain a more accurate approximation of what everyone knows about attention and how attention actually operates in real-world settings.

5.3. *Relation to other research approaches*

We have already mentioned that our Cognitive Ethology approach differs substantially from the information processing approach and the cognitive neuroscience approach. But, we would be remiss if we did not also discuss how the Cognitive Ethology approach differs from other types of approaches that have emerged in the history of psychology.

Of course, a detailed articulation of how Cognitive Ethology differs from current and previous approaches applied to the study of attention and cognition should not overshadow the fact that most approaches are defined by *several* different principles and assumptions that are often not clearly articulated by the proponents of the theories. Thus, it will become apparent that our approach shares some principles and assumptions with previous approaches. What makes our approach unique is the combination and emphasis of the assumptions and principles that underlie it. Here, we consider several previous approaches including the *ethological approach* (e.g., Carthy, 1966; see Hutt and Hutt, 1970), the *ecological approach* (e.g., Barker and Wright, 1955; Wright, 1967), *ecological optics* of J.J. Gibson (1950, 1966, 1979), Neisser's (1976) call for *ecological validity*, and *human factors engineering* (e.g., Vincente, 2003).

5.3.1. *The ethological approach*

As the name of our Cognitive Ethology approach suggests, it is in some ways similar to the ethological approach, which gained prominence during the 1960s (e.g., Carthy, 1966; see Hutt and Hutt, 1970 for a review). Ethology focuses on describing behavior *patterns* of humans and animals in their natural contexts. Our approach and the classic ethological approach are similar in that they both seek to provide a detailed description of behavior as organisms interact with and in their natural environment. Furthermore, both approaches consider it essential that natural behavior be observed and described as it normally occurs rather than being modified or probed in overly controlled settings.

There are, however, several critical differences between the two approaches. The primary difference is that, in our Cognitive Ethology approach, as implied by the term "cognitive", the aim is to relate the observations to classically cognitive concepts such as attention. Our approach views these concepts as being contextualized processes revealed by the interaction of an individual with their environment. In contrast, classical ethology was concerned exclusively with overt behavior and did not seek to draw inferences about cognition. Another difference between the approaches involves the use of subjective reports. As evidenced in the study described in this paper, our approach considers participants' subjective reports and beliefs about their experience in a given situation to be critical for understanding cognition and behavior. In contrast, the classic ethological approach rejects inferences about subjective experience as well as the validity of subjective reports (Carthy, 1966; Hutt and Hutt, 1970). Furthermore, unlike the ethological emphasis on behavior over environmental situation, our approach holds that both behavior and environment are equally important in studies of human cognition. And, finally, our approach currently makes no strong commitments to other issues central to ethology such as whether behaviors are innate or learned, and how behavior might be shaped by evolutionary pressures (see Eibl-Eibesfeldt, 1970).

5.3.2. *The ecological approach*

Our approach is also similar to the ecological approach developed during the 1950s and 1960s (e.g., Barker and Wright, 1955; Wright, 1967; see Hutt and Hutt, 1970 for a review). The ecological approach focuses on characterizing the *situations* (i.e., "habitats") in which people behave by observing and describing behavior; the approach seeks to understand how the environment (i.e., "habitat") relates to or determines behavior. The primary similarity between this and our approach is the assumption that characterizing situations is necessary for understanding human behavior.

However, Cognitive Ethology also differs from the ecological approach in several important ways. First, the approaches differ with regard to emphasis or relative importance of the environment and individual. While the ecological approach places primary emphasis on the habitat, our approach does not allow an emphasis of the habitat to overshadow the individual. Second, the approaches differ with respect to the way they treat subjective reports and personal insights of the participants in the studies. Though the ecological approach allowed for considerably more discussion of peoples' mental states than the original ethological approach, particularly those pertaining to the goals of their behaviors (Wright, 1967), the ecological approach nevertheless focuses on inferring such mental states (or "attitudes") from observable behaviors. In other words, subjective reports are not a valid method for inferring mental states within the ecological approach. Thus, our emphasis of subjective reports as being equally important as observable behavior is another way in which our approach differs from the ecological approach.

5.3.3. *Ecological optics*

There are also commonalities and differences between the Cognitive Ethology approach and the ecological optics approach put forward by J.J. Gibson (1950; 1979; see also Turvey, 1992). The central idea of Gibson's theory is that perception is driven by the structure of the environment. The Gibsonian formula is "perception is a function of stimulation and stimulation is a function of the environment" (Gibson, 1959, p. 459); therefore, perception is a function of the environment. The theory is ecological because it puts a strong emphasis on the environment, much like the "habitat" in the ecological approach described above.

There are several similarities between Gibson's approach and Cognitive Ethology. First, common to both approaches is the idea that individuals are embedded in an environment and that cognitive concepts cannot be understood as being independent of the environment. The second similarity involves rejection of the assumption of stability. Gibson believed that traditional psychophysics had focused on how the sensory receptors respond to discreet stable stimulation and that this focus had led to an unsatisfactory understanding of perception. Gibson keenly observed that "the stimulation of receptors and the presumed sensations....are variable and changing in the extreme, unless they are controlled in the laboratory" (Gibson, 1966, p. 3). His approach was based on the idea that there is considerable change from moment to moment and that this change across time and situations must be understood and integrated within a theoretical framework (see Gibson, 1959, p. 464–465). The focus of both approaches is on naturally occurring variability rather than variability that is manipulated or created in the laboratory.

But, there are also substantial differences between Gibson's ecological optics and Cognitive Ethology. First, Gibson's framework emphasizes the environment, and little consideration is given to the individual. In contrast, our framework places an equal emphasis on the characteristics of the individual and the characteristics of the environment. Second, though Gibson's framework focuses on naturally occurring variability, the ultimate goal is to derive perception–action laws "of the most basic and general kind" (Turvey, 1992, p. 86). Cognitive Ethology, on the other hand, seeks to simply describe situations. Though law-like principles might emerge across different situations, identifying a set of "laws" is not the primary goal of the approach. Finally, the approaches differ with regard to their use of introspection and participants' subjective reports. According to Gibson, introspection is only a means of generating hypotheses and subjective reports are not considered to be important data in their own right. Gibson writes: "introspection, however unbiased, is no more than a guide to the study of perception" (Gibson, 1959, p. 461). As noted earlier, in contrast to this view, Cognitive Ethology treats subjective insights as important data in their own right and seeks to ground cognitive concepts in people's everyday understanding of those concepts.

5.3.4. *Neisser's ecological validity*

Finally, we consider Neisser's (1976) call for ecological validity in cognitive psychology. We wholeheartedly resonate with Neisser's (1976) claim that "a satisfactory theory of human cognition can hardly be established by experiments that provide inexperienced subjects with brief opportunities to perform novel and meaningless tasks" (p. 8). Yet, we also notice that Neisser's call for ecological validity in cognitive psychology has had little impact on the field. It is our position that one reason for this lack of impact is that, while Neisser articulated eloquently the need for more ecological validity, he did not specify a systematic approach for attaining the ecological goal. Thus, researchers were challenged with an important goal but were left with no clear direction regarding how to attain that goal. As a result, there has emerged the general view that ecological validity is something that cannot be attained. This has led unfortunately to a degree of resignation to, and even comfort with, artificial laboratory studies. While we certainly agree with Neisser's call for more "ecological validity" in cognitive research, we believe that our approach goes substantially beyond a simple recapitulation of such a call. Our formulation of the Cognitive Ethology approach clearly articulates the assumptions and principles that must be applied in order to attain ecological validity. In other words, whereas Neisser outlined the problem in the field, we believe that we have outlined an approach that goes a long way towards providing a solution to this problem.

5.3.5. *Human engineering*

On the surface, it may seem that the Cognitive Ethology approach is simply a recapitulation of "human engineering" or "applied psychology". One might come to this conclusion because our approach advocates studying attention in real-world situations, precisely the situations that are typically of interest to human engineers or applied psychologists. Though these approaches have a common interest in studying real-world situations, Cognitive Ethology has a fundamentally different goal than does human factors engineering. Specifically, human factors engineering seeks to understand human behavior in a given—typically highly controlled—situation to create *technology* that is best suited for humans in that situation (see Vincente, 2003). Cognitive Ethology on the other hand seeks to measure human behavior in uncontrolled real-world situations for the purpose of understanding human cognition. Though Cognitive Ethology might ultimately lead to very interesting and useful technologies, it is not the goal of Cognitive Ethology. The goal is to understand human cognition by obtaining both objective and subjective measures of human behavior.

Decades ago, when experimental research on human attention was laying its foundations, human engineering and attention research were meant to coexist in a complementary fashion (see Broadbent, 1958, 1971). Indeed, some of the earliest works in the area on human attention were motivated by real-world issues that had a definite human engineering component, such as maintaining vigilance of radar operators (see Broadbent, 1958) and measuring the propensity with which people make cognitive errors in the work place (Broadbent et al., 1982). These studies in turn informed information processing theories of attention (see Broadbent, 1958, 1971). Over time, however, this tight relationship between laboratory and real-world research became separated, and human engineering focused on technological development without any real emphasis on cognitive theory or development or modeling. Importantly, the Cognitive Ethology approach outlined in this paper may very well help to bring human engineering back within the fold of cognitive research and theory.

In summary, this cursory and non-exhaustive examination of the relationship between our Cognitive Ethology approach and other approaches illustrates the uniqueness of our approach. This is not to say that studies consistent with the Cognitive Ethology approach have not been conducted in the past. On the contrary, we can point to a number of studies that have successfully applied many of the principles of this approach. For instance, studies of peoples' eye movements during driving and other everyday tasks, such as making tea, conducted by Land and colleagues (e.g., Land and Hayhoe, 2001; Land and Lee, 1994) provide excellent examples of what we refer to as Cognitive Ethology (see also, for another example, Vickers, 1996 work with basketball shooting). The only way in which these studies did not fit completely with Cognitive Ethology is that they did not include reports of peoples' subjective reports about what information they used when, for example, turning corners, preparing tea, or shooting a basketball. Thus, just as there were studies using the cognitive neuroscience approach prior to the explicit formulation of the cognitive neuroscience research area, there have been studies consistent with our approach prior to our explicit formulation of Cognitive Ethology.

5.4. *Unanswered questions and future directions*

We believe that our new approach and, more specifically, the findings from the present study point to several interesting questions that should be answered in future studies. We briefly describe some of these below:

(1) One of the main issues raised by the Cognitive Ethology approach and by the present findings is that situational context matters. The goal of the Cognitive Ethology approach is not to characterize basic mechanisms that are stable across situations, but rather to effectively describe and understand situations. In our view, situations are defined as including both the individual and the environment. As noted by Rosch (1999), such "situations are the units that require study for psychology in general" (p. 74). In the context of attention research, this view raises many fascinating questions: how does the use of attention differ across situations? Can a classification of situations that pertain to attention be established? When does attention remain invariant across situations? How does attention differ across social and non-social situations?

In addition to the numerous questions raised by the general focus on situation by our Cognitive Ethology approach, several interesting questions are also raised by the present study's finding that inferences of attention depend on situational context. Previous studies that have investigated what sorts of cues people use to infer attention have typically used attentional cues, such as eye gaze or pointing, in isolation or in a small number of combinations (e.g., Friesen and Kingstone, 1998; Langton and Bruce, 2000). The present findings illustrate the limitations of these studies by showing that situational context is a critical cue and might modify the interpretation of other cues. For instance, while direction of gaze might be regarded as a reliable cue for inferring attention in some contexts, such as an office scene, it might not be seen as being reliable in other contexts such as a basketball game, where the "no look" pass is commonly used to misdirect opponents. These possibilities raise a number of interesting questions: how does situational context influence which cues people use to infer the attentional states of others? How does situational context change for different individuals, and how does this affect inferences of attention and attentional allocation? Are there some aspects of situational context that matter more than others, and how do they vary between individuals? Are there some cues that are used to infer the attentional states of others that are relatively independent of situation?

(2) Because the Cognitive Ethology approach holds that attentional behavior depends so heavily on situations, we suggest that research should focus on studying *everyday* situations. After all, cognitive neuroscientists have always argued that the ultimate goal of their research is to understand the relation between behavior and brain function as they are revealed in everyday situations in the real world. Because in the present study we had participants view static scenes, there is the important and interesting possibility that the sorts of cues that people use to infer attention in everyday situations (i.e., as people move around in their natural settings) might be different than the ones that we found with static scenes. One particular situation that would certainly be worth studying is driving. What information does people use to infer the attentional states and the intentions of other drivers on the highway, on a busy city street, or in an intersection? Thus, it would be fruitful for future investigations to focus on understanding the sorts of cues people use to infer attention in actual situations outside of the laboratory.

(3) An interesting result that emerged from the present study was the possibility that when people are describing social scenes they are actually inferring the attentional states of others. This was suggested by points of similarity in the subjective reports and eye movement patterns across the infer and describe groups. More extensive studies are needed to establish the generality of this finding and to elucidate the extent to which people infer attentional states when they view scenes in order to describe them.

(4) A central characteristic of our new approach is allowing the participant control over both their response as well as the stimulus environment. This is in stark contrast to most work on attention in which participants have no control over the stimulus and very little, if any, over their responses. In allowing participants to have control of their behavior and the environment, our approach implies that a valuable way to study attention is by allowing participants to *explore* their environment. Human exploration has been studied to some extent in areas of child psychology (see Hutt, 1976; Hutt and Hutt, 1970) and to a much lesser extent in cognitive neuroscience (Harman et al., 1999; Heller and Myers, 1983; James et al., 2001). For instance, Harman et al. (1999) have shown that recognition for various views of objects is much better when participants are able to actively manipulate an object than when they are only able to view the object passively. As exploration dovetails with one of the key principles of Cognitive Ethology, we suggest that this line of research may prove very rewarding in the future. For example, it would be interesting to know how being active or passive in exploration impacts subjective experience of the exploration event and whether people can recognize their own exploration patterns over those of others.

Giving participants control over their responses and their stimulus environment implies that overt bodily *action* should be given a more central role in theories and studies of attention.[4] A brief consideration of how attention might be used in the real world clearly reveals numerous attentional situations involving action. For instance, how attention might operate while people cross the street might be very closely tied to their physical movement and their potential for action in that situation. Because possible relationships between attention and action are likely context-specific, future research might profit by focusing on these relationships in real-world situations.

(5) Finally, we wish to highlight the utility of grounding concepts in people's everyday understandings of the concepts. As articulated by Koch (1999): "There is a strong sense in which psychology was already "established" before it commenced as a science. Once we appreciate the vast resources of psychological knowledge coded in natural language, and internalized in the sensibilities of those who use it well, it should become a paramount matter of intellectual responsibility for those who explore the human condition to ensure that this knowledge not be degraded, distorted, or obliterated in their technical conceptualizations" (p. 27). Grounding concepts in people's everyday understandings is another central way in which our approach departs from previous approaches to the study of attention and cognition. Simply put, one of our goals is to understand in the most direct way what everyone knows about attention. We believe that this sort of grounding will also be extremely useful to other conceptualizations of mental processes in the cognitive neuroscience literature, such as memory, categorization, and visual perception, as well as more specific concepts such as vigilance and perspective.

[4] We thank an anonymous reviewer of our manuscript for highlighting the importance of action in attentional situations.

6. Concluding comments

In the past three decades, research on attention has been dominated by the information processing approach, a fact that is reflected well by the field of cognitive neuroscience. In this paper, we have articulated reasons why we believe that the cognitive neuroscience research approach is not up to the task of providing a complete understanding of human attention. Our rejection of the assumptions underlying the information processing and cognitive neuroscience approaches mirrors in some ways the rejection of structuralism by individuals such as William James (1890/1983) who argued for a functionalist approach to psychology (see Galotti, 2004; Hillner, 1984). Like information processing and cognitive neuroscience, Edward B. Titchener's structuralism was based on the idea that psychology must be studied in the laboratory "where stimuli could be stripped of their everyday meanings to determine the true nature of mind" (Galotti, 2004, p. 8). In contrast to this approach, functionalism held that the mind must be understood in terms of its function and, therefore, it will only be understood by studying the whole organism in real-world settings (see Hillner, 1984). We follow in the footsteps of William James, Ulrich Neisser, and others in arguing that the goal of attention research is to understand how attention operates in the real world and that controlled laboratory studies alone are inadequate for the task. We do not wish to imply that traditional laboratory research has no utility at all and that it should be completely abandoned (see also Kingstone et al., 2003, 2005, submitted for publication). Rather, we suggest a complementary research approach that we have termed Cognitive Ethology. In this paper, we have reported a study which constitutes our first steps towards this new approach. We believe that the Cognitive Ethology research approach has the profound potential to enable researchers to reach their ultimate goal of understanding human cognition as it operates in the real world.

7. Experimental procedures

7.1. *Subjects*

Two groups of 13 university students took part in the present experiment (9 males and 17 females). Participants all had normal or corrected vision and were naive to the purpose of the experiment. Participants were given course credit for taking part in a 1-h long session.

7.2. *Apparatus*

The present experiment used the SR Research Ltd. EyeLink eyetracking system. The EyeLink has a temporal resolution of 4 ms (sampling rate 250 Hz) and a spatial resolution of 0.005°. A lightweight headband holds two high-speed cameras taking images of both eyes and a third camera that tracks four infrared markers positioned on the display monitor for head motion compensation. We only tracked the left eye in our study. Two computers were used in the experimental setup, one to collect data from the eyetracker and one to display stimuli to the participant. The computers were linked via Ethernet, which allowed for the real-time transfer of saccade and gaze position data. The eyetracker computer displayed an image of the participant's eye, as well as calibration information.

7.3. *Materials*

Six pictures were collected from various sites on the world wide web. Each picture was in black-and-white format, contained at least two people, and portrayed a theme of some kind: people playing basketball, people painting in an art class, the Prime Minister of Japan giving a speech in Tokyo, people socializing in a courtyard, a soldier looking at his comrade, and an artist drawing a city scene. Examples of the images used in the experiment are shown in Fig. 1. To meet requirements of the EyeLink software, each picture was presented on a white 800 × 600 pixel canvas. Thus, in some cases, a picture that was slightly smaller than 800 × 600 pixels was surrounded by the white borders of the canvas. The pictures were identical for both groups of participants.

7.4. *Procedure*

Participants were seated in a lighted room with their chins supported by a chin rest so that they sat approximately 57 cm from the display computer screen. The describe group was told that they would be shown a set of 6 pictures and that they would be asked "to look at, and describe" each picture. The infer group was told that they would have to answer the following question for each picture: "where are people in the picture directing their attention, and how do you know?" Both groups were given an answer booklet, with space available for answering their assigned question for each picture in the order presented. Participants were instructed that they could view each picture for as long as they wished and that they could press the spacebar to terminate each picture viewing when they felt ready to write the answer to their question for that picture. Participants were told explicitly that they would have to write their answer for any given picture *after* they terminated the trial by pressing the spacebar and that they could take as long as they needed to write their answer. Participants completed a practice trial with a picture not used in the test trials.

At the beginning of each trial, a fixation point was displayed in the center of the computer screen in order to correct for drift in gaze position. Participants were instructed to fixate this point and press the spacebar to start the trial. Once they pressed the spacebar, 1 of the 6 pictures, chosen at random without replacement, appeared in the center of the screen. The picture remained visible until the participant pressed the spacebar again to terminate the trial. After terminating the trial, the participant wrote an answer to the question assigned to his or her group using the booklet provided. This process repeated until all 6 pictures had been viewed.

The first fixation of each trial was discarded from analysis. We chose to do this because the first fixation was often at the center of the screen, due to the requirement to fixate there to start each trial.

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