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Walk, Stop, Search: The Effect of Simulated Motion on Visual Attention

(Spine Title: The Effect of Simulated Motion on Visual Attention)

(Thesis format: Monograph)

By

Miranda d. Deller

Graduate Program in Kinesiology

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science

Faculty of Graduate Studies
Lakehead University
Thunder Bay, Ontario, Canada

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Your file *Votre référence*
ISBN: 978-0-494-21507-4
Our file *Notre référence*
ISBN: 978-0-494-21507-4

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Abstract

Responses in covert orienting of visual attention tasks (COVAT) produce a biphasic pattern of results. When the stimulus onset asynchrony (SOA) is less than 300 ms, reaction times (RTs) to cued targets are faster than uncued targets, whereas when the SOA is greater than 300 ms RTs to uncued targets are faster than cued targets. This latter phenomenon is termed inhibition of return (IOR). IOR is believed to be a mechanism that promotes efficient search by biasing attention to new locations or objects. To date, most research on IOR has been restricted to situations in which participants are seated while viewing stimuli presented on a monitor; however, many real life searches take place while the searcher is in motion. One way to look at the effect of motion on the orienting of attention is to stimulate the otoliths of the vestibular system by having people lie prone with their neck in a flexed position (known as head down neck flexion or HDNF). We had participants complete a COVAT (with SOAs of 100 and 800 ms) while in three different positions: seated, lying prone, and in HDNF. When in HDNF there was a significant decrease in the magnitude of responses compared to the other two positions; both less facilitation and less inhibition were observed. The results are discussed in terms of the relationship between vestibular activation (i.e., HDNF) and the orienting of visual attention.

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Introduction

Cognition is the act or process of knowing, including both awareness and judgment (Bourne et al., 1979). Cognitive functions include the ability to think, reason, remember, learn, make judgments, perceive, and solve problems. A key component to all cognitive functions is attention. Attention an important factor on its own - it is a vital capacity required to achieve all other cognitive functions. One must be able to attend to the stimulus in order to remember it, to complete a reaction time task, to do arithmetic manipulations, and to perform visual searches. The attention system has three main roles: orienting cognitive processes to sensory events; detecting signals for conscious processing; and maintaining an alert state (Posner & Petersen, 1990). Orienting is pivotal to attention as it is needed in order for the other two roles, detection and maintenance of an alert state, to be achieved.

Orienting Attention

Orienting attention, as defined by Posner (1980), is “aligning of attention with a source of sensory input or an internal semantic structure stored in memory” (p. 4). According to this definition, the locus of control can either be internal or external. Just as a flashing light may grab our attention from the external environment, an arrow located at a fixation point in the center of a scene can indicate the direction in which one ought to move attention. If the stimulus is external, attention is oriented exogenously. An example of an exogenous cue would be a light flashing in the periphery. The appearance of the light draws your attention to it, without having to cognitively process the meaning of the light. If the stimulus is processed internally, attention is oriented endogenously. An arrow pointing left or right is an endogenous cue. The arrow provides information

about the possible target location, but the meaning of the arrow must be processed in order to receive the information (Posner, 1980).

Attention can be oriented two ways: reflexively or voluntarily. Reflexive or bottom-up processing is determined primarily by qualities of the stimuli itself. The stimuli are very intense, loud or sudden. Bottom-up processing occurs with exogenous orienting of attention. Voluntary or top-down processing is driven by internal biases or instructional set. We intentionally exert effort in looking for particular targets among distractor stimuli, or we consciously anticipate that a particular target will occur. Top-down processing occurs with endogenous orienting of attention (Colby, 1991).

Although there is a common belief that attention lives through the eyes, this is not always the case (Posner, 1980). Attention can be summoned or shifted with or without eye movements. Movements of the eyes can either be driven by the stimulus input or can result from a search plan internal to the organism. Overt orienting of attention involves eye movements. Covert orienting of attention is achieved through central mechanisms and eye movements do not occur (Posner, 1980). Even though movement of attention cannot be seen in covert orienting of attention, it is possible to determine where attention is moving. With humans, it is possible to manipulate the direction of attention by providing the participant with instructions, or changing the probability of a target event. Processing efficiency can be measured by using reaction time (Posner, Nissen, & Ogden, 1978), threshold detection (Remington, 1978), evoked potential amplitude (Von Voorhis & Hillyard, 1977), or changes in firing rates of single cells (Mountcastle, 1976). Results from covert orienting of attention experiments make it clear that attention can be shifted independent of eye movements.

In order to measure the efficiency of detection when attention is moved to an expected position, Posner, Nissen, and Ogden (1978) had participants complete a series of reaction time tasks in which participants were required to remain fixated on the center of the display. In some cases the participants knew the probable location of the target and in others they did not. The participants were presented with a plus sign or an arrow pointing left or right. If the plus sign appeared, the stimulus was equally likely to occur on the right or left side. If the arrow was presented, there was a probability of 0.8 that the stimulus would appear on the side indicated by the arrow (valid) and probability of 0.2 that it would occur on the opposite side (invalid). Posner et al. (1978) found a significant benefit for valid cued targets and a significant cost for invalid cued targets. The benefits, faster reaction times for valid cued targets, and costs, slower reaction times for invalid cued targets, were approximately equal in magnitude. In an additional part of this experiment, the task was altered to a choice reaction time task. As the task complexity increased, the facilitation effect decreased. Posner et al. explained that the longer RTs were due to participants having to reorient attention from the spatial position to the area in memory that is available for the analysis of the discrimination.

Posner (1978) found that attention was greater in the fovea when the task demands acuity. However, if the task involved luminance detection, attention is unrelated to fovea. In a luminance detection experiment, participants were instructed that they could move their eyes on each trial if they wish. After a few trials they gave up doing so, and recognized that making the eye movements did not help with their performance. When the task was an acuity demanding task, participants clearly preferred to move their eyes, as the movements aided their ability to perform the task effectively.

Inhibition and Facilitation

Posner and Cohen (1984) using a covert orienting of visual attention task (COVAT), measured reaction times to targets at cued and uncued locations. The paradigm they created required the participants to fixate at the center of computer monitor on a central placeholder box. From a viewing distance of 40 cm the boxes were one degree square. Two peripheral placeholder boxes were located eight degrees to the right and left of the central placeholder box. The three placeholder boxes were formed by the outlines of the boxes. That is, the placeholder boxes were unfilled squares. A trial began with 150 ms of brightening the outline of one of the peripheral placeholder boxes (the cue). A filled in box (0.1°) was then presented in one of the three placeholder boxes (the target). The probability of the target appearing in the center placeholder box was 0.6. The probability of the target appearing in the right or left placeholder boxes was 0.1. The probability that the trial would be a catch trial (i.e., all events in the trial sequence were presented except no target was presented) was 0.2. The target was presented at 0, 50, 100, 200, 300 or 500 ms after the brightening of the cue. Subjects were instructed to respond to the target as quickly as possible by pressing a single key. A biphasic pattern of results was found. When the stimulus onset asynchrony (SOA) - the time between the onset of the cue (brightening of the placeholder box) and the onset of the target (filled in box) - was short, reaction times were faster to targets at cued locations than uncued locations (facilitation). Once the SOA was greater than 300 ms, reaction times to targets at cued locations were slower than reaction times to targets at uncued locations (inhibition). The inhibitory effect has been termed inhibition of return (IOR), in that the attention is thought to be inhibited from returning to previously attended locations.

Although IOR has been demonstrated in different sensory modalities including visual, auditory, and tactile stimuli, (Welsh & Elliott, 2004; Lloyd, Merat, McGlone, & Spence, 2003; Poliakoff et al., 2003) the focus of this paper is on the visual attention model.

In explanation of the facilitation effect, Posner and Cohen (1984) suggested that the cue captures the participant's attention; as a result the attention is moved to the location of the cue. If the target is presented at the same location during this time, it is detected faster. In an effort to explain the inhibitory effect, Posner and Cohen proposed three explanations. First, they suggested that it was the result of only having two alternative positions where the target and cue could appear. Failing to find a target at the cued position shortly after the cue, the participant may guess that the target is more likely to occur at the other position. Secondly, the inhibition could be a result of the movement of attention away from the cued stimulus in order to return to the center. Targets away from the cue could be responded to more rapidly because attention is inhibited to return in the direction it came from. Thirdly, they suggest that the inhibition may result from reduced efficiency by the cueing to some part of the pathway from the cued location. The reduced efficiency could occur because of the sensory cue itself, or because of the covert orienting of attention as a result of the sensory cue.

In order to test the first two hypotheses, Posner and Cohen (1984) designed an experiment that had a central placeholder box and four peripheral placeholder boxes, located 5° to the right, left, above and below the central placeholder box. The probability of the target appearing in the center placeholder box was 0.6. The probability of the target appearing in one the peripheral placeholder boxes was 0.1. With a 500 ms SOA, reaction times were slowest to a target at the cued location and the same for targets

presented at all other locations. As well, when the box opposite to the cue was compared to the two other boxes (i.e., those at 90 degrees to the cue), there was no difference in reaction times between these boxes. All three reaction times to targets in the uncued boxes were faster than the reaction time to a target presented in the cued box. Therefore, inhibition is not limited to two alternative cases. The results demonstrate that inhibition is relative to all possible locations in the visual field, and the opposite position is not a special case. Attention does not move away from the cue to the center, thus, inhibition is not a result of the difficulty of returning attention to the previously cued location.

To test their final hypothesis, concerning the sensory factor involved in inhibition, Posner and Cohen (1984) conducted an experiment in which the peripheral placeholder boxes either brightened or dimmed. If the facilitation effect was not due to forward brightening enhancement, the results should be similar for both cases. With an 80 ms SOA responses to the cued location were faster, and when the SOA was 500 ms responses were slower to the cued location, regardless if the cue was introduced as brightening or dimming of the box. To further investigate the sensory versus attentional characteristics of facilitation and inhibition, Posner and Cohen had participants complete trials using the four placeholder box paradigm in which two peripheral boxes were cued simultaneously. Because two cues are presented, these trials are called double-cued trials. When only one cue is present the trial is called a single-cue trial. The center placeholder box was used as a refixation point as it was brightened between the presentation of the cues and the targets. No targets appeared in the center box. SOAs of 80 ms and 500 ms were used. In single-cue trials there was no facilitation. In contrast, inhibition in the double-cued trials was as great as it was in single-cued trials. Since

inhibition was realized in the double cue paradigm and facilitation was not, it can be suggested that inhibition does not arise from attentional orienting but from the light energy change present at the cued position (Posner & Cohen, 1984). However, since significant facilitation was not seen in the double-cued paradigm, it is impossible to rule out attentional orienting as a necessary component for inhibition. Maylor (1985) suggests that attentional orienting may indeed be necessary for inhibition to occur.

To further examine the orienting of attention issue, Posner and Cohen (1984) investigated if orienting of attention is a sufficient basis for inhibition when no peripheral information is presented. In order to do this they used a central cue rather than a peripheral one. The trials began with an arrow located above the center box, pointing in the direction of where the participant was to attend. The targets appeared 450 ms after the cue, and had a probability of 0.8 of appearing in the location cued by the arrow, and a probability of 0.2 of appearing on the uncued location. Targets appearing at the cued location were facilitated (i.e., reacted to faster) following the arrow cue, however there was no inhibition was found with a central cue. Target detection was facilitated with a peripheral or a central cue, however, inhibition effects were only realized following a peripheral cue. Orienting of attention is not a sufficient condition for the inhibition effect, which suggests that inhibition depends primarily or exclusively on sensory information. However, Posner and colleagues (1985) later found that luminance changes were not necessary to obtain inhibition of return. They suggested that inhibition can be observed under a variety of conditions including orienting of attention.

As suggested by Posner (1980), despite the functional relationship between eye movements and attention, these two systems can operate independently. Posner found

that facilitation does not depend on moving the eyes to the stimulus but can occur when the participants keep their eyes fixated. He also found that it is possible to dissociate the direction of the eyes from the movement of the attention sufficiently for the eyes to move in one direction while the attention moves in the other.

Spatial Coordinates of Attention

Cohen (1981) was interested in determining the spatial coordinates in which attention is mapped during saccades. He proposed three possibilities: attention could move with the fovea if it is locked to fixation; it could move independently of the fovea to a position defined by retinal coordinates; or it could stay at the same position in physical space as the eyes move. In order to investigate the spatial coordinates of attention, Cohen created a paradigm which had six boxes arranged into two equal length horizontal lines. Participants were instructed to fixate on the center box of the top row. The first signal instructed participants to move their eyes to the box directly below the first fixation location (7° below). One of the right or left boxes in the top row brightened, either simultaneously or prior to the signal to instruct them to move their eyes. The brightening of this box was the cue and targets were presented in any one of the four peripheral boxes. They occurred in each box with equal probability. Cohen found that when the target was presented in the bottom row on the side of the cue (below where the cue was presented) reaction times were significantly faster and that attention tended to follow the eye movements to the bottom row. If the top row was highly probable, the tendency for attention to move could be reduced or eliminated. Cohen concluded that attention is defined in retinal coordinates, and participants have considerable voluntary

control over where facilitation will occur, supporting the idea that covert orienting of attention is a basis for facilitation.

Inhibition has typically been studied when participants are instructed to remain fixated, and therefore, have no eye movements. Posner and Cohen (1984) questioned if inhibition would be seen if eye movements were allowed. They also wanted to determine whether IOR was mapped in environmental or retinotopic coordinates. A set of two experiments were completed to determine the nature of the coordinate system in which inhibition operates. First, participants fixated at the center of the screen in which three boxes were presented. Each trial began with the presentation of a small digit in one of the two peripheral boxes. The digit served as the cue. Participants were required to read the digit and return their eyes to the center box when it brightened. The digit remained on the screen for 600 ms. Once the digit disappeared, the center box brightened for 200 ms. A lapse of either 600 or 1450 ms occurred before the target was presented. The target had equal probability of appearing at either of the two peripheral locations. There was a strong inhibitory effect at the cued location, indicating inhibition can be observed with eye movements. The second experiment required participants to make three eye movements. There were five placeholder boxes presented on the screen. The top row consisted of three placeholder boxes: a central fixation placeholder box and two placeholder boxes located to the left and right of the fixation box. There were two placeholder boxes in the second row, located directly beneath the peripheral placeholder boxes in the upper row. Participants started a trial by fixating on the center placeholder box in the top row. After a delay, a digit was presented in one of the two boxes in the lower row. A corresponding eye movement was made to the location of the digit. The

digit was read aloud. A second eye movement was made to a digit in the box located directly above the location of the first digit. The second digit was read aloud. Following a brief delay, the central fixation box was brightened. Participants moved their eyes to the central fixation location. There was environmental stimulation at the cued position but no retinal stimulation. The target appeared 600 ms or 1450 ms after the brightening of the center box. Participants showed a strong inhibitory effect for the early target, which seems to decay in the 1000 ms between the early and late targets. Since inhibition occurred immediately after the participants returned to central fixation, it suggests that inhibition must be at least primarily mapped in environmental, not retinotopic coordinates.

There are differences between facilitation and inhibition. Facilitation is a central effect that uses retinotopic coordinates, while inhibition is a peripheral effect depending on light energy and is in environmental coordinates. Posner and Cohen (1984) have considered these differences and created functional explanations for the facilitation and inhibition effects. They believe that facilitation is meant to improve the efficiency of target detection within fixation. The area selected is important for the organism and can be processed more efficiently than other areas in the visual field. Alternatively, Posner and Cohen suggest that the inhibition effect evolved to maximize sampling of the visual environment. It promotes the release of attention from a spatial position so that concentration at any single position does not become too great.

Temporal and Spatial Factors

Although the reaction time pattern observed by Posner and Cohen during the COVAT has been replicated numerous times, some studies have reported facilitation and

inhibition under different conditions. Tassinari and colleagues (1994) completed a series of experiments investigating the temporal and spatial relationships between the cue and the target. SOA values of 60 ms, 130 ms, 300 ms and 900 ms were equally probable and randomly assigned to trials. In Experiment 1, the cue duration was 16 ms. For Experiment 2, the cue remained present for the entire SOA and for 300 ms after target presentation. In the final two experiments the cue duration was 130 ms. In Experiment 1, inhibition was observed when the SOA was 300 ms and the cue duration was very short (16 ms). In the other three experiments, there was no inhibition for targets in cued locations when the cue remained on during target presentation and outlasted target offset. Facilitation was not seen for any SOA-cue duration combination. The results indicate that at each cue-target SOA, the effect the cue has depends on whether or not the cue remains visible during target processing (Tassinari, Aglioti, Chelazzi, & Peru, 1994).

The study by Tassinari and colleagues (1994) has brought into question what role temporal properties play in covert orienting of visual attention. Using a similar paradigm as Tassinari et al. (1994), contradicting results were found by Berger, Dori, and Henik (1999). Berger et al. (1999) used three cue durations (50 ms, 100 ms, and 200 ms) presented in a blocked manner, and seven different SOA values (50 ms, 100 ms, 150 ms, 200 ms, 250 ms, 300 ms, and 600 ms) which were mixed within blocks. A clear biphasic pattern of results with early facilitation and later inhibition was found, regardless of the duration of the cue. Berger et al. suggest that the difference between these results and Tassinari et al.'s (1994) findings could be the consequence of the mixed presentation of cue duration used by Tassinari et al. compared to their blocked presentation of cue duration (Berger, Dori, & Henik, 1999). The second experiment done in this series used

mixed presentation of cue duration and found similar results to the first experiment: early facilitation and late inhibition regardless of cue duration. In an effort to replicate the Tassinari et al. (1994) study, Berger et al. did a final experiment in which they used both a narrow (4°) and wide (10°) eccentricities. They also used both a short (16 ms) and a long (1000 ms) target duration. Tassinari et al. (1994) used the narrow eccentricity and short target duration in their study, while previous experiments by Berger et al. have used the wide eccentricity and long target duration. The same SOAs were used in the third experiment as were used in the first two experiments. Again, Berger et al. found the biphasic pattern of reaction time results. A larger effect on the more peripheral location was seen, which may partially explain why Tassinari et al. (1994) did not observe facilitation (Berger et al., 1999).

Maruff, Yucel, Danckert, Stuart, and Currie (1999) had participants complete a COVAT task with both overlapping and non-overlapping peripheral cues. In the overlapping condition the cue remained present until the participant responded, while in the non-overlapping condition the duration of the cue was 50 ms. Trials with three different SOAs (150 ms, 350 ms, 850 ms) were randomly assigned into six blocks of 128 trials. The results indicated that facilitation occurred only when the SOA was 150 ms. and when there was temporal overlap between the cue and the target, while inhibition occurred when the SOA was greater than 150 ms. and there was no temporal overlap (Maruff et al., 1999). These results support Tassinari et al.'s (1994) findings that the presence and magnitude of facilitation and inhibition are related to the temporal properties of the cue and target.

The importance of temporal factors in facilitation and inhibition has been further supported in a study completed by Collie, Maruff, Yucel and Danckert (1999). They had participants complete a protocol similar to the one Maruff et al. (1999) used, but included eccentricities of both 9° and 18° for cue and target location. For the non-overlapping trials no significant IOR or facilitation was seen at the 150 ms SOA, but IOR was seen at the 850 ms SOA. For the overlapping trials, significant facilitation was seen at 150 ms SOA, and no facilitation or IOR was seen at 850 ms. The results support the findings of Maruff et al. (1999), and reinforce the idea that temporal factors contribute to the facilitation and inhibitory effect. In the second experiment, they compared the reaction times to 18° targets following 9° cues, with reaction times to 9° targets following 18° cues. When the cue appeared at the 18° location, significant facilitation was found for targets appearing at both the 18° and 9° location in the same field. When the cue appeared at the 9° location, there was facilitation only for the 9° location in the same field. When a peripheral cue causes a reflexive attentional shift, it extends from fixation to the cue but not beyond the cue to more lateral locations. These results suggest that facilitation arises as a consequence of attentional shift rather than reflecting sensory processes (Collie, Maruff, Yucel, Danckert, & Currie, 2000).

Further investigation into the temporal and spatial factors involved in COVATs was completed by McAuliffe and Pratt (2005). The first experiment used a paradigm similar to Posner and Cohen (1984), in which the cue was brightening of a placeholder box, and the target was a filled in box located in one of the placeholder boxes. Five different SOA values were used (50 ms, 100 ms, 200 ms, 400 ms, 800 ms), created from a total of 11 different cue durations and inter-stimulus intervals (ISI). There were two

types of cues for the 50 ms SOA: temporal overlap and non-temporal overlap. In the temporal overlap condition the cue remained illuminated until a keypress response occurred. In the non-temporal overlap there was no time between offset of the cue and the onset of the target: these two events occurred simultaneously. There was facilitation at short SOAs with temporal overlap conditions and IOR on longer SOAs when there was no temporal overlap between cue and targets.

In Experiment 2, McAuliffe and Pratt investigated spatial overlap between the cue and the target, in determining reaction time results to COVATs. The same cue durations, ISI, and SOAs were used, but in this study the cues and targets spatially overlapped. The cue was a filled-in square, slightly smaller than the target square, and was presented in one of the placeholder boxes. Participants were instructed to respond to the second box that appeared on the screen. Due to the spatial overlap it was not feasible to have the conditions from the previous experiment that had a 0 ISI and temporal overlap, and therefore, they were removed from this experiment. The results indicated that spatially overlapping cues and targets produced greater inhibition across ISIs at the 400 ms and 800 ms SOAs. They also found no facilitation at short SOAs regardless of ISI condition. Inhibition was still found at the longer SOAs, but ISI had less of an effect (McAuliffe & Pratt, 2005).

Although most of the results from McAuliffe and Pratt's experiments are typical COVAT findings, they did report some unique findings. They found no IOR in Experiment 1 when the SOA was 800 ms and there was temporal overlap. Because inhibition begins shortly after the onset of the cue, but is masked by the facilitation effect brought about by the shift in attention, no IOR was observed with temporal overlap and

longer SOAs. The longer the cue duration, the longer the attentional facilitation, the less the inhibition is unmasked. This emphasizes that both SOA and ISI are important in revealing IOR. In Experiment 2, there was a reduced amount of facilitation at short SOAs, and increased inhibition at long SOAs, in both cases when ISIs were short. In both cases there was spatial overlap between the cue and the target, and as a result there is confusion between the cue stimulus and the target stimulus. Short ISIs can both reduce inhibition in non-spatial overlap conditions, and increase inhibition in spatial overlap conditions (McAuliffe & Pratt, 2005).

Lupiañez and Weaver (1998) noted this same confusion, in a commentary they wrote about the Tassinari et al. (1994) paper. When the ISI was zero, both the cue and the target appeared simultaneously, altering the task being completed. If temporal overlap occurs, the task is a discrimination task, while when there is no temporal overlap it is a detection task. The Lupiañez and Weaver article questions Tassinari et al.'s claim that IOR can occur when the ISI is zero, because the negative effect that Tassinari et al. found was the result of the discrimination task which is much harder in cued than in uncued trials.

Reaction time responses to COVATs have been investigated by numerous scientists over the past two decades. The biphasic pattern of reaction times has been reproduced a significant number of times. Although there can be some temporal and sensory issues with observing facilitation, inhibition is very robust. Facilitation is an indicator of where attention is at a certain point in time, while IOR indicates where attention has been (Klein, 2000). The robustness of IOR has been demonstrated in detection tasks with simple key press responses (Maylor & Hockey, 1985), with choice

key press responses (Maylor, 1985), with eye movements (Abrams & Dobkin, 1994) and when practiced (Pratt & McAuliffe, 1999; Weaver, Lupianez, & Watson, 1998). IOR has been studied in a variety of populations, and has been observed in infants (Simion, Valenza, Umiltà, & Dalla Barba, 1995; Clohessy, Posner, Rothbart, & Vecera, 1991), in children and adolescents (MacPherson, Klein, & Moore, 2003), and with older adults (Castel, Chasteen, Scialfa, & Pratt, 2003; McCrae & Abrams, 2001; Faust & Balota, 1997).

Two different models have been proposed to explain IOR: an attentional model and a motor response model (Ro, Farne, & Chang, 2003). Numerous current studies have supported the notion that both attentional and motor systems may be involved in the generation of IOR (Ro et al., 2003; Klein, 2000; Rafal, Posner, Friedman, Inhoff, & Bernstein, 1988; Sapir, Hayes, Henik, Danziger, & Rafal, 2004; Sapir, Soroker, Berger, & Henik, 1999). These studies have shown certain neural structures are involved in both eye movements and attention. The structures are the superior colliculus and the frontal eye fields (Rafal et al., 1988). Klein (2000) suggested that the superior colliculus plays an important role in IOR. Patients with damage to their superior colliculus have reduced or eliminated IOR effects. Further evidence for superior colliculus involvement is described in a case study done by Sapir, Soroker, Berger, and Henik (1999). The patient had unilateral damage to the superior colliculus. Monocular presentation of the IOR paradigm was presented. They found that IOR developed only to the cues that were presented in the visual field projecting to the intact superior colliculus, supporting the involvement of the superior colliculus in the generation of IOR.

The frontal eye fields are known to be primarily involved with generating voluntary eye movements, but are heavily connected with the superior colliculus and may be involved in the generation of IOR (Kustov & Robinson, 1996). Ro, Farné and Chang (2003) suggest that the frontal eye fields are the critical brain regions necessary for producing the attentional bias away from previously cued locations. Ro et al.'s results are consistent with other studies done by Dorris and colleagues in 1999 and 2002, suggesting that the superior colliculus codes IOR, but that it is generated within some cortical region (Dorris, Taylor, Klein, & Munoz, 1999; Dorris, Klein, Everling, & Munoz, 2002). Activation within the superior colliculus is necessary but not sufficient for generating IOR. Without the superior colliculus no initial orienting of attention will take place. One theory explaining IOR proposes that when a visual cue is presented, the superior colliculus reflexively orients towards the cue and generates a motor command for a saccade towards it. However, the opposing frontal eye field generates a saccade command for the opposite direction to help maintain the required fixation, leading to the reorienting of attention towards the novel hemifield. The latter command generated in the frontal eye field leads to the origin of IOR, causing enhanced visual detection on the side contralateral to the cue (Ro et al., 2003).

IOR is believed to be an adaptive mechanism resulting in more efficient visual searches, by biasing attention away from previously attended locations and to new locations in the visual field. To date, research on COVATs has been restricted to situations in which the participant is stationary, seated viewing stimuli presented on a computer monitor. However, visual searches are performed in many situations, and not

only when in the stationary position. It is important to determine if reflexive orienting of attention works the same way when in motion.

Vestibular System during Motion

The vestibular system functions to provide the answers to two important questions “‘What way is up?’ and ‘Where am I going?’” (Kandel, Schwartz & Jessell, 2000, p. 801). During changes in velocity while in motion, the vestibular apparatus is activated, detecting changes in the position and movement of the head. The peripheral organization of the vestibular system includes the otolith organs and the semicircular canals. The otolith organs provide information about linear movement and head orientation with respect to gravity, while the semicircular canals are responsive to rotation (angular acceleration) (Barnack, 2003). The focus of the current study is on linear acceleration, as a result only a detailed explanation of the otolith system is necessary.

Sensory transduction in the otoliths takes place at a one mm² patch of sensory neuroepithelium called the macula. The macula is covered with hair cells that are mechanoreceptors sensitive to the displacement of projecting hairs. Each hair cell is topped with a tuft of 40-110 stereocilia arranged against a kinocilium. The gelatinous otolithic membrane lies just above the stereocilia so that only their tips are embedded. The otolithic membrane is studded with dense calcium carbonate crystals called otoconia or otoliths. The otoconia function to increase the mass of the top of the membrane, giving additional leverage as the otolithic membrane tilts during positional changes to cause greater movement of the underlying stereocilia. Adequate stimulus for transduction is bending or deflection of the stereocilia, resulting in depolarization or hyperpolarization depending on the direction of movement (Vander, Sherman, &

Luciano, 2001). When velocity is constant, motion is not sensed with the vestibular system. Once continuous velocity is achieved – there is no acceleration - the otoliths quickly straighten on their sensory hair cells and depolarization rates return to normal. The vestibular nuclei make up the central organization of the vestibular system as they process nerve impulses from the otolith and semicircular canals. The information processed by the vestibular nuclei is projected to regions of the brain including the parietal visual cortex and the thalamus (Barmack, 2003).

Vestibular information is used for a variety of visual attention processes. The vestibular system works in conjunction with the optical system, to stabilize gaze and maintain spatial orientation of the retina during rotation and translations of the head and body in space (Raphan & Cohen, 2002). The visual-vestibular interactions operate in complementary fashion to maintain target fixation in a variety of situations. One modality contributes more when information from the other is limited. For example, in a dark environment where visual cues are limited, the majority of the information required for eye movements will be provided by vestibular inputs (Paige, Telford, Seidman, & Barnes, 1998). In addition, there are two different reflex responses related to the different subsystems of the vestibular system. Associated with angular motion and the semicircular canal activation is the angular vestibulo-ocular reflex (AVOR), while the linear vestibulo-ocular reflex (LVOR) is a result of linear motion and activation of the otoliths (Telford, Seidman, & Paige, 1997).

When translational movements of the head occur, eye movements are required to minimize retinal image slip. A brief translation of the observer or the visual scene induces eye movements that are inversely related to the viewing distance (Busetini,

Miles, Schwarz, & Carl, 1994b). In cases where the observer was moved and the room was dark, responses were attributed to the LVOR resulting from the motion sensed by the otolith organs. When the scene was moved, ocular following was invoked, and the scene was projected and adjusted in size and speed so that the retinal stimulation was the same at all distances. Paige (1989) had participants perform trials in darkness and with head-fixed targets and found that while visual following did influence the results, the major proportion of the LVOR response was driven by the vestibular inputs.

The magnitude of eye movements has been shown to relate to the viewing distance: as the distance increases to infinity, eye movements are not required to maintain retinal image stability, but become increasingly large as the distance decreases (Paige, 1989; Busetini, Miles, Schwarz, & Carl, 1994a; Schwarz, Busetini, & Miles, 1989). Eye movements also depend on the axis in which the linear motion is occurring. When the motion is along the interaural axes, the head motion is roughly orthogonal to the line of sight. Responses under these linear movements are modulated by the vergence (in meter angle, the reciprocal of binocular fixation distance) (Paige & Seidman, 1999). Motion along the nasooccipital axes entails head movements that are parallel to the line of sight. Nasooccipital linear movements provoke responses that are independent of fixation characteristics; the direction of the response depended on the direction of the gaze. The eyes moved upward during up-gaze, downward during down-gaze, rightward during right-gaze and leftward during left-gaze (Paige & Tomko, 1991).

Vestibular information is also used in a reflex mechanism for maintaining upright posture by contributing to muscle tone (Ishikawa & Miyazawa, 1980). In addition, the information is used to provide conscious awareness of the position and acceleration of the

body, perception of space surrounding the body, and memory of spatial information in order to maintain balance (Vander et al., 2001). Recently, vestibular information has been linked with blood pressure regulation, and thus, orthostatic tolerance (Yates et al. 1999) These functions all involve the activation of the autonomic nervous system (ANS).

Vestibular System and Arousal

Arousal of the ANS has been shown to affect cognitive function. Physiological arousal resulting from exercise has been linked to both an increase and decrease in cognitive performance (Reilly & Smith, 1986; Brisswalter, Durand, Delignieres, & Legros, 1995; Levitt & Gutin, 1971). Reilly and Smith (1986) had ten young men complete an arithmetic computation task while pedaling a bicycle at various workloads ranging from 0% of VO_2 max to 85% of VO_2 max. An inverted U shaped relationship was observed. When the workloads were between 25% and 70% of VO_2 max. cognitive performance was enhanced, and was compromised when the workload reached 85% of VO_2 max. The same inverted-U results have been found when the cognitive task performed was a simple reaction time task (Brisswalter et al., 1995), a choice reaction time task (Chmura, Nazar, & Kaciuba-Uscilko, 1994; Salmela & Ndoeye, 1986; Levitt et al., 1971), a complex problem solving task (McMorris & Graydon, 1996), and a visual search task (Aks, 1998).

Research has investigated how activation of the vestibular apparatus affects the ANS (Uchino, Kudo, Tsuda, & Iwamura, 1970; Tang & Gernandt, 1969; Ishikawa et al., 1980; Yates, Yamagata, & Bolton, 1991; Yates, 1992; Ishikawa et al., 1980). The vestibular system can alter sympathetic outflow (Ray, Hume, & Shortt, 1997; Tang et al., 1969; Lee, Wood, & Welsch, 2001; Ishikawa et al., 1980; Ray & Hume, 1998; Hume &

Ray, 1999). Ishikawa and Miyazawa (1980) studied the effect of stimulation of vestibular afferents in anesthetized cats on renal sympathetic outflow. There was a distinct excitation period post stimulation. In an effort to trace the neural connectivity between the vestibular nerve and the ventrolateral medulla, Yates, Yamagata and Bolton (1991) measured extracellular recordings from 50 neurons of the subretrofacial nucleus. The effect of vestibular nerve stimulation on all but one of the neurons was inhibition. Yates and Miller (1994) have indicated that it is mainly the otolith organs that appear to produce the vestibulosympathetic reflex. The vestibulosympathetic reflex has been demonstrated to for a duration of 30 minutes, while in head down neck flexion, resulting in elevated muscle sympathetic nerve activity (MSNA) (Hume et al., 1999).

While the effects of vestibular stimulation on peripheral sympathetic outflow are being clarified, the question of how ANS activation affects cognitive abilities remains to be elucidated. Yardly, Gardner, Lavie, and Gresty (1999) investigated whether significant attentional resources were required to accurately monitor changes in bodily orientation, using vestibular information. They had participants complete an auditory reaction time task, independently and in conjunction with an active orientation perception task. Participants were positioned in a motorized chair that rotated in a darkened room. Once the rotation was complete, the participant was required to use a joystick attached to the chair to return to the original starting position. When the auditory reaction time task was performed in conjunction with active orientation perception, reaction times increased. In a second experiment, they required the participants to perform mental arithmetic while the chair was being moved. Accuracy on the subsequent repositioning of the chair decreased. The deficit in performance observed when the two tasks were

combined resulted from some attentional capacity, or cognitive effort being required to monitor direction and amplitude of movement (Yardley, Gardner, Lavie, & Gresty, 1999).

To further investigate the effect of vestibular input on cognitive function Redfern, Jennings, Martin, and Furman (2001) had participants perform a reaction time task while undergoing postural challenge conditions. The challenge conditions included seated, standing on firm surface, standing on sway-referenced floor, and standing on sway-referenced floor while viewing a sway-referenced screen. Performance on the reaction time task was influenced by the postural conditions. The condition that had the greatest effect was when participants were on sway-referenced floor and viewing sway-referenced screen. This challenge of sensory selection appeared to interfere with processes required for information processing tasks, suggesting a “bottle-neck” that delays information processing (Redfern, Jennings, Martin, & Furman, 2001).

Furman, Muller, Redfern and Jennings (2003) continued to investigate the issue. They had younger, (mean age = 23.5 yrs, S.D.= 2.9 yrs) and a group of older (mean age = 69.3 yrs, S.D. =3.2 yrs) participants perform an information processing task during visual-vestibular stimulation. The participants completed a reaction time task under a variety of conditions: (1) no movement, darkness (NO), (2) no movement, fixation (FIX), (3) no movement, pursuit (P), (4) earth-vertical axis rotation, (EVAR) in darkness, (5) EVAR with fixation (E-FIX), (6) off-vertical axis rotation (OVAR) in darkness, and (7) OVAR with fixation (O-FIX). The older participants had longer reaction times for all combinations of stimulus conditions. Reaction times were slower for both the younger and the older participant during EVAR compared to NO, and during OVAR for the

younger group. Reaction times were also slower during FIX and P compared to NO. There was no difference in reaction time for EVAR and OVAR compared to E-FIX and O-FIX. The significant elongation of reaction times suggests that reflexive sensorimotor behaviours such as VOR can interfere with higher-order cognitive processing. (Furman et al., 2003).

An alternative activation method of the vestibular system that evokes a response similar to that observed during linear acceleration is to tilt the head downward while lying in the prone position (Essandoh, Duprez, & Shepherd, 1988). During static head-down neck flexion (HDNF) the otoliths are the primary vestibular organ activated (Shortt & Ray, 1997). In the HDNF position the otoliths are continually under the 9.8m/s^2 acceleration of gravity. HDNF changes the way we experience the gravity vector. During linear motion of constant velocity, acceleration is complete. Therefore, motion is no longer sensed by the vestibular system.

Responses to COVATs can be monitored in the HDNF position with the eyes and head remaining stationary. Manipulating the head position provides a simulation of motion (i.e., acceleration), allowing observation of how the visual system operates when a person is experiencing one aspect involved in motion. The goal of this experiment is to determine if activation of the vestibular system, through HDNF, affects orienting of visual attention in young adults.

Experiment 1

The primary goal of the research program will be accomplished by having the participants do a COVAT in three different positions: seated, lying prone with head supported, and HDNF.

Methods

Participants:

A sample of fifteen undergraduate students from Lakehead University was recruited for the experiment. Participants were asymptomatic young adults between the ages of 18 and 25 with normal or corrected to normal vision. Participants were also screened for any inner ear or vestibular apparatus pathologies through self-reports. Each participant volunteered his/her time and the session lasted between 30 and 45 minutes. Recruitment was done through classroom announcements. Participants were free to withdraw from the study at any time. The Lakehead University Research Ethics Board approved the study.

Apparatus and Task:

The procedure was similar to that used by Posner and Cohen (1984) and is illustrated in Figure 1. Each trial began with a blank screen for 1000 ms. Following that, participants were presented with a display on a computer monitor consisting of the outline of two squares (1° wide and 1° high) located on the horizontal meridian 5° to the left and right of a central fixation dot (filled in circle 0.2° in diameter). All stimuli were presented as white (49.2 cd/m^2) on a black (0 cd/m^2) background. After the initial display was presented for 1000 ms, a cue consisting of enlarging one of the peripheral boxes was presented for 50 ms and then removed. The enlargement of the box to 1.1° square gave the appearance of brightening of the box. For the 100 ms SOA there was a delay of 50 ms (interstimulus interval or ISI) and then the target was presented. The target consisted of a filled in square (0.70° square) centered 5.5° to the right or left of the central fixation cue, located inside one of the boxes. The target remained on until the participant

responded or 1500 ms elapsed. For these trials the stimulus onset asynchrony (SOA) was 100 ms. One additional SOA interval was used in the experiment. The 800 ms SOA was created by using a cue duration of 50 ms and an ISI of 750 ms. The intertrial interval was 1000 ms.

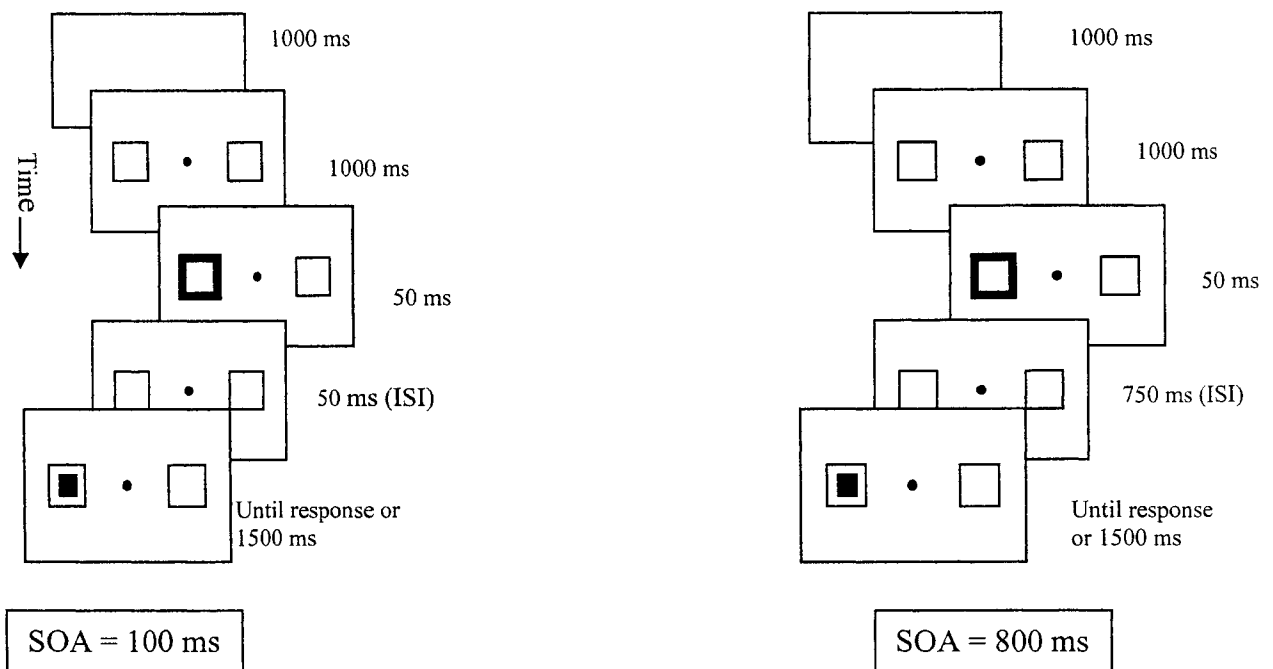


Figure 1. Example of trial sequence for 100 and 800 ms SOA

For all trials, participants were instructed to remain fixated on the center fixation point for the duration of each trial and to respond to the appearance of the target by pressing a button on a hand held microswitch as quickly as possible. Half of the peripheral cues appeared on the right, and half on the left. Half of the targets appeared on the same side as the cue, and half on the opposite side. The cue location provided no useful information about the location of the target, thus participants were instructed to ignore the cue. Catch trials were included on 20% of the trials. Catch trials consist of all

the events in the trial sequence except for the presentation of the target. Participants were instructed not to respond on catch trials. A short error tone sounded if participants responded too quickly (less than 100 ms after the appearance of the target), too slowly (greater than 1500 ms), or on a catch trial.

In each block, participants completed 100 trials. Fifty trials with an SOA of 100 ms, and 50 trials with an SOA of 800 ms. Initially the participants were seated at a table approximately 40 cm directly in front of a computer monitor in a dimly illuminated, sound-attenuated room (See Figure 2). A chin rest was used to prevent head movements. In the second block, the participants lay on his/her stomach (prone position) on a table with his/her neck extended and chin supported by a headrest. A monitor was placed on a stand 40 cm in front of the participants and at a height that would provide a viewing angle of 15 degrees below the horizontal, replicating the positioning of the seated protocol. Once again, the participants used a hand held microswitch to make responses (See Figure 3). In the third block, the headrest was removed and the participants lowered their heads over the edge of the table. The transition time from the head supported to the head lowered was approximately one to two seconds. The computer monitor was moved to a location that replicated the original seated position (i.e., 40 cm viewing distance) (See Figure 4). In the final block, the participants returned their head to the prone starting position. The head was supported with the headrest and the participants completed a final block of 100 trials.

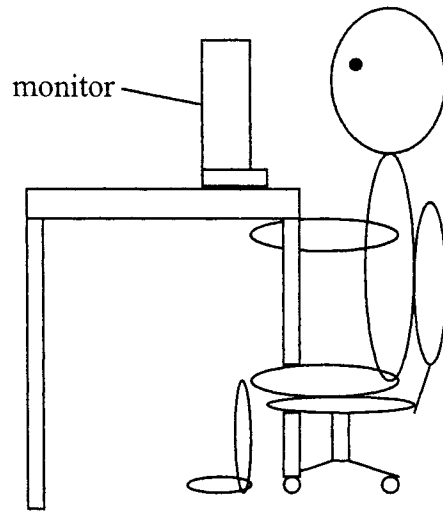


Figure 2. Seated Position

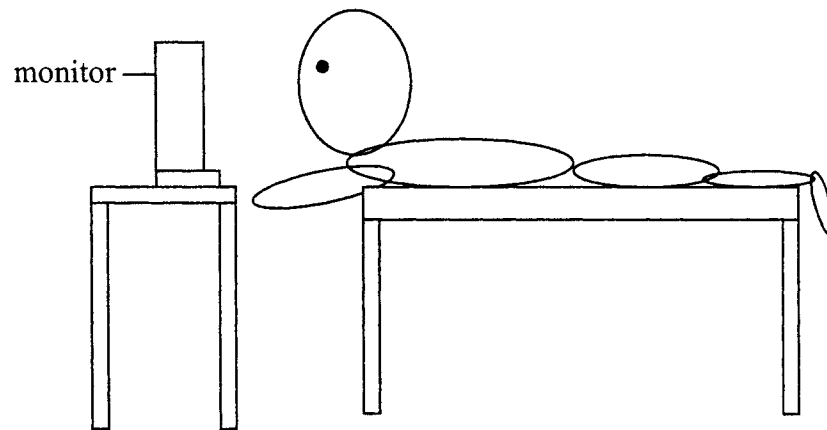


Figure 3. Prone head supported position

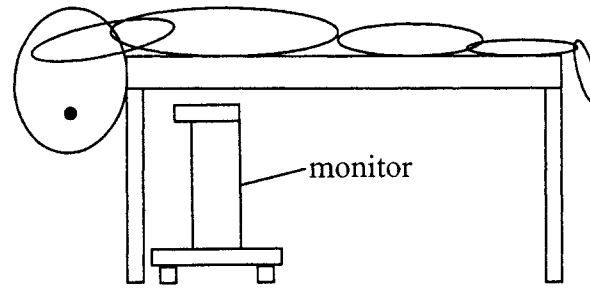


Figure 4. Head down neck flexion position

Procedure:

Participants performed a total of 400 trials – 100 trials per block in each of the four positions (seated, prone, HDNF, and prone). Each block of 100 trials was comprised of 50 trials of each SOA (100 and 800 ms). For each SOA, there were 20 cued trials, 20 uncued trials. For the 20 cued trials, the cue was presented on the left for 10 trials (with the target also presented on the left) and on the right for 10 trials (with the target also presented on the right). For the 20 uncued trials, the cue was presented on the left for 10 trials (with the target presented on the right) and on the right for 10 trials (with the target presented and the left). Cues and targets were equally likely to occur in the right or left box. Twenty percent of the total trials (20 trials) were catch trials. All trial types for each SOA were presented in randomly within a block of 100 trials.

Obvious saccades made during trial sequences were monitored using a Logitech QuickCam Pro 4000 camera. The video of the participants' eye movements was monitored on a laptop computer during the trials in a separate room from the participant. Movements were coded, and if any participants that made eye movements on more than 5% of trials, their data was omitted from any further analysis.

Results:

Mean RTs from the errorless trials are shown in Table 1 (with mean cueing effects plotted in Figure 5). The mean RTs were analyzed using a 4 (block: seated, prone, HDNF, prone) by 2 (SOA: 100 ms, 800 ms) by 2 (trial type: cued, uncued) ANOVA. There were significant main effects for block [seated = 382ms, prone = 367ms, HDNF = 376ms, prone = 360ms; $F(3, 42) = 3.53$, $MS_e = 594$, $p < .05$], SOA [100ms = 383ms, 800ms = 359 ms; $F(1, 14) = 7.45$, $MS_e = 4666$, $p < .05$], and trial type [cued = 378ms, uncued = 364ms; $F(1, 14) = 25.10$, $MS_e = 460$, $p < .0001$].

The two-way interaction between SOA and trial type [$F(1, 14) = 90.60$, $MS_e = 544$, $p < .0001$] was significant. Post hoc Newman-Keuls tests were conducted to determine the nature of the interactions. When the SOA was 100 ms, mean RT for cued trials (376 ms) was faster than uncued trials (390 ms). This is the typical facilitation effect. When the SOA was 800 ms, the mean RT for cued trials (380 ms) was slower than uncued trials (338 ms), indicating the typical IOR effect. There was no significant interaction of block and SOA [$F(3, 42) = 0.59$, $MS_e = 445$, $p > .05$] or block and trial type [$F(3, 42) = 0.82$, $MS_e = 282$, $p > .05$]. The block by SOA by trial type interaction was significant [$F(3, 42) = 6.13$, $MS_e = 164$, $p < .01$]. The interaction was due to a reduction in the cueing effect in block 3 and block 4. There was significant facilitation in block 1 (seated) (-25 ms, $p < .0001$) and block 2 (prone) (-21 ms, $p < .001$), however block 3 (HDNF) (-6 ms, $p > .05$) and block 4 (-7 ms, $p > .05$) there was no longer significant facilitation. There was significant IOR in all for blocks of trials (seated = 43 ms, $p < .001$; prone = 51 ms, $p < .0001$; HDNF = 32 ms, $p < .0001$, prone = 44 ms, $p < .0001$). Similar to the results with

facilitation there was less IOR in block 3 (HDNF), however, the reduction in the inhibition effect did not persist into block 4 (return to prone position).

Overall errors were made on less than 1% of the trials. Three types of errors were possible: false positives (responding on catch trials), responding too fast (RTs less than 100 ms) and responding too slow (RTs greater than 1500 ms). On average, participants committed 0.3 false positive errors per session, which represents less than 1% of catch trials (40 trials). Participants averaged 2.0 errors out of the 400 trials for responding too quickly and no errors were committed for responding too slowly. Errors were less than 1% on all target present trials (all non-catch trials). Participants' eyes were monitored during the duration of the experiment in order to ensure that the participants were focused on the central fixation dot throughout the duration of the trials. No participants made eye movements on greater than 5% of trials.

Table 1: The Mean Cued and Uncued Reaction Times (RT's, in milliseconds) for Experiment 1

	Cued RT (msec)	Uncued RT (msec)	Cued-Uncued RT (msec)
SOA 100 ms			
B1	382	407	-25
B2	367	388	-21
B3	383	389	-6
B4	370	377	-7
SOA 800 ms			
B1	390	347	43
B2	382	331	51
B3	382	350	32
B4	367	323	44

B1 = block 1, seated; B2 = block 2, lying prone; B3 = block 3, HDNF; B4 = block 4, lying prone; SOA = stimulus onset asynchrony; RT = reaction time

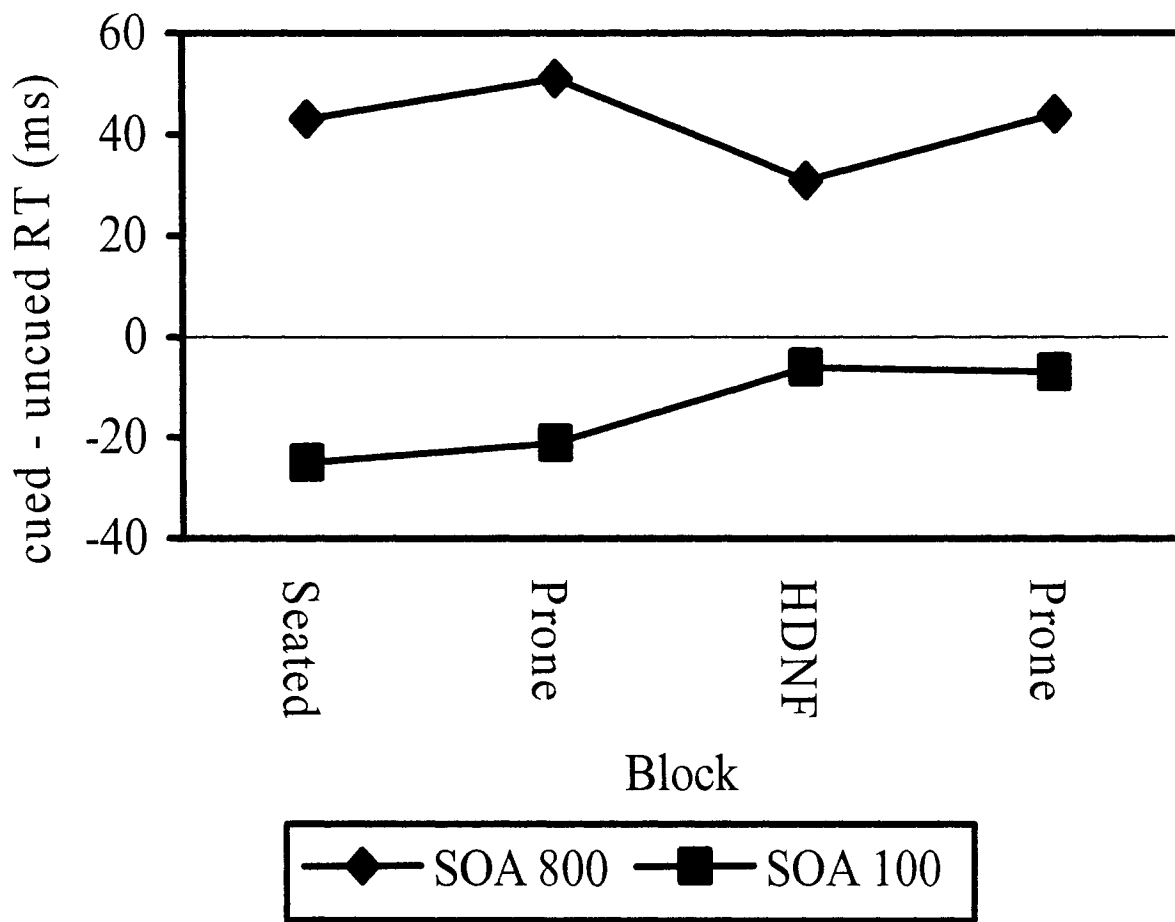


Figure 5. The mean cueing effect for Experiment 1. SOA = stimulus onset asynchrony; RT = reaction time

Discussion:

When the SOA was 800 ms, there was a decrease in the amount of inhibition in the head down neck flexion (HDNF) position (Figure 5). There was no difference between the trials in the seated position and the initial set of trials in the lying prone position, indicating that the change in IOR scores was not a result of completing the COVAT while lying in the prone position. In the fourth block (lying prone), when the participant came out of HDNF, there was no evidence of a carryover effect. That is, magnitude of IOR returned to the level obtained in the prone and seated conditions.

When the SOA was 100 ms there was a decrease in the amount of facilitation in the HDNF position. Similar to trials with an SOA of 800 ms, there is no difference between the mean reaction times of trials in the seated and initial prone position. In the trials performed following HDNF, facilitation scores continue to be suppressed. Less facilitation observed in the fourth block, suggests that there is a carryover effect for facilitation following HDNF.

HDNF influences COVAT responses with SOAs of 100 ms and 800 ms. The decrease in facilitation and inhibition occurred as participants completed trials 200 to 300. Weaver et al. (1998) found evidence that a practice effect with COVAT responses may exist with as little as 190 trials. They suggested that IOR magnitude decreased due to habituation. Since the HDNF trials were completed beyond the participants 200th trial, the change in COVAT responses may have been influenced by practice. However, Pratt and McAuliffe (1999), using the same paradigm as used in the current study, failed to find evidence for practice effects with IOR. To further discuss the results of Experiment 1 in terms of the HDNF maneuver the possibility that the changes found in Experiment 1 were due to practice must be determined.

Experiment 2

To account for any potential practice effect as an explanation for the change in cueing effects in block 3 of Experiment 1, the same experiment was run with the condition that all participants completed all trials in the seated position similar.

Methods

Participants:

A sample of fifteen undergraduate students from Lakehead University was recruited for the experiment. Participants were asymptomatic young adults between the age of 18 and 25 with normal or corrected to normal vision. Each participant volunteered his/her time and the session lasted between 30 and 45 minutes. Recruitment was done through classroom announcements. Participants were free to withdraw from the study at any time. The Lakehead University Research Ethics Board approved the study.

Apparatus and Task:

The apparatus and task was the same as that used in Experiment 1. The only difference was that all participants completed blocks 1, 2, 3, and 4 in the seated position. The manipulation of HDNF was not used.

Results

The mean reaction times (RTs) from the errorless trials are shown in Table 1 and the mean cueing effects are plotted in Figure 6. Mean RTs were analyzed using a 4 (block: 1, 2, 3, 4) by 2 (SOA: 100 ms, 800 ms) by 2 (trial type: cued, uncued) ANOVA. There was a main effect for block [block 1 = 406ms, block 2 = 396ms, block 3 = 385ms, block 4 = 382ms; $F(3,42) = 4.75$, $MS_e = 4.7$, $p < .05$]. From block 1 to block 4 RTs became faster. There was a main effect for trial type [cue = 403ms, uncued = 380ms; $F(1, 14) = 39.79$, $MS_e = 39$, $p < .0001$], as RTs on uncued trials were faster than cued trials. Despite realizing both significant inhibition and facilitation effects, overall RTs were faster on uncued trials due to the magnitude of inhibition being greater than the magnitude of

facilitation. There was no main effect for SOA [100 ms = 396, 800 ms = 388; $F(1,14) = 1.37$, $MS_e = 2845$, $p > .05$].

There was a significant two-way interaction between SOA and trial type [$F(1, 14) = 88.65$, $MS_e = 88$, $p < .0001$]. Post hoc Newman-Keuls tests were conducted to determine the nature of the interactions. When the SOA was 100 ms, RTs on cued trials (391 ms) were faster than on uncued trials (401 ms). This is the typical facilitation effect. When the SOA was 800 ms, RTs on cued trials (415 ms) were slower than on uncued trials (361 ms), indicating the typical IOR effect. There was significant facilitation in block 3 (-22 ms, $p < .05$) and block 4 (-18 ms, $p < .05$), but not in block 1 (-6 ms, $p > .05$) or block 2 (5 ms, $p > .05$). There was significant inhibition in every block of trials (block 1 = 58 ms, $p < .0001$; block 2 = 53 ms, $p < .0001$; block 3 = 53 ms, $p < .0001$; block 4 = 54 ms, $p < .0001$). There was no significant interaction of block and SOA [$F(3, 42) = 1.32$, $MS_e = 621$, $p > .05$] or block and trial type [$F(3, 42) = 1.39$, $MS_e = 512$, $p > .05$]. To observe a practice effect, a significant interaction between block and trial type would be needed. The three-way interaction for block by SOA by trial type was also not significant [$F(3, 42) = 1.57$, $MS_e = 381$, $p > .05$].

Overall errors were made on less than 1% of the trials. Three types of errors were possible: false positives (responding on catch trials), responding too fast (RT's less than 100 ms) and responding too slow (RT's greater than 1500 ms). On average, participants committed 2.0 false positive errors per session, which represents 0.05% of catch trials (40 trials). As well, participants averaged 2.1 too fast errors and 0.2 too slow errors per session. The total target-present trials that had errors were less than 1%. Participants'

eyes were monitored during the duration of the experiment to ensure no eye movements occurred during trials. No participants made eye movements on greater than 5% of trials.

Table 2: The Mean Cued and Uncued Reaction Times (RT's in milliseconds) for Experiment 2

	Cued RT (ms)	Uncued RT (ms)	Cued-Uncued RT (ms)
SOA 100 ms			
B1	413	418	-5
B2	402	396	6
B3	376	398	-22
B4	374	392	-18
SOA 800 ms			
B1	425	367	58
B2	419	366	53
B3	409	356	53
B4	408	354	54

B1 = block 1, seated; B2 = block 2, seated; B3 = block 3, seated; B4 = block 4, seated; SOA = stimulus onset asynchrony, RT = reaction time

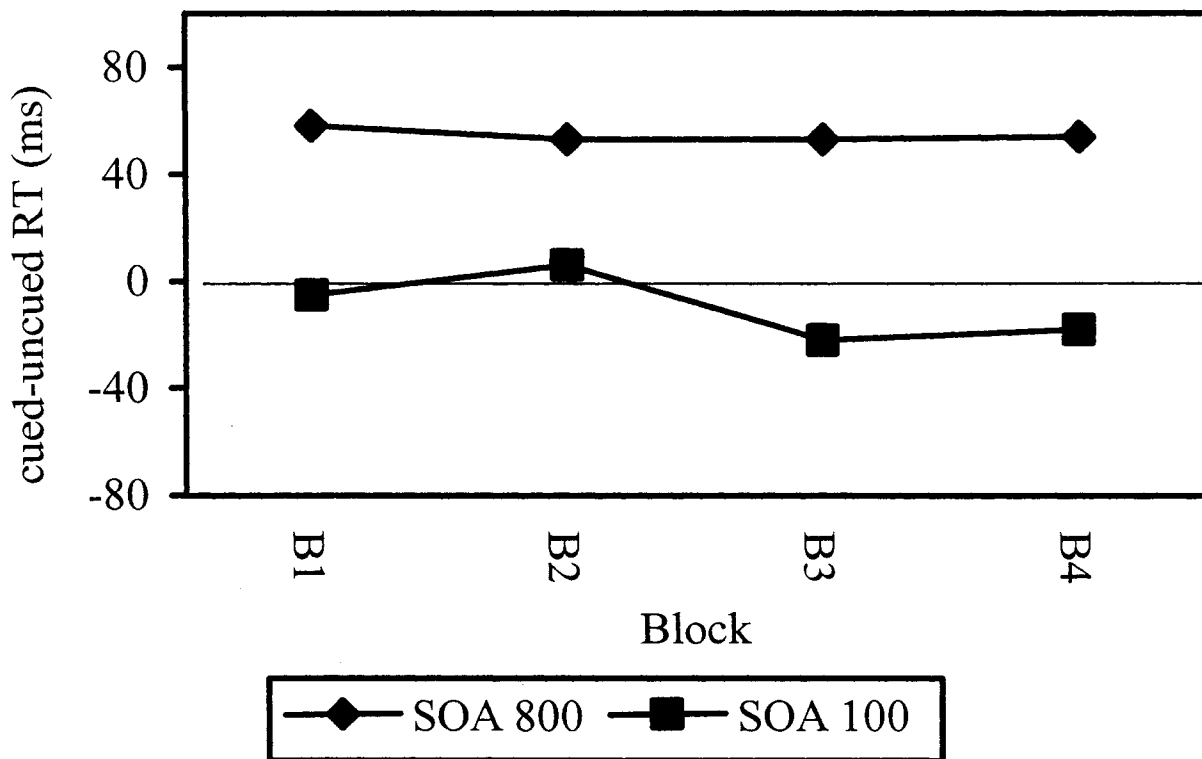


Figure 6. The mean cueing effects for Experiment 2. B1 = block 1, seated; B2 = block 2, seated; B3 = block 3, seated; B4 = block 4, seated; SOA, stimulus onset asynchrony; RT = reaction time.

Discussion

On trials with SOAs of 100 ms and 800 ms there was no change in cueing effects over the four trial blocks. There was no interaction between the block and trial type, block and SOA, or trial type and SOA (see Figure 6). There is no evidence to support the notion that the participants responses to the uninformative peripheral cue lessened due to habituation. The stimuli used in the current experiment were the same as those used by Pratt and McAuliffe (1999) who also did not find a practice effect. As a result, the data from Experiment 1 can be discussed in terms of the experimental manipulation – HDNF.

The main effect for block was the result of RTs decreasing with increasing practice. It is important to note that RTs decreased for both cued and uncued trials; therefore, the cueing effect (difference between cued trial and uncued trial) did not change. Pratt and McAuliffe (1999) and Weaver et al. (1998) also found a main effect for block, as RTs decreased as the number of trials completed increased. A main effect for block was also seen in Experiment 1, but the pattern of results was different. The overall trend was a decrease in RT across the blocks, except for the block 3 when participants were in HDNF. The mean reaction time for block 3 (381 ms) increased to approximately the same level as block 1 (376 ms). The number of errors in block 3 was not different from the number of errors in any other block, indicating no speed-accuracy trade-off. The increase in mean RTs may be due to a dampening of the general alerting effect when in HDNF.

General Discussion

The present experiments were designed to examine how cueing effects are affected by simulated linear acceleration. In order to examine visual attention, participants completed a series of trials of the typical COVAT paradigm, in which they detected targets at cued and uncued locations. In Experiment 1, participants performed the COVAT task in four blocks of trials. In each block, the participant changed body position, starting with seated, then lying prone, then in head down neck flexion (HDNF) and finally lying prone again. Head down neck flexion simulates movement in a linear pathway, by evoking a response in the vestibular system that is similar to actual linear acceleration (Essandoh et al., 1988). We found that during simulated linear acceleration, individuals' response to a peripheral non informative cue, which reflexively orients

attention, was different than when stationary. During the simulated linear motion of HDNF there was an overall decrease in the cuing effect. Regardless of the SOA (100 ms or 800 ms), the peripheral cue did not evoke the same magnitude of response as it did when participants responded in the seated or lying prone position. Both less inhibition and less facilitation were observed. Further, the data from Experiment 2 support the notion that the reduction cuing effects observed in Experiment 1 were due to the HDNF manoeuvre and not due to practice effects.

Similar to Posner and Cohen (1984), participants were seated during the first block of trials. The results of the present study were similar to the biphasic pattern of results observed by Posner and Cohen, when the SOA was less than 300 ms, RTs to cued targets were faster than RTs to uncued targets. Conversely, when the SOA was greater than 300 ms, RTs to uncued targets were faster than RTs to cued targets. A period of early facilitation was followed by a later period of inhibition.

There are differences between the facilitatory and inhibitory effects. In a series of experiments with central and peripheral cues (i.e., cues consisted of either brightening or dimming of the box) a six box display, in which participants responded by making eye movements to targets, Posner and Cohen (1984) describe facilitation as a central effect that uses retinotopic coordinates, while inhibition is a peripheral effect depending on light energy and is in environmental coordinates. The effect HDNF had on facilitation and inhibition was also different. A decrease in the cuing effect was observed in both facilitation and inhibition during HDNF, but the pattern of results in the recovery block after HDNF differed. When participants were lying prone following HDNF, IOR scores returned almost to baseline values, while facilitation effects remained suppressed which

further supports Posner and Cohen contention that facilitation is a different process than inhibition.

Posner and Cohen (1984) proposed that the purpose of facilitatory processes was to improve the efficiency of target detection within fixation and that inhibitory processes have evolved to maximize sampling of the visual environment. The results of the current study suggest that individuals are able to rapidly return to sampling our visual environment, once movement has stopped. Conversely, our ability to detect targets closer to fixation following motion does not rebound as quickly. Unlike IOR, facilitation can be observed with endogenous cues (arrow pointing in direction of target) (Posner & Cohen, 1984). The type of processing that occurs with facilitation may be different than processing for IOR.

In a COVAT paradigm there is bottom up, or reflexive, orienting of attention. Stimulation of the otolith system through HDNF is reflexive stimulation. The interaction between HDNF and COVAT scores implies that bottom-up orienting of attention can be influenced by bottom-up responses in the otoliths of the vestibular apparatus. The nature of the observed interaction between HDNF and COVAT performance is still unknown. It is possible that the reflexes interacted in an additive nature, separate nature or hierarchically ordered. Further research must be completed to understand the exact nature of the interaction.

Attention can also be oriented volitionally through endogenous cues. Does activation of the ANS through otolith activation affect volitional orienting of attention? In an effort to answer this question, an experiment could be conducted in which participants complete an endogenously cued paradigm while in the HDNF position.

Because endogenous cues use top-down processing, there is a higher cognitive load and greater information processing. Currently there is some evidence that vestibular apparatus activation has a negative influence on the ability to perform on information processing tasks (Redfern, Jennings, Martin, & Furman, 2001; Furman, Muller, Redfern, & Jennings, 2003). Based on the findings from Redfern and colleagues using a series of experiments with both older and younger adults in which RTs elongated when postural challenge conditions became more difficult, it may be suggested that reflexive sensorimotor behaviour, such as vestibular ocular reflex, can interact with higher-cognitive processing. This implies that a bottom-up reflex can affect top-down processing. Dissociation of the reflexive and volitional attentional systems with the otolith activation would further contribute to attentional theory. Much of what we know about the neurology of attention has been obtained through the use of neuroimaging techniques. Isolating various attentional systems while the participant is simultaneously influenced by activation of the autonomic nervous system provides a novel neurophysiological means of studying attention.

The orienting signal (the cue) used in the current experiments has two effects on the participants: (1) spatial orienting and (2) general arousal. Arousal of the ANS has been shown to affect cognitive function. An inverted-U relationship exists, where very low or very high levels of arousal have detriments on performance. The arousal and performance relationship has been demonstrated when the cognitive task performed was a simple reaction time task (Brisswalter et al., 1995), a choice reaction time task (Chmura, Nazar, & Kaciuba-Uscilko, 1994; Salmela & Ndoye, 1986; Levitt et al., 1971), a complex problem solving task (McMorris & Graydon, 1996), and a visual search task

(Aks, 1998). In the current study, it was not possible to delineate the separate arousal and orienting effects of the cue. Further research should be completed in order to separate the spatial orienting effects of the cue and the arousal effects of the cue.

One explanation for the decrease in inhibition and facilitation scores is related to the concept that the vestibular apparatus works in conjunction with the optical system. Movements that are linear in nature provoke a reflex called linear vestibulo-ocular reflex (LVOR) (Telford, Seidman, & Paige, 1997). The LVOR acts by focusing the eyes to the center in order to minimize retinal image slip (Raphan et al., 2002). The stabilization of gaze achieved by the LVOR may have influenced the responses on the COVATs in Experiment 1. Peripherally located cues are used in COVAT experiments to draw the attention of the participant away from central fixation to peripheral locations in the field of vision. It has been proposed by researchers in the field of visual attention, that the IOR mechanism functions by biasing eye movements in order to create a more effective search pattern of the visual environment (Klein & MacInnes, 1999). If LVOR is influencing the responses on the COVAT, it can be suggested that the LVOR reflex not only stabilizes gaze, but also stabilizes attention thus reducing the cueing effect.

The series of stimuli used in the current study were selected to ensure that a biphasic pattern of results would be observed. In order to see facilitation the SOA must be below 300 ms. and there needs to be temporal overlap between the cue and the target. Inhibition requires an SOA greater than 300 ms. and no temporal overlap between the cue and the target (Posner et al., 1984; Maruff et al., 1999; McAuliffe & Pratt, 2005). A SOA of 100 ms., cue duration of 50 ms. and an ISI of 50 ms. was used in order to demonstrate facilitation. For inhibition, the SOA was 800 ms., cue duration was 50 ms. and the ISI

was 750 ms. The series of stimuli we used did produce the biphasic pattern of results in the current study.

In the current study, participants were able to perform the covert orienting of attention task effectively while in the seated and lying prone positions, but when in HDNF their performance declined. The data supports the notion that the way attention is oriented when we are in motion (i.e., acceleration) is different from when we are stationary. However, in this study the participants were never actually moved. HDNF simulates a response in only one system (the otoliths of vestibular system) that is consistent with when we are accelerating in a linear direction. For a more complete understanding of how attention functions when we are in motion, more work is required. Further research on the relationship between stimulation of the ANS and visual attention will help us better understand how we move through our environment – something we do everyday.

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