A Framework for Studying Age-related Change and

Individual Variation in Selective Attention

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The concept of selective attention is fundamental to understanding human behavior. And in everyday life, it is clear that there are marked differences in attention between individuals. Some have special talents and others face special challenges; individuals of different age display predictably different capacities. Some of these differences reflect a genetically determined plan governing neural growth, maturation and senescence, whereas others reflect specific events: positive events such as the acquisition of expertise, and negative events such as pathology or injury. In this article we address three questions: What is attention? How does attention change during childhood? What are the consequences of these changes in daily life? We examine these questions primarily for the visual modality, though we believe that attention in other modalities follows similar principles.

A harsh reality that confronts all students of selective attention is that the literature is fragmented, making the study of individual differences a daunting task. This is especially true of individual differences that stem from human development and aging. The basic research on adults is carried on in isolation from the work on children and older adults. These literatures in turn make little contact with studies of special populations and there is little communication between those doing basic and applied research. In this chapter we propose an ambitious new framework that has the potential to integrate our understanding of attentional performance in individuals of all kinds, both in how they perform experimental tasks and in how they perform common day-to-day tasks such as taking part in sports and driving.

We begin by describing the framework in broad terms. We then apply this framework to the study of age-related changes in children. In doing so, it will become clear that this framework is also useful in the study of senior citizens, as well as other special populations, such as persons with autism, elite athletes, and

crash-prone automobile drivers. Our goal is to provide a way of understanding not only the sources of age-related change but also the sources of stability, the origins of both individual diversity and the consistencies that define a common human nature.

To start, what is attention? If one examines the variety of tasks used to measure it (e.g., covert orienting, visual search, filtering, multiple target tracking, dual tasks and multiple action monitoring) it becomes clear that all measures require selection of one kind or another. Selection is needed because there is simply too much information for all of it to be used in the ongoing and timely control of action. Some signals must be selected while others are ignored, choices must be made, and priorities must be set. For these reasons we define attention as selection.

It is also clear that there are different types of selection. It is our view that selective attention can best be understood in terms a framework based on two fundamental dimensions (Trick, Enns, Vavrik, & Miller, in press), as shown in Figure 1. The first concerns whether selection occurs with or without awareness. Selection without awareness has been variously called preattentive, inattentional, subconscious, unconscious, and unintentional.   The key feature of this type of selection is that it is <u>automatic</u> (Shiffrin & Schneider, 1977), which is to say that selection is rapid, effortless, and without intention. Automatic selection is triggered by the presence of certain stimuli in the environment and runs to completion with little interference from other processes. Thus, some stimuli are selected even when the focus of conscious awareness is elsewhere or on another task.

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Selection with awareness has been variously called attentive, conscious, or intentional. Stimuli that are selected in this way are given full perceptual analysis and transferred to working memory. This type of selection involves <u>control</u> (Shiffrin

& Schneider, 1977), which is to say that selection is effortful and slow, but it can be started, stopped, or modified at will, a feature that makes this type of processing flexible and intelligent. Controlled processes can produce changes in explicit long-term memory through learning, and with adequate practice some types of controlled processes may even become automatic providing there is a fixed relationship between specific stimuli and responses (e.g., a search task where certain items are always targets and others are always distractors). The fundamental limitation is that only one controlled process can be conducted at a time.

The second dimension concerns the origin of the selective process. Some processes are innately specified, meaning that they do not need to be learned and are thus common to all. Exogenous selection occurs as a result of the way humans are built and is initiated by specific stimuli. In this case, external (exogenous) stimuli seem to trigger selection but the reason they have this effect is because of the way the nervous system is organized. Specifically, there is an innate continuum of stimulus salience, with some types of stimuli more likely to receive exogenous selection than others.

Others processes are engendered by an individual's specific goals at a given time and are thus idiosyncratic and situation-specific. Endogenous selection results from what people know about an environment and what they want to achieve. People actively search the environment for information relevant to specific goals or intentions; they perform these tasks in ways that are consistent with their expectations and previous learning (endogenous factors). Expectancies may act as a 'perceptual set,' causing people to look for specific objects at certain locations. A perceptual set can be advantageous because it directs viewers to goal-relevant

information, but at the same time it impedes the perception of stimuli that do not conform to expectations or goals.

Four modes of selection

Figure 2 outlines the central features of each of the four modes of selection. Two of these modes involve automatic processes. <u>Reflexes</u> are innately specified and triggered by the presence of certain stimuli in the environment. In contrast, <u>habits</u> come into existence when the operations necessary to fulfill a certain goal are carried out so often in a certain context that they become automatic. There are two critical differences between reflex and habit. First, though both are "triggered" by the presence of certain stimuli, the triggers for reflexes are innately specified (and common to all) whereas the triggers for habits are learned (and idiosyncratic, specific to an individual's learning history). Second, reflexes emerge on a developmental timetable and are stable once acquired whereas habits can be formed at any time, and can fade or be replaced at any time due to lack of practice or new learning. Both can be problematic in that they may be triggered in situations where they are inappropriate, in which case processes involving deliberate selection will be required to compensate: processes that require time, effort, and planning.

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The other two modes involve controlled processes. <u>Exploration</u> is the default mode for controlled processing, a type of selection carried out in the absence of specific goals. We argue that innate preferences set the default for what is attended when humans explore environments that they have no specific goals for or expectations about, environments lacking the stimulus triggers necessary to evoke reflex or habit. Exploration requires controlled processing because in most cases full

object recognition requires attention. In contrast, <u>deliberation</u> involves the execution of a specific chosen attention-demanding process at the expense of other processes. It involves goals that reflect an individual's specific knowledge, plans, and strategies for a certain situation. Deliberate processing is noticeably effortful and time consuming, but of all the modes of processing, it is the most flexible and responsive to new information because it is conscious and internally directed. Deliberate selection is also necessary when unwanted habits or reflexes must be brought under control.

Age-related changes in the four modes of selection

This framework predicts that age-related change and individual variation will be more apparent in some modes of selection than others. Three guiding principles emerge:

(1) There is more age-related change in the two endogenous modes of selection (habit and deliberation) than in the two exogenous modes (reflex and exploration) because the former are driven by specific goals for certain situations. They are also more idiosyncratic because they reflect specific learning histories, which will vary as a function of age and experience. In contrast the two exogenous modes represent innately specified default settings that give certain types of stimuli increased salience in a common way for all humans.

(2) Age-related change is also more evident in the two controlled modes of selection (exploration and deliberation) than in the two automatic modes (reflex and habit) because the areas of the brain mediating controlled processes (i.e., prefrontal cortex) are among the last to develop and the first to deteriorate with age. It is controlled processing that suffers first in the event of injury and pathology.

(3) By combining the first two principles we can predict that, among the four modes of selection, reflexive selection will show the least change with age whereas deliberate selection will show the greatest variability and idiosyncracy.

Because of the breadth of this framework, we cannot provide a comprehensive review of all relevant research. Instead, we will work through the four modes of selection, from the least to the most variable, highlighting findings that exemplify these principles. In each section we will begin with developmental research, but then also point to studies involving senior adults and finally other populations such as athletes and crash-prone drivers in which these same principles apply.

Visual reflexes

Among the most universal response tendencies of humans is orienting toward the location of an abrupt transient in illumination (Egeth & Yantis, 1997). Under everyday circumstances, such orienting is evident in movements of the body, head, and eyes to align the source of the new signal with the highly sensitive fovea (center) of the eye. This tendency is evident at birth (Colombo, 2001) and it persists through a wide variety of human neuropathology, including autism (Burack et al., 1997), Down syndrome (Serna & Carlin, in press). It is also strongly present in the elderly (see Kramer & Kray, this volume). Spatial orienting of this kind has the obvious adaptive advantage that it allows for the careful inspection of an object that appears abruptly in the visual field, either because the object is entering the same environment as the individual or because the individual has made an eye movement that brings the object into view.

Attention researchers often distinguish between the observable consequences of orienting, such as head and eye movements (called <u>overt orienting</u>), and the less directly observable orienting of the 'mind's eye' toward the location of an abrupt visual signal (called <u>covert orienting</u>). Of the two, covert orienting is the more difficult to measure in many participant populations, because it cannot be indexed by direct observation. The most common behavioral technique involves the participant performing a primary task, such as target detection or discrimination, while the experimenter manipulates the visual events that precede the presentation of the target. For example, if the event that precedes a visual target is a brief presentation of a non-target stimulus at the same location as the target, the response to the target is speeded and made more accurately. If the same event occurs at a non-target location it tends to slow target responding and reduce accuracy.

The measurement of covert orienting is therefore only possible for participants willing and able to perform a target detection or discrimination task. In the study of healthy human children, this usually means that the youngest studied age groups are three to five year of age (Enns & Brodeur, 1989; Randolph , 2002; Ristic et al, 2002). For many developmentally disabled populations, the lower age bound is considerable higher (Burack & Enns, 1997).

Yet, within these constraints, the data have been quite consistent in showing that covert orienting differs little in the course of typical development across the lifespan and even differs little between the various special populations that have been tested (Plude et al, 1994; Burack & Enns, 1997). In our own laboratory, we have also taken the approach of testing whether covert orienting is more strongly developed in participants who might be expected to have extra incentive or opportunity to engage in covert orienting in the course of their skilled activities.

These include elite junior hockey players (Enns & Richards, 1997) and university athletes in swimming, track, soccer and volleyball (Lum et al., 2002). So far, the answer has been 'no.' The basic covert orienting reflex seems to be very stable even for these experts in orienting.

A second example of an important visual reflex is the strong tendency to orient spatial attention in the direction indicated by the eye gaze (Friesen & Kingstone, 1998) finger pointing (Langton & Bruce, 1999) or body posture (Langton et al, 2000) of another human that is being observed. For example, in the study by Friesen & Kingstone (1998) college-aged observers performed a simple detection task in which the target could appear suddenly either on the left or the right of fixation. Importantly, a simple cartoon face preceded the target, with eyes drawn as simple open circles. Prior to the appearance of the target, the eyes suddenly acquired 'pupils' (small black discs) that were shifted either to one side of the 'eyes' (open circles) or the other. Although these shifts in eye gaze direction were randomly associated with target location, they nonetheless speeded target detection when the direction of gaze coincided with the target location.

This spontaneous sensitivity to the direction of gaze in a human face has been demonstrated in 10-week old human infants (Hood, Willen & Driver, 1998), adult chimpanzees (Povinelli & Eddy, 1996) and 3- to 5-year old preschoolers (Ristic, Friesen & Kingstone, 2002). In a study of preschoolers (Ristic et al, 2002), the only study in which the methods used with young children could be compared directly to those of adults, the children showed an even more robust tendency than the adults to orient in the direction of the gaze of the schematic face. Our interpretation is that the gaze orienting reflex is attenuated to some extent in older participants, in much the same way that older participants in developmental studies often show

smaller effects of covert orienting to unpredictable luminance transients (Plude et al, 1997). In those studies, it has also been shown that the relative age-ordering of the orienting effects can be reversed by making the luminance transient a predictive signal to the location of the target (Enns & Brodeur, 1989). We will have more to say about the modulation of visual reflexes in the upcoming section on deliberation.

Interestingly, adolescent individuals with autism, who are diagnosed around the age of two years on the basis of failing to show typical effects of social interaction, also fail to show gaze-directed cuing effects, at least for eye gaze cues that are non-predictive (Kingstone et al, 2003). However, these same individuals show eye gaze cuing effects when the eye direction is made to be highly predictive of the target location. This is in keeping with their relatively high visual-motor ability, when contrasted with their limited social skills. It is consistent with the anecdotal observations often made about individuals with autism, that they treat other humans in the same utilitarian way that they treat other objects in their environment.

A final class of important visual reflexes can be found among the so-called visual-geometric illusions (Coren & Girgus, 1978). These are patterned stimulus events that lead to perceptions that are at odds with the actual physical conditions. We are surrounded by visual illusions at all times and for the most part we are oblivious to them. Perhaps the everyday illusions we pay least attention to are pictures. Photos, representational art, line drawings and even cartoons, are all examples of stimuli that evoke in us immediate and meaningful perceptions, usually of three-dimensional objects and scenes, even though they are completely flat and static reproductions of events. Pictures mimic, in some minimal respects, the important qualities of the physical conditions that usually give rise to our

perceptions when we are viewing the three dimensional world. They do this, and yet at the same time, we can be acutely aware of the fact that we are viewing a flat picture in addition to having the meaningful experience evoked by the depicted objects. Gregory (1966) has aptly referred to this as the 'dual reality' of picture perception.

Although there are many aspects of picture perception that are dependent on experience, we know that pictures evoke responses in infants that are often identical to the reactions evoked by the real object, such as their own mother (Spelke, 1990). In one of the most daring developmental experiments ever undertaken, Julian Hochberg and Virginia Brooks (1962) raised their son for the first two years of life with no exposure to pictures of any kind. They did this because they were so confident that picture perception was innate. The experiment was heroic because it meant that the television, magazines, books, and product wrappers were not in his environment. On occasional rides in the car, his older sister was assigned the task of shielding his eyes from road signs. At the age of 2 years, the son passed the test of naming line-drawn objects with flying colors. The conclusion was that no special learning was required to recognize objects based only on a pictorial representation of their edges.

The developmental research on many other geometric illusions shows that some of them decrease in strength during childhood whereas others increase in strength (Coren & Girgus, 1978). It seems reasonable to assume, as was the case for covert orienting, that those that decrease in strength with age do so because other developmental processes permit the observer to understand and overcome the illusion. Interestingly, what the age-decreasing illusions have in common with each other is that they are based on the Gestalt principles of perceptual grouping. These

principles allow the visual system to locate contours in images and to group them into clusters based on whether they are adjacent, similar, and can form continuous lines. This is clearly advantageous in most cases in our visual world, but research has shown is that these principles lead to interesting illusions when the visual system examines simple displays on a flat surface (Enns & Girgus 1985).

The research on driving also warns that not all illusions are confined to the flat surface. For example, some roadway designs contribute to safety and while others induce car accidents (Shinar, Rockwell & Malecki, 1980). Hills (1980) describes a 'perceptual trap' created inadvertently when two non-connected roads nonetheless appeared to be coextensive from the driver's perspective. Drivers failed to notice the turn in the first road and sometimes drove right off the highway. The warning signs that were subsequently posted worked to some extent to prevent accidents, but for the present purposes the important point is that these signs were only able to warn of the illusion. They were not able to undo the illusion in the visual system of the drivers. Bringing reflexes under control requires valuable processing time, sustained mental effort, and the mechanisms involved in deliberate selection, and it is here both individual variation and age-related change are most evident, as we will discuss in that section.

Visual habits

When a goal is enacted repeatedly, carrying it out can become habitual and unconscious, and the processes associated with it eventually become effortless and almost impossible to prevent. Perhaps the visual habit that is most widespread and similar among individuals within the same language community is that of reading text. As those of us who can remember our own early childhoods can vouch, and as

everyone with their own child can attest, reading is a slowly acquired skill that takes effort, training, and much practice. At the same time, the fact that we cannot turn this visual habit off, once it has been learned, is clearly illustrated in the famous Stroop effect (MacLeod, 1991); naming the ink color of words that spell incongruent color names is an effortful and slow task.

Research on color-naming Stroop effects in children shows that this is one task in which younger participants are actually better able than older participants to ignore task irrelevant visual information (Schiller, 1966). This is because these younger participants are not yet reading as automatically as older participants and so the written words do not interfere as readily with the color-naming task. Indeed, when a Stroop task has been compared in good versus poor readers it is the good readers that show the greatest interference (Comalli et al., 1962; Fournier et al. (1975).

Words and other conventional visual symbols, such as arrows, have recently been shown to have a powerful influence on the orienting of visual attention. In one study, college-aged participants were presented with symbols at the center of gaze prior to a simple visual search for the target letter X (Hommel, Pratt, Colzato & Godijn, 2001). The X appeared randomly in one of four outline boxes, with the remaining boxes being filled with three different letters drawn randomly from the remainder of the alphabet. No-target trials occurred 20% of the time to ensure that the X was really found before the participant responded. A half second prior to the presentation of the target display, either an arrow pointing randomly to one of the four boxes, or the word 'left,' 'right,' 'up' or 'down' appeared randomly at the center of the display. Both of these kinds of signals, although they conveyed no reliable information to the participant, and although participants were instructed to ignore

them, had a strong influence on the search for the X. Response times were reliably faster on those trials when the X appeared at the location corresponding to the arrow or word.

These findings indicate that, at least for adults, some directional symbols are so well rehearsed and familiar that their meaning cannot be ignored, just as the word spelling a color name interferes with actual color naming in the Stroop task. This was emphasized in a control experiment (Hommel et al., 2001) in which the arrows and words were made 80% predictive of the actual target location. The magnitude of the orienting effect was similar in the predictive and non-predictive conditions, suggesting that these orienting effects were occurring for over-learned communicative symbols, independently of the expectations of the participant.

A recent study tested for non-predictive spatial cuing by centrally presented arrows in 4- and 5-year old children (Ristic, Friesen & Kingstone, 2002). The results showed that arrows were as effective as eye gaze in influencing the spatial direction of attention in children this young. Response times to the target object (cartoon snowman or cat) were faster when the target appeared in the location indicated by the central arrows. This indicates that these young participants have already learned the visual habits associated with the meaning of an arrow. Future studies will need to test for possible habits associated with arrows in even younger participants, though it seems unlikely that infants will respond reliably and involuntarily to the direction indicated by an arrow. The Ristic et al (2002) study also compared the responses of children in the arrow-cuing task with those of college students. As in some of the studies on visual reflexes described in the previous section, the orienting effect was larger in absolute terms for children,

consistent with the idea that automatic responses are more difficult for young participants to modulate.

A final comparison that can be made concerning the Ristic et al (2002) and the Kingstone & Friesen (2000) study is the non-predictive orienting shown by an individual (J.W.) who has had his corpus callosum surgically severed in order to treat intractable epilepsy. This surgery prevents the cortical information in one cerebral hemisphere from communicating directly with the other hemisphere. In the Kingstone & Friesen (2000) study, J.W. was tested with non-predictive gaze cues, which are thought to orient attention via an innate reflex involving only the right cerebral hemisphere, which contains specialized neurons used in face processing. However, in the Ristic et al (2002) study, involving a similar design, J.W. was tested with non-predictive arrows, which are thought to require learning. In keeping with this expected pattern, J.W. showed an orienting effect only for left sided targets (right hemisphere processing) when gaze cues were used, but showed an orienting effect for targets on both sides when arrows were used.

When it comes to finding attention-related variables to predict automobile crash risk, a good starting point is to look at the effects of experience. Inexperienced drivers are involved in more accidents per mile of exposure than the any other group (McGwin & Brown, 1999). Some driving-related processes become automatic and habitual with practice, permitting experienced drivers to drive efficiently while performing other attention-demanding tasks (Summala, Nieminen and Punto 1996, Shinar, Meir and Ben-Shoham 1998, Wikman, Nieminen and Summala 1998). Some of these processes involve habits of selection that enable experienced drivers to know when, where, and how to look (Wikman, Nieminen, & Summala, 1998) and these habits preserve driving performance in the face of age-related deficits in other

types of processing. For example, although senior adults show greater performance deficits as a result of visual clutter, visual clutter does not have its usual deleterious effects in familiar environments (Ho, Caird, & Graw, 2001).

However, the habits can also blind individuals to the unexpected. Langham, Hole, Edwards and O'Neil (2002) compared experienced and inexperienced drivers in terms of their ability to notice police cars parked in a driving lane when the cars were parked in-line or at an angle with the lane (unexpected and expected locations). Although the experienced drivers generally responded more quickly, they had difficulties detecting the police cars parked in-line (unexpected orientation), putting the experienced drivers at greater risk for accidents. In contrast, inexperienced drivers detected parked police cars in either orientation equally well.

Visual exploration

Much of our important visual processing is done in the absence of a specific task or goal to accomplish. We often simply need to learn more about our visual environment, especially when it is new, before we are able to form more specific goals. Yet, our visual system is not a blank slate. Some visual stimuli are processed preferentially, even when a person is exploring an unfamiliar environment, with no other goal than to gain new information. As everyone who has attended a museum or a shopping mall can attest, some visually guided actions are performed for no other reason than for the pleasure of manipulating a novel object. Yet this too is not arbitrary. Certain attributes can direct visual processing when the goal is primarily to explore.

Selection through exploration is the least researched of the four modes of attention. One of our purposes in highlighting it is an interest in promoting research in this area. The research we summarize is a small step in that direction.

One of the methods that hold great promise for studying visual exploration is the <u>oddball</u> visual search task. Unlike most visual search tasks, in which the participant is explicitly instructed to search for a specific target, oddball search involves looking for an unspecified target. In other words, there is a meta-level goal of finding an object or display item that doesn't 'belong,' but this search must be undertaken without the benefit of a search image or even a conceptual category that is known ahead of time.

Research with adults is very conclusive in showing that even for so called pop-out visual search tasks — such as searching for a red item among green items or searching for a vertical bar among horizontal bars — search time is influenced enormously by whether the observer knows ahead of time which feature will be the basis of the pop-out on any give trial (Wolfe, Butcher, Lee & Hyle, 2003). That is, each of these searches is 'efficient,' in the sense that the slope of response time over the number of display items is flat, but what is influenced greatly by foreknowledge of the target is the mean response time. It can be reduced by several hundred milliseconds if the specific feature of the target is known in advance. This paradigm therefore seems ripe for developmental studies that examine age-related differences in "known" vs. "unknown" pop-out search. If the exogenous (reflexive) visual processes of younger and older children are alike, then the main developmental differences should emerge in the "known" rather than the "unknown" conditions.

One of the important functions of exploration is to notify observers of changes in the environment, but what sort of changes attract attention? The <u>change</u>

detection task (Rensink, 2002) is another method with potential to increase our understanding of exploration. This is a task in which two versions of the same scene are presented, either side-by-side or in rapid succession, and the participant's task is to determine what is different in one of the two scenes. Much recent research in this area has shown that even very large changes made to a scene can go unnoticed when there is more than an 80 millisecond blank period between scenes, when an eye movement is made during the inspection of a single scene, when a change in viewpoint occurs (e.g., movie cut), or when the sudden onset of the change is accompanied by the equivalent of 'mud splats' that occur in non-changing scene locations (Simons & Levin, 1997).   The ability to detect changes under these conditions can therefore become an index of those changes that are attention-getting (Scholl, 1999) as well as those objects that are attended because they occur to objects that are of central interest to the observer (Rensink, O'Regan & Clark, 1997). As such it is a rich testing ground for the processes involved in visual exploration.

We recently completed a study of change detection in typical, otherwise healthy 7-, 9-, 11- and 27-year-old participants (Shore, Burack, Miller, Joseph & Enns, under review). The requirements of the task were carefully selected to ensure that none of the participant groups were at a disadvantage when it came to indicating their detection of the change. That is, instead of making verbal reports as in many studies of change detection, two different pictures were presented on each trial, each alternating over time with a second version of the picture that either contained a change or was identical to the first version. Participants were asked to indicate which of the two pictures being viewed was alternating over time with a different picture, and to indicate this decision with a button press corresponding to the side of the screen on which the change was occurring. The changes made to the pictures

included changes in object color, the deletion and reappearance of a main part, and a mirror image orientation change from one view to the next.

The experiment was conducted with two different blank intervals between views of the pictures: a short blank of 50 ms was intended to assess change detection when attention was summoned by sensory cues (motion transients and local flicker signal the change) and a longer blank of 250 ms meant change could only be detected by forming a representation of one picture and comparing it with the next picture. The results showed some age differences in the effects of the sensory cues to summon visual attention to the locations of change. In general, there was a 200-300 ms speed up in response time for each successive age group in the comparison of pictures separated by a 50 ms blank interval. In addition, changes involving mirror image orientation of the pictures were detected more rapidly than changes involving color or a missing part, probably because a mirror imaged picture differs most drastically and in the most locations from one version of a picture to the other. As such, these results for the 50 ms conditions simply replicate the findings that response times decrease with age and that abrupt transients in luminance, shape and color tend to orient attention to the locations of those transients.

The more interesting results, for the question of visual exploration by children of different ages, were revealed in the comparison of the 50 and 250 ms blank conditions. When these difference scores were used to index exploratory ability, additional age-related changes were found. In particular, the youngest participants (6- to 8-year olds) were the slowest to detect change in the 250 ms condition, even after their relatively slow responses in the 50 ms condition were taken into account. For all the age groups thereafter, the additional time required in the 250 ms condition was approximately a constant of 300-400 ms.

This improvement in change detection between the ages of 7 and 9 years is consistent with other documented developmental changes in attention. For instance, the largest changes in the ability to search for targets defined by the conjunction of two visual features occurs around the same age (Trick et al., 1996), as does the ability to ignore distractors (Enns, 1993), and the ability to orient attention voluntarily in response to a predictive cue (Enns & Brodeur, 1989). This concordance in the developmental trajectory for exploratory and deliberate attentional functions gives further credence to the view, espoused in our framework (Figure 1), that these two functions are both governed by similar controlled cognitive processes.

Driving researchers were the first to notice the importance of exploratory selection. Hills (1980) noted that experienced drivers, when not fully taxed by the driving task, look away from the relevant driving-related information and exploring roadside advertising, trees, the local scenery. Although there have been periodic attempts to ensure that drivers only look at driving-relevant information, it is now commonly conceded that it is impossible to prevent exploratory selection (Coles & Hughes, 1984; Smiley, 1994). If driving does not require the drivers' full attention, they devote their attention elsewhere. Normally this type of selection does not pose a significant problem because skilled drivers can readily refocus their attention and 'shed' irrelevant information. The danger occurs when the driving situation changes suddenly. Attention switching may require a second or more and any individual differences in exploration relate less to the tendency to explore than the ability to switch attention back and forth between exploration and tasks that require visual deliberation.

What determines the attraction of attention when an individual is exploring the environment without a specific goal? Preliminary work suggests that the 'sensory conspicuity' of an object is increased by its retinal size, eccentricity, and contrast with the background (Cole & Hughes, 1984; Hughes & Cole, 1986). Efforts have been to maximize the 'sensory conspicuity' of safety-related signs, though conspicuity of an object depends on the number of competing other objects that are visible. Consequently, drivers are more likely to notice and remember the signs they see when driving at night than during the day (Shinar & Drory, 1983).

Visual deliberation

Much of our visual activity involves the deliberate selection of a specific goal. This type of processing is the most flexible and therefore responsive to new information. It provides the opportunity to change behavior rapidly (typically within a half to a full second) in response to an oral command or the messages in visual symbols. The disadvantage of this type of processing is that it is difficult to perform more than one task at a time, presumably because there is a sharp limit on the information that a person can be consciously aware of at any one time (Endsley, 1995; Reason 1990). Visual selection by deliberation is also noticeably effortful. This is manifest in self-report measures of cognitive strain and in such physiological measures as eye blink, heart rate and heart rate variability (Hancock et al., 1990; Richter, Wagner, Heger, & Weise 1998).

In a laboratory for the study of visual orienting, visual deliberation is often indexed by a task in which participants orient their spatial attention deliberately in response to cue. This response is then compared to a similar response that is made when no cue is being used or when the cue is being used in a reflexive or habitual

way. There have been many studies on the ability of children of different ages to use a predictive cue to orient voluntarily toward the source of upcoming visual information. Reviews can be found in Plude et al (1994) and Brodeur & Borden (2001).

Recently, work has also begun on the question of how rapidly children are able to switch from one visual task to another. In one study, children aged 7 to 15 years of age performed a two-target detection task in a rapid serial stream of visual shapes (Shapiro & Gerard-Cole, 2003). The first target was a blue triangle and the second was a red triangle. These target shapes appeared at random among other shapes that were presented at a rate of one per each 100 ms. The typical finding when college students perform this task is that accuracy on the first target is very high, but that there is a 500 ms period immediately after the appearance of the first target, in which the second target is missed. This is called the 'attentional blink.' The main finding of the Shapiro & Garrad-Cole (2003) study was that this blink lasted longer for younger than for older children, revealing a relative deficit in their ability to switch rapidly from one visual item to the next. This general conclusion is consistent with other work on visual search in children (Trick & Enns, 1998).

One of the most important uses of deliberate visual processing lies in the coordination of automatic and voluntary spatial orienting effects. This is important first, because of the structure of the eye; only visual events that are positioned near the fovea receive the most detailed spatial analysis that human vision is capable of. As a result it is essential to orient the eyes appropriately in order to perceive the details in shape, motion, color, and texture that are associated with the event that summoned our attention in the first place. Second, it is important because there is often more than one consideration to be made in coming to a decision to reorient.

For example, it may be socially embarrassing to let your conversational partner know you are listening to another conversation and so you will want to keep your gaze fixed on them while your auditory attention is elsewhere. On the other hand, it can also become dangerous, both for yourself and others, if you do not orient reflexively to unexpected sudden events when trying to drive safely. The skill of many athletes seems to reside in their ability to 'fake out' their opponent with movements of their body and to not respond to similar false movements on the parts of their opponents.

The modulation of visual orienting reflexes by a voluntary intention to either respond quickly to the reflexively signaled events, or to ignore these signals, depending on their predictive value, has now been the focus of several studies with elite athletes. A study by Enns & Richards (1997) tested younger and older elite junior hockey players in two conditions involving visual targets preceded by flash cues. In one condition the flashes were entirely random, meaning they were not predictive of the target location. In a second condition these same cues were highly reliable. The main finding was that the older players, as well as the more highly skilled players at all ages, showed a greater sensitivity to the predictability of these cues. Similar results have been reported for elite international water polo athletes and fencers, who were more sensitive to the predictive nature of flash cues than were elite international swimmers and non-athletes (Nougier et al., 1989).

In an even more direct study of the coordination of competing sources of information for visual orienting, Lum et al (2002) tested elite college athletes from two sports representing relatively static competitive visual environments (swimming, track) and from two sports representing more dynamic visual environments (soccer, volleyball). Within a block of trials during a target detection

task, participants were given highly predictive central arrows well in advance of the target display, as well as non-predictive flashes in closer temporal proximity to the target display. On any given trial, none of the cues may be presented, only one may be presented, or both were presented in either cooperative or competitive arrangement.

There were both sports-general and sports-specific effects. First of all, there was a tendency for all athletes to use the predictive arrow cues to greater effect than the non-athlete controls that were tested. However, when it came to the coordination of voluntary and reflexive cues, interesting sports-specific differences emerged. The athletes participating in static environments were best able to use the two cues in a cooperative fashion when they were in agreement about the target location and to ignore the flash cue when it contradicted the informative arrow cue. In contrast, the athletes from more dynamic environments were best able to inhibit visual reflexive orienting to the flashes under all conditions. Taken together, these findings suggest that skill and practice in specific visual environments alters the default arrangements concerning the coordination of visual orienting.

There are notable individual differences in deliberate selection, and these differences predict accident risk, particularly among senior drivers. Older drivers are disproportionately at risk for certain types of accident (Preusser et al, 1998) and for missing information while driving (e.g., misreading signs, failing to notice a green arrow or green light, missing an exit on a highway, Aberg & Rimmo, 1998). There are a variety of age-related changes that might be at fault, including decreased sensory acuity and motor slowing, but it is the factors related to deliberate selection that correlate most with accident risk (Ball & Owsley, 1991; Klein, 1991; Parasuraman & Nestor, 1991). Laboratory studies of attention switching in seniors

show that voluntary orienting becomes more difficult (Plude et al.1994); visual search is slowed (Trick & Enns, 1998), the 'useful field of view' is disproportionately reduced (Ball, Roenker, & Bruni, 1990; Pauzie, Gabaude, & Dennis, 1998) and dual-task interference is exaggerated (e.g., McDowd & Craik, 1988; Parasuraman & Nestor, 1991). Consistent with our framework, it is the "hybrid" measures of performance, those that involve attention switching, serial visual search, and dual tasks that best predict accident risk in driving seniors (Janke & Eberhard,1998; Lundebert, Hakamies-Blomqvist, Almkuist, and Johansson, 1998; Owsley et al., 1991; Stutts et al. 1998; Wood, 1998).

Conclusion

This paper provides a new framework for understanding attention in children, young and older adults, and other populations of related interest, including athletes and accident-prone drivers. Four modes of selection are identified, providing a rich means of assessing how individuals might differ from one another. Anchored in recent developments in the study of selective attention, this framework brings together some of the divergent threads in developmental research, as well as in research investigating performance on everyday tasks such as driving and participating in sports.

One of the main strengths of the framework is that it reduces confusion in the literature concerning the distinction between automatic versus controlled processes and exogenous versus endogenous processes, which are often conflated. It is our view that this occurs because of a confusion of the nature of a process (whether it requires conscious control or not) with its etiology (whether it arose through innate or learned processes). This conflation has led to needless controversy about some

issues and complete neglect of others; in particular neglect of the importance of exploratory selection.

Applied to the development of attention in childhood, this framework provides a way of understanding both age-related stability and age-related change. Age-related change is more apparent in the two endogenous modes of selection (habit and deliberation), which both depend on learning, than in the two exogenous modes (reflex and exploration), which rely on built-in tendencies. It is also more evident in the two controlled modes of selection (exploration and deliberation), which require conscious control, than in the two automatic modes (reflex and habit), that can occur without awareness. When these two trends are combined, it is clear that the exogenous automatic mode of selection (based on reflexive action) shows the stability with age, whereas the endogenous controlled mode (deliberation) shows the greatest individual variability and therefore the largest developmental change. We believe this framework may also be fruitfully applied to the sparing and loss of selective function in older age, as summarized in the chapter in this volume by Kramer & Kray.

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Figure Captions

<u>Figure 1</u>. Four modes of selective attention, based on the two dimensions of automaticity – control (the degree of conscious control) and exogenous – endogenous (the extent of learning required).

<u>Figure 2</u>. Aspects of each of the four modes of selective attention, including how it is acquired, what the triggering stimuli are, the degree of conscious control that is possible, and the stability of each mode over time.
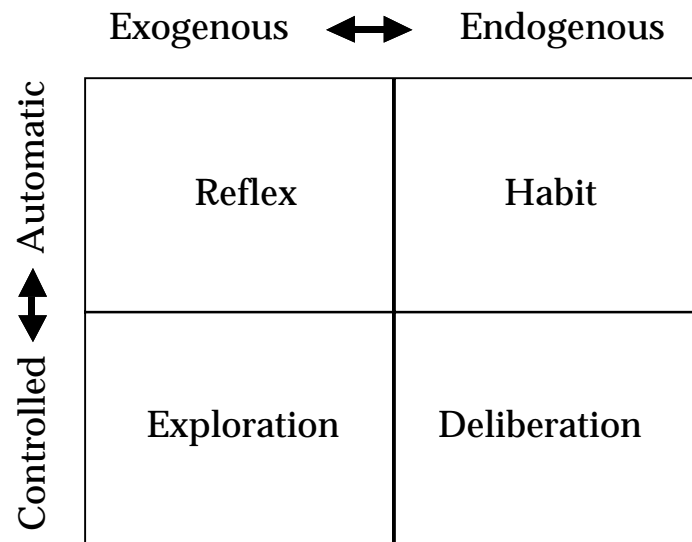
Figure 1

Exogenous ⟷ Endogenous

	Exogenous	Endogenous
Automatic	Reflex	Habit
Controlled	Exploration	Deliberation

Figure 2

Reflex	Habit
• innately specified	• learned when goal repeated in specific environment
• triggered by stimuli given priority by the nervous system	• triggered by stimuli associated with specific goals in past
• unconscious, automatic, fast, obligatory, effortless	• unconscious, automatic, fast, obligatory, effortless
• avoided only with deliberation	• avoided only with deliberation
• emerges on a developmental timetable	• can emerge at any time
• stable once acquired	• can fade or be replaced at any time; strength varies with practice
Exploration	**Deliberation**
• innately specified generic goal for novel situations	• goal is internally generated and specific to the individual and context
• default mode for controlled processing	• occurs when individuals are carrying out specific goals in a specific context
• conscious, controlled, slow, optional, effortful	• conscious, controlled, slow, optional, effortful
• occurs when the only goal is exploration	• specific goals changed at will, but switches in goals take time
	• needed to overcome unwanted automatic processes
• generic goal easily replaced by specific goal (switch to deliberation)	• interferes with other deliberately selected goals