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Covert Orienting of Attention: An Overview

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Orienting is a gateway to attention and is defined as aligning of attention with a source of sensory signal. Covert orienting is the shifting of attention without eye or head movement. It enhances performances by detecting the targets faster and more accurately. Posner's location cueing paradigm has been used to study this phenomenon scientifically and it has become one of the most important topics of research in cognitive psychology, cognitive neuropsychology, and cognitive neuroscience. In this paradigm, cue is used to orient the attention covertly where the target is likely to appear. The present paper is an endeavor to systematically define covert orienting, focus on its historical background, study this phenomenon scientifically based on the paradigm used, and explain the factors such as cue type, cue location, cue validity and SOA levels, which affects it and its exogenous and endogenous components.

Keywords: Attention, Orienting, Covert attention, Exogenous cue, Endogenous cue.

Attention is a central feature of human cognition that allows us to selectively process the vast amount of information with which we are confronted, prioritizing some aspects of information while ignoring others. Attention allows us to select information and grant it priority in processing. Selection is necessary because there are severe limits on our capacity to process information. Selective attention mechanism is complemented with another attentional mechanism known as orienting, which is thought to have an important ecological role in human beings and other species. The simplest way to select among several stimulus inputs is to orient our sensory receptors toward one set of stimuli and away from another. Orienting is one of the most primitive functions of living things. In complex organism, like humans, more complex system have evolved to orient the various receptors reflexively either towards or away from the signal source in the environment (Sokolov, 1963).

Orienting is defined as aligning of attention with a source of sensory input (Posner 1980). When attention is shifted or oriented towards a certain location, it speeds up the processing of information at that location by selecting the relevant information while ignoring the irrelevant ones. Attention can be oriented by moving one's eyes toward a location (overt attention) or by without actually directing one's gaze toward it (covert attention). Covert attention is routinely experienced in everyday situations such as searching for objects, driving, crossing the street, playing sports and dancing. Covert attention allows us to monitor the environment and guide our eye movements (overt attention) to locations of the visual field where relevant information is. The phenomena of covert orienting can be applied in a variety of settings, for example, in designing effective brain-computer interfaces (BCIs) and to improve performance during vigilance task.

Covert Orienting: Historical Overview

People have been aware of their capacity to shift attention for long periods but, tools were not available to study this phenomenon scientifically. In the 18th century, Christian Wolff pointed out the nature of attention shift in his textbooks 'Psychologia Emprica' (1738) and 'Psychologia Rahalis' (1740), in which he discussed about voluntary control of attentional processing and the relationship between an eye movement and shift of attention (Hatfield, 1998). First scientific investigation of our capacity to shift attention independent of eye movement was conducted by Helmholtz (1867/1925). He constructed an apparatus similar to tachistoscope and continuously fixed his eyes at the central fixation and did not move his eyes from that location. Before momentarily illuminating the display he decided where he wanted to concentrate his attention on. During the brief period of illumination of those letters in the area where attention was shifted were most identifiable. In contrast, letters in the vicinity of ocular fixation were difficult for him to identify.

Helmholtz systematically and scientifically demonstrated that "(a) we can shift attentional focus independent of eye movement and (b) visual analysis depended more on where we are focusing attention than where our eyes are focusing" (p. 6, Wright, & Ward,2008).

Later, in the 19th Century, James (1890) described attention shift as being active (voluntary) and passive (involuntary). Voluntary attention is controlled by observer's deliberate strategies and intentions. In contrast, involuntary attention is stimulus driven and is controlled by characteristics of the stimulus, which seems to pop-out and draw attention automatically.

In the first half of the 20th Century, little research on attention was carried out. However, there was an interest in studying the orienting responses that animals make toward stimuli that capture their attention (Pavlov, 1927; Sokolov, 1960). Orienting was defined as an adjustment of animal's position relative to stimuli in question and usually involves body, head and/or eye movements. When orienting occurs, attention is also shifted towards the stimuli.

The phenomenon of covert orienting was studied in the spirit of Helmholtz till 1970's and the detail study started when eye movement monitoring technology was refined. However, most experimental studies until the mid-1970s (e.g. Grindley & Townsend, 1968; Mertens, 1956; Mowrer, 1941; Shiffrin & Gardner, 1972) failed to demonstrate that shift in attention is independent of eye movements on empirical grounds. After 1972, a number of studies appeared, which demonstrate successfully that attention can be shifted in the absence of eye movements (Eriksen & Hoffman 1973; Posner, 1980; Posner, Nissen & Ogden, 1978; Posner Snyder & Davidson 1980).

Research in the area of covert orienting got a head start with the pioneer work by Posner and his colleagues (Posner, 1980; Posner & Cohen, 1984; Posner et al, 1980). They developed location cueing paradigm to measure the ability to shift one's visual-spatial attention to different areas without accompanying eye movements. Since then, this paradigm has been used in thousands of behavioral and neurophysiological studies to study covert orienting of attention.

Covert Orienting of Attention

Changes in spatial attention can occur with the eyes moving, overtly, or with the eyes remaining fixated, covertly. Spatial covert orienting enhances visual performances in specific areas of visual field, without eye movements to that location. Within the eye, fovea brings objects into sharp focus, which is required to perform actions such as reading, etc. Therefore, eye movement is required to move fovea to the desired goal. Prior to overt eye movement covert attention shifts to this location (Deubel, & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler, Anderson, Dosher, & Blaser, 1995; Peterson, Kramer, & Irwin, 2004). Thus, attention can be shifted to an object or a location without making eye movement (covert orienting).

Posner and his colleagues (Posner, Rafal, Choate, & Vaughan, 1985; Posner, Walker, Friedrich & Rafal, 1984) proposed that there are three subsystems that underlie covert orienting of attention: (i) the engagement; (ii) the shift and (iii) the disengagement. According to this view, to transfer attention to a new location, attention must first be disengaged from the current location, then shifted and engaged at the new location. The shifting and engagement components are both concerned with the orienting of attention to a new object or location.

Experimentally, covert orienting is manipulated by presenting a cue, indicating where a target is likely to occur in the space. Spatial cueing speeds signal detection by modulating the processing of sensory information during detection or cueing acts to create decision bias favoring inputs at the cued location. Posner (Posner et al, 1978; Posner, et al., 1980) with his location cueing paradigm demonstrated that with eyes kept still at fixation, if the participants were cued to a particular region of space where the target was likely to appear, detection was faster at cued location. Faster and accurate responses to targets appearing at cued location have been attributed to attentional processes.

Response facilitation at cued location had been studied in more detail to know how the effect of location cueing occurs. Whether it increases the perceptual sensitivity towards targets presented at the cued location or it influences observer's response criteria for reporting the presence of target presented at that location (Lappin & Uttal, 1976; Shaw, 1983). Hawkins, Hillyard, Luck, Mouloua, Downing, and Woodward (1990) suggested that spatial cueing speeds signal detection by modulating the processing of sensory information during detection or by creating a decision bias favoring inputs at the cued location. Psychophysical and electrophysiological procedures have demonstrated that location cueing increased perceptual sensitivity to targets (Bonnel, Possamai, & Schmidt, 1987; Doallo, Lorenzo-López, Vizoso, Rodríguez, Amenedo, & Bará, 2004; Downing, 1988; Fu, Caggiano, Greenwood, & Parasuraman, 2005; Muller, 1994; Muller & Humphries, 1991; Possamai & Bonnel, 1991). Muller (1994) also proposed that direct cue appears to have a greater sensitivity effect on target responses than do symbolic cues. Thus, covert orienting is conceptualized as an internal mechanism that increases visual sensitivity.

Covert Orienting and Eye Movement

Covert orienting of attention is achieved in the absence of explicit eye movements. However, a very important question is whether it is possible to shift attention independent of eye movements. Helmholtz (1867/1925) stated that it is possible, simply by a conscious and voluntary effort, to focus the attention on some definite spot in a field. However, most experimental studies until the mid-1970's (Grindley & Townsend, 1968; Shiffrin & Gardner, 1972; Mertens, 1956; Mowrer, 1941) failed to demonstrate this claim on empirical grounds. After 1972, a number of studies appeared, which seemed to demonstrate successfully the shift of attention in the absence of eye movements (Eriksen & Hoffman, 1973; Posner, et al, 1980).

Although, covert orienting usually occurs in association with overt orienting, it is possible to covertly attend to an event or stimulus without making any overt movement (Posner, 1980; Wright & Ward, 2008). Covert shift of attention is very fast, sometimes it requires only 50-100 ms (Müller & Rabbit, 1989) as compared to overt shift, which requires 220 ms to make a saccade. Also, covert attention selects the target of the next eye movement. Before a saccade, attention is shifted covertly to the saccade target object (Hoffman & Subramaniam, 1995). Thus, covert attention and eye movements are distinct, yet functionally coupled; although, covert shifts can occur without eye movements, eye movements are always preceded by a covert shift of attention (Klein, 1980).

Studies have demonstrated the relationship between covert and overt orienting. The premotor theory of attention (Rizzolatti, Riggio & Sheliga, 1994) proposes that covert and overt attention systems are supported by the same neuronal mechanisms while Posner and Petersen (1990) suggested that covert and overt shifts of attention are completely independent of one another. However, Corbetta and Shulman (2002) and Wright and Ward (2008) argued that although the two orienting systems share some neural mechanisms they are not identical; covert shifts of attention and overt shifts of attention are interdependent. Studies investigating the interaction of overt and covert attention had reached the consensus that covert attention precedes eye movements (Kowler, 2011). Even though, the two are closely related, covert orienting is usually studied separately from overt orienting.

Covert Orienting and Brain Areas

The orienting system for visual attention has been associated with posterior brain areas, including the superior parietal lobe, temporal parietal junction, and the frontal eye fields (Corbetta & Shulman, 2002). As ability to shift attention is mediated by different subsystems, studies have shown that these are associated with different anatomical areas. The posterior parietal lobe has been associated with the disengagement operation that takes place when attention is withdrawn from one place to another (Posner, 1988). The superior colliculus are related to the movement of attention to a different location i.e. shift, and the thalamus is thought to enhance the stimulus processing at the new location (Jones 1985; LaBerge & Brown 1989; Posner & Di Girolamo, 2000).

fMRI studies have shown that covert and overt shifts of attention involve similar areas (Corbetta et al. 1998). However, single-unit physiology studies in the macaque suggest that some cells in the FEFs are active during saccades and a distinct but, overlapping population of cells is involved in covert shifts of attention (Schafer & Moore 2007, Thompson, Biscoe & Sato, 2005). However, the physiological data indicates that covert attention is distinct from the motor system governing saccades, even though they clearly interact with each other (Peterson & Posner, 2012).

Posner's Location Cueing Paradigm

The most common method employed to study covert orienting is the location cueing paradigm developed by Posner and colleagues (Posner & Cohen, 1984; Posner, 1980; Posner, et al., 1978; Posner & Snyder, 1975). The logic given for this method is that the cue will elicit orienting to its location automatically. Cue is a stimulus that provides information about the target presentation. The basic paradigm involves fixing of eyes at the central fixation point and then presenting observers with a cue that precedes the presentation of a target stimulus requiring a response (e.g., target detection or discrimination). When the cue correctly indicates the location of the subsequent target, the trial is termed valid. Alternatively, when the target appears at the location other than cue, the trial is termed invalid. It is assumed that if attention is shifted to the cued location, the processing of targets on valid trials should be facilitated (i.e., benefits), and the processing of targets on invalid trials should be slowed (i.e., costs). Observed differences between valid and invalid trials are referred to as orienting effects.

Location cueing experiments have three aspects (i) a central fixation point that a subject must continuously direct their eyes throughout each experimental trial, (ii) a target item, to which a subject must respond (e.g. detect or identify) and (iii) a location cue that is presented immediately before the target appears (Fig. 1) (p. 18, Wright & Ward, 2008). The delay between a cue and the target presentation is called cue target onset asynchrony (COTA) or stimulus onset asynchrony (SOA). When a cue target onset asynchrony is less than 200 ms, subjects don't have time to make eye movement to cued location before the target appears because at least 220 ms is required to make an eye movement.

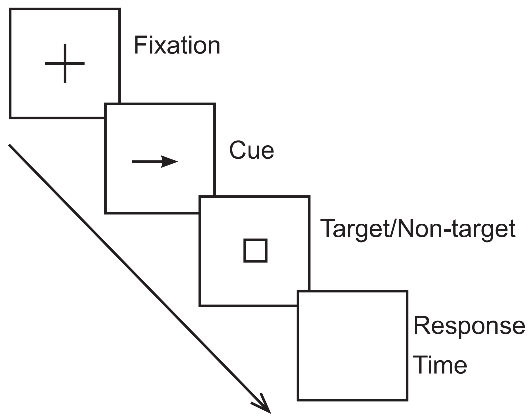

Figure 1: Systematic representation of sequence of events in location cueing experiment.

Factors influencing Covert Orienting

There are various factors such as cue type, cue location, cue validity and SOA levels, which influence the covert shift of attention.

Cue Type: Cues can be either symbolic e.g. a centrally presented arrow or a direct cue e.g., flashing of lights, underlines, outline boxes, etc (Wright & Ward, 1994) that are presented in close proximity to the expected target location. Symbolic cue is voluntary while direct cue appears to be reflexive (Jonides, 1981; Yantis & Jonides, 1990). Both types of cues initiate attentional shift in a fundamentally different manner. Symbolic cues are also referred to as central cues, push cues or endogenous cues, which orient attention voluntarily in a goal driven manner. Symbolic cues must be decoded before spatial location so that they can be determined in a designated way. Direct cues are also referred as peripheral cues; pull cue or exogenous cue, which shift attention involuntarily and is stimulus driven. Direct cues produce their effect by virtue of being close to the expected target location. Sensory activation that occurs at cued location enhances the response to targets presented at that location.

Cue Validity: Cue validity refers to whether the cues provide correct, incorrect or no information regarding the target location. Accordingly, three types of cues are used: valid cue indicates the correct location of the target, invalid cue indicates the incorrect location while a neutral cue does not provide any information about the target location, instead is serves as a temporal warning that the target is about to appear. In general, responses are faster (Posner, et al., 1978; Posner, et al., 1980) and more accurate (Bashinski & Bacharach, 1980; Henderson, 1992) with valid cue trials than with invalid cue trials. Neutral cues are used to determine whether (a) valid location cue would facilitate response and (b) invalid location cue would inhibit response. The ratio of valid and invalid cue (i.e. cue validity) influence attentional allocation; high cue validity increases the magnitude of validity effect (Eriksen & Yeh, 1985; Jonides, 1980; Madden, 1992; Riggio & Kirsner, 1997). Thus, the reaction time to valid targets decreases, if the information provided by the cue is highly valid while the reaction time to invalid targets increases. Warm, Dember, Parasuraman, Shear, Hitchcock, & Mayleben, (2003) used different cue validity and found that the performance efficiency declines for non-cued subjects while performance efficiency remained stable over time for a cue group; being best for 100% cued then 80%, then 40% then no cue. Similar results were obtained by Vossel, Thiel and Fink (2006) in their study with a central cue that the subjects responded to were significantly faster to validly cued targets in the 90% than in 60% cue validity condition.

Stimulus Onset Asynchrony(SOA): The difference between a cue and the target affects performance in terms of facilitation and inhibition. It is also known as cue target onset asynchrony (CTOA). Muller and Findlay (1987) compared large range of intervals between a cue and the target onset. With peripheral cues, the peak facilitation for cued location occurred within 150 ms after cue onset, and then it was followed by a decline between 150 – 300 ms stimulus onset asynchrony. With central cues, the facilitation for cued location required 300 ms. With longer stimulus, the onset asynchrony's peripheral and central cues had the same effect. Peripheral cues are more effective when the interval between the cue and the target (Stimulus onset asynchrony) is shorter while central cues are more effective with longer stimulus onset asynchrony (Jonides, 1981; Muller & Rabbit, 1989). Thus, the type of cue produces their strong effects at different SOAs / CTOAs.

Cue Location: Cue location—either central (endogenous) or peripheral (exogenous)—may influence whether attention is space- or object-based. Nougier, Rossi, Alain and Taddei (1996) reported that cue location has also been linked to whether covert shifts of attention are considered voluntary (for central cues) or automatic (for peripheral cues), emphasizing that practice and voluntary strategies can influence the effects of automatic allocation of attention.

Component of Covert Orienting of Attention

Attention can be oriented either automatically e.g., when a honking car attracts the attention of a pedestrian or in a controlled manner e.g., when the pedestrian monitors the traffic light waiting for the 'go' signal to appear. Posner (1980) proposed that there are two modes of control over covert visual orienting: (1) Exogenous: Involuntary, automatic and stimulus driven orienting response to a location where sudden stimulation had occurred and (2) Endogenous: Voluntary and controlled allocation of attention to information at a given location at will. Experimentally, these two types of orienting are manipulated using different cues. Exogenous orienting is manipulated using peripheral cues such as a peripheral flash and requires about 100 ms, while endogenous orienting is manipulated using central symbolic cues such as an arrow, which directs attention in a goal driven manner and requires about 300 ms (Cheal & Lyon, 1991; Müller & Findlay, 1988; Nakayama & Mackeben, 1989; Posner, 1980, Yantis, 1996).

Jonides (1981) proposed that there is a common orienting mechanism that underlies reflexive and voluntary orienting. Later, Muller and Findlay (1988) replaced this assumption and proposed that there are two separate mechanisms underlying reflexive and voluntary orienting. Their suggestion was based on difference in time course of facilitatory (i.e. benefit for cued location) and inhibitory (i.e. costs of uncued location) effects produced by central and peripheral cues.

Exogenous Orienting: Abrupt onset of intense stimuli can cause covert orienting by capturing attention. For example, abruptly appearing letters on a computer monitor capture attention and are responded faster than gradually appearing letters (Jonides & Yantis, 1988; Yantis & Jonides, 1984). If such an abrupt onset stimulus (a direct cue) appears about 100 ms before another stimulus (a target) in the same spatial location, the latter is processed faster and more accurately than if it appears in another location (Muller & Humphreys, 1991). Attention captured in this way is said to be oriented exogenously. However, such shift tends to be transient in nature: facilitation of processing at the cued location occurs almost immediately but, the effectiveness of the cue diminishes rapidly. Efficiency and rapidity provided by reflexive control of orienting plays a critical role in predation and defense.

Endogenous Orienting: Attention oriented in space or to an object voluntarily (endogenously) in a goal driven manner tells us where to look or listen. Information about where or what to look at or listen to for an environmental event prepares us for the event by orienting attention to that location (LaBerge, 1995). This advance goal driven alignment of attention enhances processing of the target when it appears there (Posner, 1980). Voluntary control over orienting is important for efficient foraging for food and other desirable objects, places, etc.

Exogenous and endogenous orienting of attention have been found to be distinguishable along a number of dimensions (e.g., Briand, 1998; Briand & Klein, 1987; Cheal & Lyon, 1991; Jonides, 1981; Lu & Dosher, 2000; Muller & Rabbitt, 1989; Yantis & Jonides, 1990). Exogenous orienting is an automatic, reflexive, stimulus-driven response that is resistant to interruption, has a relatively short time course, and elicits inhibition of return (i.e., faster reaction time for invalidly cued targets than for validly cued targets) with longer intervals between a cue and the target. In contrast, endogenous orienting is a controlled, top-down response that can be suppressed voluntarily, and elicits its maximal effects at longer intervals between a cue and the target.

Applications of covert orienting

The phenomena of covert orienting can be applied in a variety of settings. Covert orienting can be used for designing effective brain-computer interfaces (BCIs) systems as studies (for e.g. Marchetti, Piccione, Silvoni & Priftis, 2012) had suggested that BCI's performance can be modulated by different modalities of visuospatial attention orienting (exogenous vs. endogenous). Brain-computer interfaces (BCIs) are systems, which enable people (e.g. patients with locked-in syndrome, or Amyotrophic lateral sclerosis) to communicate and interact with as computers or prostheses by means of their brain signals and without the aid of the somatic division of the peripheral nervous system (Lebedev & Nicolelis, 2006). Covert orienting can be combined with the vigilance paradigm to improve performance in the vigilance task. Singh, Upadhyay, and Singh (2010) showed that performance of both young and old adults improved on vigilance task when vigilance was combined with covert orienting paradigm.

Conclusion

The present paper had endeavored to explain the concept of covert orienting of attention. From the conceptualization of this phenomenon in early eighteenth century to its first scientific investigation by Helmholtz and the Posner's paradigm has been explained. The location cueing paradigm has been used to study this phenomenon scientifically and also has played an important role in the promising advances, which are made in this direction. The methodological factors like cue type, cue validity and SOA levels has also been discussed as these are a must while designing experiments and evaluating the properties of covert attention shift. Exogenous and endogenous component of covert attention is also explained as both can be used for designing effective BCIs. Covert attention can also be combined with the vigilance paradigm to improve performance. Since, covert attention is an important phenomenon that can be applied to improve performance in a variety of settings; this phenomenon needs to be explored further.

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