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## Target eccentricity effects for defensive responses

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# TARGET ECCENTRICITY EFFECTS FOR DEFENSIVE RESPONSES

A Dissertation

Submitted to Graduate Faculty of the  
Louisiana State University and  
Agricultural and Mechanical College  
in partial fulfillment of the  
requirements for the degree of  
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in

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by

Taegyong Kwon

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## NOMENCLATURE

AT — Training in the away condition

AWAY — Away condition

C — Condition

D — Direction

DF — Degree of freedom

E — Eccentricity

EMD — Electromechanical delay

EMG — Electromyography

EMG ON — EMG onset

END — End of head movement

EOG — Electrooculography

EOG ON — EOG onset

EXC — Excursion

G — Group

ICC — Intraclass correlation coefficients

IQR — Interquartile range

LEDS — Light-emitting diodes

MT — Movement time

ONSET — Onset of head movement

POST — Post-test

PRE — Pre-test

PREMOTOR RT — Premotor reaction time

RT — Reaction time

SCM — Sternocleidomastoid

SD — Standard deviation

S-R — Stimulus-response

SRT—Saccadic reaction time

STIM ON — Stimulus onset

TOWARD — Toward condition

TT — Training in the toward condition

VEL — Peak velocity

## **ABSTRACT**

Defensive actions involving goal-directed responses to visual stimuli presented in different parts of the viewing field commonly include movements either toward (TOWARD) or away from (AWAY) the actual stimulus. One can categorize the type of defensive movements by outcome or the level of stimulus-response (S-R) compatibility, where a congruent response corresponds to a response in the TOWARD condition and an incongruent response corresponds to a response in the AWAY condition. In an effort to better understand defensive responses, which have received less attention in the literature than offensive movements regardless of their importance in combative situations, we studied the responses of quick yaw head rotations in the TOWARD and AWAY conditions to visual stimuli presented in different parts of the viewing field.

In the first experiment (chapter 2) we examined the test-retest reliability of the primary and secondary measures associated with the quick yaw head rotations. After achieving an acceptable level of reliability for most measures, we investigated the effects of S-R compatibility and target eccentricity on the primary measures of reaction time of head rotation (RT) and activity of the sternocleidomastoid muscles of the neck (premotor RT) and the secondary measures of movement time, peak velocity, head excursion and the electromechanical delay for yaw head rotations (chapter 3). We found an increase in RT and premotor RT for yaw head rotations with large increases in visual field target eccentricity and involving incongruent responses observed in the AWAY condition.

In chapter 4 we examined the effects of practice in the TOWARD or AWAY condition on performances in both conditions. We observed a shorter RT and premotor RT after 6 days of practice (over 2 weeks), regardless of condition practiced or of performance. Most subjects who

practiced in the TOWARD condition produced greater decreases in RT and premotor RT for the TOWARD condition and most subjects who practiced in the AWAY condition produced greater decreases in RT and premotor RT for the AWAY condition. These data also suggest faster reactions in response to stimuli in the central visual field occur with practice.

These results suggest reactions will be slowest for responses to objects in the far peripheral visual field and when trying to avoid object contact. RT and premotor RT at each eccentricity and for each condition can definitely improve with practice. The present results also provide small but potential added benefits for specificity of condition training. The parallel findings for RT and premotor RT suggest that outcomes observed for quick yaw head rotation RTs were primarily due to changes in neural processing time.

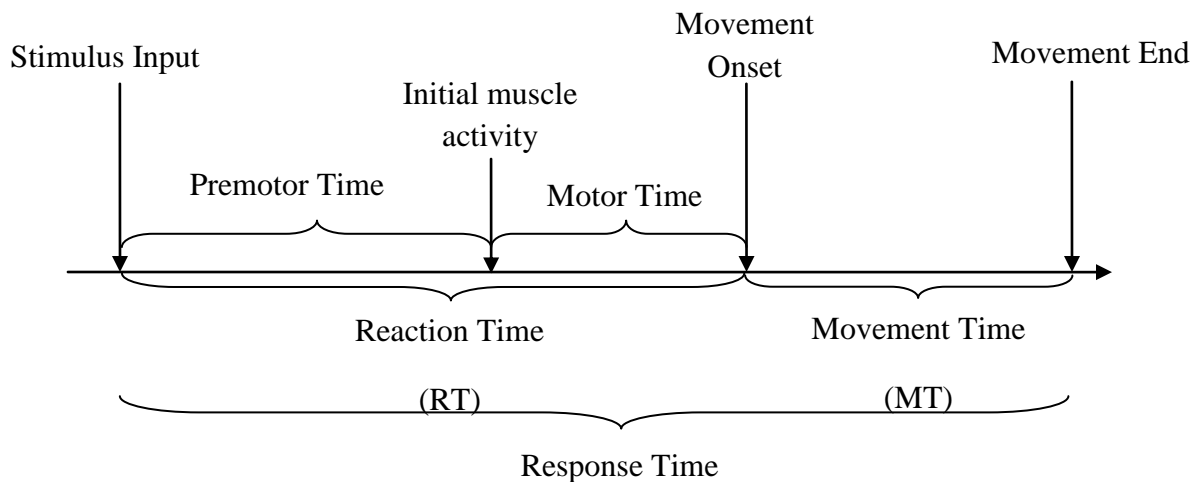
## CHAPTER 1: INTRODUCTION

When performing different tasks such as hitting (Bootsma & Van Wieringen, 1990; Brenner, de Lussanet, & Smeets, 2002; Brenner, Smeets, & Remijnse-Tamerius, 2002; Brouwer, Brenner, & Smeets, 2000; Land & McLeod, 2000), (Brouwer, et al., 2000) (Brouwer, Lopez-Moliner, Brenner, & Smeets, 2006), catching (Lacquaniti & Maioli, 1989a, 1989b; Laurent, Montagne, & Savelsbergh, 1994; Williams & McCririe, 1988), driving (Ladas et al., 2005; Langham & Moberly, 2003) and avoiding or dodging obstacles (Abernethy & Wood, 2001; King, Dykeman, Redgrave, & Dean, 1992), people constantly use visual stimuli for appropriate movement control. During driving for example, responses to visual input allow a driver to avoid obstacles such as a ball that rolls onto the road or “TOWARD” a target such as maneuvering into a parking space. The ability to avoid is also desirable in competitive sports, where to block or dodge an opponent’s attack is imperative for success (Ishihara, Imanaka, & Mori, 2002; Williams & Elliott, 1999). In these situations the athlete must constantly update the relative location of the opponent to produce an appropriate motor response, and do this quickly.

### **Response Time**

One fundamental way of assessing task performance is through temporal measures such as response time. Response time represents the time a performer can receive and process sensory information (input) and make the movement required for a specific task (Beggs & Howarth, 1972a, 1972b; Luce, 1986). The diagram in Fig. 1.1 offers an overview of response time, an inclusive time interval involving reaction time (RT) defined as “the interval of time between the onset of a signal stimulus and the initiation of a response” and movement time (MT) which defined as the time taken to physically respond to a stimulus and is defined as the interval of time between the initiation and completion of the movement (Fitts, 1954). Reaction and movement

times measure different aspects of human movement and are relatively independent measures; by definition they are easily separated. Some researchers argue that RT does not predict MT, especially when comparing different skills or different stimuli (e.g. (Helsen, Starkes, & Buekers, 1997). However, they both can be influenced by the same factors.



**Figure 1.1** The event and time intervals of response time.

There is a full complexity of human behavior that influences response time that is commonly not captured in individual studies. RT and MT generally slow with increasing age (Der & Deary, 2006; Gottsdanker, 1982; MacDonald, Nyberg, Sandblom, Fischer, & Backman, 2008; Wilkinson & Allison, 1989). MT is generally slower for females than males (Teeken et al., 1996), while the difference in RT between genders is less consistent and examples exist where it is shorter for males (Dane & Erzurumluoglu, 2003; Der & Deary, 2006) and there is no difference between genders (Solberg & Brown, 2002). Factors involving mindset and experience can also affect RT and MT and suggest that reductions in RT and MT are also influenced by lower cognitive demands (Briem & Hedman, 1995; Zhang et al., 2007) and greater level of training (Mori, Ohtani, & Imanaka, 2002; Williams & Elliott, 1999). In many cases it is not the

actual RT or MT that should concern us. Rather, it is the factors that influence the relative increase or decrease in these variables that allow us to generalize the outcomes to response time under a variety of situations.

Although RT and MT can be influenced by the same external factors (Komilis, Pelisson, & Prablanc, 1993), few studies have tested for differences in MT in response to different sensory stimuli; probably due to the lack of theoretical or scientific basis and/or the difficulty in experimental setup. Moreover, different sensory stimuli, including visual stimuli, influence response time by primarily affecting RT. Many researchers have confirmed that reaction to sound is faster than reaction to touch and the reaction to sound is faster than that to vision (Naito et al., 2000) and transduction type (Bell, Meredith, Van Opstal, & Munoz, 2006; Jaskowski, Jaroszyk, & Hojan-Jezierska, 1990) and/or distance (Harrar & Harris, 2005) are responsible for the disparity.

### **Visual Stimuli and Response Time**

It is clear that visual information and the ability to detect, identify or respond to visual stimuli play important roles to successfully perform many actions (Helsen, Starks, & Ricker, 1998). Many studies have investigated visual RT and MT to stationary and moving objects and the behavioral evidence points to faster RTs (Smeets & E. Brenner, 1995) and MTs (Van Thiel, Meulenbroek, Hulstijn, & Steenbergen, 2000) for moving stimuli compared to those for the stationary counterparts. The intimate link between the hand and eye used for hand-eye coordination is responsible for this difference, as the visual moving stimulus has a direct effect on manual movement speed by engaging faster neural circuitry more sensitive to these visual cues (Sunaert, Van Hecke, Marchal, & Orban, 1999; Zeki et al., 1991).

Many motor skills require a person to respond to visual stimuli with both speed and accuracy requirements. When both speed and accuracy are essential to respond to visual stimuli, the phenomenon known as the speed-accuracy trade off is often observed. Examples of increasing accuracy demands at the expense of speed include decreasing target size (Bootsma, Marteniuk, MacKenzie, & Zaal, 1994), increasing target movement duration (Battaglia & Schrater, 2007), decreasing target velocity (Bradshaw & Sparrow, 2001), limiting mistakes (Rival, Olivier, & Ceyte, 2003) and increasing the number of choices (Cauraugh, 1990). Clearly, installing accuracy requirements on movements produces different outcomes on RT (Cauraugh, 1990; Christina, Isabelle, & Hadrien, 2003) and MT (Rival, et al., 2003; Woodworth, 1899), depending on whether the accuracy is spatial or temporal in nature. Another item of interest in the current proposal is the influence of stimuli presented in different parts of the visual field.

### **Visual Field**

People use various parts of their visual field when performing daily tasks, including those used in sports. Interestingly, there is evidence to show that normal humans commonly use different viewing fields to perform different tasks, even though the roles of central and peripheral vision are not completely segregated. Most scientists agree that the central visual field is the area of highest visual clarity linked closely to the line of sight or direction of gaze (Sivak & Mackenzie, 1992), as it is responsible for detecting many physical characteristics of environmental objects (Sekuler & Blake, 1994), while people can detect certain spatial characteristics of the environment using peripheral vision which is that outside the center of gaze direction (Nougier, Bard, Fleury, & Teasdale, 1998). Studies on visuomotor control which exclusively assess responses to stimuli projected only on the central retina may not generalize to the peripheral target presentation. Research on the roles for using different viewing fields in



performing various tasks provides greater insight to this issue about how people respond to visual stimuli presented in different parts of the visual field.

Attention differs for location of object presentation in various parts of the visual field (Ando, Kida, & Oda, 2002), thus may contribute to responses to the given input. Although limited, investigations on abilities of people to detect and react to objects in the central and peripheral visual fields do exist (Ando, Kida, et al., 2002; Ando, Kida, & Oda, 2004; Niechwiej-Szwedo, McIlroy, Green, & Verrier, 2005). Some researchers indicate no difference in response abilities according to stimulus eccentricity (Ando, Kida, et al., 2002; Ando, et al., 2004; Ando, Kokubu, Kida, & Oda, 2002; Helsen, et al., 1997; Niechwiej-Szwedo, et al., 2005; Taniguchi, 1999), while others show differences (Schiefer et al., 2001; Wall, Kutzko, & Chauhan, 2002). Different methodologies among studies are blamed for the conflicting outcomes, making it more difficult to compare results and predict future findings.

### **Visual Field and Response Time**

Inconsistently defined viewing fields and use of different body segments are two of the items that complicate our understanding of responses to visual stimuli placed in different part of the visual fields. Although neural anatomy can be used to dictate central vision based on the retinal distribution of the cone and rod photoreceptors, some investigators use behavioral viewpoints to identify central and peripheral viewing fields. In addition, response time for the eyes (Leigh & Kennard, 2004; Sparks & Mays, 1990), hands (Barthelemy & Boulinguez, 2001, 2002a; Boulinguez, Barthelemy, & Debu, 2000; Niechwiej-Szwedo, et al., 2005), lower limbs (Terry, Charlton, & Perrone, 2008; Warshawsky-Livne & Shinar, 2002) and multiple body segments (Bard et al., 1992; Hollands & Marple-Horvat, 2001; Hollands, Ziavra, & Bronstein, 2004) will differ due to several factors, including travel distance for neural projections and

biomechanical properties (i.e. inertial of the body part). We keep these items in mind when reviewing the response time studies that follow.

Presentation of a visual stimulus within the visual field eccentric to the central fovea may cause a sophisticated ocular motor system to translate an image appearing on the peripheral retina onto fovea (Darrien, Herd, Starling, Rosenberg, & Morrison, 2001). This is achieved by the generation of saccadic eye movements, which redirect the eyes to a new position of interest, with or without the use of head movement. Several researchers have examined the influence of eccentricity of the peripheral stimulus on saccadic eye movements. Most of the research in this area involves stimulus presentation eccentric to the central fovea. Some researchers report that the latencies or RT of visually driven saccades differ according to retinal eccentricities of target stimuli (Fuller, 1996; Hodgson, 2002; Kalesnykas & Hallett, 1994). One explanation for these findings is that more peripheral targets might generate saccades with a longer latency due to the more extended conduction pathway across the retina (Darrien, et al., 2001). However, this explanation does not clarify why other researchers find no saccadic latency effects with target eccentricity (Dafoe, Armstrong, & Munoz, 2007; Fukushima, Hatta, & Fukushima, 2000). A closer look at several RT studies to eccentrically placed targets offers some insight to these findings. Table 1 shows some methodological details of these studies including whether the head was fixed or free to move, the range of eccentricities tested, the movement recording device and whether there was a RT increase or decrease with target eccentricity. One important finding observed in the table is that RT increased with increasing target eccentricities in cases where the head was not fixed, or free to move. This leads to the question, what happens to RT with eccentric targets when the head is doing the moving?

**Table 1.1** RT studies for various movements to eccentric targets

<b>Study</b>	<b>Movement</b>	<b>Head Fixed</b>	<b>Eccentricity</b>	<b>Device</b>	<b>RT with Eccentricity</b>
Fuller 1996	eyes	No	10°-80°	EOG	Increase
Hodgson 2002	eyes	Unknown	3°-9°	Eye tracker	Increase
Kalesnykas & Hallett 1994	eyes	Yes	12°-66° 0.75°-12°	Unknown	Increase No change
Fukushima et al. 2000	eyes	Yes	8°-28°	EOG	No change
Dafoe et al. 2007	eyes	Yes	0.5°-8°	Eye tracker	No change
Ishihara et al. 2002	hand	No	6°-12°	Computer mouse	Increase
Alferdinck 2006	hand	No	5°-15°	Button press	Increase
Komilis et al. 1993	Eyes & hand	Yes	30-46cm	Unknown	Increase
Helsen et al. 1997	Eyes & hand	Yes	35-45cm	Eye tracker; Button press	No change
Vercher et al. 1994	Eyes & hand	Unknown	10°-40°	EOG; a Selspot infrared system	No change
Niechwiej-Szwedo, et al. 2005	Eyes & hand	Yes	4°-33°	EOG; Button press	No change
Summala et al. 1998	Foot (Braking)	No	16°-50°	Brake pedal	Increase
Wittmann et al. 2006	Foot (Braking)	No	4.4°-50.6°	Unknown	Increase

Berg et al. 2007	Foot (Braking)	No	10°-80°	Brake pedal	Increase
Hollands et al. 2004	Eyes, head, upper body & feet	No	45°-135°	EOG; Motion analysis	Increase

Eye movements used to foveate a target within different parts of the visual field may be combined with movements of different body parts including those of the head. In these cases the eye and head work together to move toward the object of interest and response time is dependent on the movement dynamics and response latencies of both structures. When head movement is necessary to look at an object in the periphery, initiation of a saccadic eye movement usually precedes the head movement, while the amplitude of head movement is usually only about 60% to 75% of the distance to the target (Biguer, Prablanc, & Jeannerod, 1984; Gresty, 1974). The delay of head movements with respect to the beginning of a saccade has been ascribed to the large mechanical load of the head, for the neck muscles have been found to become active in synchrony with or before the start of eye movement (Suzuki & Hirai, 1998). Like ocular saccades, there are instances where the RT for head movements to visual targets decreases or increases with increasing target eccentricity. Further review of the studies suggests that this result is due to the eccentricities tested and possibly accuracy demands of the task. The decreased RT with increasing target eccentricity was observed for smaller eccentricities (10°-40°) with explicit accuracy requirements for movements, while the increased RT with increasing target eccentricity was observed between larger eccentricities tested and no noted demands for accuracy (i.e. > 40°; between 40° and 60° eccentricities, Goldring et al. 1996 and 45° and 90°, 45° and 135° and possibly 90° and 135°, Hollands et al. 2004).

Review of the literature confirms that RT increases with increasing eccentricity for eye movements and head movements when certain conditions are met. It seems evident that the head must be free to move for such eye movement latencies and that eccentricities must be fairly large (i.e. exceeding 40°) for such increases in head movement RTs to occur.

### **Away and Toward Responses**

Many investigations on the use of central and/or peripheral vision determined only perceptual responses (Ishihara, et al., 2002) or involved tasks in which moving toward a target for hitting (Bootsma & Van Wieringen, 1990; Brenner, de Lussanet, et al., 2002; Brenner, Smeets, et al., 2002; Brouwer, et al., 2000; Land & McLeod, 2000),(Brouwer, et al., 2000) (Brouwer, et al., 2006; Enns & Richards, 1997; Land & McLeod, 2000; McLeod, 1987; Niechwiej-Szwedo, et al., 2005) or catching (Amazeen, Amazeen, Post, & Beek, 1999; Bennett, Davids, & Craig, 1999; Lacquaniti & Maioli, 1989a, 1989b; Laurent, et al., 1994; Williams & McCririe, 1988) were necessary. These items are defined in the present manuscript as a TOWARD response. Few people report research on tasks in which the purpose was to move away from the target as in an AWAY response (Cooke & Graziano, 2003; Ishihara, et al., 2002; King, et al., 1992; Metoyer, Zordan, Hermens, Wu, & Soriano, 2008; Ripoll, Kerlirzin, Stein, & Reine, 1995). This is likely due to the lack of application for target avoidance during volitional movement; advancing toward a goal from what might be considered a position of offense is more common. However, many tasks require the use of avoidance techniques in isolation or in combination with accurate hitting. In the martial arts sparring partners switch from hit to avoid being hit several times within a very short time period (Mori, et al., 2002). As such, high quality motor responses of these individuals include both temporal and spatial demands. To date, few

studies report how target eccentricities affect the temporal aspects of toward and away motor responses through direct testing.

### **Defensive Responses**

There are many tasks in which goal-directed responses to different sensory stimuli include movements either toward or away from the actual stimulus. Blocking or withdrawing from sudden appearing or moving stimuli used in defensive movements are basic functions of the motor system needed for task performance. Defensive movements are common tasks used for protection and are frequently used in certain sporting situations. Moreover, the findings from temporal responses to offensive movements do not necessarily generalize to sports situations which are dynamic and involve rapidly moving visual information where avoidance is patently necessary, as in the martial arts, for example.

Defensive movements involve two distinguishable responses to stimuli used for protection: ducking or withdrawing from the direction of the stimulus or blocking an impending object with one part of the body (Cooke & Graziano, 2003; King, et al., 1992; Metoyer, et al., 2008). Withdrawing or moving away from a stimulus serves to increase the distance between the defender and stimulus before impact in an attempt to avoid the approaching object and increase the amount of time available to prepare for sequential responsive movement (Cooke & Graziano, 2003). The blocking component of defensive movements serves to deflect an impending impact. The blocking behavior reduces the distance between an approaching stimulus and affected target (Cooke & Graziano, 2003; Schiff, 1965), thus shortens the path of the stimulus. Since the goal of blocking actions involves target interception and involves movement toward an appearing or moving stimulus, they are placed in the TOWARD response category. In contrast, withdrawing

actions which describe movement away from a relevant stimulus are placed in the AWAY response category.

The TOWARD and AWAY defensive actions also correspond to two different stimulus-response (S-R) compatibility modes presented in the literature; congruent and incongruent responses. In the block the subject moves toward the visual stimulus causing a decrease in distance between an approaching stimulus and effected target forming a congruent response (Puca, Rinkenauer, & Breidenstein, 2006; Wentura, Rothermund, & Bak, 2000). In this case the subject will TOWARD the target to deflect an impending impact. Withdrawing or moving away from the visual stimulus serves to increase the distance between the defender and stimulus before impact in an attempt to AWAY the approaching object (Puca, et al., 2006; Wentura, et al., 2000). This incongruent response will also increase the amount of time available to prepare for a sequential responsive movement. In this manuscript we categorize the TOWARD response as congruent and the AWAY response as incongruent.

#### Defensive Response to Visual Cues: Central vs Peripheral vision

The ability to avoid unwanted stimuli presented in various part of visual field is a critical aspect of adaptive behavior. Defensive responses to peripheral visual cues can involve voluntary or involuntary TOWARD and AWAY responses. Seated participants playing a video game responded to suddenly appearing peripheral stimuli by rotating their heads toward or away from stimulus location (King, et al., 1992). RT for turning the head away from stimuli during avoidance movements was significantly shorter than those for orienting the head toward the target. In other study on defensive movement to looming visual stimuli standing participants fixated on a monitor located at 0° (i.e., straight ahead) with another monitor placed at 90° (i.e., near the left shoulder) during the task and were asked to “play chicken” with an approaching ball

that was projected on the computer-generated optical displays (Stoffregen & Riccio, 1990). The goal was to move only at the last possible moment to dodge the path of the ball by leaning right or left for the monitor straight ahead or forward or back for the monitor to the left, movements that would let the person avoid ball interception for different paths. Response time in central looming was significantly faster than in the periphery. In a similar voluntary heading task, participants were asked to dodge a ball by flexing the torso without rotating their eyes or head when the ball approached from various eccentricities ( $0^\circ$ ,  $20^\circ$ ,  $40^\circ$ ,  $60^\circ$ , or  $80^\circ$ ) at different velocities (1.0, 1.5, or 2.0 m/sec) (Li & Laurent, 2001). Results showed that initiation of torso flexion increased from  $0^\circ$  to  $40^\circ$  eccentricities, then decreased from  $40^\circ$  to  $80^\circ$  eccentricities, although participants successfully avoided the ball in all cases. Conflicting results may be to use of actual vs simulated stimuli, however subjects in the latter study were asked to keep their head fixed on the torso during movements. As suggested previously, allowing a free head results in increased RT with increasing eccentricities, however head stabilization has influenced RT with target eccentricity in unpredictable ways (see Table 1.1).

### Skilled-Based Differences in Defensive Responses

Studies used to examine more realistic stimuli for initiation of defensive actions in sport-specific conditions for different levels of expertise also exist and offer insight to training effects on RT (Mori, et al., 2002; Ripoll, et al., 1995; Williams & Elliott, 1999). RTs were recorded in participants performing avoid or blocking movements in response to large screen recordings of karate athletes performing offensive movements (Williams & Elliott, 1999). Response accuracy was determined by experienced coaches to judge whether participants have successfully avoided or blocked the attack. Results showed that karate experts possessed faster RTs and higher accuracy than non-experts. In a similar projection setup, participants with and without expertise



in karate were asked to decide as soon as possible whether the recorded offensive actions would be aimed at the upper or middle level of their body by pressing an appropriate key in this choice RT task (Mori, et al., 2002). The karate experts were slightly but significantly faster than those without training in responding to the video stimulus, suggesting RT training effects at least for tasks involving anticipation of the opponent's attack. Video-tapes were also used to introduce problem-solving situations simulating the natural setting of boxing (Ripoll, et al., 1995). Expert boxers had the same RT but were more accurate than intermediate and novice boxers when asked to move a joystick in a direction toward the punching movement in the video. Although these findings suggest that experts in combat sports are quicker at withdrawing and quicker and/or more accurate at blocking than those with less or no training, it is not completely clear how these differences affect true outcomes of movement performance.

### **Summary**

The purpose of the aforementioned review of literature was to gain insight to the association among response time components, visual field stimulation and defensive actions. Research showed that the two components of response time, RT and MT, were influenced by many factors including age, gender, cognitive loads, arousal states, practice and experience. It is sometimes difficult to compare these components in relation to different parts of the visual field because of several differences in central and peripheral field determination and/or the use of different target eccentricities and methodology used. However, response time to a visual stimulus was clearly influenced by the use of different body segments (the eyes, hands, and feet), concurrent use of multiple body segments, target speed, and demands on accuracy.

Because the abilities of athletes to pay attention to central and peripheral visual field information are very important for good performance in many sport situations, the response to

visual stimuli will play a role in determining quality of performance. Although some studies have been successful in identifying response differences to different visual field stimuli, others have indicated no differences. Those researchers, who investigated the use of central and/or peripheral vision, have primarily done so to determine responses for tasks which involve moving toward target location. Few have studied these responses during defensive tasks requiring avoidance or during defensive tasks requiring avoidance and interceptions. Studies involving TOWARD and AWAY responses to visual stimuli presented in different parts of the viewing field are more rare, yet would offer insight to performance of various activities, including driving and sparing as described previously.

## **CHAPTER 2: TARGET ECCENTRICITY AND STIMULUS-RESPONSE COMPATABILITY DURING QUICK YAW HEAD ROTATIONS: A TEST-RETEST RELIABILITY STUDY**

### **Introduction**

Defensive actions are common movements used for protection (King, et al., 1992; Mori, et al., 2002; Williams & Elliott, 1999) and are required for good performance in certain sporting situations. Defensive actions involving goal-directed responses to visual stimuli presented in different parts of the viewing field include movements either toward (block) or away from (withdrawal) the actual stimulus (Cooke & Graziano, 2003; King, et al., 1992; Metoyer, et al., 2008). A quick and successful block can be used to stop a goal in various team sports or shield a defender from harm in combative situations. Successful withdrawals are also observed for a player who will duck to avoid being hit by an approaching ball on a path out of bounce or a fighter who will withdraw from an incoming right hook. Good performance in each case is dependent on the ability of the performer to perceive and react to the visual input as rapidly as possible.

Table 2.1 shows the specific characteristics of the two types of defensive actions. In the block the subject moves toward the visual stimulus causing a decrease in distance between an approaching stimulus and effected target forming a congruent response (Puca, et al., 2006; Wentura, et al., 2000). In this case the subject will TOWARD the target to deflect an impending impact. Withdrawing or moving away from the visual stimulus serves to increase the distance between the defender and stimulus before impact in an attempt to AWAY the approaching object (Puca, et al., 2006; Wentura, et al., 2000). This incongruent response will also increase the amount of time available to prepare for a sequential responsive movement. Therefore, one can

categorize the type of defensive movements by outcome (TOWARD and AWAY) or the level of stimulus-response (S-R) compatibility (congruent and incongruent).

**Table 2.1** Characteristics of the two types of defensive movements

	<b>Block</b>	<b>Withdrawal</b>
Movement direction	toward the target	away from the target
Distance	decreases	increases
Categorical response	TOWARD, congruent	AWAY, incongruent

Previous behavioral studies that have attempted to examine the effect of S-R compatibility on reaction time (RT) tasks have yielded inconsistent results for suddenly appearing visual cues. For example, RT decreased when participants pressed a key when an object appeared (congruent response) compared to when they released the key (incongruent response) in simple RT tasks (Wentura, et al., 2000), while others reported no RT difference when participants moved their forearm toward a stimulus appearing on a computer screen (congruent response) compared to when they moved their forearm away from a different stimulus (incongruent response) in a 2-choice RT task (Puca, et al., 2006). Moreover, RTs for turning the head away from an approaching object (incongruent response) was significantly shorter than those for orienting the head toward the stimuli (congruent response) in a self-selected response paradigm (King, et al., 1992). These stimulus-response compatibility differences can be explained by the specific task requirements employed, as RT differences have been observed previously for the use of different response complexity, such as simple vs choice RTs (Puca, et al., 2006; Wentura, et al., 2000) and self-selected vs predetermined RTs (King, et al., 1992).

Quick defensive responses to visual stimuli require the use of all parts of the visual viewing field, making appearance of stimuli in different aspects of the viewing field a critical aspect of adaptive behavior. Although the roles of central and peripheral vision are not completely segregated (Schiefer, et al., 2001; Wall, et al., 2002), RT responses of eye movement (Schiefer, et al., 2001; Wall, et al., 2002), upper limb/hand movement (Ando, Kida, et al., 2002; Marzi, Mancini, Metitieri, & Savazzi, 2006) and lower limb/foot movement (Hollands, et al., 2004; Wittmann et al., 2006) to visual stimuli within these fields have been shown to increase with increases in eccentricity of visual stimuli. In contrast, some researchers indicate no difference in the RT of the eyes (Helsen, et al., 1997; Taniguchi, 1999) and upper limb (Niechwiej-Szwedo, et al., 2005) according to stimulus eccentricity. Methodological differences can explain these inconsistent results, including one important finding in which RT increases with increasing target eccentricities in cases where the head was free to move. This leads to the question, what happens to RT with eccentric targets when the head is doing the moving?

Table 2.2 summarizes the results of all known studies presenting head movement RT to visual stimuli located at different horizontal eccentricities. These findings show that there are instances where the RT for head movements to visual targets decreases or increases with increasing target eccentricity. Review of the different methodologies suggests that the conflicting results coincide with the eccentricities tested and/or the accuracy demands of the task. The decreased RT with increasing target eccentricity was observed for smaller eccentricities (10°-40°) with explicit accuracy requirements for movements, while the increased RT with increasing target eccentricity was observed between larger eccentricities tested and no noted demands for accuracy (i.e. > 40°; between 40° and 60° eccentricities (Goldring et al. 1996) and 45° and 90°, 45° and 135° and possibly 90° and 135° (Hollands et al. 2004)). It appears that head movement

RT increases with increasing target eccentricity that are fairly large (i.e. exceeding 40°), while RT decreases or remains the same with increasing target eccentricity that are relatively small (i.e. 40° or less). Further testing is warranted to confirm such hypotheses.

**Table 2.2** RT studies involving head movement to eccentric targets

Study	Movement	Eccentricity	Device	RT with Eccentricity
Biguer et al. 1982	Head & eyes	10°- 40°	Potentiometer & EOG	Decrease
Biguer et al. 1984	Head & eyes	10°- 40°	Potentiometer & EOG	Decrease
Goldring et al. 1996	Head & eyes	5°- 60°	Potentiometer & EOG	Increase
Hollands et al. 2004	Head, eyes, upper body & feet	45°- 135°	Motion analysis & EOG	Increase

Although previous research has lead to interesting findings regarding RT and target eccentricity, to date we found no research on whether target eccentricity influences congruent and incongruent defensive responses. Thus we plan study compatibility effects on head rotation responses to visual stimuli presented in different parts of the eccentric viewing field. To gain insight into the subdivisions of RT, we select rotational head movements as (1) they are a realistic expectation of a defensive movement (King, et al., 1992), (2) we expect no sided bias of such movement and (3) we can record from the same muscle for opposing categorical responses (i.e. records from the right sternocleidomastoid (SCM) muscle for a left head rotation will occur for a congruent movement to a right visual stimulus and for an incongruent movement to a left visual stimulus). Although we reasoned through the outcome discrepancies in previous results,

one can always question the reliability of recording techniques or of subject performance from one day to the next. Of the studies involving RT measures for yaw head rotations and the associated neck muscles, there have been no known investigations which addressed the reproducibility of these measures in a between day test-retest reliability study. Therefore, the specific purpose of the current experiment was to describe the between day reliability of two primary measures (RT of yaw head rotation and neck muscle (SCM) EMG) for congruent and incongruent rotational head movement responses to eccentrically placed visual stimuli. With reliability of two choice RT to visual stimuli over a 1-13 day between test protocol of  $r = 0.79$  (Iverson, Lovell, & Collins, 2003) and reliability of peroneous longus muscle EMG RT to passive ankle inversions over 1 week between two sessions of  $ICC = 0.71$  (Eechaute, Vaes, Duquet, & Van Gheluwe), we hypothesized excellent agreement levels ( $> 0.75$ , (Eechaute, et al., 2007; Iverson, et al., 2003)) for intra-subject reliability on primary measures.

## **Methods**

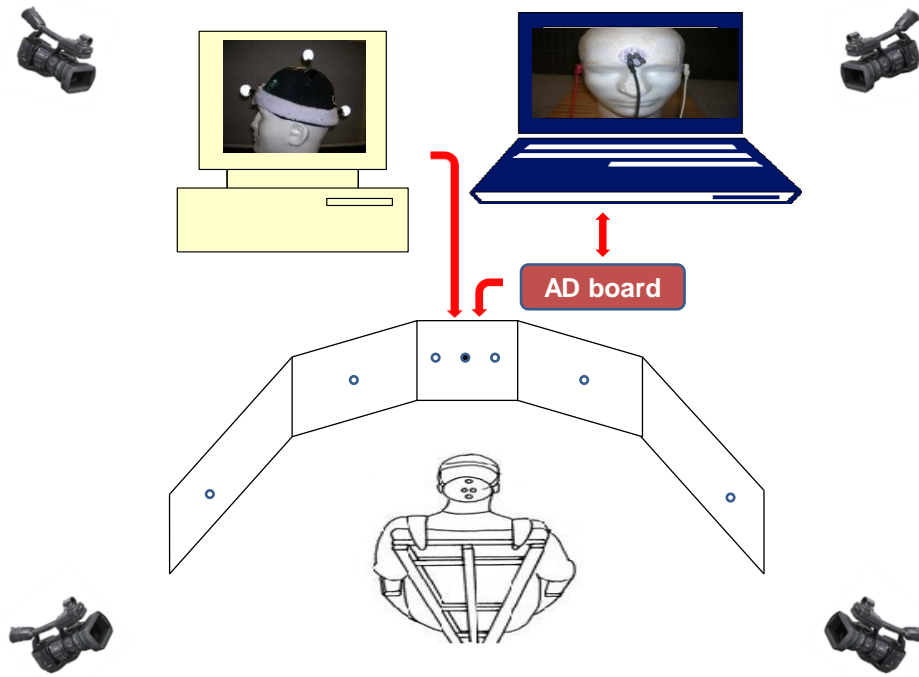
### **Subjects**

Sixteen healthy subjects (ten males, six females; age range 19-25 years, mean = 22.43 years) with no known pathologies volunteered to participate in this study. Visual acuity of each subject was obtained to ensure normal or corrected to normal vision. Each subject gave written informed consent prior to participation in the experimental protocol approved by the Internal Review Board at Louisiana State University.

### **Task**

After warming up subjects were instructed to perform yaw head rotations as rapidly as possible in response to a suddenly appearing visual stimulus presented in different portions of the

eccentric horizontal hemi-field. Subjects were asked to make a complete horizontal head rotation regardless of target eccentricity in an attempt to keep amount of rotation similar across trials. The experiment consisted of two response conditions: TOWARD and AWAY conditions. In the TOWARD condition subjects rotated their head in the direction ipsilateral to target appearance for a congruent response. In the AWAY condition subjects rotated their head contralateral to target appearance for an incongruent response.



**Figure 2.1** Experimental set-up. Head marker locations (left monitor), EOG setup (right monitor), approximate camera locations (4 corners) and subject, fixation point (solid central circle) and target locations (open circles) are shown.

Figure 2.1 shows the experimental setup. Subjects sat with their trunk strapped to a chair back facing the center of the visual field ( $0^\circ$ ) where a green circle served as the visual fixation point. Six red light-emitting diodes (LEDs) 4 mm in diameter served as eye-level targets located



at left and right eccentricities of 4°, 20° and 80°. Radial distance between targets and the nasion of the subject was 1.5 m. The task was performed in a dimly lit room.

**Table 2.3** Number of trials for target eccentricity, target direction and condition

Condition	Target	Target	Total trials
	direction	eccentricity	
TOWARD	Left	80°	9
		20°	9
		4°	9
	Right	4°	9
		20°	9
		80°	9
AWAY	Left	80°	9
		20°	9
		4°	9
	Right	4°	9
		20°	9
		80°	9
Total			108

A trial proceeded as follows. A verbal "ready" signal was given after initial fixation for the first trial in a block. After a 1, 2 or 3 s delay, 1 of the 6 targets was illuminated for 50 ms to signal the subject to perform a yaw head rotation as rapidly as possible. Subjects held the rotated position for about 1 second before rotating their head back to a neutral position to fixate the central circle. Subjects were given 2 seconds to complete the movement, hold and return to

fixation before the next delay period started. The short duration for target display was used to prevent target fixation during and after head rotations, while the inter-trial interval was varied to minimize anticipatory responses. A customized program was used to control target presentation. Before data collection began in each condition (TOWARD or AWAY), subjects warmed up by practicing 6 trials in the given condition at comfortable, faster and fast as possible speeds.

Half the subjects completed all trials for the TOWARD condition prior to the AWAY condition, while the remaining subjects completed trials in the AWAY condition prior to the TOWARD condition. Subjects performed 9 trials to each target (left and right eccentricities of 4°, 20°, and 80°) in each condition (TOWARD and AWAY) for a total of 108 trials each visit (Table 2.3). Trials were presented in 9 blocks for each condition so that each block consisted of 6 trials. Trial randomization was across every 3 blocks.

Rest periods between blocks lasted one minute. Although encouragement to make complete right or left head rotations and to move as quick as possible were given between each block, no feedback was given on performance. An investigator monitored head marker movements on a computer screen online to ensure subject movement in the proper direction. For a single mistake (incorrect direction or no response) within a block, the trial was excluded from analyses. Complete blocks were repeated for several mistakes within a block (7 blocks were repeated for 4 subjects) or when technical difficulties occurred with recordings (7 blocks were repeated for 5 subjects).

Subjects completed the same test protocol in a different order on a second visit to determine intra-subject between day test-retest reliability on the primary and secondary variables of interest. Subjects who performed trials in the TOWARD condition first on the first visit

performed trials in the AWAY condition first on the second visit and vice-versa. The intervals between the first and second visits were 13-15 days.

## Data Collection

Neck muscle activity was measured along with head and eye movements during task performances. Bilateral EMG (Electromyography) activity was recorded at 1000 Hz (Biopac systems, Goleta) from the left and right sternocleidomastoid (SCM) muscles. Similar to previous work (Oude Nijhuis et al., 2007) we used 2 pairs of 10 mm diameter disposable surface electrodes (Nikomed USA Inc. Doylestown, PA) spaced 2 cm apart (center-to-center). The electrodes were placed equidistant between the mastoid process and the medial end of the clavicle (Harvey & Peper, 1997), while the ground electrodes were placed on the left and right acromion. In addition 3D movements of markers placed on the head were recorded at 240 Hz from using a 4 camera Qualisys motion analysis system (Qualisys Medical AB, Gothenburg). Three reflective markers were mounted in the sagittal plane on the front, top, and back of a cap worn by the subjects (see Fig. 2.1). Horizontal movements of the eyes were also recorded with EOG (electrooculography). Electrodes for EOG recordings were applied to the left and right outer canthi to measure horizontal eye position with the ground electrode attached to the center of the forehead similar to other studies (Fukushima, et al., 2000). Recordings represent the corneal-retinal potential, which changes with respect to the reference electrode during horizontal eye movement. EOG signals were DC amplified and sampled at 1000 Hz with the Biopac. EMG and EOG signals were also sent via an A/D board for synchronization with the head movement data at 240 Hz (Qualisys Medical AB, Gothenburg).

## Variables Developed to Analyze Data

Variables of interest included primary and secondary measurements. The primary measures included reaction time (RT) and premotor reaction time (Premotor RT) of yaw head rotation, as it is the analyses of these variables that will be used to answer hypotheses of the primary experiments (Chapters 3 and 4). The saccadic reaction time (SRT) of eye movement, electromechanical delay (EMD), movement time (MT), excursion (EXC) and peak velocity (VEL) of yaw head rotation were selected as secondary measures to offer insight to task performance. The following text offers a description of how each variable was calculated.

(1) RT was determined as the time interval in ms between the onset of the visual stimulus and the beginning of the movement of head. It has also been termed EMG RT in previous work (Murakami, 2010).

(2) Premotor RT was determined as the time interval in ms between the onset of the visual stimulus and the first discernable change in electrical activity of the SCM agonist. It has also been termed EMG RT in previous work (Murakami, 2010).

(3) SRT was determined as the time interval in ms between the onset of the visual stimulus and the first discernable change in electrical activity of the EOG trace.

(4) EMD was determined as the time interval in ms between the start of the EMG activity and the beginning of the movement of head. It has also been termed motor RT elsewhere (Murakami, 2010).

(5) MT was determined as the interval of time in ms between the initiation and completion of head movement.

(6) EXC was determined as the amount of yaw head rotation in radians between the initiation and completion of head movement.

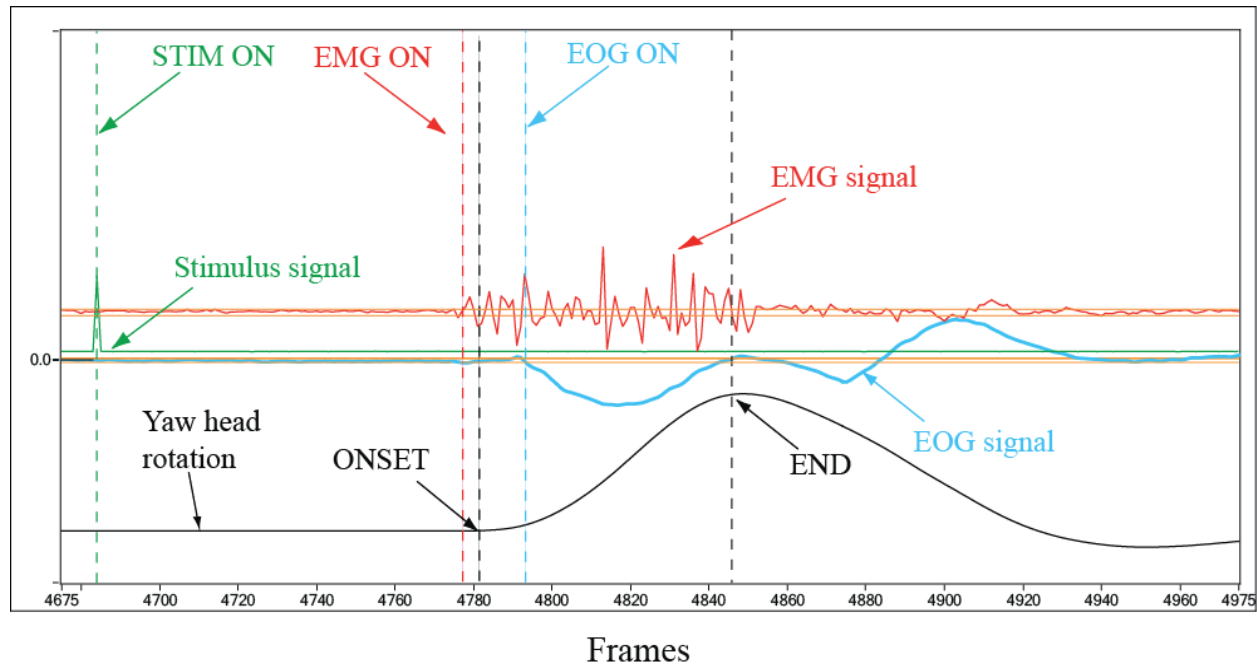
(7) VEL was determined as the maximal yaw head rotational velocity in radians/s between the initiation and the completion of head movement.

## Data Analyses

Position data of head markers were filtered using a zero-phase lag 10 point averaging process. Tangential velocity profiles were calculated using five point differentiation of the filtered position data. Synchronized EMG signals were highpass filtered at 15 Hz (Oude Nijhuis, et al., 2007), while synchronized EOG signals were filtered through a 0.1-40 Hz bandpass filter (Felblinger et al., 1996). Mean EMG and EOG values and standard deviations (SD) were determined at baseline 200 ms prior to the visual stimulus onset. Stimulus presentation, EMG, EOG and the yaw position data and the baseline mean  $\pm$  2.5 SD for EMG and EOG signals were plotted across time, visually scanned and marked to determine points of interest using a customized LabView program (see Fig. 2.2). Frames were marked when signals deviated from baseline more the 2.5 SD for the first time for more than 50 ms (Oude Nijhuis, et al., 2007) to determine EMG onset (EMG ON) and for more than 30 ms to determine EOG onset (EOG ON). The onset of the stimulus (STIM ON) was marked at the frame where the stimulus signal increased. The onset of head movement (ONSET) was marked at the frame just prior to the yaw head rotation signal change in the appropriate direction, while movement end (END) was determined as the frame just after the last frame of yaw head rotation change for the given direction. Note that onset of eye movement occurred after that of head movement and that it was relatively smooth overtime (see blue plot, Fig. 2.2). These findings were identified across all

trials and suggest no evidence for saccadic eye movements in subjects for the given task.

Accordingly SRT data were discarded and not analyzed further.



**Figure 2.2** Markings for one trial. Data for the stimulus signal (green), EMG signal (red) on the affected side, EOG signal (blue) and yaw head rotation profiles (black) used for identifying time marks needed to calculate variables of interest. Data are from one trial in TOWARD condition (subject 6). STIM ON (vertical green dashed line) = stimulus onset; EMG ON (vertical red dashed line) = onset of EMG; EOG ON (vertical blue dashed line) = onset of eye movement; ONSET (left vertical black dashed line) = onset of head movement; and END (right vertical black dashed line) = end of head movement.

We used one investigator to mark all trials to limit errors in data reduction. One block of trials for a subject was marked 3 different times on a single day (morning, evening and night) and variables of interest were calculated to quantify such errors and determine the within rater consistency.

Trials were rejected and eliminated from analyses if muscle activity preceded stimulus onset or if onset of muscle activity could not be determined due to inadequate EMG recordings. About 4% of the trials were discarded from analyses because of subject mistakes or inadequate recordings (138 trials for 16 subjects). In order to filter for outliers we first defined the

interquartile range (IQR) as the difference between the first and the third quartile,  $Q3 - Q1$  for EXC and VEL variables. These variables were chosen according to instructions for subjects: to make a complete head rotation as fast as they can. As suggested in the literature, we multiplied the IQR by 1.5 to identify any values  $1.5 \times \text{IQR}$  below  $Q1$  and above  $Q3$  as outliers (Rosner, 1986) and discarded them from analyses. Three percent of the trials were identified as outliers (109 trials for 15 subjects). This left us with 93% of the trials to test hypotheses and describe the task performance.

### Statistical Analyses

To quantify errors due to data reduction, records from 1 block of 1 subject (6 trials) was marked on 3 separate occasions. Intraclass correlation coefficients (ICC) were determined for each variable of interest to determine the intra-rater reliability.

Between day test-retest reliability on the variables of interest was assessed with a Pearson's correlation coefficient ( $r$ ) and an intraclass correlation (ICC) (Shrout & Fleiss, 1979). The Pearson correlation measures associations between variables by assessing between-subject variance. However, the ICC will be a more realistic estimate of agreement if there is considerable individual variation in scores from first test to second test because it assesses the within-subject variance (Bartko, 1991). Both statistics are reported to account for between and within-subject variance. Both calculations produce a value between zero and 1; values closer to 1 indicate less error variance and stronger reliability. Recommendations for the more conservative ICC interpretation are diverse. We used the ratings suggested by Shrout and Fleiss on agreement levels: poor,  $< 0.40$ ; fair to good,  $> 0.40$  and  $\leq 0.75$ ; and excellent,  $> 0.75$  (Shrout & Fleiss, 1979). These levels have been used in recent studies to investigate RT reliability (Eechaute, et al.,

2007; Eechaute, Vaes, Duquet, & Van Gheluwe, 2009; Mercer, Hankins, Spinks, & Tedder, 2009) similar to the present work. A paired student's *t* test was also performed on each variable of interest to investigate systematic outcome biases between visits (Hopkins, 2000).

In this study, correlations for each measure were performed on the average values for each subject,  $N = 16$  cases, to evaluate the overall repeatability of the test. However, we also computed correlations based on the average values for each condition and subject, which treats each condition for each subject as a separate case,  $N = 2 \times 16 = 32$  cases and the average values for each eccentricity, condition and subject, which treats each eccentricity within each condition for each subject separately,  $N = 6 \times 2 \times 16 = 192$  cases. The latter scenario utilizes average data to be used in experiments in which we test the effects of stimulus-response compatibility and target eccentricity on primary and secondary measures.

Pearson's correlations and *t* tests were performed using Statistica (version 6.0, StatSoftInc., Tulsa, Usa) and ICC were assessed using SPSS (version 11.0, SPSS Inc., Chicago, Usa) to compute ICCs. The level of significance was set a priori at  $p < 0.05$ .

## **Results**

We used one investigator to mark all trials to limit errors in data reduction. Table 2.4 showed the results of the within rater consistency for each measure. The ICC values for each measure were stable among morning, evening and night on a single day.



**Table 2.4** ICC correlations for intra-rater consistency

RT (s)	Premotor RT (s)	EMD (s)	MT (s)	EXC (rad)	VEL (rad/sec)
<b>0.99**</b>	<b>0.99**</b>	<b>0.96**</b>	<b>0.95**</b>	<b>0.97**</b>	<b>1.00**</b>

The ICCs for each measure are shown. Data from 1 block of 1 subject (6 trials) used in analyses were marked three different times on a single day (morning, evening and night). Bold text represents a significant correlation among three times ( $p < 0.01$ ). \*\*excellent reliability.

Table 2.5 shows the EXC and VEL ranges for 16 subjects on 1<sup>st</sup> and 2<sup>nd</sup> visits for a more direct qualitative comparison of these measurements between the 2 visits. Thirteen of 16 subjects had larger range of yaw head excursion on first visit compared to the second visit. A similar pattern of yaw head rotation across subjects was observed such that the low EXC on first visit of 0.511 radians (29°) was smaller than the low EXC on the second visit of 0.765 radians (44°), while the high EXC on the first visit of 1.706 radians (98°) was larger than the high EXC on the second visit of 1.657 radians (95°). For peak rotational velocity measures only 9 of the 16 subjects revealed a higher VEL range on the first visit than on their second visit. The overall low (3.692 radians/s) and high (14.259 radians/s) VEL measurements on the first visit increased slightly on the second visit (low = 4.263 radians/s and high = 15.756 radians/s). This qualitative comparison reveals individual subject and visit differences not necessarily captured in the quantitative comparisons for the mean data presented next.

**Table 2.5** High and low values of EXC and VEL for each subject on 1<sup>st</sup> and 2<sup>nd</sup> visits

Sub	EXC		VEL	
	1 <sup>st</sup>	2 <sup>nd</sup>	1 <sup>st</sup>	2 <sup>nd</sup>
1	0.946-1.554	1.133-1.567	8.725-13.174	8.636-13.278
2	0.958-1.365	1.069-1.465	7.944-11.187	7.479-12.631

3	0.996-1.680	0.797-1.269	9.239-14.030	8.156-10.848
4	0.834-1.336	0.868-1.499	6.598-11.171	8.252-15.756
5	1.088-1.617	1.306-1.657	7.682-10.914	5.982-9.638
6	1.086-1.451	1.071-1.398	9.611-14.031	9.397-12.755
7	1.307-1.645	1.024-1.645	8.609-11.265	8.537-11.489
8	0.758-1.251	0.875-1.239	5.129-10.013	5.744-10.141
9	1.020-1.312	1.006-1.271	5.548-8.017	5.592-7.842
10	0.995-1.529	1.195-1.542	6.517-10.114	7.891-10.996
11	1.108-1.409	1.021-1.386	10.310-13.305	10.069-12.834
12	1.117-1.398	1.206-1.467	6.423-9.298	7.123-10.372
13	0.511-1.246	0.765-1.188	5.503-11.884	5.965-10.872
14	0.723-1.307	1.232-1.530	6.765-9.983	9.289-11.212
15	1.086-1.706	1.161-1.550	8.963-14.259	10.351-14.164
16	0.750-1.466	0.924-1.317	3.692-7.442	4.263-8.202

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Table 2.6 shows the means and standard deviations of the primary and secondary variables for each visit. RT, Premotor RT, MT, EXC and VEL of second visit were slightly higher than the first visit only for comparisons in which condition, eccentricity and subject were treated as separate cases. On average subjects responded 13 ms slower, took 9 ms longer to rotate their heads, had 0.299 radians/s larger peak rotational head velocities and 0.033 radians (1.9°) larger yaw head excursions on the second visit.

**Table 2.6** Means (SD) of primary and secondary measures

	N=16		N=32		N=192	
	1 <sup>st</sup>	2 <sup>nd</sup>	1 <sup>st</sup>	2 <sup>nd</sup>	1 <sup>st</sup>	2 <sup>nd</sup>
RT (s)	0.364 (0.050)	0.378 (0.056)	0.364 (0.056)	0.377 (0.060)	<b>0.364</b> <b>(0.062)</b>	<b>0.377</b> <b>(0.065)</b>
Premotor RT (s)	0.308 (0.047)	0.319 (0.058)	0.308 (0.052)	0.319 (0.061)	<b>0.308</b> <b>(0.059)</b>	<b>0.320</b> <b>(0.066)</b>
EMD (s)	0.055 (0.012)	0.058 (0.010)	0.055 (0.012)	0.058 (0.010)	0.055 (0.013)	0.060 (0.011)
MT (s)	0.317 (0.088)	0.327 (0.101)	0.317 (0.089)	0.327 (0.102)	<b>0.318</b> <b>(0.089)</b>	<b>0.327</b> <b>(0.102)</b>
EXC (rad)	1.207 (0.167)	1.238 (0.150)	1.207 (0.171)	1.238 (0.152)	<b>1.207</b> <b>(0.176)</b>	<b>1.240</b> <b>(0.158)</b>
VEL (rad/s)	9.253 (1.890)	9.552 (1.843)	9.255 (1.881)	9.552 (1.850)	<b>9.253</b> <b>(1.884)</b>	<b>9.552</b> <b>(1.856)</b>

Means and standard deviations for various measures are provided. Significant results of *t* tests between 1<sup>st</sup> and 2<sup>nd</sup> visits are identified in bold text. N-number of means used in analyses (see text for details); 1<sup>st</sup>-first visit; 2<sup>nd</sup>-second visit. RT = reaction time; Premotor RT = premotor reaction time; EMD = electromechanical delay; MT = movement time; EXC = excursion; VEL = peak velocity.

Table 2.7 shows the Pearson correlations and ICCs for each measure, thus the main results of the test-retest reliability. Analyses on single subject means (N = 16), condition by subject means (N = 32) and eccentricity by condition by subject means (N=192) are shown. For all measures Pearson correlations were the same or larger than ICC values, as expected. Coefficients are highest for all variables for analyses on the averaged data for the single subject means, indicating greater consistency in these comparisons. Most correlations were significant and were above the minimum value (0.40) to achieve fair-good reliability (Shrout & Fleiss, 1979). Of these data results show slightly greater variability for EXC. In contrast the ICC and

Pearson correlations of the EMD were not significant for analyses on the single subject mean comparisons and were only designated as poor on the reliability scale in the remaining cases (Shrout & Fleiss, 1979). As a result, the greatest within and between subject variability was identified for this measure.

**Table 2.7** Intra-subject correlations

	Pearson correlation			ICC correlation		
	N=16	N=32	N=192	N=16	N=32	N=192
RT (s)	<b>0.82**</b>	<b>0.78**</b>	<b>0.74*</b>	<b>0.81**</b>	<b>0.78**</b>	<b>0.74*</b>
Premotor RT (s)	<b>0.84**</b>	<b>0.80**</b>	<b>0.75**</b>	<b>0.83**</b>	<b>0.79**</b>	<b>0.74*</b>
EMD (s)	0.39	<b>0.37</b>	<b>0.35</b>	0.38	<b>0.36</b>	<b>0.34</b>
MT (s)	<b>0.83**</b>	<b>0.82**</b>	<b>0.80**</b>	<b>0.83**</b>	<b>0.81**</b>	<b>0.79**</b>
EXC (rad)	<b>0.66*</b>	<b>0.64*</b>	<b>0.62*</b>	<b>0.65*</b>	<b>0.63*</b>	<b>0.62*</b>
VEL (rad/s)	<b>0.82**</b>	<b>0.80**</b>	<b>0.78**</b>	<b>0.82**</b>	<b>0.80**</b>	<b>0.78**</b>

The Pearson correlations and ICCs between first and second visits for each measure are shown. N is based on the average values for 16 cases, 32 cases and 192 cases. Bold text represents a significant correlation for first and second visits ( $p < 0.01$ ). No asterisk indicates poor reliability; \*fair to good reliability; \*\*excellent reliability. RT = reaction time; Premotor RT = premotor reaction time; EMD = electromechanical delay; MT = movement time; EXC = excursion; VEL = peak velocity.

## **Discussion**

Measurements of RT can offer key insights into defensive responses to visual stimuli for sporting and combative situations. Measurements of congruent and incongruent rotational head

movements provide a natural response that has occurred in defensive movements for monkeys (Cooke & Graziano, 2003) and humans (King, et al., 1992), however little information pertaining to responses of these movements are provided in the literature. This study was designed to test the reproducibility of these responses used in a between day test-retest reliability scheme prior to testing effects of S-R compatibility utilizing visual stimuli presented in different parts of the viewing field.

In this study, we found that our primary measures of RT and Premotor RT and secondary measures of MT, EXC and VEL of head rotational movement were relatively stable over a two week period. These findings were true regardless of trial order presentation and whether performing the TOWARD or AWAY condition first, which were randomized among subjects as would be expected in such a study. During data collection we controlled for potential location/background influences on performances (Jaskowski & Sobieralska, 2004; Trimmel & Poelzl, 2006) by performing tests in the same environment and during data analyses we controlled for potential inter-rater bias by having one investigator reduce the data and prepare it for analyses. We expect that these factors contributed to the high level reliability observed in the current study.

The present results provided support for the hypothesis that we would observe excellent agreement reliability levels on our primary measures. RT r-values from 0.74-0.82 corresponded well to the 0.79 value presented previously for a 1-13 day between test reliability study involving a two choice RT to visual stimuli when participants pressed a key (Iverson, et al., 2003). Although slightly larger, the premotor RT ICC values from 0.74-0.84 also corresponded well to previous work where reliability of the peroneous longus muscle EMG RT to passive ankle inversions of ICC = 0.71 was reported (Eechaute, et al., 2007). Together with reliability on our

primary measures, good and excellent agreement level of ICC for MT (0.79-0.83), EXC (0.62-0.66) and VEL (0.78-0.82) also confirm the applicability of the measurement techniques and protocol. To our knowledge, this study is the first to examine the test-retest reliability of MT, EXC and VEL for head rotations. The ICCs for the EMD of passive ankle movements of 0.55 (Eechaute, et al.) and for the EMDs of the SCM during maximal lateral head bending (0.68) and flexion (0.52) in a 7-8 day test-retest protocol (Almosnino, Pelland, Pedlow, & Stevenson, 2009) exceeded those of the present work (ICC range = 0.34-0.38). However, correlation values for EMD of the present work were comparable to the 0.31 ICC value for the EMD of maximal voluntary SCM contractions during head protraction observed (Almosnino, et al., 2009). The discrepancy in the EMD results can be attributed to methodological differences, which include the use of different body segments and different tasks (self-selected initiation vs response to visual or acoustic signal). While the reasons for the poor reliability of EMD using EMG are not completely clear, it is possible that providing more practice in the direction specified during the pre-testing procedures could improve outcomes (Almosnino, et al., 2009).

Interestingly, the excellent reliability values identified for RT, Premotor RT, MT, EXC and VEL were also associated with subtle differences in these measures between visits that could only be determined when data were separated for condition, eccentricity and subject. Review of the data shows that these outcomes were clearly due to the increased power associated the increased numbers, as the means and standard deviations were almost exactly the same for the different comparisons (Table 2.6).

Subjects in the present study had difficulty making similar yaw head excursions across trials within each visit (Table 2.5). These findings are best explained by the experimental setup. First, subjects were given no instructions regarding eye movements. Although the room was

dimly lit, the surrounding environment at eye level was quite similar and would not offer a specific external cue to help subjects maintain fixation at the same location to help with the amount of head excursion across trials if they did choose to focus on an external target. Second, subjects received no feedback regarding the final excursion of the head. When no feedback from performance is available, amplitude control can worsen (Keele, 1968). Apparently, it did worsen for our subjects.

In conclusion, the results of this reliability study suggest that the primary measures of RT and Premotor RT and secondary measures of MT, EXC and VEL of head rotational movement can be measured with an acceptable level of precision using the current methodology. Based on these results, we plan to utilize these measurements in subsequent investigations in which we test the effects of S-R compatibility and target eccentricity on primary and secondary measures as well as explore relevant changes in these measures with extended practice.

## **CHAPTER 3: THE INFLUENCE OF TARGET ECCENTRICITY AND STIMULUS-RESPONSE COMPATIBILITY DURING QUICK YAW HEAD ROTATIONS**

### **Introduction**

People use defensive movements to protect themselves against various stimuli presented in different parts of their viewing field. In combative situations people can attempt to duck or dodge an approaching stimulus to avoid it, or try to hit it by blocking or batting the stimulus away. Although the accuracy demands increase for contact with a target compared to the multiple directions that one can avoid an approaching target, the outcome in these situations is AWAY from or TOWARD the stimulus. One can categorize the type of defensive movements by outcome or the level of stimulus-response (S-R) compatibility. The corresponding S-R compatibility response involves moving away from the stimulus for an incongruent response as in the AWAY situation or moving toward the stimulus for a congruent response as in the TOWARD situation. Each response will depend on the task requirements, yet also be influenced by the stimulus location within the visual field.

Effects of location of the stimulus presentation in various parts of the visual field on reaction time (RT) have yielded inconsistent responses in laboratory settings. Some researchers indicate no difference in response abilities according to stimulus eccentricity (Ando, Kida, et al., 2002; Ando, et al., 2004; Ando, Kokubu, et al., 2002; Helsen, et al., 1997; Niechwiej-Szwedo, et al., 2005; Taniguchi, 1999), while others show differences (Dafoe, et al., 2007; Fukushima, et al., 2000). Most studies involve tasks in which moving toward a target as in a congruent response for hitting (Enns & Richards, 1997; Land & McLeod, 2000; McLeod, 1987; Niechwiej-Szwedo, et al., 2005) or catching (Amazeen, et al., 1999; Bennett, et al., 1999) were necessary. Despite its importance for defensive actions, few people report research on tasks in which the purpose was



to move away from the target as in an incongruent response (King, et al., 1992; Metoyer, et al., 2008).

As mentioned previously, defensive actions can be characterized by the level of S-R compatibility. Although observing level of S-R compatibility does not necessarily indicate an action is defensive, the associated outcomes can offer insight to the responsive actions. In one study simple RT decreased when participants pressed a computer key in response to a suddenly appearing stimulus (congruent response) compared to when they released it (incongruent response) (Wentura, et al., 2000). In contrast, no RT differences were observed for a 2-choice response paradigm where participants extended their forearm toward a suddenly appearing picture indicating a pleasant occurrence (congruent response) or flexed it away from a suddenly appearing picture indicating an unpleasant occurrence (incongruent response) (Puca, et al., 2006). Although these results provide insight to S-R compatibility outcomes, they do not involve common features of defensive movements, including the type of response observed and the use of various parts of the visual field. Head and eye movement responses have been recognized as a more direct indicator for defensive movement than moving a joystick or pressing and releasing a button (Cooke & Graziano, 2003; King, et al., 1992), thus would offer more generalized outcomes in this regard. In one such study RTs for turning the head away from an approaching object from right side of the subject's head in the peripheral visual field (incongruent response) was significantly shorter than those for orienting the head toward the stimuli (congruent response) in a self-selected response paradigm (King, et al., 1992). Therefore, RT differences for S-R compatibility differed for different response complexities, including simple (Wentura, et al., 2000) vs choice RTs (Puca, et al., 2006) and RTs for self-selected vs predetermined responses (King, et al., 1992).

Several questions remain in regards to associations among response time components, visual field stimulation and defensive actions. Although MT is an important component of responding to stimuli, there is still a lot to be learned about RT in these situations. It is the latter measure that is of primary interest in the present work. Accordingly, the goal of the current study was to investigate the effects of target eccentricity on RT to visual stimuli during congruent and incongruent responses. Specifically, we studied the response of quick yaw head rotations toward (TOWARD) and away from (AWAY) visual stimuli presented in different parts of the viewing field to gain better insight to defensive reactions to eccentric stimuli. Review of the literature shows that head movement RT increases with increasing target eccentricity for fairly large target eccentricities (i.e. exceeding 40°), while RT decreased or remained the same with increasing target eccentricity that are relatively small (i.e. 40° or less). Since we plan to compare responses to targets located in small and large eccentricities, we hypothesized that RT to visual stimuli would increase with large target eccentricities. We also hypothesized that performances in the AWAY condition will have a shorter RT to visual stimuli than performances in the TOWARD condition.

## **Methods**

Most methods for this study were the same as those observed in Chapter 2 and are reiterated below for the reader's convenience. In fact, it was the data from visit 1 that were analyzed to determine the effects of target eccentricity and S-R compatibility on quick yaw head rotational responses.

## Subjects

Sixteen healthy subjects (ten males, six females; age range 19-25 years, mean = 22.43 years) with no known pathologies volunteered to participate in this study. Visual acuity of each subject was obtained to ensure normal or corrected to normal vision. Each subject gave written informed consent prior to participation in the experimental protocol approved by the Internal Review Board at Louisiana State University.

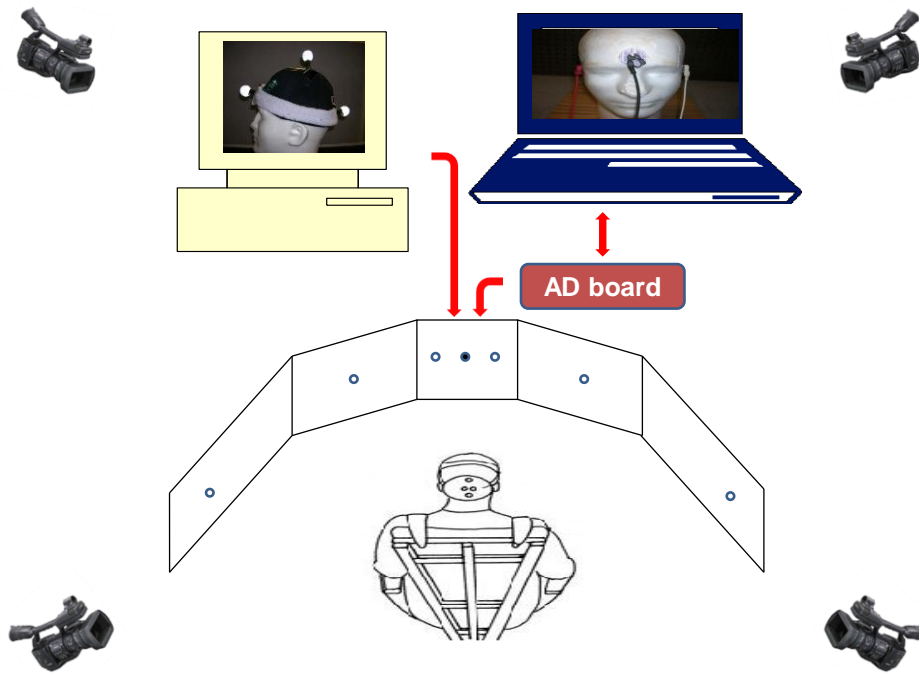
## Task

After warming up, subjects were instructed to perform yaw head rotations as rapidly as possible in response to a suddenly appearing visual stimulus presented in different portions of the eccentric horizontal hemi-field. Subjects were asked to make a complete horizontal head rotation regardless of target eccentricity in an attempt to keep amount of rotation similar across trials. The experiment consisted of two response conditions: TOWARD and AWAY conditions. In the TOWARD condition subjects rotated their head in the direction ipsilateral to target appearance for a congruent S-R response. In the AWAY condition subjects rotated their head contralateral to target appearance for an incongruent S-R response.

Figure 3.1 shows the experimental setup. Subjects sat with their trunk strapped to a chair back facing the center of the visual field ( $0^\circ$ ) where a green circle served as the visual fixation point. Six red light-emitting diodes (LEDs) 4 mm in diameter served as targets located at eye level at left and right eccentricities of  $4^\circ$ ,  $20^\circ$  and  $80^\circ$ . Radial distance between targets and the subject was 1.5 m. The task was performed in a dimly lit room.

A trial proceeded as follows. A verbal "ready" signal was given after initial fixation for the first trial in a block. After a 1, 2, or 3 s delay, one of the 6 targets was illuminated for 50 ms

to signal the subject to perform a yaw head rotation as rapidly as possible. Subjects held the rotated position for about 1 second before rotating their head back to a neutral position to fixate the central circle. Subjects were given 2 seconds to complete the movement, hold and return to fixation before the next delay period started. The short duration for target display was used to prevent target fixation during and after head rotations, while the inter-trial interval was varied to minimize anticipatory responses. A customized program was used to control target presentation. Before data collection began in each condition (TOWARD or AWAY), subjects warmed up by practicing 6 trials in the given condition at comfortable, faster and fast as possible speeds.



**Figure 3.1** Experimental set-up. Head marker location (left monitor), EOG setup (right monitor), approximate camera locations (4 corners) and subject, fixation point (solid central circle) and target locations (open circles) are shown.

Half the subjects completed all trials for the TOWARD condition prior to the AWAY condition, while the remaining subjects completed trials in the AWAY condition prior to the TOWARD condition. Subjects performed 9 trials to each of 6 target locations (left and right

eccentricities of 4°, 20°, and 80°) in each condition (TOWARD and AWAY) for a total of 108 trials on one visit (Table 3.1). Each block consisted of 6 trials, however every 18 trials were randomly presented to help prevent predictive responses.

**Table 3.1** Trial numbers for targets and direction for each condition

Condition	Direction of target	Target eccentricities	Total trials
TOWARD	LEFT	4°	9
		20°	9
		80°	9
	RIGHT	4°	9
		20°	9
		80°	9
AWAY	LEFT	4°	9
		20°	9
		80°	9
	RIGHT	4°	9
		20°	9
		80°	9
Total			108

Rest periods between blocks lasted 1 minute. Although encouragement to make complete head rotations to the given side and to move as quick as possible were given between each block, no feedback was given on performance. An investigator monitored head marker movements on a computer screen online to ensure subject movement in the proper direction. Blocks were

repeated when technical difficulties occurred with recordings (2 blocks were repeated for 2 subjects) or if a subject did not respond to the stimuli or the direction response was incorrect for more than 1 trial in the block (5 blocks were repeated for 3 subjects). However, if a subject did not respond to the stimuli or the direction response was incorrect for only 1 trial in the block, the trial was excluded from analyses. Trials were also rejected if muscle activity preceded stimulus onset or if onset of muscle activity could not be determined due to inadequate EMG recordings when data were analyzed.

## Data Collection

Neck muscle activity and head and eye movements were measured during task performance. Bilateral EMG (Electromyography) activity was recorded at 1000 Hz (Biopac systems, Goleta) from the left and right sternocleidomastoid (SCM) muscles. Similar to previous work (Oude Nijhuis, et al., 2007) we used 2 pairs of 10 mm diameter disposable surface electrodes (Nikomed USA Inc. Doylestown, PA) spaced 2 cm apart (center-to-center). The electrodes were placed equidistant between the mastoid process and the medial end of the clavicle (Harvey & Peper, 1997). The ground electrodes were placed on the left and right acromion. In addition, three dimensional head movements were recorded at 240 Hz from 3 reflective markers mounted on a cap worn by the subjects using a 4 camera Qualisys motion analysis system (Qualisys Medical AB, Gothenburg). Markers were placed in a sagittal plane on the front, top, and back of the head (see Fig. 3.1). Horizontal movements of the eyes were also recorded with electro-oculography (EOG). Electrodes for EOG recording were applied to the left and right outer canthi to measure horizontal eye position with the ground electrode attached to the center of the forehead similar to other studies (Fukushima, et al., 2000). Recordings represent the corneal-retinal potential, which changes with respect to the reference electrode during

horizontal eye movement. EOG signals were DC amplified and sampled at 1000 Hz with the Biopac. EMG and EOG signals were also sent via an A/D board for synchronization with the head movement data at 240 Hz (Qualisys Medical AB, Gothenburg).

#### Variables Developed to Analyze Data

Variables of interest included primary and secondary measurements. The primary measures included reaction time (RT) and premotor reaction time (premotor RT) of yaw head rotation, The saccadic reaction time (SRT) of eye movement and the electromechanical delay (EMD), movement time (MT), excursion (EXC) and peak velocity (VEL) of yaw head rotation were selected as secondary measures to offer insight to task performance. The following text offers a description of how each variable was calculated.

(1) RT was determined as the time interval in ms between the onset of the visual stimulus and the beginning of the movement of head.

(2) Premotor RT was determined as the time interval in ms between the onset of the visual stimulus and the first discernable change in electrical activity of the SCM agonist. It has also been termed EMG RT in previous work (Murakami, 2010).

(3) SRT was determined as the time interval in ms between the onset of the visual stimulus and the first discernable change in electrical activity of the EOG trace.

(4) EMD was determined as the time interval in ms between the start of the EMG activity and the beginning of the movement of head. It has also been termed motor RT elsewhere (Murakami, 2010).

(5) MT was determined as the interval of time in ms between the initiation and completion of head movement.

(6) EXC was determined as the amount of yaw head rotation in radians between the initiation and completion of head movement.

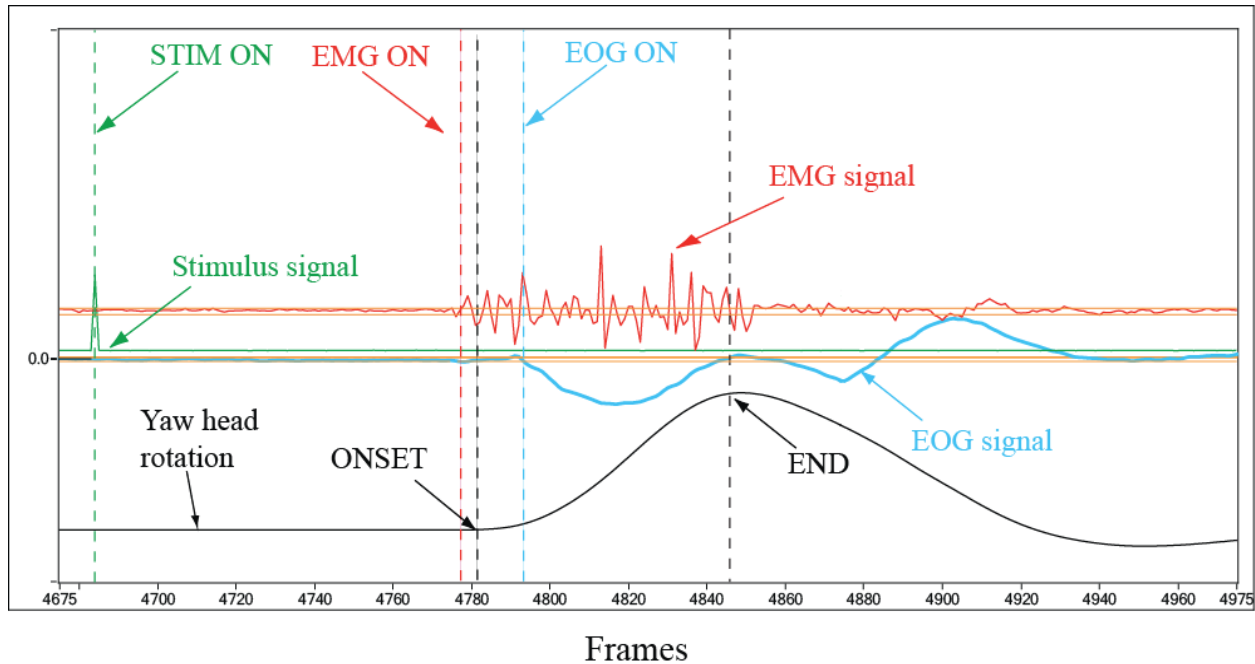
(7) VEL was determined as the maximal yaw head rotational velocity in radians/s between the initiation and the completion of head movement.

### Data Analyses

Position data of head markers were filtered using a zero-phase lag 10 point averaging process. Tangential velocity profiles were calculated using five point differentiation of the filtered position data. Synchronized EMG signals were highpass filtered at 15 Hz (Oude Nijhuis, et al., 2007), while synchronized EOG signals were filtered through a 0.1-40 Hz bandpass filter (Felblinger, et al., 1996). Mean EMG and EOG values and standard deviations (SD) were determined at baseline, 200 ms prior to the visual stimulus onset. Stimulus presentation, EMG, EOG and the yaw position data and the baseline mean  $\pm$  2.5 SD for EMG and EOG signals were plotted across time, visually scanned and marked to determine points of interest using a customized LabView program (see Fig. 3.2). Frames were marked when signals deviated from baseline more the 2.5 SD for the first time for more than 50 ms (Oude Nijhuis, et al., 2007) to determine EMG onset (EMG ON) and for more than 30 ms (Felblinger, et al., 1996) to determine EOG onset (EOG ON). The onset of the stimulus (STIM ON) was marked at the frame where the stimulus signal increased. The onset of head movement (ONSET) was marked at the frame just prior to the yaw head rotation signal change in the appropriate direction, while movement end (END) was determined as the frame just after the last frame of yaw head rotation change for the



given direction. Note that onset of eye movement occurred after that of head movement and that it was relatively smooth overtime (see blue plot, Fig. 3.2). These findings were identified across all trials and suggest no evidence for saccadic eye movements in subjects for the given task. Accordingly SRT data were discarded and not analyzed further.



**Figure 3.2** Markings for one trial. Data for the stimulus signal (green), EMG signal (red) on the affected side, EOG signal (blue) and yaw head rotation profiles (black) used for identifying time marks needed to calculate variables of interest are shown. Data are from one trial in the TOWARD condition (subject 6). STIM ON (vertical green dashed line) = stimulus onset; EMG ON (vertical red dashed line) = onset of EMG; EOG ON (vertical blue dashed line) = onset of eye movement; ONSET (left vertical black dashed line) = onset of head movement; and END (right vertical black dashed line) = end of head movement.

We used one investigator to mark all trials to limit errors in data reduction. One block of trials for a subject was marked 3 different times on a single day (morning, evening and night) and variables of interest were calculated to quantify such errors and determine the within rater consistency.

Trials were rejected and eliminated from analyses if muscle activity preceded stimulus onset or if onset of muscle activity could not be determined due to inadequate EMG recordings. About 4% of the trials were discarded from analyses because of subject mistakes or inadequate recordings (78 trials for 16 subjects). In order to filter for outliers we first defined the interquartile range (IQR) as the difference between the first and the third quartile,  $Q3 - Q1$  for EXC and VEL variables. These variables were chosen according to instructions for subjects: to make a complete head rotation as fast as they can. As suggested in the literature, we multiplied the IQR by 1.5 to identify any values  $1.5 \times \text{IQR}$  below  $Q1$  and above  $Q3$  as outliers (Rosner, 1986) and discarded them from analyses. Three percent of the trials were identified as outliers (47 trials for 15 subjects). This left us with 93% of the trials to test hypotheses and describe the task performance.

### Statistical Analyses

Before applying statistical procedures, average values of the variables of interest for each direction (left and right) and eccentricity ( $4^\circ$ ,  $20^\circ$ , and  $80^\circ$ ) in each condition (TOWARD and AWAY) for each subject were determined. Repeated measure ANOVAs were used to ascertain differences in dependent variables according to condition, direction and target eccentricity. Tukey's HSD post-hoc tests were performed when significant main or interaction effects were identified. Significance was predetermined at  $\alpha = 0.05$ . The statistical analyses were undertaken using Statistica 6.0 (StatSoftInc., Tulsa, USA).

## **Results**

**Table 3.2** EXC and VEL range for each subject

Subject	EXC	VEL
1	0.946-1.554	8.725-13.174
2	0.958-1.365	7.944-11.187
3	0.996-1.680	9.239-14.030
4	0.834-1.336	6.598-11.171
5	1.088-1.617	7.682-10.914
6	1.086-1.451	9.611-14.031
7	1.307-1.645	8.609-11.265
8	0.758-1.251	5.129-10.013
9	1.020-1.312	5.548-8.017
10	0.995-1.529	6.517-10.114
11	1.108-1.409	10.310-13.305
12	1.117-1.398	6.423-9.298
13	0.511-1.246	5.503-11.884
14	0.723-1.307	6.765-9.983
15	1.086-1.706	8.963-14.259
16	0.750-1.466	3.692-7.442

EXC = Excursion; VEL = Peak velocity

Table 3.2 shows the range of head excursions and peak velocities for each subject across trials. These data indicate that subjects had difficulty making similar yaw head excursions across trials and maintaining a consistent high peak velocity. It was unclear whether these inabilities would influence the results of the study, as RT has been shown to increase for larger (Hollands,

et al., 2004) and faster (P. Weiss, Stelmach, & Hefter, 1997) movements. Accordingly, we performed within subject Pearson's correlations on trial data to determine whether associations were significant between our primary variable of RT and VEL and between RT and EXC. We identified a significant positive correlation between RT and EXC in 1 of the 16 subjects and significant negative correlations between RT and EXC in 4 subjects and between RT and VEL in 3 subjects. The non-significant correlations identified for most subjects indicated that final excursion of head movement and peak velocity were not confounding factors for RT. Thus all trials not eliminated due to performance errors, inadequate recordings or outliers were included in analyses. We begin the remainder of the results with outcomes from primary measures followed by those for the secondary measures.

#### Reaction Time (RT) and Premotor Reaction Time (Premotor RT)

Results from analyses on RT and premotor RT indicated similar outcomes. Analyses revealed main effects of condition and eccentricity for both primary measures (see corresponding columns, Table 3.3) such that times in the TOWARD conditions were less than those in the AWAY conditions (Fig. 3.3A and 3.3B) and that times for the 20° target were less than those for the 4° and 80° eccentricities (Fig. 3.4A and 3.4B). Interestingly, the significant two-way interaction of condition x eccentricity indicated that this latter relationship was only true for the TOWARD condition, because RT and premotor RT for the 80° targets were greater than those for the 4° and 20° target locations in the AWAY condition (Fig. 3.5A and 3.5B). Figure 3.6 shows the results of the significant three-way interactions for RT (A) and premotor RT (B) and the main findings of this study. The condition x direction x eccentricity interaction revealed that: (1) for the TOWARD condition with left head rotation mean RT and premotor RT for the 20° target were less than the corresponding times for the 4° and 80° targets; (2) for the TOWARD

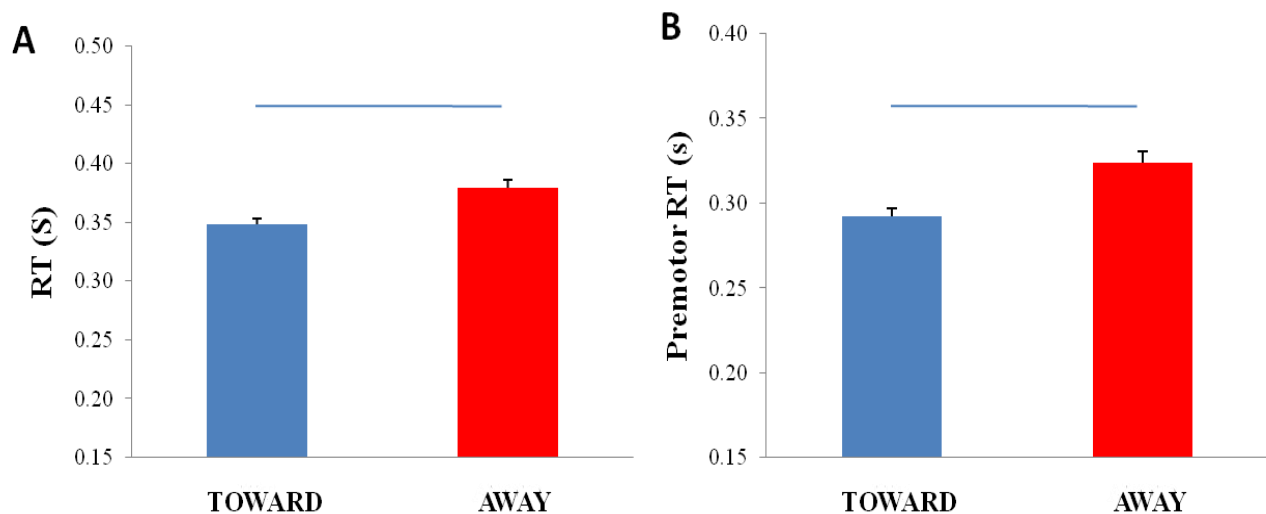
condition with right head rotation mean RT and premotor RT for the 20° target were less than the corresponding times for the 4° target; (3) for the AWAY condition with left head rotation mean RT and premotor RT for the 20° target were less than the corresponding times for the 80° target; (4) for the AWAY condition with right head rotation mean RT and premotor RT for the 4° and 20° targets were less than the corresponding times for the 80° target; and (5) except for the 4° target during left head rotation, RT and premotor RT of each target for each direction in the AWAY condition had longer RTs than the TOWARD condition. Overall, these data suggest the slowest movements for responses to the 80° targets and for the AWAY condition.

**Table 3.3** Results of ANOVAs

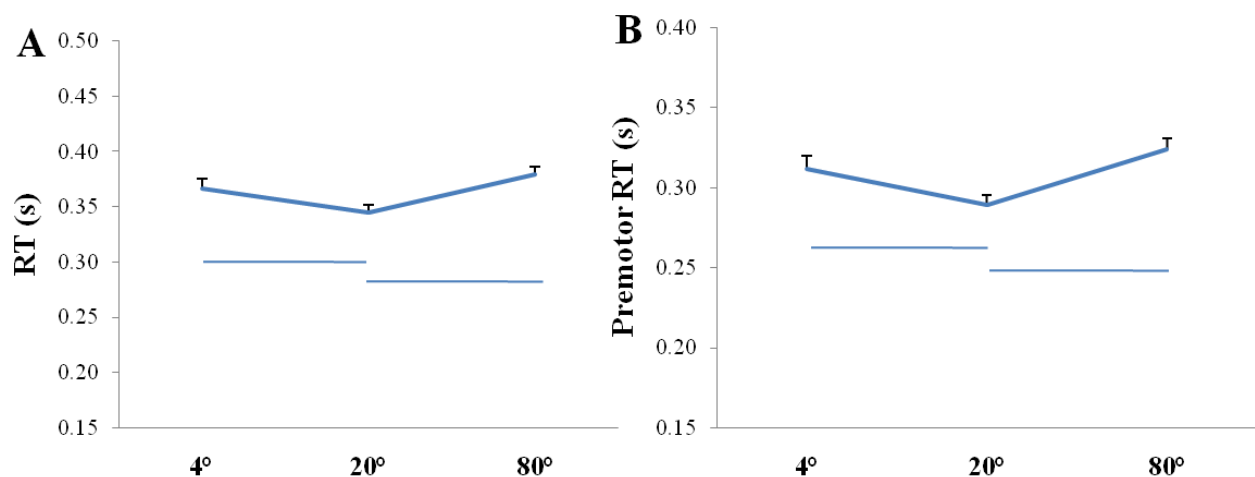
Effect (df)	RT	Premotor RT	EMD	MT	EXC	VEL
Condition (Cond) (1,15)	<b>F=9.59</b> <b>P&lt;0.01</b>	<b>F=10.43</b> <b>P&lt;0.01</b>	F=0.003 P=0.96	F=2.47 P=0.13	<b>F=6.48</b> <b>P&lt;0.05</b>	F=1.28 P=0.28
Direction (Dir) (1,15)	F=3.01 P=0.10	F=3.00 P=0.10	F=0.007 P=0.93	<b>F=4.62</b> <b>P&lt;0.05</b>	F=0.25 P=0.62	F=0.52 P=0.48
Eccentricity (ECC) (2,30)	<b>F=11.87</b> <b>P&lt;0.001</b>	<b>F=12.06</b> <b>P&lt;0.0001</b>	F=0.24 P=0.79	F=0.21 P=0.80	F=0.93 P=0.41	F=1.57 P=0.23
Cond x Dir (1,15)	F=2.33 P=0.15	F=4.52 P=0.05	F=2.16 P=0.16	<b>F=22.11</b> <b>P&lt;0.001</b>	F=2.38 P=0.14	F=1.60 P=0.23
Cond x ECC (2,30)	<b>*F<sub>(2,14)</sub>=3.8</b> <b>P&lt;0.05</b>	<b>*F<sub>(2,14)</sub>=4.1</b> <b>P&lt;0.05</b>	F=0.30 P=0.75	F=2.71 P=0.08	F=0.56 P=0.58	F=0.86 P=0.43
Dir x ECC (2,30)	F=0.73 P=0.49	F=0.56 P=0.58	F=0.28 P=0.76	F=1.82 P=0.17	F=0.37 P=0.70	<b>F=4.03</b> <b>P&lt;0.05</b>

Cond x ECC x Dir (2,30)	<b>F=4.28</b> <b>P&lt;0.05</b>	<b>F=4.10</b> <b>P&lt;0.05</b>	F=0.26 P=0.77	F=0.64 P=0.53	F=1.32 P=0.28	F=0.07 P=0.94
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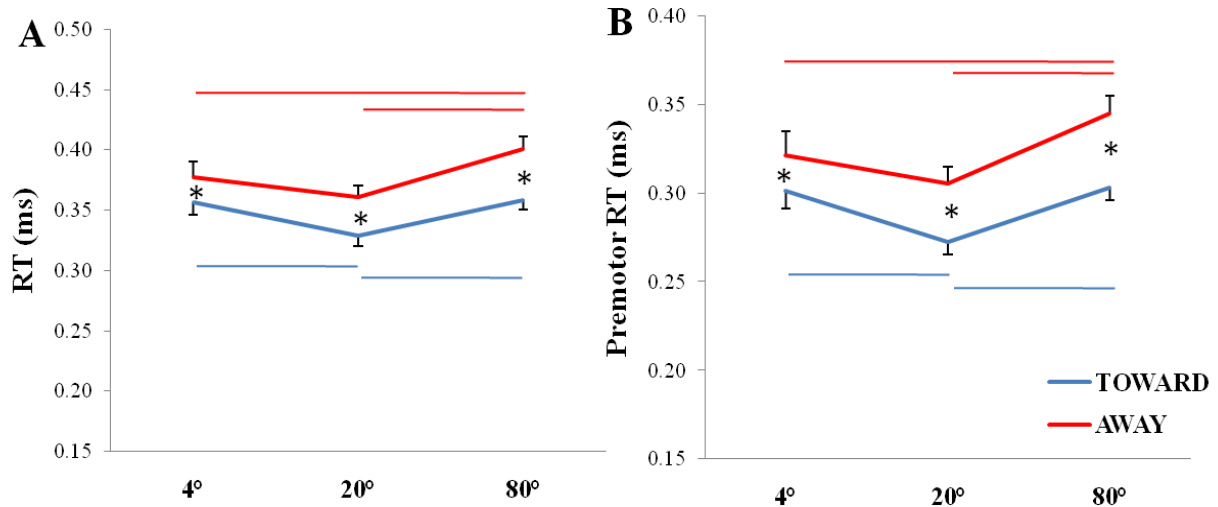
F-values and P-values of each measure are provided. Significant results are identified in bold text ( $p < 0.05$ ). df = degree of freedom. RT = reaction time; Premotor RT = premotor reaction time; EMD = electromechanical delay; MT = movement time; EXC = excursion; VEL = peak velocity. Asterisks indicate violated sphericity and multivariate values with new df provided.



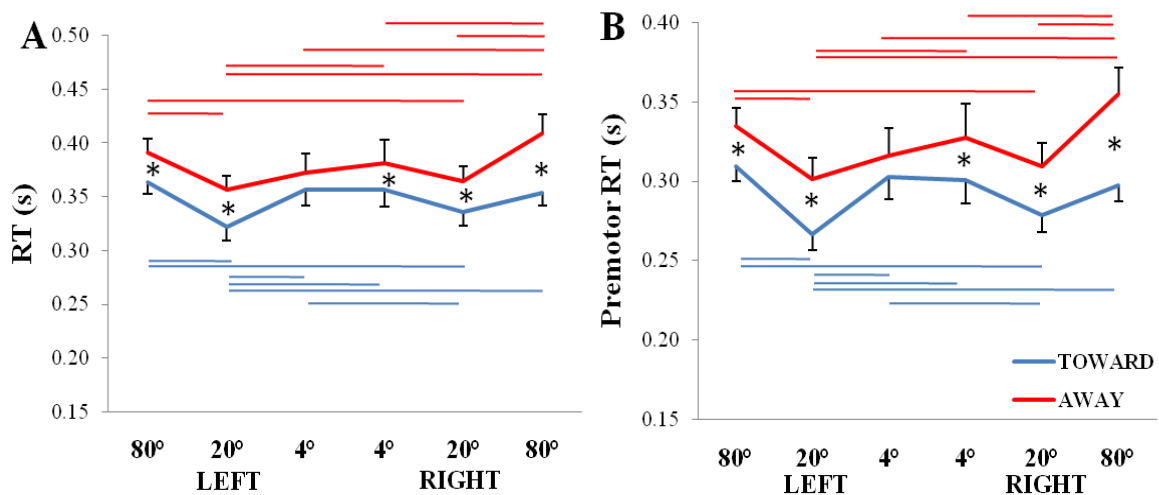
**Figure 3.3** Mean values of the RT (A) and premotor RT (B) in TOWARD and AWAY conditions. Blue and red colors represent TOWARD and AWAY conditions, respectively. Horizontal lines represent a significant difference between the bars at the line ends. Error bars represent 1 standard error.



**Figure 3.4** Mean values of RT (A) and premotor RT (B) for Eccentricity. Horizontal lines represent a significant difference between bars at the line ends. Error bars represent 1 standard error.



**Figure 3.5** Mean values of RT (A) and premotor RT (B) for the condition x eccentricity interaction. Blue and red colors represent TOWARD and AWAY conditions, respectively. Asterisks indicate significant differences between TOWARD and AWAY values at the given eccentricity. Horizontal lines represent a significant difference between data points at the line ends and are color coded to match TOWARD or AWAY accordingly. Error bars represent 1 standard error.



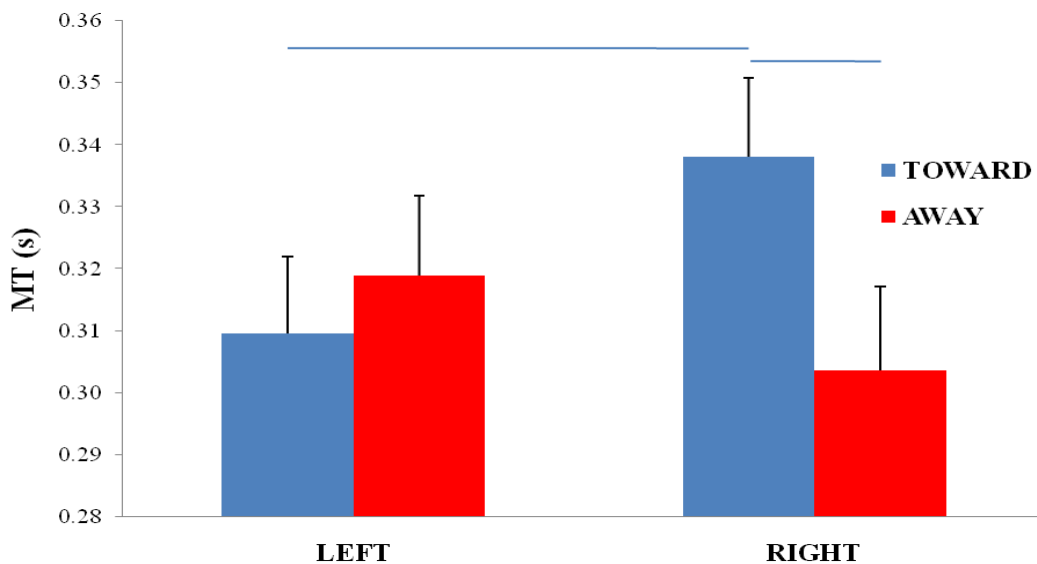
**Figure 3.6** Mean scores of RT (A) and premotor RT (B) for the eccentricity x direction x condition interaction. Blue and red colors represent TOWARD and AWAY conditions, respectively. Asterisks indicate significant differences between TOWARD and AWAY values at

the given eccentricity. Horizontal lines represent a significant difference between data points at the line ends and are color coded to match TOWARD or AWAY accordingly. Error bars represent 1 standard error.

#### Electromechanical Delay (EMD)

No significant effects were identified for EMD. These findings indicate no changes in EMD occur with direction, eccentricity or condition.

#### Movement Time (MT)



**Figure 3.7** Mean scores of MT for the condition x direction interaction. Mean MT of the TOWARD and AWAY conditions are presented in blue and red colors, respectively. Horizontal lines represent a significant difference between bars at the line ends. Error bars represent 1 standard error.

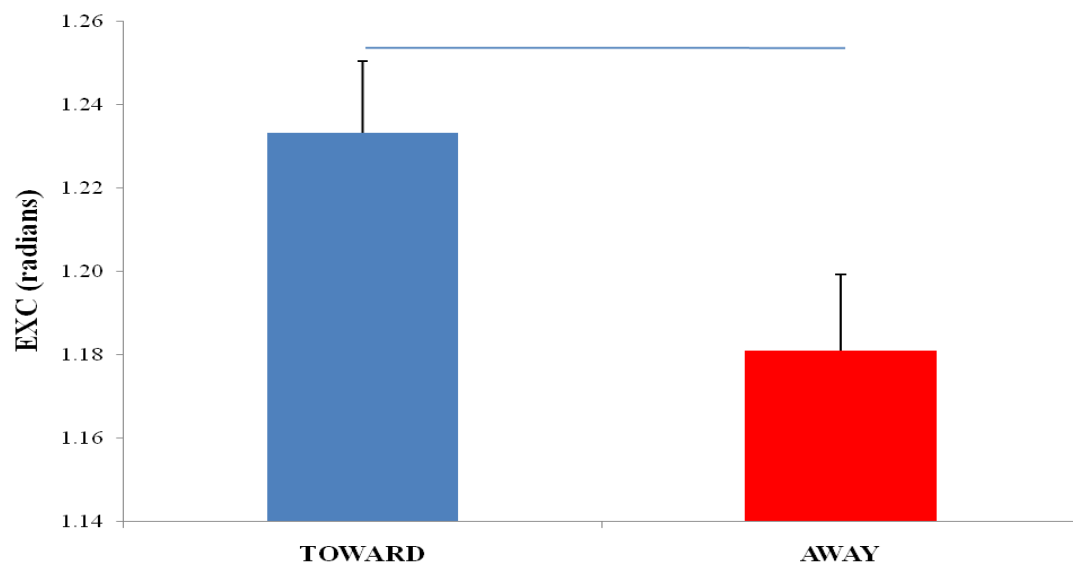
A main effect of direction was identified for MT to show that the right head rotation was significantly larger, thus slower, than MT for the left head rotation. However, the significant condition x direction interaction indicated that this relationship was only true for the TOWARD condition, because there were only significant MT differences between directions for this condition (Fig. 3.7). Figure 3.7 also reveals that MT for the TOWARD condition exceeded that



for the AWAY condition for right side rotations and suggest longer movements for the TOWARD condition during right side rotations.

#### Excursion (EXC)

A main effect of condition was observed for head excursion. Analyses revealed that head excursions in the TOWARD condition were greater than those in the AWAY condition (Fig. 3.8) and suggested that subjects made larger rotations in the TOWARD condition than the AWAY condition.

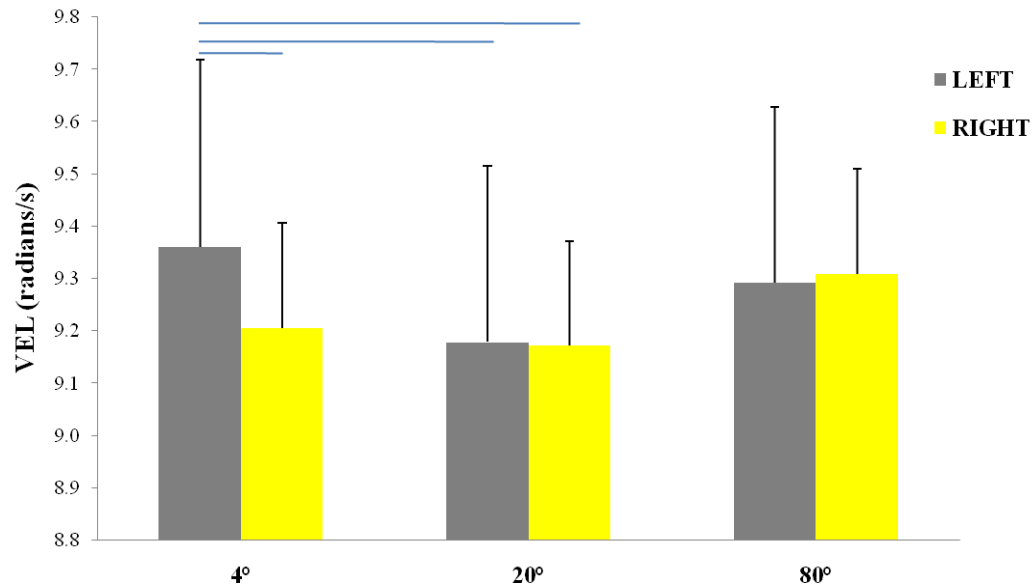


**Figure 3.8** Mean scores of EXC for condition. TOWARD and AWAY conditions are presented in blue and red colors, respectively. Horizontal lines represent a significant difference between bars at the line ends. Error bars represent 1 standard error.

#### Peak Velocity (VEL)

Although no significant main effects were observed for VEL, a significant direction x eccentricity interaction was identified. Results indicated that VEL was significantly greater, thus faster, when the target was presented at 4° in the left direction compared to when it was

presented at 4° in the right direction and 20° in either direction (Fig. 3.9). No other differences were significant.

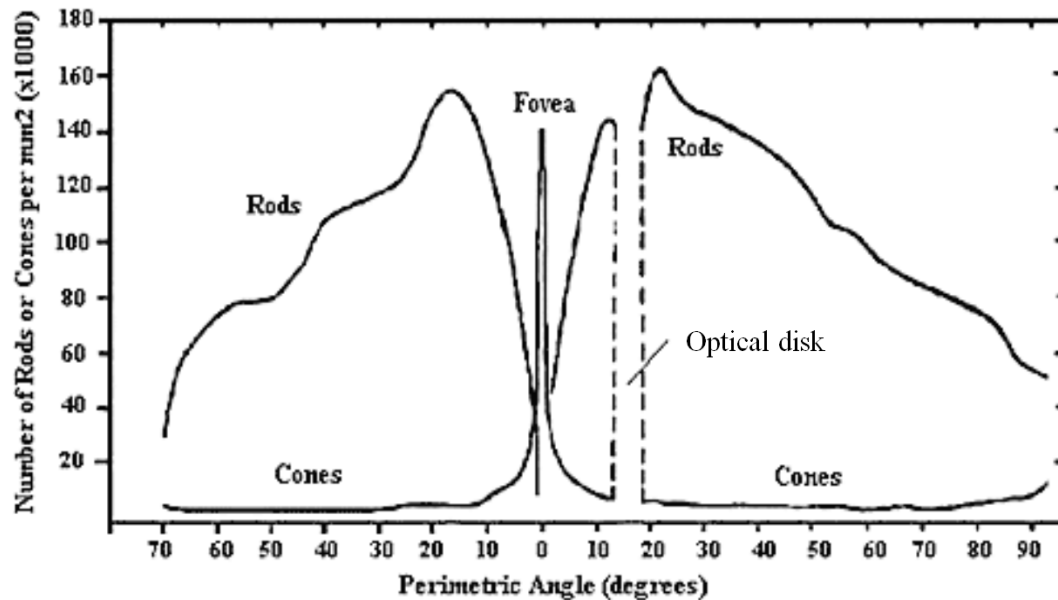


**Figure 3.9** Mean scores of the peak velocity for the direction x eccentricity interaction. Left and right directions are presented in gray and yellow colors, respectively. Horizontal lines represent a significant difference between bars at the line ends. Error bars represent 1 standard error.

## Discussion

The main purpose of the present study was to determine whether yaw head rotational RT and premotor RT to visual stimuli would increase according to target eccentricity for TOWARD and AWAY conditions. We also wanted to determine whether these primary measures for the AWAY condition would be shorter than those for the TOWARD condition, as seen previously. Results indicated that RT and premotor RT increased with for large target eccentricities regardless of condition as expected, however, RT and premotor RT in the TOWARD condition were shorter than those in the AWAY condition against our predictions. We will discuss the

effects of target eccentricity and S-R compatibility on primary (RT and premotor RT) and secondary measures (EMD, MT, EXC and VEL).



**Figure 3.10** Photoreceptor density is plotted as a function of distance from the fovea (Modified from Figure 2.9 (Wolfe, O'Neill, & Bennett, 1998))

Results from the present study confirmed the hypothesis that RTs were greatest for targets presented at large peripheral eccentricities (see 80° target comparisons in Figs. 3.4-6). Longer conduction pathways across the retina (Darrien, et al., 2001), reduced visual acuity in the periphery (Poggel & Strasburger, 2004; Tynan & Sekuler, 1982) and relatively greater central retina densities (Rains, 1963; Wall, et al., 2002) have been used to explain the longer latencies for more eccentric target locations in the past. The difference in conduction length and reduced visual acuity appear to be minimal, as they do not explain why the shortest responses were for the 20° target over the 4° target in the present study or at 17° eccentricity, elsewhere (Stephen et al., 2002). A greater photoreceptor density (sum of rods and cones) does exist in this region (Fig. 3.10) and offers support for shorter RTs with stimuli presented in visual fields corresponding to

greater receptor densities (Payne, 1966; Rains, 1963) and/or the associated receptor downstream circuitry differences across the retina (Schiller & Malpeli, 1978).

Observing subcomponents of RT allowed us to determine greater insight to the control used in responses. Premotor RT and EMD reflect different types of movement preparation corresponding to the nervous system's processing time and muscle contraction time, respectively. With no differences identified for the EMD, the present study provides evidence that the longer premotor RTs for yaw head rotations in the periphery were not due to muscle contraction time. The similarities between the premotor RT and head rotation RT outcomes further provide additional evidence that greater processing time is to blame for increases that occur at greater eccentricities (Ando, Kida, & Oda, 2001) that apparently occurs with fewer receptors (Poggel & Strasburger, 2004), regardless of the faster axonal conduction speeds from the peripheral retina compared to their central counterparts (Darrien, et al., 2001; Stephen, et al., 2002).

Data from the present study did not confirm our second hypothesis that performances in the AWAY condition, involving an incongruent response, would have a shorter RT and premotor RT to visual stimuli than performances in the TOWARD condition, involving a congruent response. Remember that RT and premotor RT in the TOWARD condition were significantly faster than those for the AWAY condition for most target eccentricities (see Fig. 3.6) and regardless of the greater head excursions (Fig. 3.8) and MTs (see right direction, Fig. 3.7) observed for the TOWARD condition. These findings support previous findings that RT and premotor RT for a congruent side response of the upper limb (e.g. a quick left manual button release response to a left visual stimulus) were faster than those for an incongruent side response (e.g. a quick left manual button release response to a right visual stimulus) with (Kato, Endo,

Kizuka, & Asami, 2005) or without a precue (Kato & Asami, 1998). In the latter study authors also showed this S-R compatibility for premotor RT and EMD of the lower limb. These findings directly contrast reports that RTs for turning the head away from an approaching object (incongruent response) were significantly shorter than those for orienting the head toward the stimulus (congruent response) (King, et al., 1992). Apparently the self-selected response to a real moving target where a real threat of being hit is present (King, et al., 1992) differs from that of a stationary target where no threat is evident. Taken together, these results indicate facilitation of RT and its components for congruent responses compared to incongruent responses for a “no threat” situation and facilitation of RT and its components for incongruent responses compared to congruent responses for a “threat” situation. Moreover, these findings offer evidence to support perceptual influences over the control of an action.

There is evidence that interhemispheric processing time (Barthelemy & Boulinguez, 2002a) and the biomechanical constraints on contralateral movements (Carey, Hargreaves, & Goodale, 1996) are computationally more complex, thus elicit longer movement times compared to ipsilateral movements when subject reach or point with the upper limb. We did not expect a significant difference between left and right head rotations due to the nature of the task and muscles used, which are not known for lateral dominance like that of the limbs. Although there were some influences of direction for the given variables (Figs. 3.7 and 3.9), these were not consistent in terms of ipsilateral and contralateral control. Interestingly, the greater VEL and shorter MTs for left head rotations that were identified do correspond to left visual field superiority. These findings support previous findings that RT to stimuli presented in the left visual field are consistently faster than those to stimuli presented in the right visual field (Anzola, Bertoloni, Buchtel, & Rizzolatti, 1977).

In summary, we found an increase in RT and premotor RT for yaw head rotations with large increases in visual field target eccentricity and involving incongruent responses with no threat. These first results suggest a stimulus location effect for different types of defensive movements, which are dependent on light projections to different parts of the retina with different cell densities. The latter of these results combined with other findings in the literature suggests that the S-R compatibility will change according “threat” perception. With perceptual difficulties noted in the peripheral visual field (Alferdinck, 2006; Hodgson, 2002; Wall, et al., 2002), one could surmise that the decrease in such perception would also contribute to slower responses observed for the most eccentric targets.

## **CHAPTER 4: PRACTICE IN DIFFERENT STIMULUS-RESPONSE COMPATABILITY MODES IMPROVES REACTION TIME FOR QUICK YAW HEAD ROTATIONS**

### **Introduction**

Quick defensive responses to visual stimuli are desirable in competitive sports and combat, where to block or dodge an opponent's attack is imperative for success (Ishihara, et al., 2002; Williams & Elliott, 1999). In these cases there is a need to move quickly toward or away from a given stimulus. Studies used to examine initiation of defensive actions in sport-specific conditions for different levels of expertise exist and offer insight to training effects on reaction time (RT) (Mori, et al., 2002; Ripoll, et al., 1995; Williams & Elliott, 1999). These findings suggest that experts in combat sports are quicker at recognizing an offensive action (Mori, et al., 2002) and quicker (Ripoll, et al., 1995) and/or more accurate (Williams & Elliott, 1999) at blocking than those with less or no training.

The ability to respond to visual stimuli in different parts of the visual field is a critical aspect of defensive movement. However, stimuli have almost always been presented to participants in central vision in previous research (Li & Laurent, 2001). Although central field vision plays an important role for defensive actions, orienting the body toward the object of interest it is not always possible or practical. For example, in the martial arts the opponents hand or foot can approach from many directions and within a very short time period (Mori, et al., 2002). It has been shown that peripheral visual field RT increases relative to more central visual field RT with large changes in target eccentricity, at least when the head is free to move and movements are made toward the targets of interest (Biguer, Jeannerod, & Prablanc, 1982; Biguer, et al., 1984; Goldring, Dorris, Corneil, Ballantyne, & Munoz, 1996; Hollands, et al., 2004).

Interestingly and regardless of target eccentricity, key press RTs in response to visual stimuli decrease with practice (Ando, et al., 2001; Ando, Kida, et al., 2002; Ando, et al., 2004).

Possessing abilities to block well and dodge appropriately suggests a certain competency for different levels of stimulus-response (S-R) compatibility. An appropriate block indicates a case where the subject will move toward the same side of target appearance for a congruent response, whereas an appropriate dodge indicates a case where the subject will move away from or to the opposite side of target appearance for an incongruent response. RTs for subjects with martial arts training were faster than those without training when moving a joystick as quick as possible toward an attacking opponent presented on video (Ripoll, et al., 1995) and suggest that RT for congruent movements can decrease with practice. Previous research also shows that button press RT in congruent and incongruent responses can improve with practice (Proctor & Dutta, 1993). In this study a two-choice reaction task was used to evaluate changes in S-R translation with practice. S-R location affected RT performance after practice.

Taken together the above findings suggest that RTs to stimuli in different parts of the visual field of different S-R compatibility levels would likely improve with practice. However, we found no research that directly tests the effects of practice on RT while accounting for different target eccentricities and different S-R compatibilities, items important for defensive movements. Moreover, it is unclear whether practice in one S-R compatibility condition (congruent or incongruent response) will transfer to performance in the opposite condition (incongruent or congruent response, respectively). Thus the primary goal of the current study is to examine the congruent and incongruent response practice effects of quick yaw head rotations in response to visual stimuli presented in different parts of the eccentric viewing field. We choose the task head rotation due to its natural link to defensive movements with no obvious side



bias (i.e., movements toward and away from a stimulus presented on either side of the body). Based on previous work (Ando, et al., 2001; Ando, Kida, et al., 2002; Ando, et al., 2004; Mori, et al., 2002) we hypothesized that head rotation RT will decrease with training. According to the specificity of learning hypothesis, we also hypothesized that head rotation RT will decrease with training in the practiced condition more than that in the condition without practice.

## **Methods**

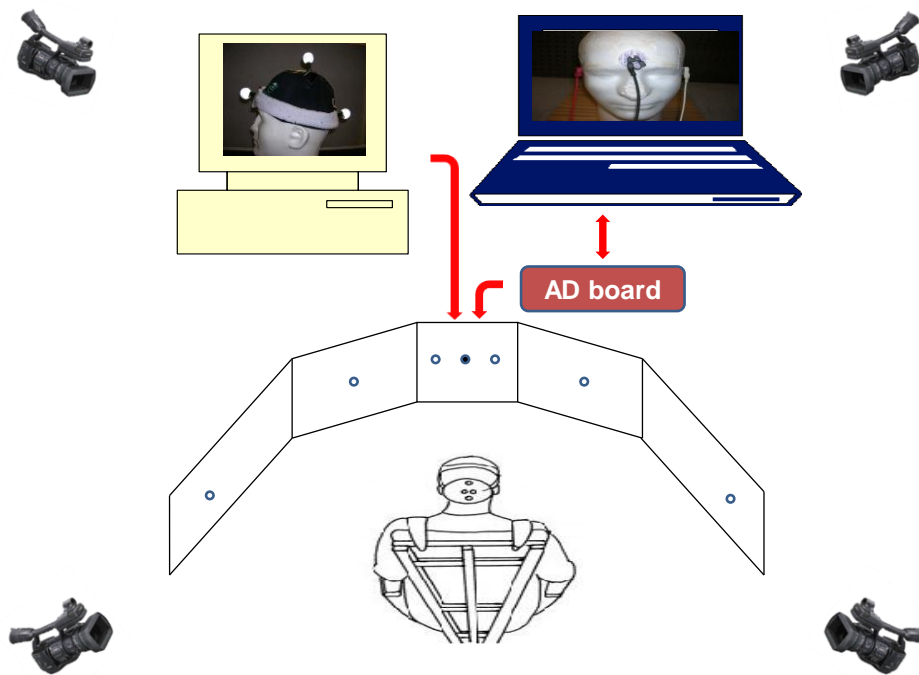
### **Subjects**

Twenty four healthy subjects (nine males, fifteen females; age range 20-25 years, mean = 21.83 years) with no known pathologies volunteered to participate in this study. Visual acuity of each subject was obtained to ensure normal or corrected to normal vision. Each subject gave written informed consent prior to participation in the experimental protocol approved by the Internal Review Board at Louisiana State University.

### **Task**

The task was the same as presented in previous chapters, but briefly reiterated here for convenience. After warming up, subjects were instructed to perform yaw head rotations as rapidly as possible in response to a suddenly appearing visual stimulus presented in different portions of the eccentric horizontal hemi-field. Subjects were asked to make a complete horizontal head rotation regardless of target eccentricity in an attempt to keep amount of rotation similar across trials. The experiment consisted of two response conditions: TOWARD and AWAY conditions. In the TOWARD condition subjects rotated their head in the direction ipsilateral to target appearance for a congruent S-R response. In the AWAY condition subjects rotated their head contralateral to target appearance for an incongruent S-R response.

Figure 4.1 shows the experimental setup. Subjects sat with their trunk strapped to a chair back facing the center of the visual field ( $0^\circ$ ) where a green circle served as the visual fixation point. Six red light-emitting diodes (LEDs) 4 mm in diameter served as targets located at eye level at left and right eccentricities of  $4^\circ$ ,  $45^\circ$  and  $80^\circ$ . Radial distance between targets and the subject was 1.5 m. The task was performed in a dimly lit room.



**Figure 4.1** Experimental set-up. Head marker location (left monitor), EOG setup (right monitor), approximate camera locations (4 corners) and subject, fixation point (solid central circle) and target locations (open circles) are shown.

A trial proceeded as follows. A verbal "ready" signal was given after initial fixation for the first trial in a block. After a 1, 2, or 3 s delay, one of the 6 targets was illuminated for 50 ms to signal the subject to perform a complete yaw head rotation as rapidly as possible. Subjects held the rotated position for about 1 second before rotating their head back to a neutral position to fixate the central circle. Subjects were given 2 seconds to complete the movement, hold and return to fixation before the next delay period started. The short duration for target display was

used to prevent target fixation during and after head rotations, while the inter-trial interval was varied to minimize anticipatory responses. A customized program was used to control target presentation. Before data collection began in each condition (TOWARD or AWAY), subjects warmed up by practicing 6 trials in the given condition at comfortable, faster and fast as possible speeds.

**Table 4.1** Trial numbers for targets and direction for each condition

Condition	Direction of target	Target eccentricities	Total trials
TOWARD	LEFT	4°	9
		45°	9
		80°	9
	RIGHT	4°	9
		45°	9
		80°	9
AWAY	LEFT	4°	9
		45°	9
		80°	9
	RIGHT	4°	9
		45°	9
		80°	9
Total			108

Half the subjects completed all trials for the TOWARD condition prior to the AWAY condition, while the remaining subjects completed trials in the AWAY condition prior to the

TOWARD condition. Subjects performed 9 trials to each target (left and right eccentricities of 4°, 45°, and 80°) in each condition (TOWARD and AWAY) for a total of 108 trials on one visit (Table 4.1). Each block consisted of 6 trials however every 18 trials were randomly presented to help prevent predictive responses.

Rest periods between blocks lasted 1 minute. Although encouragement to make complete head rotations to the given side and to move as quick as possible were given between each block, no feedback was given on performance. An investigator monitored head marker movements on a computer screen online to ensure subject movement in the proper direction. Blocks were repeated when technical difficulties occurred with recordings (2 blocks were repeated for 2 subjects) or if a subject did not respond to the stimuli or the direction response was incorrect more than 1 trial in the block (5 blocks were repeated for 3 subjects). However, if a subject did not respond to the stimuli or the direction response was incorrect for only 1 trial in the block, that trial was excluded from analyses. Trials were also rejected if muscle activity preceded stimulus onset or if onset of muscle activity could not be determined due to inadequate EMG recordings when data were analyzed.

All subjects participated in the following sequence of testing and training: (1) Pre-test (two days before the first training day), (2) Training (6 days over 2 weeks), and (3) Post-test (two days after last training day). Pre-tests and Post-tests were as described above. During the training period, 12 subjects only practiced 54 trials each day in the TOWARD condition (TT group), while the other half practiced 54 trials each day in the AVOID condition (AT group). Each practice session included warm-up and mandatory 1 minute rest periods to avoid fatigue. Subjects were able to take longer rests when requested, however this did not occur.

## Data Collection

Neck muscle activity was measured along with head and eye movements during task performance on pre- and post-tests. Bilateral EMG (Electromyography) activity was recorded at 1000 Hz (Biopac systems, Goleta) from the left and right sternocleidomastoid (SCM) muscles. Similar to previous work (Oude Nijhuis, et al., 2007) we used 2 pairs of 10 mm diameter disposable surface electrodes (Nikomed USA Inc. Doylestown, PA) spaced 2 cm apart (center-to-center). The electrodes were placed equidistant between the mastoid process and the medial end of the clavicle (Harvey & Peper, 1997). The ground electrodes were placed on the left and right acromion. Three dimensional head movements were recorded at 240 Hz from 3 reflective markers mounted on a cap worn by the subjects using a 4 camera Qualisys motion analysis system (Qualisys Medical AB, Gothenburg). Markers were placed in a sagittal plane on the front, top, and back of the head (see Fig. 4.1). Horizontal movements of the eyes were also recorded with electro-oculography (EOG). Electrodes for EOG recording were applied to the left and right outer canthi to measure horizontal eye position with the ground electrode attached to the center of the forehead similar to other studies (Fukushima, et al., 2000). Recordings represent the corneal-retinal potential, which changes with respect to the reference electrode during horizontal eye movement. EOG signals were DC amplified and sampled at 1000 Hz with the Biopac. EMG and EOG signals were also sent via an A/D board for synchronization with the head movement data at 240 Hz (Qualisys Medical AB, Gothenburg).

## Variables Developed to Analyze Data

Variables of interest included primary and secondary measurements. The primary measures included reaction time (RT) and premotor reaction time (Premotor RT) of yaw head rotation, The saccadic reaction time (SRT) of eye movement and the electromechanical delay

(EMD), movement time (MT), excursion (EXC) and peak velocity (VEL) of yaw head rotation were selected as secondary measures to offer insight to task performance. The following text offers a description of how each variable was calculated.

(1) RT was determined as the time interval in ms between the onset of the visual stimulus and the beginning of the movement of head.

(2) Premotor RT was determined as the time interval in ms between the onset of the visual stimulus and the first discernable change in electrical activity of the SCM agonist. It has also been termed EMG RT in previous work (Murakami, 2010).

(3) SRT was determined as the time interval in ms between the onset of the visual stimulus and the first discernable change in electrical activity of the EOG trace.

(4) EMD was determined as the time interval in ms between the start of the EMG activity and the beginning of the movement of head. It has also been termed motor RT elsewhere (Murakami, 2010).

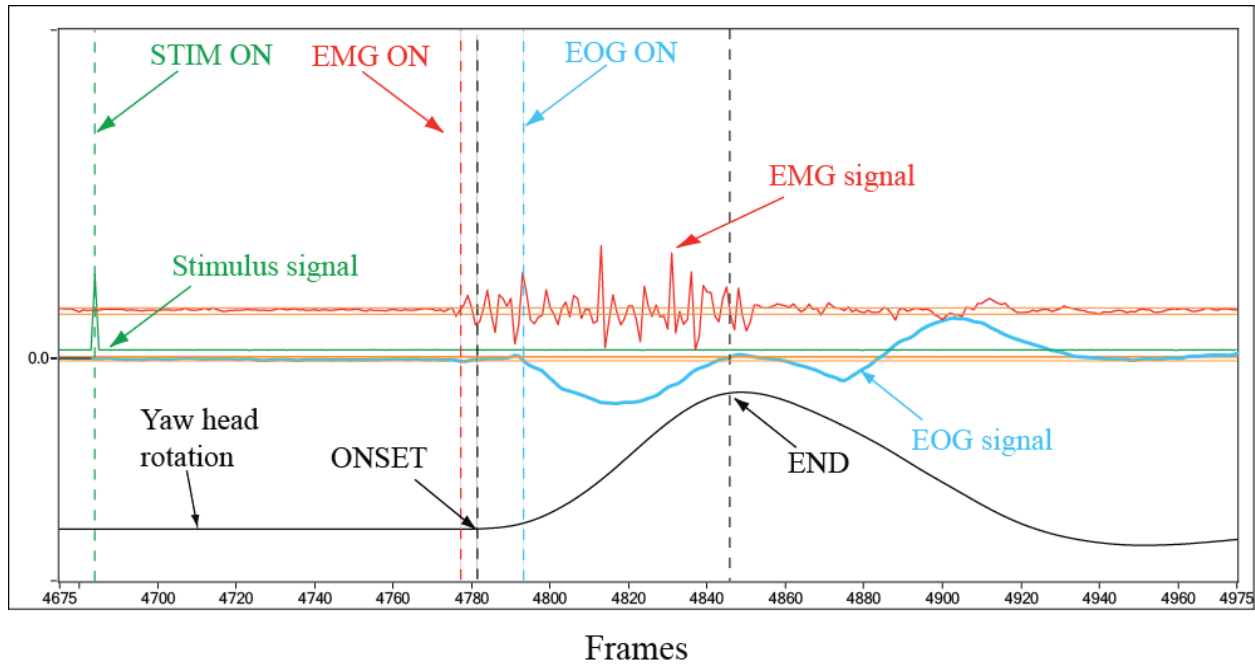
(5) MT was determined as the interval of time in ms between the initiation and completion of head movement.

(6) EXC was determined as the amount of yaw head rotation in radians between the initiation and completion of head movement.

(7) VEL was determined as the maximal yaw head rotational velocity in radians/s between the initiation and the completion of head movement.

## Data Analyses

Position data of head markers were filtered using a zero-phase lag 10 point averaging process. Tangential velocity profiles were calculated using five point differentiation of the filtered position data. Synchronized EMG signals were highpass filtered at 15 Hz (Oude Nijhuis, et al., 2007), while synchronized EOG signals were filtered through a 0.1-40 Hz bandpass filter (Felblinger, et al., 1996). Mean EMG and EOG values and standard deviations (SD) were determined at baseline, 200 ms prior to the visual stimulus onset. Stimulus presentation, EMG, EOG and the yaw position data and the baseline mean  $\pm$  2.5 SD for EMG and EOG signals were plotted across time, visually scanned and marked to determine points of interest using a customized LabView program (see Fig. 4.2). Frames were marked when signals deviated from baseline more the 2.5 SD for the first time for more than 50 ms (Oude Nijhuis, et al., 2007) to determine EMG onset (EMG ON) and for more than 30 ms (Felblinger, et al., 1996) to determine EOG onset (EOG ON). The onset of the stimulus (STIM ON) was marked at the frame where the stimulus signal increased. The onset of head movement (ONSET) was marked at the frame just prior to the yaw head rotation signal change in the appropriate direction, while movement end (END) was determined as the frame just after the last frame of yaw head rotation change for the given direction. Note that onset of eye movement occurred after that of head movement and that it was relatively smooth overtime (see blue plot, Fig. 4.2). These findings were identified across all trials and suggest no evidence for saccadic eye movements in subjects for the given task. Accordingly SRT data were discarded and not analyzed further.



**Figure 4.2** Markings for one trial. Data for the stimulus signal (green), EMG signal (red) on the affected side, EOG signal (blue) and yaw head rotation profiles (black) used for identifying time marks needed to calculate variables of interest are shown. Data are from one trial in the TOWARD condition (subject 6). STIM ON (vertical green dashed line) = stimulus onset; EMG ON (vertical red dashed line) = onset of EMG; EOG ON (vertical blue dashed line) = onset of eye movement; ONSET (left vertical black dashed line) = onset of head movement; and END (right vertical black dashed line) = end of head movement.

We used one investigator to mark all trials to limit errors in data reduction. One block of trials for a subject was marked 3 different times on a single day (morning, evening and night) and variables of interest were calculated to quantify such errors and determine the within rater consistency.

Trials were rejected and eliminated from analyses if muscle activity preceded stimulus onset or if onset of muscle activity could not be determined due to inadequate EMG recordings. About 2 % of the trials were discarded from analyses because of subject mistakes or inadequate recordings (16 trials for the TT group and 26 trials for the AT group). In order to filter for outliers we first defined the interquartile range (IQR) as the difference between the first and the third quartile,  $Q3 - Q1$  for EXC and VEL variables. These variables were chosen according to



instructions for subjects: to make a complete head rotation as fast as they can. As suggested in the literature, we multiplied the IQR by 1.5 to identify any values  $1.5 \times \text{IQR}$  below Q1 and above Q3 as outliers (Rosner, 1986) and discarded them from analyses. Three percent of the trials were identified as outliers (32 trials for the TT group and 32 trials for the AT group). This left us with 93% of the trials to test hypotheses and describe the task performance.

### Statistical Analyses

Before applying statistical procedures, variables of interest were determined by calculating the average value and SD for each direction (left and right), eccentricity ( $4^\circ$ ,  $45^\circ$ , and  $80^\circ$ ), condition (TOWARD and AWAY) and test (pre and post) for each subject. Repeated measure ANOVAs were used to determine differences in dependent variables according to condition, direction, target eccentricity, test and group (TT and AT). Tukey's HSD post-hoc tests were performed when significant main or interaction effects were identified. Significance was predetermined at  $\alpha = 0.05$ . The statistical analyses were undertaken using Statistica 6.0 (StatSoftInc., Tulsa, USA). Results will be limited to the significant main effects of test and group and their interaction with the remaining variables of condition, direction, and target eccentricity to focus on the outcomes of interest associated with hypotheses and questions posed.

## **Results**

Results from statistical analyses are presented in Table 4.2. For practical purposes of brevity and to direct the readers' attention to outcomes associated with hypotheses, we limited result presentation to significant findings involving group or test effects and their interactions.

**Table 4.2** Results of ANOVAs

Effect (df)	RT	Premotor RT	EMD	MT	EXC	VEL
(G) (1,22)	F=1.33 P=0.26	F=0.66 P=0.42	F=0.76 P=0.39	F=0.31 P=0.58	F=0.33 P=0.57	F=1.18 P=0.28
(T) (1,22)	<b>F=48.15</b> <b>P&lt;0.0001</b>	<b>F=49.52</b> <b>P&lt;0.0001</b>	F=0.08 P=0.76	<b>F=13.03</b> <b>P&lt;0.01</b>	F=2.84 P=0.10	<b>F=27.40</b> <b>P&lt;0.0001</b>
T x G (1,22)	F=0.006 P=0.93	F=0.03 P=0.85	F=0.51 0.48	F=1.71 P=0.20	F=0.60 P=0.44	F=0.30 P=0.58
C x G (1,22)	F=3.35 P=0.08	<b>F=4.91</b> <b>P&lt;0.05</b>	F=2.78 P=0.10	F=1.58 P=0.22	F=0.26 P=0.61	F=0.0001 P=0.99
D x G (1,22)	F=0.07 P=0.79	F=0.19 P=0.66	F=1.04 P=0.31	F=0.63 P=0.43	F=1.77 P=0.19	F=0.26 P=0.61
E x G (2,44)	F=0.64 P=0.53	F=1.07 P=0.034	F=2.33 P=0.10	F=0.35 P=0.70	F=0.15 P=0.85	F=0.27 P=0.75
T x C (1,22)	F=1.49 P=0.23	F=0.41 P=0.52	<b>F=7.56</b> <b>P&lt;0.05</b>	F=0.01 P=0.92	F=1.30 P=0.26	F=1.45 P=0.24
T x C x G (1,22)	<b>F=11.05</b> <b>P&lt;0.01</b>	<b>F=7.84</b> <b>P&lt;0.05</b>	<b>F=4.55</b> <b>P&lt;0.05</b>	F=0.94 P=0.34	<b>F=12.17</b> <b>P&lt;0.001</b>	F=0.10 P=0.74
T x D (1,22)	F=0.55 P=0.46	F=0.68 P=0.41	F=0.08 P=0.77	F=0.09 P=0.75	F=0.007 P=0.93	F=0.57 P=0.45
T x D x G (1,22)	F=0.79 P=0.38	F=1.12 P=0.29	F=1.23 P=0.27	F=0.01 P=0.89	F=0.27 P=0.60	F=0.09 P=0.75
C x D x G	F=0.74	F=0.39	F=0.05	F=1.14	F=0.01	F=0.82

(1,22)	P=0.39	P=0.53	P=0.81	P=0.29	P=0.89	P=0.37
T x E	<b>*F<sub>(2,22)</sub>=4.0</b>	*F <sub>(2,21)</sub> =3.3	F=0.79	F=0.89	F=0.47	F=0.50
(2,44)	<b>P&lt;0.05</b>	P=0.06	P=0.45	P=0.41	P=0.62	P=0.60
T x E x G	F=0.50	F=0.41	F=0.23	F=0.70	F=0.08	F=0.05
(2,44)	P=0.60	P=0.66	P=0.79	P=0.49	P=0.92	P=0.94
C x E x G	F=1.90	F=1.92	F=0.10	F=0.95	F=1.01	F=1.38
(2,44)	P=0.16	P=0.15	P=0.90	P=0.39	P=0.37	P=0.26
D x E x G	F=0.35	F=0.20	F=1.18	F=0.36	F=0.39	F=0.28
(2,44)	P=0.70	P=0.81	P=0.31	P=0.69	P=0.67	P=0.75
T x C x D	F=0.05	F=0.00	F=0.25	F=1.75	F=0.02	F=3.23
(1,22)	P=0.81	P=0.99	P=0.62	P=0.19	P=0.87	P=0.08
T x C x D x G	F=2.43	F=0.51	F=1.51	F=0.59	F=0.66	F=0.84
(1,22)	P=0.13	P=0.48	P=0.23	P=0.44	P=0.42	P=0.36
T x C x E	F=2.15	F=2.24	F=0.10	F=1.31	F=0.91	F=0.26
(2,44)	P=0.12	P=0.11	P=0.90	P=0.27	P=0.40	P=0.36
T x C x E x G	F=2.41	F=2.71	F=0.99	F=1.47	F=0.74	<b>*F<sub>(2,21)</sub>=5.1</b>
(2,44)	P=0.10	P=0.07	P=0.37	P=0.23	P=0.47	<b>P&lt;0.05</b>
T x D x E	F=0.17	F=0.32	F=2.16	F=0.19	F=1.46	F=1.72
(2,44)	P=0.83	P=0.72	P=0.12	P=0.82	P=0.24	P=0.18
T x D x E x G	F=0.35	F=0.30	F=0.89	F=1.49	<b>F=5.12</b>	F=1.18
(2,44)	P=0.70	P=0.74	P=0.41	P=0.23	<b>P&lt;0.05</b>	P=0.31
C x D x E x G	F=1.26	F=1.31	F=0.67	F=0.06	F=0.68	F=2.4
(2,44)	P=0.29	P=0.27	P=0.51	P=0.93	P=0.50	P=0.09
T x C x D x E	F=0.64	F=0.65	F=0.16	F=0.01	<b>F=3.39</b>	F=1.81
(2,44)	P=0.52	P=0.52	P=0.84	P=0.98	<b>P&lt;0.05</b>	P=1.08

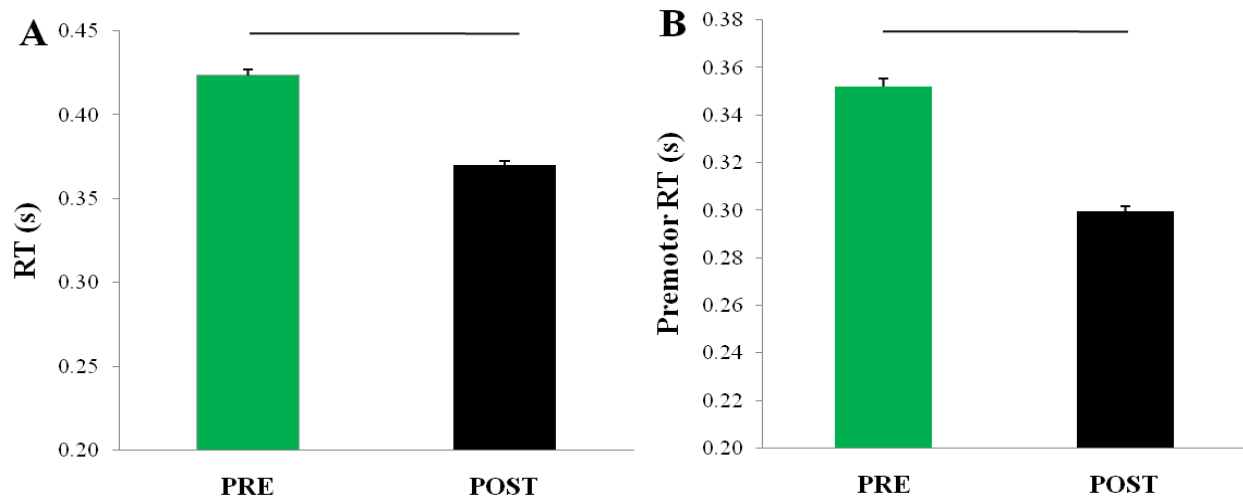
T x C x D x E x G (2,44)	F=0.07 P=0.92	F=0.37 P=0.69	F=1.36 P=0.26	F=0.87 P=0.42	F=0.13 P=0.87	F=0.17 P=0.34
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Significant results are identified in bold text ( $p < 0.05$ ). df= degree of freedom; G=group; T=test; C=condition; D= direction; E=eccentricity. Asterisks indicate violated sphericity and multivariate values with new df presented.

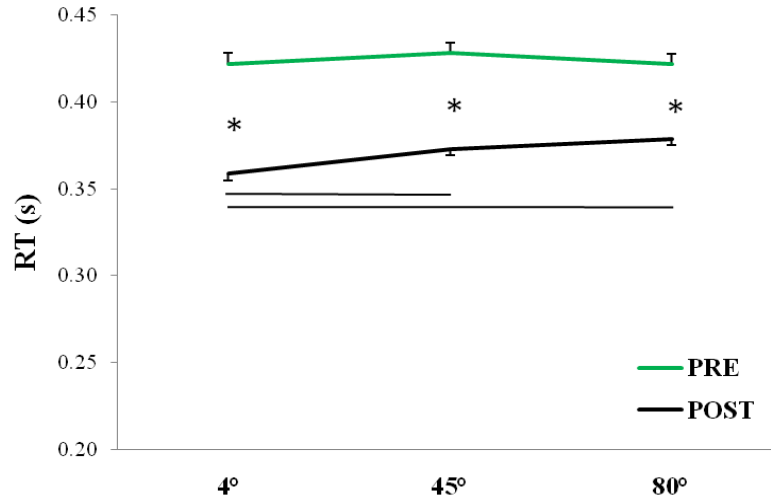
#### Reaction Time (RT) and Premotor Reaction Time (Premotor RT)

Results from analyses on RT and premotor RT indicated similar outcomes. With the exception of the significant two-way interaction of condition x group for premotor RT, which revealed no significant post-hoc results, results of the two primary variables paralleled each other closely. Analyses revealed significant main effects of test for RT and premotor RT (see corresponding columns, Table 4.2) such that times in the post-tests were less than, thus shorter than those in the pre-test (Fig. 4.3A and 4.3B). The significant two-way interaction of test x eccentricity indicated that RT at each eccentricity for the post-tests were less than, thus shorter than those for the pre-test and smallest for the 4° target location in the post-test (Fig. 4.4). The significant three-way interaction of test x condition x group revealed that in both groups RT and premotor RT in both conditions for the post-test were less than, thus shorter than those in the pre-test regardless of condition (Fig. 4.5A and 4.5B). Follow up calculations also shows greater pre/post improvements in the TOWARD condition for the TT group (8 of 12 subjects) and greater pre/post improvements in the AWAY condition for the AT group (10 of 12 subjects for premotor RT and 11 of 12 subjects for RT). Also note the red pre/post lines are steeper for the

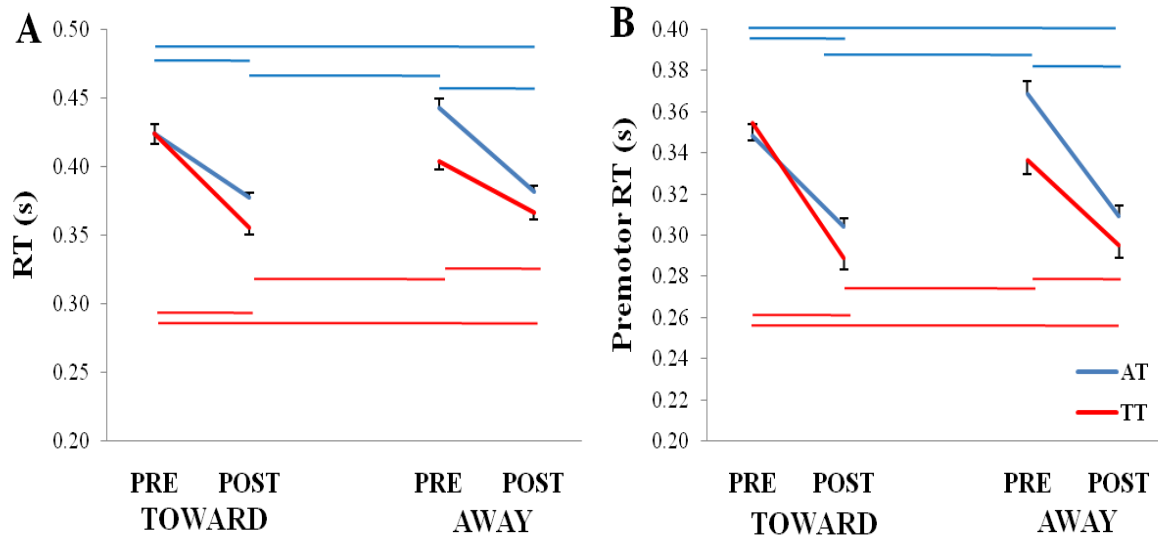
TOWARD condition and the blue pre/post lines are steeper for the AWAY condition.



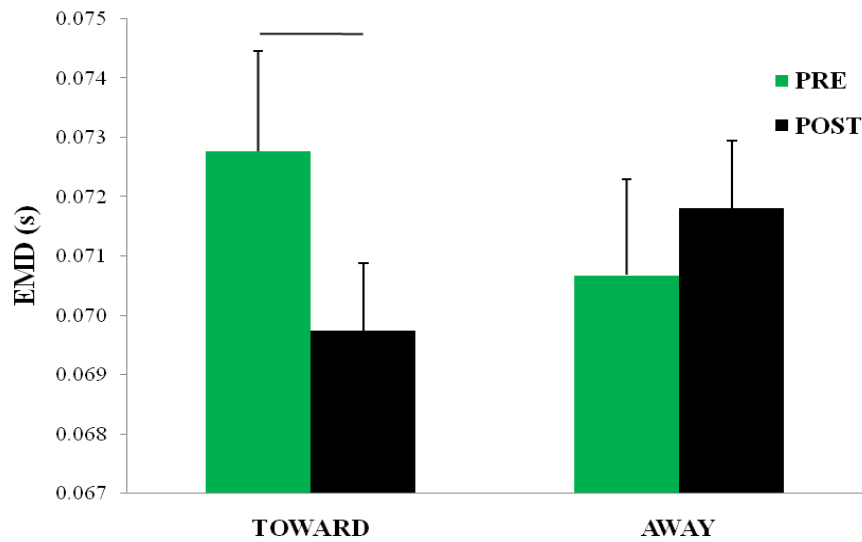
**Figure 4.3** Mean scores of RT (left) and Premotor RT (right) according to test. PRE and POST tests are presented in green and black colors, respectively. Horizontal lines represent a significant difference between bars at the line ends. Error bars represent 1 standard error.



**Figure 4.4** Mean scores of RT according to the test x eccentricity interaction. PRE and POST tests are presented in green and black colors, respectively. Asterisks indicate significant differences between PRE and POST values at the given eccentricity. Horizontal lines represent a significant difference between data points at the line ends and are color coded to match PRE or POST accordingly. Error bars represent 1 standard error.



**Figure 4.5** Mean scores of RT and Premotor RT according to the test x condition x group interaction. AT and TT groups are presented in blue and red colors, respectively. Horizontal lines represent a significant difference between data points at the line ends and are color coded to match AT or TT accordingly. Error bars represent 1 standard error.



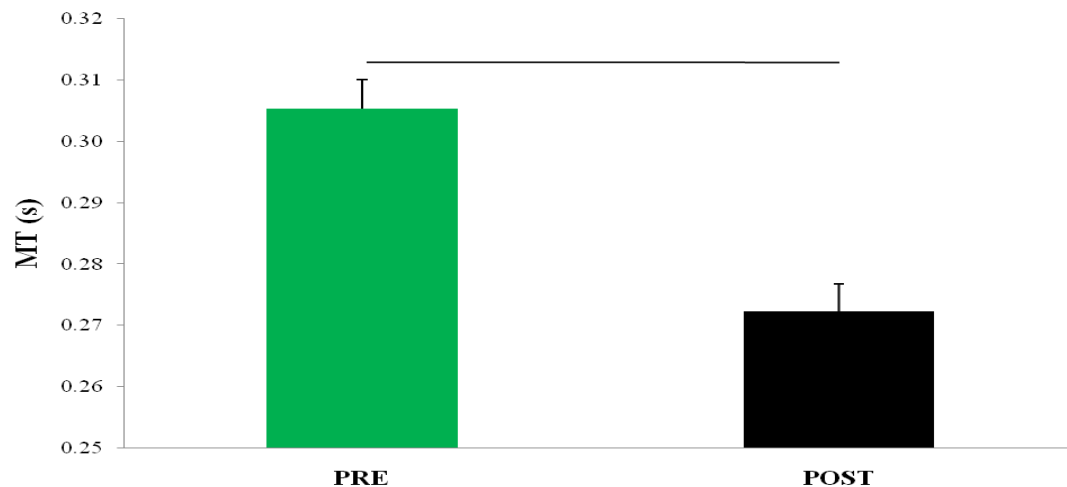
**Figure 4.6** Mean scores of EMD according to the test x condition interaction. PRE and POST tests are presented in green and black colors, respectively. Horizontal lines represent a significant difference between bars at the line ends. Error bars represent 1 standard error.

## Electromechanical Delay (EMD)

No significant main effects of group or test were identified for EMD. However, the significant two-way interaction of test x condition indicated that in the TOWARD condition EMD for the pre-test was greater than, thus slower than for the post-test (Fig. 4.6). The significant three-way interaction of test x condition x group for EMD revealed no significant post-hoc effects.

## Movement Time (MT)

A main effect of test was observed for MT (Fig. 4.7). Analyses revealed that MT in the post-test was smaller, thus faster than that in the pre-test.

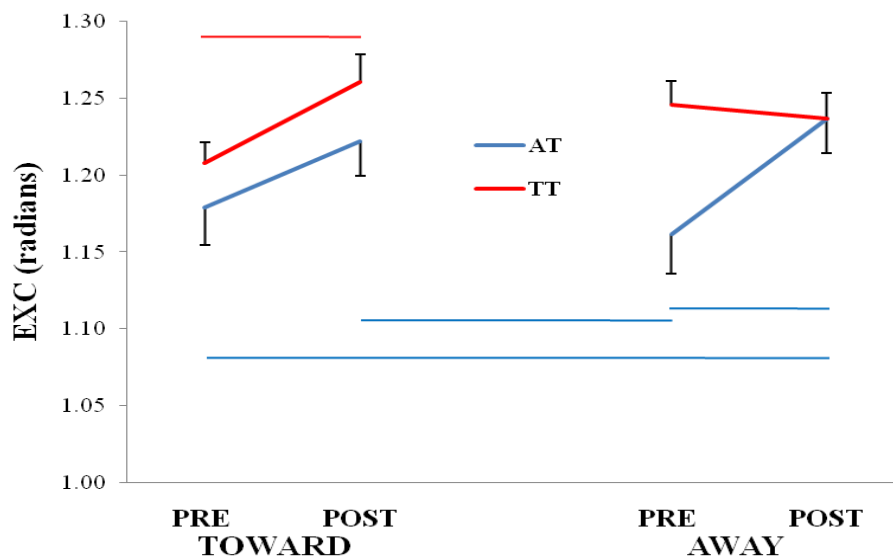


**Figure 4.7** Mean scores of MT according to test. PRE and POST tests are presented in green and black colors, respectively. Horizontal lines represent a significant difference between bars at the line ends. Error bars represent 1 standard error.

## Excursion (EXC)

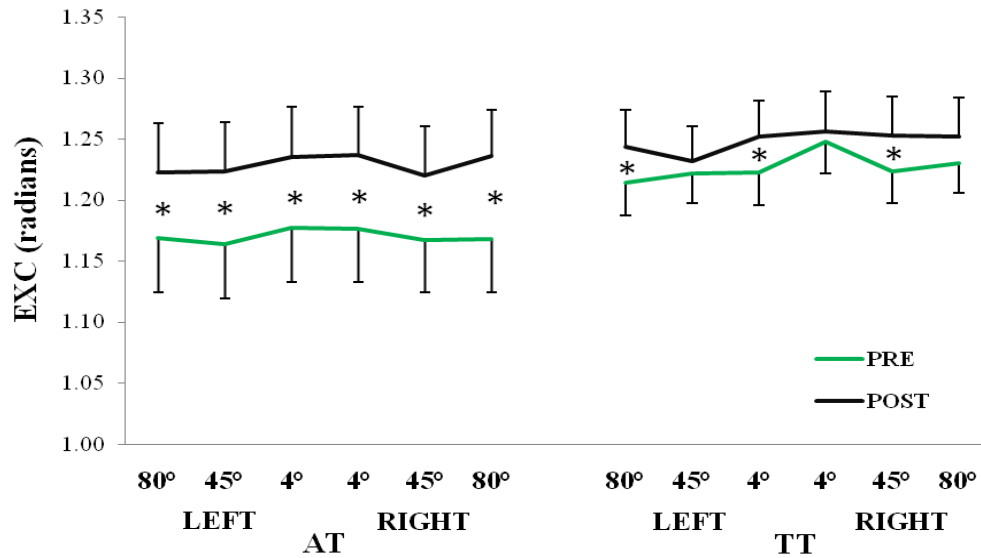
Figure 4.8 shows the results of the significant three-way interaction of test x condition x group for excursion. The interaction revealed that for the AT group EXC for the pre-test was less

than that in the post-test for both conditions and for the TT group EXC for the pre-test was less than that for the post-test in the TOWARD condition only. There was a significant four-way interaction of test x direction x eccentricity x group. It revealed that for the AT group all EXC for the pre-test were less than those for the post-test and for the TT group EXC for the 80° and 4° targets for the left direction and the 45° target for the right direction for the pre-test were greater than corresponding values for the post-test (Fig. 4.9). The significant test x condition x direction x eccentricity interaction revealed that overall, EXC at all eccentricities in the both directions in both conditions for the pre-test were less than corresponding post-test values (Fig. 4.10). Moreover, subjects revealed the greatest EXC for the 4° target during right head rotations in the AWAY condition.

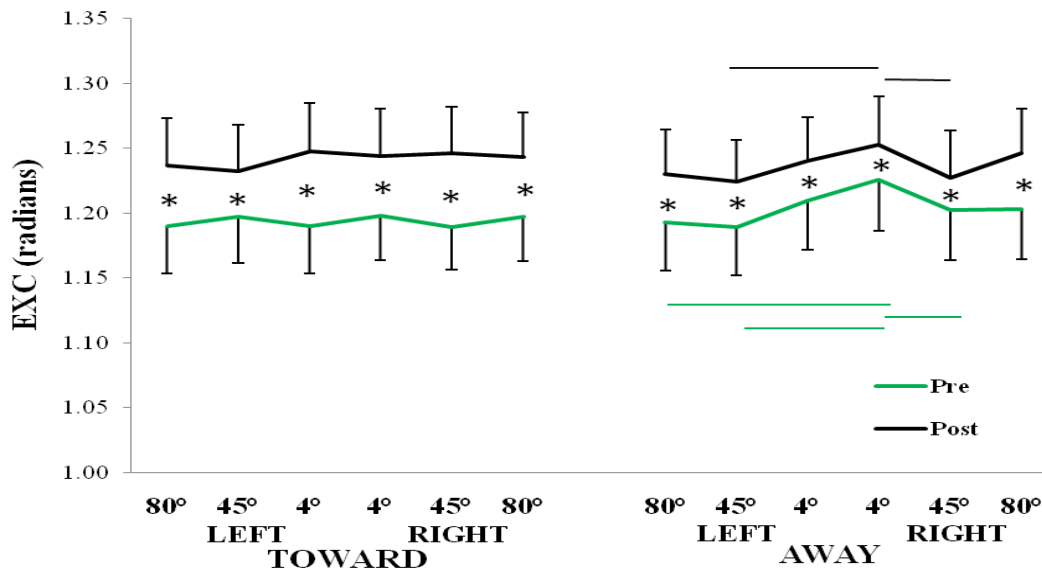


**Figure 4.8** Mean scores of EXC for test x condition x group. AT and TT groups are presented in blue and red colors, respectively. Horizontal lines represent a significant difference between data points at the line ends and are color coded to match AT or TT accordingly. Error bars represent 1 standard error.





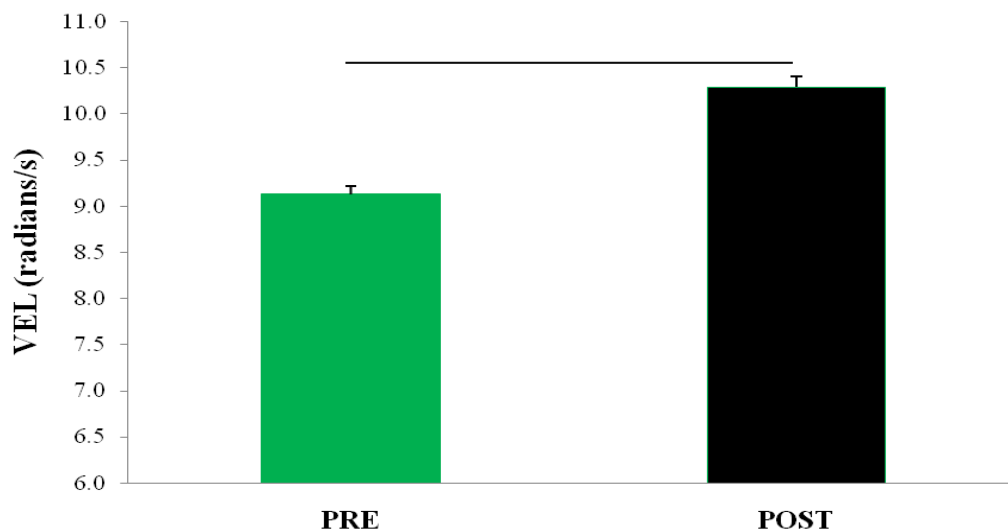
**Figure 4.9** Mean scores of EXC for test x direction x eccentricity x group. PRE and POST are presented in green and black colors, respectively. Asterisks indicate significant differences between PRE and POST values at the given eccentricity. Error bars represent 1 standard error.



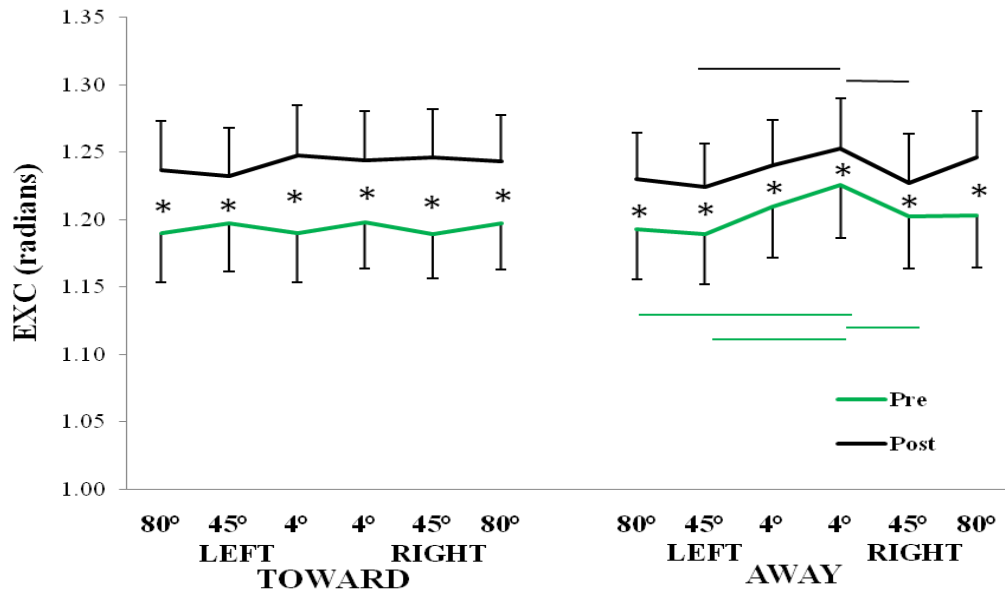
**Figure 4.10** Mean scores of EXC for test x condition x direction x eccentricity. PRE and POST tests are presented in green and black colors, respectively. Asterisks indicate significant differences between PRE and POST values at the given eccentricity. Horizontal lines represent a significant difference between data points at the line ends and are color coded to match PRE or POST accordingly. Error bars represent 1 standard error.

## Peak Velocity (VEL)

A main effect of test was observed for VEL (Fig. 4.11). Analyses revealed that VEL for the post-test was greater than, thus faster than that for the pre-test. Interestingly, there also was a significant four-way interaction of test x condition x eccentricity x group (Fig. 4.12). These results showed that for both groups VEL values for all target locations in both conditions for post-tests were greater, thus faster than those for the pre-tests. Also note that in the AWAY condition VEL at the 4° target location was faster than that at the 45° target location for the AT group post-test and the TT group pre-test.



**Figure 4.11** Mean scores of VEL for test. PRE and POST conditions are presented in green and black colors, respectively. Horizontal lines represent a significant difference between bars at the line ends. Error bars represent 1 standard error.



**Figure 4.12** Mean scores of VEL for test x condition x eccentricity x group. PRE and POST are presented in green and black colors, respectively. Asterisks indicate significant differences between PRE and POST values at the given eccentricity. Horizontal lines represent a significant difference between data points at the line ends and are color coded to match PRE or POST accordingly. Error bars represent 1 standard error.

## Discussion

The first purpose of the present study was to determine whether yaw head rotational RT and premotor RT to visual stimuli in central and peripheral visual fields would improve with practice. We also wanted to determine whether RT and premotor RT to visual stimuli for the TOWARD and AWAY conditions would be shorter with practice in the given condition. Results indicated that RT and premotor RT decreased at each target eccentricity regardless of practice type and that practice in one condition was likely produce greater reductions in premotor RT and RT for that condition. In the discussion we emphasize the effects of practice and practice type on primary (RT and premotor RT) and secondary (EMD, MT, EXC and VEL) measures.

As predicted, our results provided evidence that RT and premotor RT for defensive actions can improve with training. Since RT and premotor RT decreased at each eccentricity for both conditions and groups, it is clear that improvements were observed in central (4°) and peripheral (45° and 80°) visual fields. With RT and premotor RT differences noted between the 4° and other targets post-test, and not pre-test, our results also showed a greater improvement in central visual field RT and premotor RT compared those in the peripheral visual field. These findings extend previous research in which RT for both peripheral visual field and central visual field decrease with practice after three weeks of training, where subjects responded to visual stimulus by pressing the space key of the computer as fast as possible (Ando, et al., 2001; Ando, Kida, et al., 2002; Ando, et al., 2004) like the TOWARD condition response of the present study. Moreover, this 0.053 s faster RT differs from the 0.013 s slower RT performance observed for the same task performed 1 week apart in the test-retest reliability study (chapter 2). Not only did we observe practice improvements for quick yaw head rotations, but we also observed the transfer benefits of 6 days of practice for each condition similar to previous work (Proctor, Yamaguchi, Zhang, & Vu, 2009). We were not surprised to see the greater decreases in RT and premotor RT in the TOWARD condition for the TT group and in the AWAY condition for the AT group. These findings follow the specificity of learning hypothesis, in which learning in one condition is more effective if the practice and test conditions coincide and less effective if the practice and test conditions differ (Barnett, Ross, Schmidt, & Todd, 1973). Observing subcomponents of RT allowed us to determine greater insight to the control used in these responses. Premotor RT and EMD reflect different types of movement preparation corresponding to the nervous system's processing time and muscle contraction time, respectively. With no main effects identified for the EMD (Table 4.2), the present study showed that faster RTs identified for post-test improvements paralleled, thus were primarily due to the improved premotor RTs for

post-test performances. Together, these results suggest that improvements in RT were due primarily to improvements in the time to process information as observed previously (Kato & Asami, 1998; Kato, et al., 2005).

Unlike previous findings, our results revealed no congruent S-R advantage for quick rotational head movements before or after training. Manual key and button press responses to visual stimuli have revealed faster RTs for compatible responses than incompatible responses prior to practice (Fitts & Deininger, 1954; Fitts & Seeger, 1953; Proctor & Dutta, 1993; Proctor, Dutta, Kelly, & Weeks, 1994; Proctor & Reeve, 1988; Reeve & Proctor, 1988; Roswarski & Proctor, 2003). Moreover, subjects who practiced quick left and right hand two-choice button press reactions for 3 days significantly reduced RTs for performances in the incongruent condition, but revealed even greater reductions in RT for performances in the congruent condition (Proctor & Dutta, 1993). In addition we also noted that RTs for yaw head rotations for the incongruent response were greater, thus slower than those for the congruent response in chapter 3. Thus task differences cannot explain the lack of a pre-test congruent S-R compatibility advantage observed here. It is possible that subjects used in the current experiment had experience that would overcome the incongruent S-R compatibility disadvantage, as it has been proposed that athletes can overcome it with repeated practice (Schmidt & Wrisberg, 2004). However, we have no data to support such speculation.

The changes in the primary measures of interest were accompanied by several changes in the secondary variables. The faster reaction times of the yaw head rotations were associated with faster movements after training as observed in shorter MTs (Fig. 4.7) and greater VELs (Figs. 4.11 and 4.12) for post-test performances. Subjects moved their heads through greater excursions in each condition after practice, but only when accounting for direction and eccentricity. In fact,

the greater post-test head excursion for the TT group in the TOWARD condition and for the AT group in the AWAY condition (Fig. 4.8) suggests head excursion increases are condition-specific. Interestingly and unlike the TT group, the post-test head excursion increases for the AT group were only observed for certain eccentricity and direction combinations (Fig. 4.9). Although the graph shows greater head excursion similarities between groups after practice, no significant differences were observed for pre-test comparisons, suggesting large variability among subjects for head excursion.

In conclusion, we observed shorter yaw head rotation RT in TOWARD and AWAY conditions after 6 days of practice in TOWARD and AWAY conditions. We found the greater observations especially for the centrally placed target. Our results indicated that subjects primarily improved their time to process information after 6 practice sessions in a two week period. Moreover, greater performance improvements were observed for most subjects when practice and testing were within the same condition, indicating support for the well-known learning specificity phenomena.

## CHAPTER 5: GENERAL DISCUSSION

In this study, we found that our primary measures of RT and Premotor RT and secondary measures of MT, EXC and VEL of quick yaw head rotations were relatively stable over a two week period. Based on these results, we are able to utilize these measurements in subsequent investigations in which we tested the effects of S-R compatibility and target eccentricity on the primary and secondary measures (chapter 3) and explored whether these measures were influenced by 6 days of practice over a two week period in one S-R compatibility mode (chapter 4).

### **Key Results**

In chapter 2 we investigated the between day test-retest reliability of the primary and secondary measures of yaw head rotation for TOWARD and AWAY responses to visual stimuli located at 4°, 20° and 80° eccentricities. Results showed that the primary measures of RT and Premotor RT had good agreement levels. Agreement levels for secondary measures varied from excellent for MT and VEL, to between fair and good for EXC, to poor for EMD. These findings suggest that all but EMD of the SCM muscles can be measured with an acceptable level of precision during rapid head rotational responses to visual stimuli in the eccentric viewing field.

Investigation of the effects of target eccentricity on rapid yaw head rotational responses to visual stimuli for TOWARD and AWAY conditions were explored in chapter 3. Target eccentricities were located at 4°, 20° and 80° in the left and right visual hemi-field. Results indicated that RT and premotor RT were commonly the slowest for the largest eccentric target of 80° regardless of condition and shortest for the 20° target location where when projected on to the retina would represent a location where photoreceptor density is highest. RT and premotor

RT were also shorter in the TOWARD condition than in the AWAY condition regardless of the larger head excursions for the TOWARD condition to suggest faster reactions for congruent responses for this task.

Chapter 4 was used to explore the effects of practice with different levels of S-R compatibility on quick yaw head rotations using different levels of S-R compatibility. We altered the location of two targets so that target presentation was at 4°, 45° and 80° in the left and right visual hemi-field. As expected, RT and premotor RT at each eccentricity decreased with practice. These times decreased more, while EXC increased more, for most subjects when practice and performance were in the same S-R compatibility mode (e.g. practice and performance in the TOWARD condition). Moreover, faster movements according to target eccentricity were not observed until training was completed and revealed the fastest RTs and premotor RTs for performances corresponding to the 4° target locations. These data suggest faster reactions in response to stimuli in the central visual field occur with practice.

The following sections will focus on discussion of the relationship among the major results not previously discussed. Limitations of the current work and suggestions for future research directions complete this chapter.

### **Discussion of the Key Results**

Different measurement outcomes were observed for subjects who practiced between test periods versus those who did not. Subject performance was observed at two time points with either no practice for a week in chapter 2 or 6 days of practice over 2 weeks in chapter 4. Results from Table 2.6 showed that RT, Premotor RT, MT, EXC and VEL of second visit were slightly higher than the first visit only for comparisons in which condition, eccentricity and subject were



treated as separate cases. On average subjects responded slightly slower (RT = 13 ms; premotor RT = 12 ms), took slightly longer to rotate their heads (9 ms), had slightly larger peak rotational head velocities (0.299 radians/s) and slightly larger yaw head excursions (0.033 radians) on the second visit. These observations not only gave us insight to the test-retest reliability of our measures, they also provided evidence that without extended practice one would not expect these measurements to change much. However, results in chapter 4 indicated a significant change in RT, premotor RT, EMD, MT, EXC and VEL measures with extended practice such that subjects responded faster (RT = 54 ms; premotor RT = 53 ms), took less time to rotate their heads (33 ms), had faster peak rotational velocities (1.164 radians/s) and larger head excursions (0.040 radians) on the post-test, thus second visit. These findings suggest faster responses and faster and larger movements with extended practice, regardless of the practice condition. Together these findings suggest that healthy young adults can improve quick yaw head rotational responses to visual stimuli, but that such improvement requires practice or training.

Results from chapters 3 and 4 confirmed the hypothesis that RTs were greatest for targets presented at the largest peripheral eccentricities. A greater photoreceptor density for the 20° target projections on the retina (Payne, 1966; Rains, 1963) was used to explain the faster responses in chapter 3. However, these results do not preclude the involvement of the associated receptor downstream circuitry that differs across the retina after we accounted for the quick reactions at the 4° target location compared to large eccentricities (i.e. > 40°) in chapter 4. The division of visual information begins in the retina. The retina ganglion cells are divided into many different types of cells (De Monasterio & Gouras, 1975). However, two dominant types prevail; magnocellular and parvocellular diameter ganglion cells (De Monasterio & Gouras, 1975; Perry, Oehler, & Cowey, 1984). Converging evidence showed that the parvocellular

ganglion cells were more prevalent near the fovea and the magnocellular ganglion cells were more prevalent in the periphery (Leventhal, Rodieck, & Dreher, 1981; Perry, et al., 1984; Schiller & Malpeli, 1978). Schiller and colleagues (Schiller & Malpeli, 1978) confirmed the central and peripheral retinal stimulation correspondence with the parvocellular and magnocellular layers of the lateral geniculate nucleus (thalamus), respectively. The differences in cell size imply a difference in conduction velocities (Enroth-Cugell & Robson, 1966). This would lead to a difference in onset latencies in the areas that received information via different pathways (Enroth-Cugell & Robson, 1966; Nowak, Munk, Girard, & Bullier, 1995) and can help explain the faster responses for more centrally located targets.

In chapter 3 we found studies which showed a facilitation for RT for congruent responses compared to incongruent responses “no threat” situations (Fitts & Deininger, 1954; Kato & Asami, 1998; Kato, et al., 2005; Proctor & Dutta, 1993; Roswarski & Proctor, 2000) like our findings and facilitation of RT for incongruent responses compared to congruent responses for a “threat” situation (King, et al., 1992). We used these findings to offer evidence to support for perceptual influences over the control of an action, however, we ignored a second S-R compatibility mechanism for a moving stimulus scenario also present in the latter study (King, et al., 1992): the direction of movement (Brenner & Smeets, 1995). Thus although stimulus location was congruent or incongruent to the head rotation response, the actual movement of the object was incongruent or congruent, respectively. Such observation offers a second possibility to explain the S-R compatibility differences and the contrary findings; that movement S-R compatibility overrides stimulus location S-R compatibility, at least in the peripheral visual field. These findings appear to directly influence real world situations, where a moving object

approaches the defender. In this case the defender would likely respond faster in the direction of moving stimulus, especially if it was threatening.

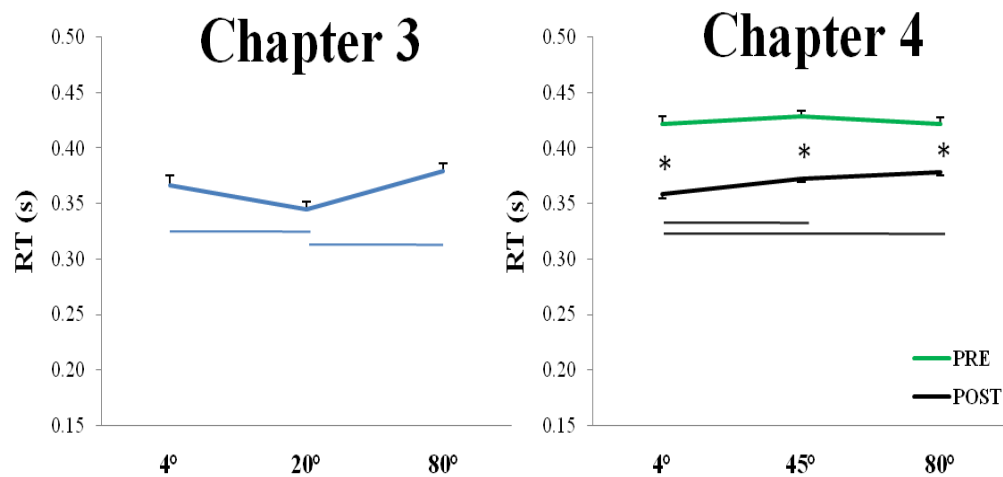
In martial arts and combat situations the approaching stimuli are real and involve a perceptual threat with greater accuracy demands for movements toward the target for blocking compared to those away from the target for dodging. The speed accuracy trade-off is another important factor in defensive movements where a real object which can produce perceptual threat approaches. RT increases as the precision requirement to the task increases (Fitts & Peterson, 1964). For example, Cauraugh (1990) investigated response preparation and accuracy performances which elucidated the speed-accuracy operating characteristics. Participants used the index and middle fingers of both hands which were placed on four computer keys corresponding to four white squares presented on the computer screen. Participants were told to be accurate and fast in making a two- or four-choice response, however accuracy and speed were emphasized in different portions of the experiment. Slower RTs and higher accuracy rates were noted when accuracy was emphasized and provided support that RT was influenced by the speed-accuracy trade off (Cauraugh, 1990). From general finding of speed accuracy trade-off, we can assume that RT when a defender moves away from a visual stimulus will be faster than RT when the person moves toward the stimulus because of the greater accuracy requirements in later condition.

A major finding of chapters 3 and 4 that requires further attention was the effects of target eccentricity on the RT of quick yaw head rotations to visual stimuli. In chapter 3 subjects responded to visual targets presented at left and right 4°, 20° and 80° eccentricities, while in chapter 4, subjects responded to visual targets presented at left and right 4°, 45°, and 80° eccentricities. The change from 20° to 45° allowed for additional comparisons noted in the

summary of the literature, where different methodologies helped explain the conflicting results coinciding with the eccentricities tested. We observed that head movement RT increased with increasing target eccentricities for fairly large eccentric target locations (i.e. exceeding 40°) (Goldring, et al., 1996; Hollands, et al., 2004), while RT decreased or remained the same with increasing target eccentricities for relatively small eccentric target locations (i.e. 40° or less) (Biguer, et al., 1982; Biguer, et al., 1984).

Direct comparisons of the results from chapters 3 and 4 offer tangible evidence to support our observations. Figure 5.1 summarizes these findings. Although we identified the slowest RT for the largest eccentricity of 80° (see Fig. 3.5) in chapter 3, we also identified the fastest RT for the 20° target location (see left panel, Fig. 5.1 below and Fig. 3.5 in chapter 3), which corresponds to projections on the retina where a greater photoreceptor density exists (Payne, 1966; Rains, 1963; Wolfe, et al., 1998). These findings offered support for shorter RTs with stimuli presented in visual fields corresponding to greater receptor densities (Payne, 1966; Rains, 1963). The right panel and Fig. 5.1 (Fig. 4.4 from chapter 4) shows that RTs were similar for each target eccentricity for the pre-test, that RTs for each eccentricity decreases, thus is faster after training and that RTs for the 45° and 80° target locations were greater than, thus slower than the 4° target locations for the post-test. Not only do these findings support our observations that head movement RT increases with increasing target eccentricity for large eccentric target locations (i.e. exceeding 40°) and decreases with increasing target eccentricity for small eccentric target locations (i.e. 40° or less), but they also have implications for absolute speed of the response. Note that the RTs in chapter 3 (left panel, Fig. 4.1) were similar to those identified for the post-test in chapter 4 (see black plots, right panel, Fig. 4.1). It was only in these situations

that RT differences were identified according to target eccentricity. As mentioned previously,



**Figure 5.1** Mean scores of RT according to eccentricity from chapter 3 (A) and RT according to test and eccentricity interaction from chapter 4 (B). PRE and POST tests are presented in green and black colors, respectively. Asterisks indicate significant differences between PRE and POST values at the given eccentricity. Horizontal lines represent a significant difference between bars at the line ends (A). Horizontal lines represent a significant difference between data points at the line ends and are color coded to match PRE or POST accordingly (B). Error bars represent 1 standard error.

our subjects did have difficulties achieving similar yaw head excursions and similar peak velocities across trials (see Tables 3.2 in chapter 3). Less consistent performances could easily explain the non significant findings for the pre-test as results are based on the premise that subjects are making movements as quick as possible. Subsequent analyses on data from chapter 4 revealed a significant effect of test on RT standard deviations ( $F(1,22) = 19.26$ ,  $P < 0.001$ ) such that RT variability for pre-test (0.058 s) was greater than that for the post-test (0.047 s), which was also greater than the RT variability observed in chapter 3 (0.050 s). Together these results suggest a need to account for absolute target eccentricity and ensure a certain level of movement consistency during performances to achieve similar outcomes to those observed here. These findings also suggest that people will react the fastest when they are oriented in the general

direction of the incoming stimulus (within a 40° radius of the visual field), and thus provide the best defense.

### **Limitations**

Limitations that may affect generalization of findings exist in every study. Those linked to stimulus characteristics are listed first. This is followed by those linked to the tasks performed of subjects.

One of the primary limitations of the present work is that associated with type of stimulus used. Stimuli used in this present study were motionless LEDs flashed for a short period of time. In martial arts and combat most situations would involve an approaching object that would not be removed from sight and would involve a perceptual threat. However, in the current study we used varied stimulus locations and a head rotational movement that might actually be used in combative situations, which offered insights to presentation of stimuli presented in different parts of the visual field.

Another limitation of the present work was the poor test-retest reliability for EMD of the SCM muscles. It is possible that the SCM muscle contraction times does not vary much for the given movement, thus may not have been the best muscle to observe recordings.

The last limitation to note is that of subject performance. Subjects did not consistently move their heads at their highest peak velocities or make the largest head excursions for each movement. Although correlation analyses revealed no significant relationship between these measures and RT, one could still wonder whether greater consistency would alter the present findings.

## **Future Directions**

The ability to avoid the sudden appearance of stimuli and to protect the body from an attack is an essential function for humans (Cooke & Graziano, 2003; King, et al., 1992; Schiff, 1965), which can be used for defensive actions in various environments, including combative sports. The need to better understand responses for defensive movements using central and peripheral visual fields provided motivation for the present work. Although the present work added to the findings in this regard, future studies are needed to provide greater insight to understanding response control for defensive movements.

It is clear that the limitations of the present work will contribute to future studies. The major limitation of the present work was the stimulus characteristics. As such, future work should incorporate several of the characteristics that we did not. This would include the use of moving stimuli which are known to produce different responses from static stimuli (Aschersleben & Musseler, 1999; Smeets & E. Brenner, 1995; J. B. Smeets & E. Brenner, 1995). This would also include the use of stimuli that produce a perceived threat for the subjects. Outcomes of these studies would offer a more direct generalization to combative situations. We also advise that in future studies recording of activity of multiple muscles corresponding to the movements of the body segments of interest. Recordings from multiple muscles would increase the chances of obtaining changes in muscle contraction times that can occur in different synergist muscles (Place, Matkowski, Martin, & Lepers, 2006). Changing subject performances can be accomplished best by feedback which has been shown to improve performance consistency (Winstein, 1991). As such, providing a visual cue to achieve similar head rotations across trials could be used in the future work.

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## **APPENDIX A---LITERATURE REVIEW**

**The influences of target eccentricity on AWAY and TOWARD responses:**

General Examination

Literature Review

Submitted to the Graduate Faculty of the  
Louisiana State University and Agricultural and Mechanical College  
in partial fulfillment of the requirements of the general examination  
for the degree of Doctor of Philosophy

in

The Department of Kinesiology

by

Taegyong Kwon

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## REFERENCES

## I. INTRODUCTION

When performing different tasks such as hitting (Brenner, de Lussanet, et al., 2002; Brenner, Smeets, et al., 2002; Brouwer, et al., 2000), catching (Laurent, et al., 1994; Williams & McCririe, 1988), driving (Ladas, et al., 2005; Langham & Moberly, 2003) and avoiding or dodging obstacles (Abernethy & Wood, 2001; King, et al., 1992), people constantly use visual stimuli for appropriate movement control. During driving for example, responses to visual input allow a driver to avoid obstacles such as a ball that rolls onto the road or “TOWARD” a target such as maneuvering into a parking space. The ability to avoid is also desirable in competitive sports, where to block or dodge an opponent’s attack is imperative for success (Ishihara, et al., 2002; Williams & Elliott, 1999). In these situations the athlete must constantly update their relative location and produce an appropriate motor response.

In the real world objects are commonly presented in various parts of the visual field. Attention differs for location of object presentation (Ando, Kida, et al., 2002). Studies on visuomotor control which exclusively assess responses to stimuli projected only on the central retina have their limitations, as these findings may not generalize to the peripheral target presentation. Although limited, investigations on abilities of people to detect and react to objects in the central and peripheral visual fields do exist (Ando, Kida, et al., 2002; Ando, et al., 2004; Niechwiej-Szwedo, et al., 2005). Some researchers indicate no difference in response abilities according to stimulus eccentricity (Helsen, et al., 1997; Taniguchi, 1999), while others show differences (Schiefer, et al., 2001; Wall, et al., 2002). Different methodologies among studies are blamed for the conflicting outcomes, making it more difficult to compare results and predict future findings. A critical evaluation of the associated literature should lead to additional studies

on the ability to detect and react to stimuli in different visual fields for better understanding of this topic.

Many investigations on the use of central and/or peripheral vision determined only perception responses (Ishihara, et al., 2002) or involved tasks in which moving toward a target for hitting (Enns & Richards, 1997; Land & McLeod, 2000; McLeod, 1987; Niechwiej-Szwedo, et al., 2005) or catching (Amazeen, et al., 1999; Bennett, et al., 1999) were necessary. These items are defined in the present manuscript as a *TOWARD*-response. Few people report research on tasks in which the purpose was to move away from the target as in an *AWAY*-response (Cooke & Graziano, 2003; Ishihara, et al., 2002; King, et al., 1992; Metoyer, et al., 2008; Ripoll, et al., 1995). However, many tasks require the use of avoidance techniques in isolation or in combination with accurate hitting. In the martial arts sparing partners switch from hit to avoid being hit several times within a very short time period (Mori, et al., 2002). As such, high quality motor responses of these individuals include both temporal and spatial demands. To date, few studies report how target eccentricities affect the temporal aspects of hit and avoid motor responses through direct testing.

The purpose of this manuscript is to better understand the association between target eccentricity presentation and different aspects of response time during movement toward and away from target locations. Accordingly, the review will be divided to several sections. These will include overviews of response time, visual field, response to visual stimuli, review of studies conducted on the effect of target eccentricities on avoid and hit responses, especially for defensive actions, and links to the information processing approach, a summary of these topics, and proposed directions for future research.

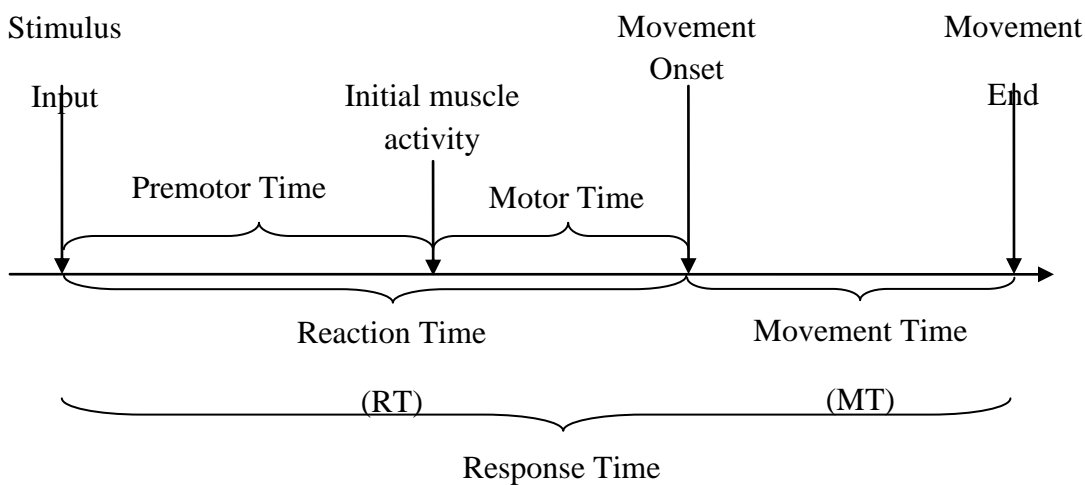
## **II. OVERVIEW OF RESPONSE TIME**

One fundamental way of assessing task performance is through temporal measures such as response time. Since the actual response determines the quality of movement, researchers have studied stimulus-response relationships in terms of spatial and temporal accuracy (Jasiewicz & Simmons, 1996; Newell, Carlton, Kim, & Chung, 1993). A number of factors that affect the time required to complete a movement in response to a stimulus will be the emphasis of this portion of the review, however some information on spatial accuracy will be included for completeness.

### **A. Definition of Response Time**

Response time represents the time a performer can receive and process sensory information (input) and make the movement required for a specific task (Beggs & Howarth, 1972a, 1972b; Luce, 1986). The diagram in Fig. 1 offers an overview of response time, an inclusive time interval involving reaction time (RT) and movement time (MT). Reaction time, defined as “the interval of time between the onset of a signal stimulus and the initiation of a response” can be further divided into a premotor time, the interval between the stimulus input and the first discernible change in muscle activity, and a motor time, the time from the onset of muscle activity to the onset of movement (A. D. Weiss, 1965). The premotor time is a more precise indicator of information processing time whereas motor time represents the sensitivity of the motor neuronal pool to the central command (Fischman, 1984). It is important to note that RT which designates generation of the motor response (A. D. Weiss, 1965) does not include the movement itself. MT is the time taken to physically respond to a stimulus and is defined as the interval of time between the initiation and completion of the movement (Fitts, 1954). MT recordings vary and primarily depend on task and recording equipment. For instance, determining movement onset and end will differ for uses of kinematics analyses, button presses

and external timers such as a stop watch. Reaction and movement times measure different aspects of human movement and are relatively independent measures; by definition they are easily separated. Some researchers argue that RT does not predict MT, especially when comparing different skills or different stimuli (e.g. (Helsen, et al., 1997). However, RT and MT can be influenced by the same external factors, one of which can be a visual stimulus (Komilis, et al., 1993).



**Figure 1 The event and time intervals of response time**

## **B. Response Time and Different Sensory Inputs**

In the real world we are exposed to different types of sensory stimuli that affect our abilities to control movement. Each sensory modality of a stimulus may provide a unique and independent perspective on the world. We use these stimuli to determine the state of our environment and our body. Driving a car involves visual input (seeing the road), auditory input (hearing an automobile horn), and somatosensory input (feeling the steering wheel and knowing the locations of the hands). A major factor affecting the stimulus-response time involves the

sensory modality of the stimulus, primarily because RTs vary across different sensory modalities.

RT will differ for a person making the same movement in response to different stimuli used to trigger the behavior. Although many believe that vision dominates the human experience (Colavita, 1974), this does not necessarily imply that RT to a visual stimulus is the fastest among the different sensory stimuli. Typically, RT to a visual stimulus is found to be longer than RT to an auditory stimulus (Colavita, 1974). Mean RT was 306.1 ms for a visual stimulus, 275.4 ms for an auditory stimulus, and 283.4 ms for touch stimulus when right-handed participants were asked to press a button with their right thumb as quick as possible to the sudden appearance of a visual cue, a sudden noise, or a touch on the right index finger (Naito, et al., 2000). These results have different values but are similar to the relative RTs summarized from various studies and indicate reaction to vision is slow (180 to 200 ms), reaction to touch is faster (140 to 160 ms), and reaction to audition is the fastest (120 to 140 ms) (Todd, 1912). Relative differences in RT among these types of stimuli persist whether the participant is asked to make a simple response or a response which is more complex, however absolute values differ greatly by task. Although the auditory pathway is slightly shorter than the visual pathway (King, 2005), this distance is negligible relative to transduction time (Arrighi, Alais, & Burr, 2006). The biophysical difference of the nature of transduction receives the primary blame for the divisions (Spence & Squire, 2003) because the process of sound transduction by the hair cells of the inner ear (mechanotransduction) is many times faster than phototransduction, the process of visual transduction by photoreceptors in the retina (Fain, 2003).

Tactile information provided from areas across the whole body, like audition, also involves mechanotransduction (Harrar & Harris, 2005), thus is relatively fast from the



transduction perspective. The difference between speed to visual and auditory stimuli compared to that to tactile stimuli depends on location of the applied tactile stimulus. A tactile stimulus applied to different parts of the body will vary in the amount of time to reach the brain for a volitional response. Given a typical conduction velocity of 55 m/s (Macefield, Gandevia, & Burke, 1989), tactile information applied to the face produces a very fast reaction compared to one applied to the foot (by about 30 ms), simply due to the distance of the applied stimuli from the cerebral cortex.

Differences within a sensory stimulus, other than distance of the applied stimulus, can also influence RT. Performance of a RT task can be strongly influenced by the physical properties of the stimuli used, including stimulus intensity (Boch, Fischer, & Ramsperger, 1984; Darrien, et al., 2001). For vision, a high intensity stimulus facilitates the triggering of quicker re-positional eye movements compared to a low-intensity stimulus (Bell, et al., 2006). Increasing visual stimulus intensity reduces processing time in the intermediate layers of the superior colliculus, known for its involvement for controlling gaze shifts (Bell, et al., 2006). Similar intensity based facilitation for audition occurs where participants respond more quickly to loud tones than to soft ones (Corneil, Van Wanrooij, Munoz, & Van Opstal, 2002; Perrault, Vaughan, Stein, & Wallace, 2003; Seitz & Rakerd, 1997). Increasing tactile intensity also should reduce RT (Wallace, Wilkinson, & Stein, 1996). Although some suggest the neural responses that allow RT reduction in the audition and touch modalities in intensity are unclear (Wallace, et al., 1996), it appears that the responses due to more intense stimuli in these modalities likely reduce processing time similar to that of vision (Recanzone & Beckerman, 2004; Spence, Shore, & Klein, 2001).

MT for a particular task does not differ in response to different sensory stimuli (Breen, De Haemer, & Poock, 1969). Most scientists would likely be surprised to find a difference in MT

due to sensory stimulation type (auditory vs visual stimulation) as there is no reasonable basis to expect such an effect when the sensory feedback during the movement is likely the same. For example, Breen et al (1969) investigated the effects of auditory and visual stimulation on RT and MT for a discrete motor response task. The participants held a lightweight metal writing stylus, equipped to record RT and MT, and were asked to react and execute a pointing movement with a stylus as fast as possible in response to an auditory tone or visual cue. Authors identified no significant effects of stimulus on MT (Breen, et al., 1969). In contrast, if the sensory feedback during the movement was altered, one would expect MT to differ for similar reasons offered for differences in RT in response to different sensory modalities. This was true in one study where Akamatsu et al (1995) investigated the addition of different sensory modalities in a human-computer interface using a modified mouse. After a random interval of 0.5 to 1.5 seconds, a visual warning cue disappeared signaling the start of a trial. At this time participants were instructed to move the cursor as quickly and accurately as possible to a targeted area and press the left mouse button in response to different stimuli (auditory, tactile or visual) to acknowledge they were in the area. Significant differences were found in the final positioning times; the time from the cursor entering the target to selecting the target, so that ranking of final positioning time from fastest to slowest was tactile (237 ms), auditory (262 ms) and visual (265 ms) (Akamatsu, MacKenzie, & Hasbrouc, 1995). Clearly, MT does not differ for response to different sensory modalities unless the information is used as a feedback mechanism during the movement. Further study on the use of such feedback is required to make final conclusions in this regard.

Different sensory stimuli influence response time by primarily affecting RT. Many researchers have confirmed that reaction to sound is faster than reaction to touch and the reaction to sound is faster than that to vision (Naito, et al., 2000) and blame transduction type (Bell, et al.,

2006; Jaskowski, et al., 1990) and/or distance (Harrar & Harris, 2005) for the disparity. Stronger stimulus intensities within each sensory mode also produce faster reactions. However, few studies have tested for differences in MT in response to different sensory stimuli, probably due to the lack of theoretical or scientific basis and/or the difficulty in experimental setup. The next section focuses on factors other than sensory modes that influence response time including RT and MT.

### **C. Other Factors that Influence Response Time**

It is well known that estimations of response time differ due to multiple factors, eliminating a single, universal value for response time and its subsections. The previous section described influences of different sensory inputs, which primarily influence RT. We will continue a list of other factors that affect RT next, followed by those that affect MT.

Methodological differences among studies can influence experimental results, including RT. Manual timers such as stopwatches or button boxes (Bohannon, 1995; Helsen, et al., 1997; Ishihara, et al., 2002), foot pedals (Ownes, Antonoff, & Francis, 1994; van Winsum & Brouwer, 1997) and computers (Aschersleben & Musseler, 1999; Becker, Vonthein, Volpe, & Schiefer, 2005) have been used to determine RT of participants. Clearly, when comparing differences in RT, the device must be fast enough to detect these differences, thus possess adequate recording accuracy. Studies in which more variable devices with less accurate recording ability (i.e. manual timers) were used may not identify subtle differences and help explain contradictory findings (Langham & Moberly, 2003). Other factors influencing RT deal with the stimulus and stimulus presentation, as mentioned previously. Testing conditions can also influence MT. Tasks involving greater movement distances (Smyrnis, Evdokimidis, Constantinidis, & Kastrinakis, 2000), multiple or different movement selections (Pessiglione et al., 2003) and other multiple

response components (Norrie, 1974) are reported to increase MT compared to smaller movement distances, single movement selections and single response components, respectively. We attempt to account for methodological differences in presenting the remaining major factors that influence the subcategories of response time: RT and MT.

Age and gender are factors that can influence RT and MT. Simple RT studies reveal a general slowing with increasing age (Der & Deary, 2006; Gottsdanker, 1982; MacDonald, et al., 2008; Wilkinson & Allison, 1989). Older drivers often hit their brakes more slowly than younger counterparts when driving (Broen & Chiang, 1996; Margolis et al., 2002). However, older drivers are more consistent in making a rapid decision to the brake pedal once the hazard has been recognized (Green, 2000). In terms of gender, visual RTs were longer in women than in men when participants were asked to press a button as soon as a target was presented on a computer screen (Dane & Erzurumluoglu, 2003; Der & Deary, 2006). Another study also found that men had faster reactions than women when aiming at a target (Barral & Debu, 2004). In this study participants were required to aim fast and accurately at one of three possible targets under a choice RT protocol where participants are given more than one option. Some studies revealed no RT differences between adult males and females when responding to randomly presented visually eccentric targets with a key press (Solberg & Brown, 2002). In regards to MT, older adults completed reaching movements to two randomly presented directions slower compared to their younger counterparts (Yan, Thomas, & Stelmach, 1998). Greater age was strongly associated with slower MTs for discrete aiming tasks and reciprocal tasks, requiring a series of back-and-forth movements (Teeken, et al., 1996). Male participants also moved faster than female participants in a discrete aiming task (Teeken, et al., 1996), however males were also slower than females when braking to quickly to a visual stimulus (Warshawsky-Livne & Shinar,

2002). The latter results contradict the well-known speed advantage for males in various racing events. Together, these findings suggest more consistency in age-related RT and MT differences than those identified for gender. Overall, they suggest that younger adult males will be in the group reacting the fastest and moving the quickest.

Factors involving different cognitive loads and arousal states can also affect response time. Attention is a limited resource, so any factor that draws from the available resource pool might distract the participant from detection of the signal and slow RT (Alm & Nilsson, 1994; Jaskowski, et al., 1990; Korteling, 1990; Reddi & Carpenter, 2000). Results from empirical research show that drivers using cellular phones have slower brake RTs (Briem & Hedman, 1995). Although this could be due to the dual task performance, it could also be due to cognitive demands shown to slow RT for braking in older adults (Zhang, et al., 2007). High arousal loads can actually quicken RT. For example, drivers responded faster under greater urgency to prevent or minimize a collision possibly due to the greater arousal (Fuller, 1984; Green, 2000). Cognitive states may also influence MT of performance. Zhang et al. (2007) measured brake RT of releasing the gas pedal and brake MT to depressing brake for older participants (age 67-87 years) when a traffic light turned red in their driving simulator. Participants underwent a series of tests that measure certain aspects of cognition for attention and mental status. They revealed that brake RT and MT increased with poor test scores indicating low levels of cognition (Zhang, et al., 2007). Relationships between anxiety and RT and MT were observed for people with different levels of anxiousness when anticipating a threatening demands or dangers (trait-anxiety). Participants performed the Stroop tasks, where the word and color were compatible (e.g. the word blue was blue) or incompatible (e.g. the word blue was red), and were asked to press a button located 7 cm to the left of start position if they heard a pure tone auditory cue or

press a button location 7 cm to the right if they saw a visual cue (a red circle appear on a computer screen) (Hainaut, Monfort, & Bolmont, 2006). RTs were not influenced by trait-anxiety levels according to compatibility. In contrast, MT decreased in the visual modality for high trait-anxiety participants and in the auditory modality for low trait-anxiety participants for the incompatible condition. Together, these results indicate that MT increases with greater attentional demands and lower arousal states and can be altered by level on anxiousness.

Differences between the expert and novice martial artist and other athletes offer evidence for expertise-based RT differences. Capitalizing on tasks specific to karate athletes, researchers asked participants to indicate as soon as possible whether a video-taped offensive attack would be aimed at the upper or middle level of their body (Mori, et al., 2002). Authors determined that karate athletes who had 4-6 years of experience showed faster RTs than novice who had no experience in pressing the appropriate key corresponding to the body level. In a very similar situation others showed that expert karate athletes who had about 6 years of training were no faster than the novices who had never taken part in any type of formal martial arts training when asked to respond to a video-taped offensive action by moving as if to avoid being struck with a block or avoid response (Williams & Elliott, 1999). However, these experts were more accurate than the novice in defending the attack. The accuracy demands, discussed in more detail below, explain such differences, however RT recording accuracy of 50 Hz may not have captured subtle differences. Expertise-based RT differences in other sports also exist. Professional baseball players had faster RT than and nonathletes when pressing a keyboard with their right index finger when the middle frame of a computer screen turned green (Kida, Oda, & Matsumura, 2005). Advanced water polo players also reacted faster than novices when lifting the foot that corresponded to a left, right, forward or backward directional visual cue (Kioumourtzoglou,

Kourtessis, Michalopoulou, & Derri, 1998). These studies provide evidence that experts in different sports react faster than non-experts when accuracy demands are equal.

MT commonly depends on the expertise of the participant. This is obvious in athletes where expertise is based on time, including runners, swimmers and rowers. Quick MTs are also observed anecdotally in team sports where an offensive player can beat a defensive opponent to the goal during one-on-one coverage. Other examples may be less obvious. For instance, MT is one of the factors relevant to score when kicking an opponent in the martial arts. Falco et al. (2009) compared MT of the basic roundhouse kick in expert and novice Taekwondo athletes. They used two force platforms to measure the time from kicking leg lift off to the time of maximum impact force from with a target. Experts produced faster kicks than the novice competitors. Expert tennis players also produce faster strokes when hitting a tennis ball (Shim, Les Carlton, & Kwon, 2006). In these cases faster MT discriminates the expert and novice athlete, however in others cases consistency of MT is the discriminating factor. Expert performers in ball games, such as baseball (Hubbard & Seng, 1954), table tennis (Bootsma & Van Wieringen, 1990) and field hockey (Franks, Weicker, & Robertson, 1985) execute their offensive strokes with remarkably consistent movement times. Whether it is faster actions or less variability movements, MT differences between the expert and novice athlete exist.

#### **D. Summary**

There is a full complexity of human behavior that influences response time that is commonly not captured in individual studies. RT and MT generally slow with increasing age. MT is generally slower for females than males, while the difference in RT between genders is less consistent. Factors involving mindset and experience can also affect RT and MT and suggest that reductions in RT and MT are also influenced by lower cognitive demands and greater level

of training. In many cases it is not the actual RT or MT that should concern us. Rather, it is the factors that influence the relative increase or decrease in these variables that allow us to generalize the outcomes to response time under a variety of situations. Converging evidence among similar studies enables reasonable estimates for specific situations.

### **III. OVERVIEW OF VISUAL FIELD**

People use various parts of their visual field when performing daily tasks, including those used in sports. Not only do people vary their gaze direction, thus the representation of objects within the visual field to attend to those objects (Ando, Kida, et al., 2002), but attention to an object differs due to its presentation in the visual field (Ando, Kida, et al., 2002). Prior to understanding how people respond to visual stimuli presented in different parts of the visual field, it is important that we understand the major divisions of the visual field. Therefore, the focus of this section is to review the central and peripheral visual fields, various eye movements, as well as central and peripheral vision as they are described in the literature.

#### **A. Visual Fields**

Central vision, defined here as vision using the central viewing field, is linked closely to the line of sight or direction of gaze (Sivak & Mackenzie, 1992). Gaze direction relies on the orientation of the eyes within the environment, thus the orientation of light reflecting off objects and onto the macula, which is located on the central portion of the retina. The macula has a diameter of around 5 mm and is often defined as having two or more layers of ganglion cells, which transmit photoreceptor input through the visual pathway (Iwasaki & Inomata, 1986). It covers approximately 10 degrees of visual arc (Hudson et al., 1997) representing the parafoveal region in Fig. 2. The fovea lies within the macula covering approximately 1-2 radial degrees of



the retina (Zeki, 1993), thus at least 2 degrees of the visual field (Fig. 2). Photoreceptors (cones) and retinal ganglion cell density, which is approximately 200% greater in the fovea than in the periphery (Curcio & Allen, 1990), enable fine visual acuity in this area (Sivak & Mackenzie, 1992). Clarity of the visual image drops off dramatically as the stimulus moves eccentrically into the parafoveal region (Pinel, 1993) due to the reduction in concentration of cone cells and increase in rod receptors (Ruch, 1965). Thus, the greatest visual acuity is sensitive to the different parts of the visual field in relation to the eccentricity from the fovea (Strasburger & Rentschler, 1996), however external light conditions (Poppel & Harvey, 1973), and object movement (Sachsenweger, 1986) also influence visual acuity and cannot be ignored.

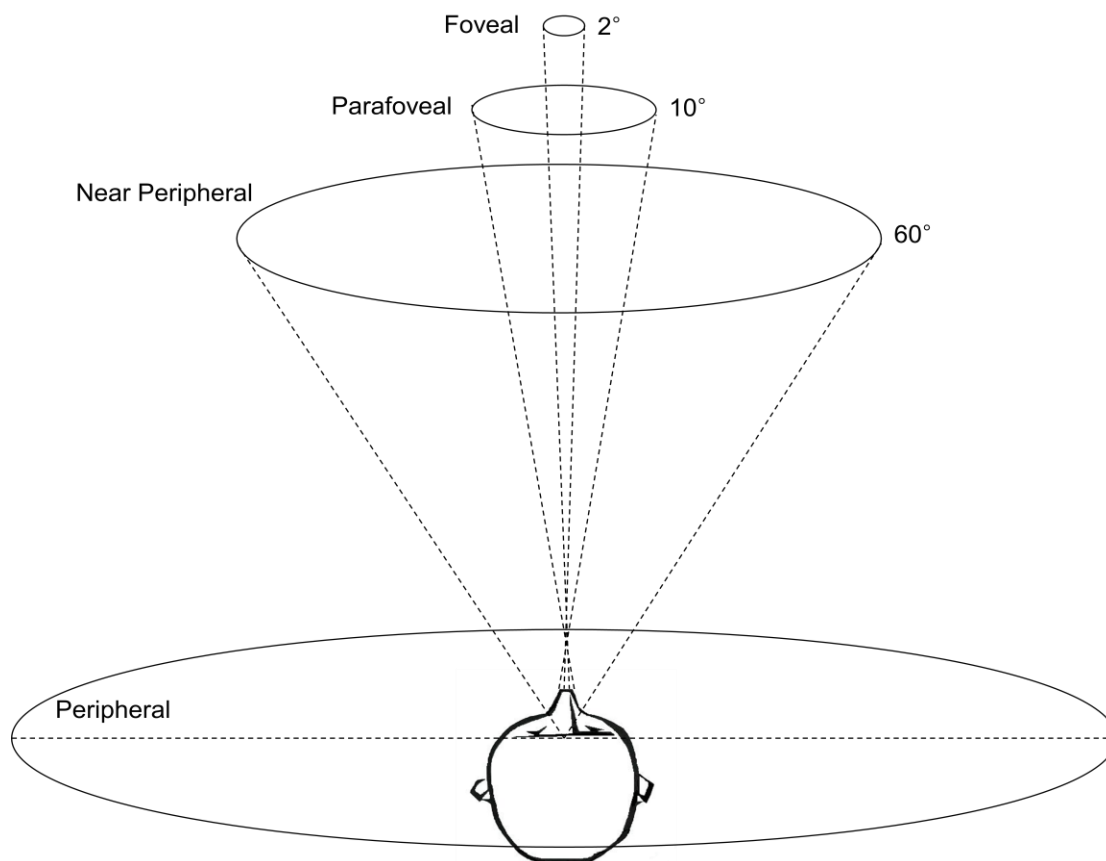


Figure 2. Cone of vision showing foveal, parafovea, near peripheral and peripheral vision (Here the angles measure the field of vision from one side to the other (Modified from Figure 1.7, Solso).

The peripheral visual field is that outside the center of gaze direction (Nougier, et al., 1998). The peripheral visual field of the retina has a low density of cones and is dominated by rods. The highest density of rods is between 10-30 degrees eccentricity from the central retina (fovea), peaking around 20 degrees (Stabell & Stabell, 1976). Clarity of the visual image decreases more rapidly in the periphery, which extends up to 80 radial degrees vertically and 100 radial degrees horizontally due to photoreceptor reduction (see Fig. 3) (Harrington, 1964). Photoreceptor density plotted in Fig. 3 offers insight to the use of cones and rods in photopic (daylight) and scotopic (night vision) conditions, respectively.

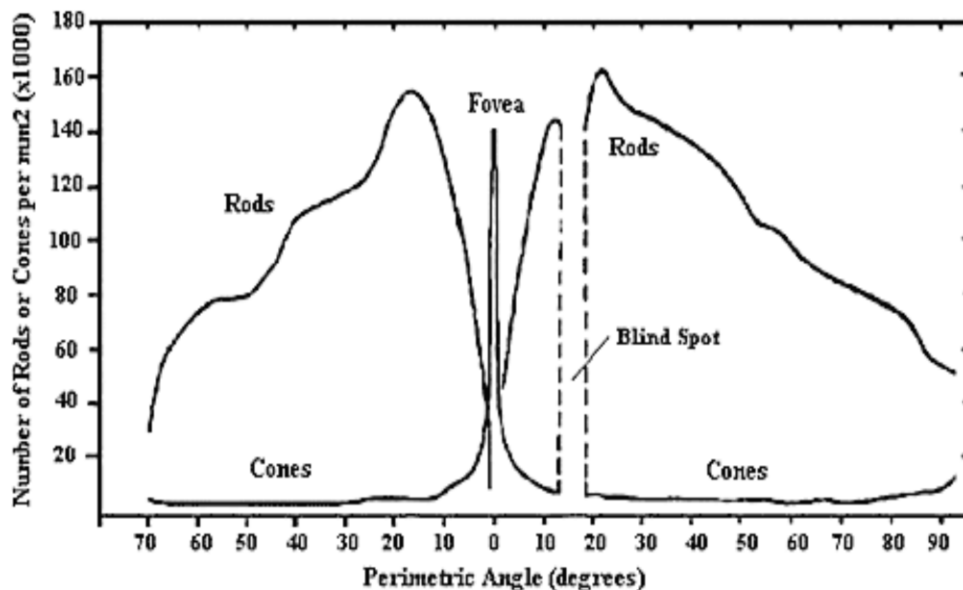


Figure 3. Photoreceptor density is plotted as a function of distance from the fovea (Modified from Figure 2.9 Wolfe et al.)

Under photopic conditions the highest visual sensitivity for detection of light is registered at the fovea utilizing cone-dominated vision (Sivak & Mackenzie, 1992), while under scotopic conditions the highest visual sensitivity is found on the macula beyond the parafoveal region where rod vision dominates (Poppel & Harvey, 1973). Rod receptors are more sensitive to light and motion, but because of their “many-to-one” correspondence with the underlying ganglion cells, lack the ability to pick up detail and color used for visual clarity (Pinel, 1993). However, with the established rod receptor sensitivity to light and motion, vision processed in the peripheral visual field is well known for its role in identifying relative movement between observer in and object (Sekuler & Blake, 1994). Whether using cone-dominant or rod-dominant vision it is clear that a person must continually adjust the positioning of the fovea of the eyes, thus their gaze direction, for common task performances.

## **B. Eye Movements**

By redirecting gaze toward an object people gather critical information about the object’s characteristics, including identification of the object itself (Darrien, et al., 2001). As such, our ability to see fine detail is dependent upon the ability to keep images on the fovea fairly stable as the observer or objects move. There are four types of conjugate eye movements (i.e. both eyes move in the same direction together) that encourage image projection on the fovea of both eyes: smooth pursuit, saccades, vestibulo-ocular reflex (VOR), and optokinetic reflex (OKR). A brief description of each is presented. Readers are referred elsewhere for greater details on this topic (Squire & Bloom, 2008),

Smooth pursuit and saccades are two types of conjugate eye movements that can occur without head movement. Smooth pursuit enables the eyes to track slow-moving targets within the visual field, such as a ball or an opponent and have a fairly short latency of 100 ms (Carl &

Gellman, 1987). The maximum velocity of these eye movements is around 100°/s, although the eye tracking abilities begin to deteriorate at around 30°/s (Rosenbaum, 1975). Saccades are responsible for the rapid repositioning of the eyes that bring a new part of the visual field into foveal vision (Carpenter, 1988; Rosenbaum, 1991). Therefore, saccades are rapid movements of the eyes to a new fixation point and are the fastest voluntary movements in humans, but have a longer latency of approximately 200 ms due to their cognitive demands that require attention (Fischer & Ramsperger, 1984; Kowler, Anderson, Doshier, & Blaser, 1995; Krauzlis & Miles, 1996). A saccadic eye movement is programmed and executed to bring the eccentric stimulus onto the fovea, where it can be processed with highest acuity. On average, saccades undershoot stationary targets and only account for about 90% of the distance between eye and the target (Carpenter, 1988). Within horizontal saccadic eye movements up to 20° amplitude, participants with no neurological deficits can undershoot target locations (Bahill, Clark, & Stark, 1975). Clearly, saccadic undershoots and overshoots depend on eye movement amplitude.

When the head is moving two other conjugate eye movements, the VOR and OKR, are heavily recruited. The VOR functions to stabilize gaze and ensure clear vision during fast head movements, as commonly seen with head rotations to induce vestibular system involvement. The VOR maintains the shortest latency for eye movements, about 20 ms (Schweigart, Mergner, Evdokimidis, Morand, & Becker, 1997), allowing object stabilization on the retina during very fast head rotations of 350°/s (Pulaski, Zee, & Robinson, 1981) or between 5-6 Hz head oscillations (Schweigart, et al., 1997). The OKR, which stabilizes gaze during relatively slow head movements, provide visual tracking assistance during sustained head movements (Schweigart, et al., 1997). It allows one to maintain gaze fixation during tasks that require head translational (i.e. keeping an eye on a person in crowd during your approach). The latency of the

OKR is relatively slow compared to the VOR, about 100 ms, due to its use of visual feedback (Miles, 1997).

The success of the visual systems in achieving a stable retinal image depends on the speed of the moving target which the eyes are required to follow (Sekuler & Blake, 1994). Due to their relatively slow nature, some aspects of certain sports make it difficult to visually follow an object using pursuit tracking eye movements (Haywood, 1984). Some eye movements help a person pick up information from other players. Saccades are used to redirect the eyes to another player, moving object or target, where the VOR and OKR help keep the eyes fixed on a player or goal during fast or slow head movements, respectively. Although the eye movements described are known for their role in orienting the fovea, they will also influence photoreceptor activation in the peripheral visual field.

### **C. Separate Viewing Fields for Central and Peripheral Vision**

Inconsistently defined viewing fields complicate our understanding of central and peripheral visual fields and vision. Although neural anatomy can be used to dictate central vision based on the retinal distribution of the cone and rod photoreceptors, some investigators use behavioral viewpoints to identify central and peripheral viewing fields. For example, Nougier et al. (1997) defined central vision as the central 10° of the visual field (Nougier, et al., 1998), whereas Brandt et al (1973) defined central vision up to the central 60° of the visual field (Brandt, Dichgans, & Koenig, 1973). Clearly, the link between receptor distribution and behavioral viewpoints would differ greatly in these experiments. To complicate matters divergent projections from photoreceptors pass through the primary visual pathway and beyond, suggesting links between central and peripheral field projections (Braccini, Gambardella, Sandini, & Tagliasco, 1982).

## **D. Summary**

Interestingly, there is evidence to show that normal humans commonly use different viewing fields to perform different tasks, even though the roles of central and peripheral visions are not completely segregated. Most scientists agree that central vision is linked closely to high visual acuity in normal room lighting, as it is responsible for detecting many physical characteristics of environmental objects (Sekuler & Blake, 1994). Note, that people can detect certain spatial characteristics of the environment using peripheral vision (Westheimer, 2001). Research on the roles for using different viewing fields in various motor actions provides greater insight to this issue and is presented later in the next section.

## **IV. RESPONSE TO A VISUAL STIMULUS**

It is clear that visual information and the ability to detect, identify or respond to visual stimuli play important roles to successfully perform many actions (Helsen, Starkes, & Ricker, 1998). This is not to deny that other forms of sensory information are important, it is just that visual information is the source upon which we rely most in certain instances. For example, a martial arts specialist is heavily dependent on the visual systems to provide much of the information in order to respond appropriately to the abrupt appearance of an opponent's attack.

As mentioned previously, response time to a visual stimulus can be influenced by several factors. The focus of the following section is to summarize the literature on how different factors influence response time to visual stimuli and identify the gaps in the literature on this topic. The factors emphasized include target movement, body segments used, visual field activation and the effect of the speed accuracy trade-off on response time, while accounting for general factors affecting response time inherent within these categories.

## **A. Stationary vs Moving Targets**

As we interact with a complex, dynamic environment to make goal-directed movements, our nervous system has to specify the position and timing of a goal. Consider an extreme example in martial arts, in which a player must attack a stationary or moving target, avoid a moving target or avoid a stationary target during movement. Many studies have investigated visual RT to stationary and moving objects, however there are few attempts comparing RTs of moving and stationary stimuli directly. The focus here is to review the literature in which such comparisons are made.

In order to gain insight into the process of visual information in motor control, most researchers have studied simple hitting or reaching and/or grasping RT toward stationary or moving targets. When participants were asked to use a hard, transparent plastic rod to intercept the appearance of a stationary spider or a spider running from left to right on a computer screen as fast and accurately as possible, they found that the RT was shorter for fast spiders than for the slowest and static spiders (Smeets & E. Brenner, 1995). Participants in another study were asked to press a key as fast as possible after the appearance of moving or stationary stimulus also showed the shortest RT in response to the moving stimulus (Aschersleben & Musseler, 1999). In agreement with these findings, both individuals Parkinson's disease (PD) and healthy participants could react faster when they grasp a moving ball as fast as possible compared to grasping a stationary ball (Majszak, Kaminski, Gentile, & Gordon, 2008). Clearly, a visual moving stimulus can induce a shorter movement initiation. Researchers suggest that the faster reactions exist because moving targets are more easily detected (Schenk, Baur, Steude, & Botzel, 2003) and that processing of moving stimuli seems to be faster than to stationary stimuli (Van Thiel, et al., 2000). These findings are not surprising when one considers that certain object

properties and object location are processed through different neural pathways (Goodale, Milner, Jakobson, & Carey, 1991).

Not only are moving targets more quickly detected, several studies showed that the MT for a movement made toward moving stimuli was shorter than the MT for movement toward stationary stimuli. For example, authors investigated how hemiparetic and healthy participants performed unimanual aiming movements toward stationary and moving targets. Targets appeared either at 4 cm left, 0 cm, or 4 cm right lateral to the projection of the tip of a handheld rod on computer screen, remained stationary or moved with constant velocities of either 6 cm/s, 9cm/s, or 12 cm/s (Van Thiel, et al., 2000). Results showed that the moving target evoked faster the mean MT compared to stationary targets when both groups were instructed to intercept the target with the tip of the rod as fast as possible upon target appearance (Van Thiel, et al., 2000). Participants with Parkinson's disease (PD) and healthy participants reached to grasp a ball from a ramp as fast as possible in stationary and moving ball conditions. MTs of participants with Parkinson's disease and healthy participants were shorter when reaching to grasp a moving ball compared to a stationary ball (Majsak, et al., 2008). The faster responses to moving stimuli compared to stationary stimuli are consistent in participants with and without movement impairment.

The behavioral evidence just presented points to faster RTs and MTs for moving stimuli compared to those for the stationary counterparts. The intimate link between the hand and eye used for hand-eye coordination is blamed for this difference, as the visual moving stimulus has a direct effect on movement speed by engaging faster neural circuitry more sensitive to visual cues, i.e. the parvocellular or ventral visual pathway (Sunaert, et al., 1999; Zeki, et al., 1991).



## **B. The Effect of Speed Accuracy Trade off on Response Time**

One of the most common occurrences in motor behavior is known as the speed-accuracy trade-off, meaning simply that when performers attempt to do something more quickly, they typically do it less accurately. The concept of the speed accuracy trade-off for movement control was systematically introduced by Woodworth in the late 1800s (Woodworth, 1899). However, it was not until 1954 when Fitts developed the notion of an index of difficulty to determine the time required to make accurate skilled movements (Fitts, 1954). A few examples of different items that influence accuracy, thus reaction and movement times, are presented next.

RT increases as the precision requirement to the task increases (Fitts & Peterson, 1964). Cauraugh (1990) investigated response preparation and accuracy performances which elucidated the speed-accuracy operating characteristics. Participants used the index and middle fingers of both hands which were placed on four computer keys corresponding to four white squares presented on the computer screen. Participants were told to be accurate and fast in making a two- or four-choice response, however accuracy and speed were emphasized in different portions of the experiment. Slower RTs and higher accuracy rates were noted when accuracy was emphasized and provided support that RT was influenced by the speed-accuracy trade off (Cauraugh, 1990). Demanding accuracy requirements for a visuo-manual (pointing) task performed by individuals aged 6, 8 and 10 years and adults, alike increases RT speed (Christina, et al., 2003). Changing target size for accurate reaching tasks altered RT, so that it increased with reaches to smaller targets which require more precision (Quinn, Schmidt, & Zelaznik, 1980). Although evidence that the speed-accuracy trade off influences RT, it is probably best known for its role in MT responses.

Installing spatial accuracy requirements on many movements produces well known slowing of the actual MT. As the need for spatial accuracy increases, the speed of movement commonly decreases (Rival, et al., 2003; Woodworth, 1899). This phenomenon occurs whether spatial accuracy constraints are verbally imposed to participant making reaching movements toward the sudden appearance of a target (Rival, et al., 2003) or visually imposed in a manual aiming task between two targeted locations (Woodworth, 1899)

Studies show that installing temporal accuracy requirements also affects MT (e.g. (Newell, Hoshizaki, & Carlton, 1979)). Participants, who try to move a handle a specified distance while matching a given MT, decreased absolute and variable timing errors with decreasing target MTs and increasing movement speeds (Newell, et al., 1979). Many studies on intercepting moving targets show that people hit fast targets more quickly than slow ones (Carnahan & McFadyen, 1996; Fayt, Bootsma, Marteniuk, Mackenzie, & Laurent, 1997; Savelsbergh, Whiting, Burden, & Bartlett, 1992; van Donkelaar, Lee, & Gellman, 1992). One of possible reason for increased temporal accuracy for the fast movement is that participants simply make larger errors in estimating longer MTs (Schmidt, 1969) and make smaller errors if the movement is quick (Brouwer, et al., 2000). Moreover, target speed has a larger effect on the MT than accuracy determined by size of the moving target (Tresilian & Lonergan, 2002).

The phenomenon known as the speed-accuracy trade off is observed often. Examples of increasing accuracy demands include decreasing target size (Bootsma, et al., 1994), increasing target movement duration (Battaglia & Schrater, 2007), decreasing target velocity (Bradshaw & Sparrow, 2001), limiting mistakes (Rival, et al., 2003) and increasing the number of choices (Cauraugh, 1990). Clearly, installing accuracy requirements on movements produces different outcomes on MT, depending on whether the accuracy is spatial or temporal in nature.

## **C. Different Body Segments**

Response time for the eyes (Leigh & Kennard, 2004; Sparks & Mays, 1990), hands (Barthelemy & Boulinguez, 2001, 2002a; Boulinguez, et al., 2000; Niechwiej-Szwedo, et al., 2005), lower limbs (Terry, et al., 2008; Warshawsky-Livne & Shinar, 2002) and multiple body segments (Bard, et al., 1992; Hollands & Marple-Horvat, 2001; Hollands, et al., 2004) will differ due to several factors, including travel distance for neural projections discussed previously and biomechanical properties (i.e. inertial of the body part). The focus of the following sections is to review the findings reported on how the use of different body segments (the eyes, hands, and feet) and concurrent use of multiple body segments influences response time components.

### **C.1.The Eyes**

In order to get clear vision of an object of interest, the projection of this object onto the retina must fall on the fovea, which is the central area of the retina where visual acuity is high (Gardner & Lisberger, 2001; Leigh & Kennard, 2004; Orban de Xivry & Lefevre, 2007; Smeets & Bekkering, 2000). Therefore, humans orientate their visual axis to targets of interest so light reflections from objects project to the fovea. These objects can be stationary or moving.

Remember that humans can track objects of interest in the environment using two types of eye movements: smooth pursuit and saccades. A large number of studies have demonstrated that the neural pathways and the properties underlying smooth pursuit eye movements differ considerably from those underlying saccades (Keller & Heinen, 1991; Lisberger, Morris, & Tychsen, 1987; Sparks & Mays, 1990). Although the velocity of the pursuit eye movement is typically closely related to that of the target, the smooth pursuit gain (eye velocity/target velocity) is generally found to be smaller than unity (Collewyn & Tamminga, 1984; Murphy, Kowler, & Steinman, 1975) and the observer has to initiate a high velocity saccadic eye

movement (catch up saccade) to maintain foveation (Gardner & Lisberger, 2001; Leigh & Kennard, 2004; Orban de Xivry & Lefevre, 2007). Thus, it is important to know the temporal aspects of the different eye movements during goal-directed performances. Behavioral properties of saccades and smooth pursuit are listed below.

Saccades are typically used to respond to a sudden repositioning of the target and correct for the position mismatch between the gaze direction and the object of interest (Leigh & Kennard, 2004; Sparks & Mays, 1990; Walker, Walker, Husain, & Kennard, 2000). Although visual information cannot be acquired during saccadic eye movements due to the fast nature of the movement and slow processing of visual input (Bridgeman, Hendry, & Stark, 1975; Bridgeman, Van der Heijden, & Velichkovsky, 1994), the relatively long interval between target presentation and onset of saccade movement allows for visual processing and motor programming. This results in a saccade to align the eyes on the new target and is dependent on stimulus properties, such as luminance, and the nature of the task (e.g. one versus multiple target locations) (Leigh & Kennard, 2004). It is well known that saccadic RTs to an unexpected stimulus normally are approximately 200 ms (Fischer & Ramsperger, 1984; Krauzlis & Miles, 1996; Saslow, 1967; Wheelless, Boynton, & Cohen, 1966). Some researchers found that saccadic RTs are sensitive to changes in sensory information in the visual field and depend on the interval between the offset of a central fixation cue and the onset of a target cue (gap-paradigm) (Fischer & Ramsperger, 1984; Saslow, 1967). This gap-paradigm can reduce saccadic RT from the typical 200 ms down to 120-150 ms (Fischer & Ramsperger, 1984; Reuter-Lorenz, Hughes, & Fendrich, 1991). Fischer and Ramsperger (1984) have shown that visually guided saccades can occur with even shorter RTs. They can be as low as 100-120 ms, if the onset of the peripheral

target is postponed by about 200 ms to fixation cue offset. Because of their very short latency, these saccades are called "express saccades" (Fischer & Ramsperger, 1984).

Saccades are very fast eye movements, reaching hundreds of degrees per second and are usually completed in tens of milliseconds (Harwood, Mezey, & Harris, 1999). Saccades have consistent relationships between their movement amplitude, speed and MT; MT of a saccade depends directly on its amplitude, which is the angular distance that the eye travels during the movement. Thus, the bigger the saccade, the greater its peak velocity and the longer its MT. Saccade MT ranges from 20-100 ms, the latter of which is less than the response time of the visual system (Leigh & Kennard, 2004; Orban de Xivry & Lefevre, 2007). As their duration is very short, saccades cannot be controlled by continuous visual feedback, which is characterized by a delay of at least 100 ms (Bridgeman, 1995; Collewyn, Erkelens, & Steinman, 1988; Harwood, et al., 1999).

Unlike saccades, smooth pursuit eye movements stabilize the projection of a target onto the fovea and attempt to minimize the difference between target and eye velocity (Krauzlis & Stone, 1999; Rashbass, 1961). If a target starts to move suddenly, pursuit initiation has to be as fast as possible, since the retinal position error increases steadily with time. Initial eye acceleration, taken as a measure for the strength of pursuit initiation, increases with target speed and is adjusted to the target's movement direction when a single target is tracked (Lisberger & Westbrook, 1985; Tychsen & Lisberger, 1986). Most investigators have found that the onset of smooth target motion evokes pursuit after a latency (RT) of 100 ms (e.g. (Carl & Gellman, 1987), mainly because of delays caused by different visual parameters, including the target's contrast, size, velocity and initial position in the visual field. As target contrast (Lisberger & Westbrook, 1985), size (Heinen & Watamaniuk, 1998) and velocity (Carl & Gellman, 1987;

Tychsen & Lisberger, 1986) increase, smooth pursuit latency decreases. Latencies for smooth pursuit increased as a function of increasing target eccentricity (Knox & Bekkour, 2004). In addition, the RT of smooth pursuit increases or lags behind during unexpected target movements and can be reduced or even turned into a lead if target movement can be anticipated (Badler & Heinen, 2006).

The performance of the smooth pursuit system depends on the spatio-temporal characteristics of target motion (Buizza & Schmid, 1986; Carl & Gellman, 1987; Carpenter, 1988; Fischer, 1987). After initiation of smooth pursuit, the eye movement can lag, lead, or follow the target of interest, making MT of smooth pursuit difficult to determine. When lag and lead eye movements are present, a corrective saccade can be used to correct the offset. It is suggested that adults can accurately pursue objects moving at speed of up to 30°/s without use of saccades (Stork, Neggers, & Musseler, 2002). In this case smooth pursuit MT equals that of the target movement. Other participants were asked to fixate on a stationary crosshair in the middle of a circle and were told track a moving dot along the circular path when it appeared (Storke et al. (2002)). In one condition, participants pressed a button when they believed their eyes were on target and stopped eye movement. In another condition, they stopped eye movement when the target randomly stopped moving. The difference between stop time of the point of gaze and the target was such that termination of the eyes lagged behind termination of the target by 29 ms in the button press condition and by 47 ms when time of target termination was random. Hence, MT of the eyes was slightly longer than MT of the target, but improved when participant had knowledge of target termination.

In summary, most researches show that saccades and smooth pursuit do not have the same reaction or MT. Standard latencies are 100 ms for smooth pursuit and 200 ms for saccades,

however these can be influenced by different factors. MT for saccadic eye movements is tightly coupled with movement amplitude and velocity, commonly ranging from 20 ms for very short movements and 100 ms for very long movements. MT for smooth pursuit is somewhat coupled with target movements when these movements are relatively slow (less than 30 %/s). However, during some visual tracking tasks smooth pursuit and saccadic eye movement work together to maintain gaze on the object of interest, possibly making MT of a specific eye movement an inappropriate variable of measurement. In this and similar cases RT and lag or lead time of the stimulus make more useful variables of interest.

## **C.2. The Hand(s)**

A wide variety of hand or arm movement actions form essential features of our daily lives. Pressing a key on a computer or blocking opponent's attack require hand or arm movement toward the spatial location of interest for successful completion of the tasks. This must occur at the appropriate time if the target is moving. Accordingly, researchers pursue spatial and/or temporal responses of hand movement in different ways, including handedness comparisons and ipsilateral and contralateral movements toward target locations. The focus of this section is to review the manual asymmetries and ipsilateral and contralateral movements during goal-directed performances using the arm and hands.

Manual performances for each hand depend on the aspect of the task under scrutiny. Some researchers shows that the temporal nature of the difference between left and right hands for reaching movements in right-hand dominant people revealed shorter latencies for movement initiation using the left hand (Barthelemy & Boulinguez, 2001, 2002a, 2002b; Boulinguez, et al., 2000; Carson, Chua, Goodman, Byblow, & Elliott, 1995). Interestingly, left-handed handball player produced faster RTs than right-handed players when asked to press a button as soon as the

target was presented on computer screen using the left hand (Dane & Erzurumluoglu, 2003). With no difference between the reaction times using the right hand, authors concluded that left-handed people have an inherent RT advantage. In particular, it has been suggested that performance differences in left and right hands are due to differences in the information processing capabilities of the left and right hemisphere of the brain (Flowers, 1975; Todor & Cisneros, 1985; Todor & Doane, 1978). In the study of Boulinguez and his colleagues, they compared RT of the two hands in right-handers depending on whether the direction or the amplitude of the movement had to be programmed. RTs were shorter for left-hand movements than for right-handed movements in both direction and amplitude condition when participants were asked to aim at and touch a target with the stylus as soon as the target (LED) was lit. The left hand advantage in movement preparation inferred from shorter RTs has been interpreted as reflecting a superiority of the right hemisphere to allocate spatial attention and/or better integrate and forward information about the position and orientation of an effector with respect to the target location prior to movement initiation (Fisk & Goodale, 1985). This appears to be accurate for movements requiring a temporal response.

In contrast, there is experimental evidence suggesting that dominant hand would have an advantage over the non-dominant hands on RT tasks (Peters & Ivanoff, 1999; Tremblay, Welsh, & Elliott, 2005). Typically people who declare a right hand preference for tasks such as writing, throwing and using scissors also exhibit right hand performance advantages in executing most motor tasks. Thus, the right hand would have an advantage for right-handed people. In the study of Tremblay and colleagues, RT in the right hand exhibited an advantage when participants were required to execute rapid left-hand or right-hand aiming movements upon illumination of a target light in left or right space (Tremblay, et al., 2005). Peters and Ivanoff (1999) also found that RT



in right-handed people were faster with their right hand, but left-handed people were equally fast with both hands when instructed to move a cursor as quickly and accurately as possible to a target dot on the computer screen. However, there is some conflicting evidence show that dominant hand is faster than nondominant hand. Recent attempts to manipulate task difficulty have found that the different RTs between hands does not increase with task difficulty (Bryden, 2002). Bryden (2002) manipulated movement amplitude, cursor size and target size, resulting in eight different indices of difficulty in a manual aiming paradigm. A tone signaled participants to move a computer cursor to a displayed target and pressed the mouse button as quickly as possible, however accuracy was emphasized. Result revealed no differential effects of task difficulty on the RT of the two hands (Bryden, 2002). In another study (Gignac & Vernon, 2004) the participant was asked to place the index finger of their dominant hand on the home key, in response to a fixation point in the center of the screen. The participant was instructed to lift their finger as quickly as possible when they saw the neutral stimulus using their dominant or non-dominant hand. The RT differences between the dominant and non-dominant hands were not consistent with the evidence that the dominant hand would have an advantage over the non-dominant hand.

Hand dominance appears to have a strong influence on MT performance. MT was significantly shorter for the dominant right hand than the left hand across all ages when performing a reciprocal unimanual tapping tasks in which participants tapped alternately to two targets as fast as possible (Fagard, 1987). The results indicated a consistent advantage for the right hand in unimanual aiming task in terms of movement. In bimanual tasks, when the right and left hands are aimed simultaneously to targets, there is a steady advantage for the dominant hand that manifests through shorter MTs as compared with the non-dominant hand (Fowler,

Duck, Mosher, & Mathieson, 1991). Boulinguez et al. (2000) also tested right-handers and showed that MT of the right hand was always shorter than those of the left hand when participants were asked to react and execute the movement as fast as possible to acquire the target. Authors concluded that the difference in MTs reflects biomechanical muscle adaptations to the preferred use of the dominant arm (Boulinguez, et al., 2000). The right sided MT advantage disappeared among groups when precision and general computer mouse aiming performance by right-handers and left-handers with right-hand mouse experience and left-handers with left-hand mouse experience were compared (Peters & Ivanoff, 1999). Attentional demands altered performance for right- and left-handed children, when they were asked to focus their visual attention on the preferred or the non-preferred hand during a bimanual reciprocal tapping task. In the task children used index and middle fingers to tap two targets reciprocally as fast and accurate as possible with right and left hands, simultaneously. Regardless of accuracy, MT in the preferred hand was faster than the non-preferred hand when the children looked at the preferred hand and these difference in performance were eliminated when they looked at the non-preferred hand (Pellegrini, Andrade, & Teixeira, 2004). MT was used to examine the effects of task difficulty in a study where participants moved one of two cursor of different size to one of four targets of different size. Right-handers made the manual aiming task using right or left hands to move a modified computer mouse on the graphics tablet. A significant main effect of hand was found for time to peak velocity, where the left hand took significantly longer to reach peak velocity than the right hand. In general, the most difficult conditions resulted in longer movement times. However results revealed no differential effects of task difficulty on the MT between the two hands (Bryden, 2002). Although some studies have been successful in identifying differences because the preferred hand benefits from over practice in aiming task other studies have indicated no difference in MT in both hands due to attention or experience.

Another important factor for hand movement responses is the stimulus-response (S-R) compatibility effect, in which RT depends on the extent to which the S-R relationship is compatible or incompatible. Reaching toward ipsilateral visual targets (compatible mapping) typically show advantages compared to aiming movements made toward targets in the contralateral visual field (incompatible mapping) (Fitts & Deininger, 1954; Fitts & Seeger, 1953; Kornblum, Hasbroucq, & Osman, 1990). Undoubtedly, the fastest RT occurred when the participants were instructed to make fast reaching movements toward the target mapped in compatible space or when they simply pressed a left or right key in response to the stimulus on the same side of the button being pressed.

RT and MT of the left and right hand can differ and are highly dependent on the specified task. Researchers show a faster left hand RT bias when spatial requirements are indistinct, demonstrating a left-hand/right-hemisphere advantage in temporal movement preparation. This bias can and often switch to the right hand in right-hand dominant people when spatial accuracy demands increase, so that right-hand RT is faster than the left hand. Despite some inconsistent results, one can move the dominant hand faster, especially under conditions that require precise spatial performance. Another factor influencing RT and MT for hand movement is the stimulus-response compatibility effect; where performance is faster in compatible S-R tasks than in incompatible S-R tasks. Together these findings suggest that the fastest response times will occur in the left hand when there are little spatial constraints. Moreover, when spatial constraints exist the fastest response times will occur during movements of the dominant hand toward targets presented in the ipsilateral viewing field.

### **C.3. The Lower Limb(s)**

Fewer response time studies are performed on lower extremity movements than the upper limbs. This likely corresponds to the greater functionality of the upper limb in performing discrete movements. The most common discrete movements using only the lower limb are linked to its use in avoiding collisions. Some examples include stepping on brake when driving and taking a step during obstacle avoidance. After a review of foot asymmetries, reports related to braking time in a driving situation or avoidance of obstacles when walking are provided.

Current evidence shows that the left foot RT advantage is consistent with a right hemisphere involvement in the detection and identification of the signal (Boulinguez, et al., 2000; Eikenberry et al., 2008). This finding corresponds to that of the upper limb and is consistent with a hemispheric control hypothesis. In agreement with findings for the upper limb, left foot mean RTs (143 ms) were shorter than the those for the right foot (169 ms) when performing a sprint start from blocks (Eikenberry, et al., 2008). However, contradictory evidence to the left side advantage was found by Kauranen and Vanharanta (1996) in another attempt to examine foot asymmetry. They examined simple RTs for lower extremities which were obtained from measuring the time between a light stimulus presentation and initiating foot lift off from touch-sensitive plates which is positioned on the floor using the Human Performance Measurement/Basic Elements of Performance systems (a multifunctional system designed to measure different motor aspects of the foot, including RT and movement speed). Participants lifted the dominant foot faster than the non-dominant foot (Kauranen & Vanharanta, 1996).

Interestingly, there also appears to be strong evidence for a right foot MT advantage that is consistent with a left-hemisphere specialization in the execution of movement (Mieschke, Elliott, Helsen, Carson, & Coull, 2001; Todor & Kyprie, 1980; Todor, Kyprie, & Price, 1982). As is the

case for finger tapping, tapping the foot as fast as possible reveals that the right foot generally taps faster than the left foot (Augustyn & Peters, 1986; Peter & Durdin, 1979). This advantage was limited right-handed participants when groups were separated for handedness (Augustyn & Peters, 1986). Unfortunately, no links were made to foot preference to determine if there exists a foot dominance advantage similar to that of the hand, thus further studies are warranted to determine if a dominant foot preference for MT exists.

Fast response times of the lower limb can be imperative to driving performance when braking to avoid a collision (Terry, et al., 2008; Warshawsky-Livne & Shinar, 2002; Zhang, et al., 2007). The effects uncertainty, manipulated by the time interval between a “ready” cue and the onset of the brake light, transmission type (manual or automatic), driver age (18 to 82 years old) and gender on brake RT and MT were investigated in a driving simulator (Warshawsky-Livne & Shinar, 2002). Participants in a simulated car-following situation depressed the accelerator pedal as if driving in response to a “go” signal (verbal cue) and the brake pedal as quickly as possible to the onset of the brake lights of the “car” ahead. RT increased as uncertainty time and age increased, while MT in males was slower than females (Warshawsky-Livne & Shinar, 2002). Other studies found no slowing in brake RT for those between ages of 50-84 years (Olson & Sivak, 1986) and 61-73 years (Korteling, 1990). Zhang et al. (2007) also measured brake RT of releasing the gas pedal and MT to brake for older participants (age 67-87 years) when a traffic light turned red in their driving simulator. They revealed that brake RT and MT increased with age and for females compared to males (Zhang, et al., 2007). RT to a yellow light decreased a half second as speed increased from 25 mph to 40 or 55 mph (Chang, Messer, & Santiago, 1985). Thus, urgency, as it relates to braking from fast speeds can also improve RT performance.

Response times of the lower extremities are also considered for people when avoiding obstacles that could lead to a fall. Studies showed the time between obstacle presentation and detection is the major determinant for successful avoidance (H. C. Chen, Ashton-Miller, Alexander, & Schultz, 1994; Weerdesteyn, Nienhuis, & Duysens, 2005; Weerdesteyn, Nienhuis, Mulder, & Duysens, 2005). Twenty-three to 73 year old people approached and tried to avoid stepping on a band of light suddenly appearing in different locations on a walkway. Older adults had longer RT to lift their foot than that of the young whether gaze was not restricted or it was directed forward so that the light appeared in the lower peripheral field (H. C. Chen, et al., 1994). Participants changed their stepping trajectories in as little as 120 ms after the sudden presentation of an obstacle in an over ground walking path (Patla, Beuter, & Prentice, 1991; Reynolds & Day, 2005a, 2005b; Weerdesteyn, Nienhuis, Hampsink, & Duysens, 2004). Step RT toward illuminated floor panels was slower in older adults compared with young adults and in self-reported fallers compared to non-fallers (Lord & Fitzpatrick, 2001). Others showed that there was a speed-accuracy trade-off effect for forward stepping movements. Fast steps resulted in greater absolute and variable error than slow steps when participants were asked to place the foot on stationary floor-mounted targets as accurately as possible after the appearance of an obstacle or a sudden shift in target location. In fact, participants had difficulty completing the task successfully (i.e. avoiding the obstacle) when maximum speed was  $1.43 \pm 3$  m/s (Reynolds & Day, 2005b).

In general, response time differences observed for the feet are similar to those observed for the hands. The left foot RT is faster than the right foot RT, whereas the right foot MT is shorter than left foot. As you can see several factors such as age, gender, vehicle transmission type and uncertainty of event can influence braking RT and MT which is a critical component in driving.

Stepping responses to suddenly appearing obstacles or changes in step location have short RTs (around 120 ms), however require longer MTs to produce accurate and successful performances.

#### **C.4. Multiple Body Segments**

Until now, we reviewed RT, MT and their association with spatial accuracy for primarily a single segment movement of body. However, in daily activities we commonly move body segments together. For example, we coordinate the upper and lower limbs when walking, driving and performing many daily tasks. One important aspect in the control of using multiple body segments is the temporal relationship between segments. Several studies have examined the interaction and relative timing of eye and hand movement as a way of assessing the nature of the coupling between eye and hand movements (Carey, 2000). Although studies have demonstrated the existence of coordinated eye and hand movements (Helsen, Elliott, Starkes, & Ricker, 2000; Helsen, et al., 1997; Helsen, Starkes, Elliott, & Buekers, 1998), few reports on the temporal characteristics of the other body segments exist (Hollands, et al., 2004). As a result the focus of this section is primary on response of the eyes and hand, however a few studies on multiple segment responses are also reviewed.

Fixating a target provides the control systems with visual information about the location of the target and eventually the hand as it approaches the target (Elliott, Calvert, Jaeger, & Jones, 1990; Elliott, Carson, Goodman, & Chua, 1991). The evidence that eye movement onset latency is short relative to the hand is based on the information that the eyes begin to move toward a target 40-100 ms prior to hand movement (Angel, Alston, & Garland, 1970; Biguer, et al., 1982). For example, participants' eye movements initiated approximately 70 ms before the hand when seated participants were asked to move their hand to press one of three target buttons located 35, 40, or 45 cm to the right, as fast as possible (Helsen, et al., 1997). Electromyography (EMG)

studies show that the motor time of the upper limb is initiated simultaneously with or in some cases prior to eye movement (Biguer, et al., 1982; Gribble, Everling, Ford, & Mattar, 2002), hence the RT of the eyes begins more quickly than the upper limb due to the relative inertia properties (Biguer, et al., 1982; Gribble, et al., 2002) rather than neural transmission responses.

Recent studies reported faster saccadic eye movement latencies when eye movement was accompanied by a coordinated arm movement toward one of two target locations (Lunenburger, Kutz, & Hoffmann, 2000; Snyder, Calton, Dickinson, & Lawrence, 2002). In contrast, other studies reported no significant differences (Niechwiej-Szwedo, et al., 2005) or even slower eye response latencies (Bekkering, Adam, Kingma, Huson, & Whiting, 1994; Engel & Soechting, 2003) when manual and ocular responses were executed concurrently compared with a separate movements. Smooth pursuit eye movement latencies slowed for directional changes when tracking a moving target on a computer with the index finger (Engel & Soechting, 2003). Saccadic RTs also slowed when the eyes and hand produced rapid pointing movements toward right or left eccentric target locations (Bekkering, et al., 1994). Niechwiej-Szwedo et al. (2005) showed that concurrent pointing and eye movements without head movement did not significantly affect saccadic latencies for targets presented in one of ten random locations. The greater spatial uncertainty of target locations may partially explain these differences (Lunenburger, et al., 2000; Neggers & Bekkering, 2001), however it appears that coordinated arm movements in humans can result in either speeded or slowed RTs (Lunenburger, et al., 2000; Neggers & Bekkering, 2001).

Although common preparation and initiation may characterize temporal coupling between eye and hand movements, one feature of coordination that appears to be invariant is the MT relationship (Engel & Soechting, 2003). When performing manual-aiming movements to specific



positions in space quickly, the eyes finish their movement and acquire the target position before the hand; they commonly arrive in the target area just after the hand achieves peak acceleration (Abrams, Meyer, & Kornblum, 1990; Binsted & Elliott, 1999). Not only does the low inertia of the eyes enable the shorter MT, but their early arrival to the target also makes sense from a control perspective. The early arrival places the eyes in a position to optimize the visual information at a time when it is most needed for accuracy (Carlton, 1981).

Performing dual body segment movements has similar effects on RT and MT to that of the eyes and hands (Bard, et al., 1992; Swinnen, Serrien, Walter, & Philippaerts, 1995). When asked to flex the elbow and extend the knee in response to a visual stimulus as quick as possible, RT increased compared to those of the elbow or knee independently (Swinnen, et al., 1995). During single-limb conditions, RTs in the upper limb were shorter than in the lower limb in accordance with efferent nerve conduction time estimates. Conversely, the lower limb was initiated before the upper limb during simultaneous movements. This observed response of lower to upper limb RT is not in agreement with another observation in which hand movements preceded the foot movement during simultaneous ipsilateral finger extension and heel raising (Bard, et al., 1992). This discrepancy is likely linked to the inertial disparity or interpretation of instructions or both. Interestingly, performing the movements together seems to influence the absolute RT and MT differences of the effected body segments, but appears to maintain the relative MT differences. These findings suggest some variant and invariant features in regards to MT.

#### **D. Visual Field and Response Time**

The abilities of athletes to pay attention to central and peripheral visual field information are very important for good performance in many sport situations (Brown, Halpert, & Goodale, 2005; Williams & Elliott, 1999). Anecdotal evidence for use of visual input in central and

peripheral vision exists. For example, a boxer may fixate on the head or chest of the opponent's body in central vision while using peripheral vision to monitor the abrupt appearance of an opponent's strokes (Mori, et al., 2002). In situations where objects approach from various parts of the visual field one can learn to avoid the objects as an essential survival skill (Brown, et al., 2005; Metoyer, et al., 2008; Puca, et al., 2006). Therefore, information on the dependency of response time on target eccentricity is of particular interest in this section where findings on visual field inputs and response time as they apply to various body segments are reviewed.

#### **D. 1. The Eyes**

The visual system is continually pressed to deal with rapid and complex environmental demands; high spatial resolution is necessary to process detailed visual information but high temporal resolution is required to process rapidly changing aspects of the large visual environment. A visual stimulus must be presented within a person's viewing field in order to elicit a response to that stimulus. Presentation of a visual stimulus within the visual field eccentric to the central fovea may cause a sophisticated ocular motor system to translate an image appearing on the peripheral retina onto fovea (Darrien, et al., 2001). This is achieved by the generation of saccadic eye movements with or without head movement. Several researchers have examined the influence of eccentricity of the peripheral stimulus on saccadic eye movements. Most of the research in this area involves stimulus presentation eccentric to the central fovea. The focus of this section will be on RT, as we already showed previously that MT corresponds directly to saccade amplitude.

The latencies or RT of visually driven saccades that differ according to retinal eccentricities of target stimuli in some studies (Fuller, 1996; Hodgson, 2002; Kalesnykas & Hallett, 1994) do not in others (Dafoe, et al., 2007; Darrien, et al., 2001; Fukushima, et al.,

2000). Saccadic latencies for rightward movement amplitudes ranging from  $10^{\circ}$  to  $80^{\circ}$  were determined from starting positions  $0^{\circ}$ ,  $20^{\circ}$  or  $40^{\circ}$  left of the midline in participants with no restrictions on head movement (Fuller, 1996). Target positions were limited to the  $40^{\circ}$  right or left of straight ahead and eye movements were measured by electro-oculography (EOG) (1000 Hz). The latency of saccades initiated from  $0^{\circ}$  increased as the amplitude of a target increased. When the eyes started left of the target, the saccadic latency was shortened according to saccade amplitude so that the mean latency of a  $40^{\circ}$  saccade initiated from  $0^{\circ}$  was 50 ms longer than one initiated from  $40^{\circ}$  left of the midline and the latency of a  $60^{\circ}$  saccade initiated from  $20^{\circ}$  left of the midline was 38 ms longer than one initiated from  $40^{\circ}$  left of the midline. Use of the free moving head for active eye-head coordination was blamed for the differences (Fuller, 1996). Longer latencies with greater left or right eccentricities in the  $12^{\circ}$ - $66^{\circ}$  range also occurred for participants with the head fixed (Kalesnykas & Hallett, 1994). No change in saccade latencies were identified in records obtained from a pupil eye tracker for eccentric targets in the  $0.75^{\circ}$ - $12^{\circ}$  range. In contrast, saccadic latencies within this range (between  $3^{\circ}$  and  $9^{\circ}$  target eccentricities) differed by 20 ms determined by infra-red limbus tracker records obtained at 1000 Hz (Hodgson, 2002). One explanation for these findings is that more peripheral targets might generate saccades with a longer latency due to the more extended conduction pathway across the retina (Darrien, et al., 2001). This explanation does not clarify why other studies find no saccadic latency effects with target eccentricity. Authors used EOG (1000 Hz) to determine saccadic latencies did not vary for target eccentricities within an  $8^{\circ}$ - $28^{\circ}$  range for adults (Darrien, et al., 2001; Fukushima, et al., 2000) or children (Fukushima, et al., 2000) making eye movements with a stable head. However, latencies of the children were longer than adults (Fukushima, et al., 2000). Interestingly, latencies of visually driven saccades measured using an infrared eye tracker (250 Hz) for the  $0.5^{\circ}$  target eccentricity was about 20 ms longer than targets at  $1^{\circ}$ ,  $2^{\circ}$ ,  $4^{\circ}$  and  $8^{\circ}$

eccentricities for which latency did not differ (Dafoe, et al., 2007). Neural responses explain no RT differences with target eccentricity in that peripheral ganglion cells, which possess faster axonal conduction velocities than their centrally located counterparts, indicate that the conduction time to the lateral geniculate nucleus for stimulation of peripheral retina should be no longer than for stimulation of central retina (Ogden & Miller, 1966). Since neither temporal cell responses nor extended conduction pathways explain the conflicting findings for target eccentricity and saccade latency, there is a need for future research in this area. One possibility could be related to target stimulus intensity, as this does influence saccadic RT (Bell, et al., 2006).

## **D. 2 Manual Response**

One alternative approach to examine whether eccentricity has the effect on processing visual information is to observe manual responses in different portions of the visual field. Manual response in the performance of a variety of motor tasks has generally attributed to the temporal characteristics of processing of sensory and motor information. Sections for manual responses with and without concurrent eye movements are separated, as concurrent body movements do affect the response.

### **D. 2.1 Manual Response with Eye Movement**

Most researchers have measured the RT taken to detect visual stimulus for different visual fields using a simple manual responses such as pressing button, finger lifting and manual aiming to a target. Processing fovea stimuli used for manual responses occurs faster than the processing of peripheral stimuli with a free moving head (Alferdinck, 2006; Ishihara, et al., 2002). Although this response has occurred for movements with a fixed head (Komilis, 1993 #408), the difference

with eccentricity more commonly disappears when the head remains stationary (Biguer, et al., 1984; Helsen, et al., 1997; Niechwiej-Szwedo, et al., 2005).

Manual RTs to different target locations can slow for more peripheral target locations when the head is free to move. Right-handed participants with no eye or head movement restrictions were quicker lifting an index finger of their right hand from a centrally placed button with and without a subsequent movement to touch the center of a graphic circular disk on a touch-panel monitor located centrally or peripherally at 6° or 12° visual angles (Ishihara, et al., 2002). Interestingly, RTs for responses with a subsequent movement to the left targets were significantly longer than the RTs for the other targets. Authors blame information processing of the spatial nature of visual targets for this longer RT. Manual RT differences according to target eccentricity also occur during dual performance tasks. Drivers with no head or eye movement restrictions were instructed to keep the car between the lines of the road in a driving simulator, while responding to peripheral target appearance by pushing a small button that was taped to the right index finger of participant (Alferdinck, 2006). The target could appear at left and right eccentricities (5°, 10° and 15°) relative to straight ahead. The longest RTs were found at the 15° eccentricities with no RT differences between the eccentricities of 5° and 10°. It is impossible to determine whether manual RT increases in this task with small eccentricities due to no target appearance at 0° for comparison, however other results suggest this occurs for relatively small eccentricities (6°) when the head is free to move (Ishihara, et al., 2002).

Manual RTs to different target locations do not always slow for more peripheral target locations. Manual RT also increases for small eccentric differences in the peripheral visual field. Participants with the head fixed reached quickly and accurately to targets at 30, 36, 40 and 46 cm to the right along a horizontal line (Komilis, et al., 1993). Hand latencies which would best

reflect planning movement as the result of eccentricity did significantly increase with target eccentricity. These findings contradict the more common finding that manual RT does not differ with target eccentricity when the head is fixed and eyes are free to move. Fast eye and hand movements with a stationary head in a speeded aiming task, requiring movement from the home button to press one of three target buttons 35, 40 or 45 cm to the right, resulted in no manual RT effects (Helsen, et al., 1997). Increasing target eccentricity (10°, 20°, 30° and 40°) did not alter pointing RT performed with eye movements (Vercher, Magenes, Prablanc, & Gauthier, 1994). RT for simple pressing movements of the finger and finger abduction/adduction pointing movements toward the target did not differ for participants required to look at eccentric target locations (4°, 11°, 19°, 26°, and 33°), while making the finger response (Niechwiej-Szwedo, et al., 2005). RT in this case increased for the point response compared to the press response. The greater complexity known to affect RT (Henry & Rogers, 1960) explains the longer RT for the point task.

Overall, target detection performance, as indicated through manual RT, decreases with increasing target eccentricity when the head is free to move. This relationship changes so that there is often no change in RT with target eccentricity when manual performance is tightly coupled with a saccade and head movement is restricted.

#### **D. 2.2 Manual Response without Eye Movement**

It is important to understand the effect of target eccentricity on manual response without eye movement because often, eye movements towards peripheral visual stimuli must be suppressed during certain goal-directed behaviors. In martial arts and boxing, performers may fixate on a central point such as their opponent's head or chest, but may utilize peripheral visual field information for detecting limb movement of their opponent's attack (Mori, et al., 2002;

Williams & Elliott, 1999). The focus of this section is on RT of upper limb movement while the eyes remain stationary.

RT of a manual response without eye movement has been linked to the eccentricity of visual stimulus presentation (Ando, Kokubu, et al., 2002; Marzi, et al., 2006; Wall, et al., 2002). Healthy right-handed young adults and one left-handed hemianopic woman patient (35 years old) maintained gaze steadily onto the fixation point and were to press a keyboard space-bar with right or left index-fingers as quickly as possible in response to presentation of a luminous square presented at 2° or 8° eccentricities along the horizontal meridian. (Marzi, et al., 2006). RT was faster for stimuli presented at 2° than at 8°. Wall and colleagues investigated the relationship among RT, stimulus intensity and visual field eccentricity in clinical perimetry, which is the systematic measurement of differential light sensitivity at various places in the visual field. Participants were asked to respond to the stimulus which was located at 10°, 20°, 30°, 40° and 50° along the horizontal meridian as quickly as possible. RT was shortest at the fovea and increased significantly with each visual field eccentricity (Wall, et al., 2002). For manual response without eye movement a strong influence of the target eccentricity was observed by Ando et al. (2002). Subjects responded to the onset of each stimulus by pressing the response key as fast as possible while keeping their eyes on the cross in the middle of computer screen. The targets were in one of four possible locations (0°, 10°, 20°, and 30° to the right) along the horizontal meridian. RT at the 30° location was significantly longer than the RTs at the 0° and 10° locations in random location condition. However, there were no significant differences in the mean RT between conditions at the 10° and 20° locations. It seems likely that the results of the Ando et al. can be explained by the midlocation placement strategy. In other words, attention was oriented to intermediate locations, i.e., the 10 and 20 locations, out of four locations within

large area of the visual field (Ando, Kokubu, et al., 2002). Gradual decrease in RT as a result of target eccentricity was explained by the density of retinal ganglion cells in these areas and the associated cortical magnification factor, which describes how many neurons in an area of the visual cortex are “responsible” for processing a stimulus of a given size, as a function of visual field location (Chelazzi et al., 1988; Kitterle, 1986). Again, a greater probability of triggering an impulse with more receptors was blamed for the shorter the RT (Rains, 1963).

RT does not always increase with target eccentricity when the eyes are fixed (Niechwiej-Szwedo, et al., 2005; Stephen, et al., 2002). Participants responded to visual stimulus appearing in 10 eccentric target locations either by pressing or pointing while fixating on a star in the center of a computer display (Niechwiej-Szwedo, et al., 2005). Target eccentricity had no effect on RT, however, data showed that pointing was initiated significantly more quickly than pressing. Stephen et al (2002) studied ventral versus dorsal stream activation in response to central and peripheral field stimulation. Participants were required to maintain fixation on the fixation cross without eye movement during the entire experiment when targets were presented at central (eccentricity  $2.3^\circ$ ) and peripheral locations (eccentricity  $24^\circ$ ). The results showed that RT for peripheral field stimulation was shorter than that of central field (Stephen, et al., 2002). Targets in the peripheral visual field may reflexively elicit attention to its location, allowing resources to be concentrated rapidly (Briand & Klein, 1987; Jonides & Irwin, 1981; Muller & Rabbitt, 1989).

Like findings from manual responses with eye movement, some studies have been successful in identifying manual RT differences between central and peripheral target presentation without eye movement (Ando, Kokubu, et al., 2002; Marzi, et al., 2006; Wall, et al., 2002), while others indicate no difference (Niechwiej-Szwedo, et al., 2005) or even increases (Stephen, et al., 2002). The general lack of consensus may be related to the method employed to



measure peripheral visual function. More experiment research is required to clarify the functional relationship of peripheral field vision on RT.

### **D.3 The Lower Limb(s)**

We identified some studies on lower limb responses for different visual field stimuli. Much of the reported work on lower limb responses for different visual field stimuli has been related to brake RT because one task of driving is to avoid a potential hazard on the road where a fast reaction is essential. Potential hazards, such as cars, pedestrians, and animals, do not always appear in front of car, often they come into view from the side and require the use of peripheral vision.

Attending to in-car tasks may continue to be detrimental RT of braking in detecting potential hazards. Participants in a driving simulator pressed the brake in response to brake lights on a lead car, while fixating on a digital display at three different eccentric locations ( $16^\circ$ ,  $27^\circ$  and  $50^\circ$ ) on the dashboard (Summala, Lamble, & Laakso, 1998). Brake RT increased markedly with the increased eccentricity for three different skill levels with no differences identified between levels of experience. Participants instructed to focus on one of seven different starting dashboard locations, ranging from  $4.4^\circ$ - $50.6^\circ$  eccentricity relative to the hood where a visual light would appear, were asked to react to the light by pressing a brake pedal as quick as possible (Wittmann, et al., 2006). Brake RT almost doubled when participants focused on eccentric locations in the bottom half of the console and decreased when focusing at greater eccentricities above the middle console compared to the more centrally located speedometer (Wittmann, et al., 2006). Participants with free moving heads performing a controlled driving task (within a specified speed range and a specified driving lane) had slower brake RT to red lights appearing at  $10^\circ$ ,  $45^\circ$  and  $80^\circ$  lateral eccentricities from a central position within the visual field (Berg,

Berglund, Strang, & Baum, 2007). It has been suggested that the deterioration in performance with increasing eccentricity of the target may be only dependent on the decrement of the visual acuity in the peripheral vision (Berg, et al., 2007; Saarinen, 1993; Summala, et al., 1998; Virsu, Nasanen, & Osmoviita, 1987; Wittmann, et al., 2006).

In sum, studies have used stimuli in different visual field to induce braking because fast RT is critical factor for safety in driving. Brake RT studies have reported that drivers are likely to respond more slowly when eccentricity of stimulus was increased.

#### **D.4. The Multiple Body Segment(s)**

One study has compared the temporal and spatial characteristics of the multiple body segments during a coordinated whole-body movement. Participants were asked to rotate their whole bodies as a unit to face an LED that lit up in the one of six eccentric locations (45°, 90°, and 135°, left and right of centre) along the horizontal meridian (Hollands, et al., 2004). EOG and kinematic profiles of the eyes and various body segments (Head, upper body, and feet), respectively showed an increasing latency with increasing target eccentricity, so that significant differences only existed between 45° and 90° and 45° and 135°. A clear sequence of body segment orientation where the eyes lead the head, then the upper body and finally the feet (Hollands, et al., 2004) similar to sequential body segment movement onset during a change in the direction of walking (Grasso, Glasauer, Takei, & Berthoz, 1996; Hollands & Marple-Horvat, 2001).

#### **E. Summary**

The aim of this chapter was to examine several factors which can influence response time to a visual stimulus. Results showed that processing of moving stimuli as determined by RT and

MT is faster than stationary stimuli. There is a clear speed-accuracy trade off effect on response time components, where increasing accuracy demands decreases RT and MT. The response times of body segments with greater inertial properties increase compared to those with less inertia. RT and MT of the left and right hands can differ and the MT differences are highly dependent on the specified task for manual response. Demanding greater accuracy improves MT performance in the dominant hand, otherwise there appears to be a left hand, right hemisphere dominance for speed. Response time differences observed for the feet are similar to those observed for the hands, however research on responses of foot dominance is limited. Relative reaction and movement times of different body segments are highly dependent on task requirements. Unfortunately, the results reviewed on visual field inputs and response time as they apply to various body segments and those on concurrent usage of multiple body segments are not consistent. Future studies should account for known effects on RT and MT to systematically study and gain insight to these topics.

## **V. AWAY AND TOWARD RESPONSES**

There are many tasks in which goal-directed responses to different sensory stimuli include movements either toward or away from the actual stimulus. Although plenty researchers study volitional responses toward a specific goal, few study movements away from a target. The latter is likely due to the lack of application for target avoidance during volitional movement; advancing toward a goal from what might be considered a position of offense is more common. However, blocking or withdrawing from sudden appearing or moving stimuli used in defensive movements are also basic functions of the motor system needed for task performance. Defensive movements are common tasks used for protection and are frequently used in certain sporting situations. Moreover, the findings from temporal responses to offensive movements do not

necessarily generalize to sports situations which are dynamic and involve rapidly moving visual information where avoidance is patently necessary, as in the martial arts, for example.

### **A. Defensive Responses**

Defensive movements are spatially directed and can involve ducking or withdrawing from the direction of the stimulus or blocking an impending object with one part of the body (Cooke & Graziano, 2003; King, et al., 1992; Metoyer, et al., 2008). For example, lifting the arm to protect the face from jabs, uppercuts and hooks occurs often in boxing. In combat sports, a player is continually faced with the problem of avoiding an opponent's attack which emerges at different and unpredictable locations. The player may initiate blocking or withdrawing actions or some combination of both to defend attacks from opponents.

The block and withdrawal are two distinguishable responses to stimuli used for protection. Withdrawing or moving away from a stimulus serves to increase the distance between the defender and stimulus before impact in an attempt to avoid the approaching object and increase the amount of time available to prepare for sequential responsive movement (Cooke & Graziano, 2003). The blocking component of defensive movements serves to deflect an impending impact. The instrument used to block, whether a segment or the body or external object, is positioned on the approach of a stimulus to protect an area (i.e. a goal) or another body part (i.e. the head) from stimulus contact. The blocking behavior reduces the distance between an approaching stimulus and effected target (Cooke & Graziano, 2003; Schiff, 1965), thus shortens the path of the stimulus. Since the goal of blocking actions involves target interception, they are placed in the TOWARD-response category and will be defined as movement toward an appearing or moving stimulus. In contrast, withdrawing actions are placed in the avoid-response category and will be defined as movement away from a relevant stimulus.

TOWARD and avoid responses are assumed to build an interface between perception and behavior (Bargh, 1997). Many studies have distinguished between TOWARD and avoid responses in laboratory settings by using different types of stimuli, although some researches use real world circumstances to elicit actual overt defensive responses (Hancock & de Ridder, 2003; King, et al., 1992). Some researchers interpret moving away from a target as an AWAY response and moving toward it as a TOWARD response (Puca, et al., 2006) (Wentura, et al., 2000), whereas others use these actions in an opposite way (e.g. (S. Chen & Bargh, 1999). Although such opposition affects the definition of a TOWARD or AWAY movements, it also directs the use of TOWARD and AWAY responses despite the differences in focus, methodology and materials.

## **B. Response to Visual Cues: No Visual Field Restrictions**

The ability to orient the body to or away from the direction of suddenly appearing or moving stimuli and to protect the body from an attack may be a basic function of the motor system of humans (Cooke & Graziano, 2003; King, et al., 1992; Schiff, 1965). Although the focus here involves avoiding certain stimuli through voluntary movement, the involuntary response of reflexes such as the startle reflex can and should not be ignored. Startle reflexes are short involuntary reflexive contractions elicited by abrupt, intense stimuli (Kumaria et al., 1996; Yeomans, Li, Scott, & Frankland, 2002). Examples of intense stimuli include a loud noise, an unexpected tap on the shoulder and a sudden appearance of an object, while examples of the reflexive responses include eye blinks, increased muscle tension and vocalizations. A typical finding is that pleasant and unpleasant foreground stimuli can modulate the startle reflex. For example, when viewing two film clips depicting unpleasant events (fragment from a horror movie and a surgical operation), neutral events (non-argumentative conversation and a

documentary) and pleasant events (fragments from romantic movies), participant's eye blink reflex which is measured from EMG activity of the orbicularis ocular muscle of the right eye varied. Unpleasant stimuli increased the amplitude of the startle response to loud acoustic stimuli and decreased the latency of eye blinks, whereas pleasant stimuli attenuated the amplitude and increased blink latency (Kumaria, et al., 1996). The latency of eye blinks, measured by EOG, was just the opposite during positive (smiling children or appetizing food) and negative (mutilated bodies) slide presentations, so that blink latency decreased for pleasant slides and increased for negative slides (Vrana, Spence, & Lang, 1988). The negative slides were viewed for a longer period of time than neutral slides, thus were considered are highly potent in engaging visual attention, which explained this blink latency reversal.

Studies of avoidance behaviors have overwhelmingly involved motivational systems that direct attention toward or away from relevant stimuli and give rise to corresponding emotional excitement that direct activity toward or away from relevant objects (Elliot & Thrash, 2002). A number of experimental procedures have been devised to elicit individual approach and avoidance behaviors through manipulation of emotional stimuli such as incentives and threats. For example, RT was reduced for positive stimuli such as word "puppy" when participants had to perform approach movements by pulling a lever toward the body than for negative stimuli such as word "disgusting" when they had to perform avoidance movement by pushing the lever away (S. Chen & Bargh, 1999). Note these movements were relative to the participant rather than the location of the target as established in other studies. Participants, who were instructed to judge whether words were emotionally positive (e.g. peace) or negative (e.g. violence) by pressing one of two keys on a keyboard or do nothing if the word was neutral (e.g. slow), reacted faster to positive words when the word moved toward the participant than when it moved away

(van Dantzig, Pecher, & Zwaan, 2008 ), The opposite was true for RT to negative words in that RT decreased when the word move away from the participant and increased when it moved toward the participant. Overall, RT to positive words was 22 ms faster than RT to negative words. It is clear from the findings that emotional stimuli influence goal-directed behavior in that RT decreases with movements toward positive stimuli compared to stimuli associated with negative emotions.

Studies used to examine more realistic stimuli for initiation of defensive actions in sport-specific conditions for different levels of expertise also exist and offer insight to training effects on RT (Mori, et al., 2002; Ripoll, et al., 1995; Williams & Elliott, 1999). RTs were recorded in participants performing avoid or blocking movements in response to large screen recordings of karate athletes performing offensive movements (Williams & Elliott, 1999). Response accuracy was determined by experienced coaches to judge whether participant have successfully avoided or blocked the attack Results showed that karate experts possessed faster RTs and higher accuracy than non-experts. In a similar projection setup, participants with and without expertise in karate were asked to decide as soon as possible whether the recorded offensive actions would be aimed at the upper or middle level of their body by pressing an appropriate key in this choice RT task (Mori, et al., 2002). The karate experts were slightly but significantly faster than those without training in responding to the video stimulus, suggesting RT training effects at least for tasks involving anticipation of the opponent's attack. Video-tapes were also used to introduce problem-solving situations simulating the natural setting of boxing (Ripoll, et al., 1995). Expert boxers had the same RT but were more accurate than intermediate and novice boxers when asked to move a joystick in a direction required to avoid or hit the movement in the video. Although these findings suggest that experts in combat sports are quicker at withdrawing and quicker

and/or more accurate at blocking than those with less or no training, it is not completely clear that how these differences affect true outcomes of movement performance.

### **C. Response to Visual Cues: Central vs Peripheral Vision**

The ability to avoid unwanted stimuli presented in various part of visual field is a critical aspect of adaptive behavior. Many investigations on the use of central and/or peripheral vision involve TOWARD-responses for offensive rather than defensive behaviors. In such studies evidence that RT may or may not differ according to stimulus eccentricity exists. The focus of this section is to review the influence of target eccentricity on defensive responses, an area in the literature that has received very little attention.

Defensive responses to peripheral visual cues can involve voluntary or involuntary TOWARD and avoid responses. Seated participants playing a video game responded to suddenly appearing peripheral stimuli by rotating their heads toward or away from stimulus location (King, et al., 1992). RT for turning the head away from stimuli during avoidance movements was significantly shorter than those for orienting the head toward the target. In other study of defensive movement to looming visual stimuli standing participants fixated on a monitor located at 0° (i.e., straight ahead) with another monitor placed at 90° (i.e., near the left shoulder) during task and were asked to “play chicken” with an approaching ball that was projected on the computer-generated optical displays (Stoffregen & Riccio, 1990). The goal was to move only at the last possible moment to dodge the path of the ball by leaning right or left for the monitor straight ahead or forward or back for the monitor to the left, movements that would let the person avoid ball interception for different paths. Four different contact times determined the moment at which the ball moving at four different speeds would have hit the participant if the person did not move. Initial responses to the 0.5 s and 1.0 s contact times did not occur until after impact, while



responses to the 2 s and 4 s times occurred before impact. Response time in central looming was significantly faster than in the periphery. In a voluntary heading task, participants were asked to dodge a ball by flexing the torso without rotating their eyes or head when the ball approached from various eccentricities (0°, 20°, 40°, 60°, or 80°) at different velocities (1.0, 1.5, or 2.0 m/sec) (Li & Laurent, 2001). Results showed that initiation of torso flexion increased from 0° to 40° eccentricities, then decreased from 40° to 80° eccentricities, although participants successfully avoided the ball in all cases. Conflicting results may be to use of actual vs simulated stimuli.

#### **D. Summary**

Defensive behaviors allow researchers to compare TOWARD and AWAY responses to visual inputs. Defensive responses differ for the level of expertise so that athletes react faster and/or more accurate than nonathletes or those with little sporting experience. Effects of peripheral and central vision on defensive response times are limited and require further study to determine if or in what situations RT and MT for these responses will vary.

### **VI. INFORMATION PROCESSING AND MOTOR PROGRAMMING**

Rapid environmental changes in game and combat sports require flexible adaptation of behavior (Hristovski, Davids, & Araujo, 2006; Hristovski, Davids, Araujo, & Button, 2006). Many athletes who successfully react in situations with rapid reaction sequences in sports and martial arts are able to execute motor responses by the perception of movement features embedded within the perceived movement sequences of sport partners or opponents (Bootsma, 1989; Bootsma, Houbiers, Whiting, & van Wieringen, 1991; Bootsma & Oudejans, 1993). For example, boxers respond quickly to their opponent's fast actions to cope to the opponent's

attack; they switch quickly from an intended action to a new more appropriate action when needed (Hristovski, Davids, Araujo, et al., 2006). How does one explain the control used for such response to visually presented stimuli theoretically? Obviously, a person must be able to process the sensory input to some extent in order to respond to it. The information processing approach is used to assist in the explanation of such control.

One of the most popular human performance theories or models is based on the fundamental notion that humans are processors of information much like a computer. Just as a computer requires input and must process the input in order to respond, the performance of several tasks requires information processing for producing the appropriate motor response to a given stimulus (Marteniuk, 1986a, 1986b). Examine the situation where a boxer is defending opponent attacks with unexpected strokes. Although visual perception of the strokes and a response (blocking or withdrawing) seems to just happen, it is actually the end result of a complex process presented as a model that utilizes several issues previously presented. This is the information processing model.

The information processing model has been used to explain performance of various task ranging from simple reaction to visual stimulus (Carreiro, Haddad, & Baldo, 2003) to complex problem solving sport situations (Ripoll, et al., 1995). Here the three stage model is presented in terms of its application of defensive movements, a major theme in the current document. In defensive skills for combative sports or tasks the performer must recognize the opponent's attack strokes (the visual stimulus input) which can appear in the central or peripheral visual field. The ability to identify the stimulus, "recognize" the incoming stroke, occurs in the *stimulus-identification* stage or the first phase of information processing. Then during the *response-selection* stage (stage 2), the performer must select an appropriate response within the available

options. The choice of whether to block the stroke or withdraw to avoid being hit by the attack is made. After determining an appropriate reaction, the performer must organize and initiate an appropriate response. Movement preparation and the initiation of the selected motor program are represented in the *response-programming* stage, the third stage of information processing. The *response-programming* stage is tightly coupled with level of expertise and development of motor programs which are a memory representation that stores information needed to perform an action (ref). The key advantage of the motor program is that the problem of movement timing is simplified so that processing demands are reduced merely to predicting the moment of initiation, thereby reducing the computational burden on performers (Tyldesley & Whiting, 1975). Thus, rather than organizing detailed control of all muscles required to block an attack, the performer only chooses how and possibly when to start the chosen blocking action. This model can explain the abilities to dodge a front jab and block a right hook. Each stage of the model is presented briefly below as it relates items presented in the current manuscript. Readers are referred elsewhere for more details on the information processing model (Salmoni, Schmidt, & Walter, 1984).

### **A. Stimulus Identification**

Sport situations requiring information processing are characterized by detecting stimulus or target in various forms of energy flowing through the environment, including light rays (Bootsma, 1989; Bootsma & Oudejans, 1993). The environmental changes which can be perceived from this energy flow over space and time are mostly used to support the goal-directed actions of the athlete. Remember, it is not only the type of stimulus that will influence transmission of the signal (Naito, et al., 2000) and the time required to for stimulus identification, it also involves properties of the stimulus itself such as intensity (Bell, et al., 2006)

or complexity and abilities of the performer such as age (Czigler, Csibra, & Ambro, 1996). An athlete's ability to quickly and accurately perceive relevant information will facilitate decision making and allow more time for preparation and organization of motor behavior (Mori, et al., 2002; Ripoll, et al., 1995; Williams & Elliott, 1999).

## **B. Response Selection**

Selecting a response is required for the second stage of information processing and is used to make a decision based on identifying the information through environmental cues. In combat sports, an athlete must make rapid decisions about whether to block or avoid the opponent's attack based on information obtained from stimulus identification similar to that of choice RT tasks with opposing actions. Appropriate response selection is crucial to good performance (Di Russo, Taddei, Apnile, & Spinelli, 2006; L. R. Williams & Walmsley, 2000), thus increasing choice selection which also increases RT (Hick, 1952) of the response will have direct effects on response selection and indirectly affect response programming.

## **C. Response Programming**

The *response-programming* stage of the information processing approach is used to execute the response selected in the *response-selection* stage. Successful performance in block and withdrawal responses is at least somewhat dependent upon efficient and accurate execution of movement. Thus, practice effects have been consistently found to be the most important variable affecting organization and initiation of movement for response programming (Klapp, 1995). More complex situations require appropriate organization through a comparison with an internalized memory structure based on past experiences in similar situations. Selection of the appropriate motor program that is temporally consistent with the desired action will reduce the

processing demands (Tyldesley & Whiting, 1975). However, emphasizing accuracy which is well-known RT (Cauraugh, 1990) and MT (Newell, et al., 1979) of the response will have direct effects on response programming and defensive performance. It is not surprising that level of expertise is used to highlight the *response-programming* stage of information processing (Long & Vogel, 1998).

#### **D. Summary**

Information processing is a relatively simplistic model used to explain control of defensive actions. The three stages involve the use of sensory input, the selection of a response and organization and initiation of the response in order to complete movement performance. The use of a motor program, which is based on previous experience, helps reduce processing demands to produce more automated performances.

### **VII. SUMMMARY/CONCLUSION**

The purpose of this manuscript was to gain insight to the association among response time components, visual field stimulation and defensive actions. Research showed that the two components of response time, RT and MT, were influenced by many factors including age, gender, cognitive loads, arousal states, practice and experience. It is sometimes difficult to compare these components in relation to different parts of the visual field because of several differences in central and peripheral field determination and/or the use of different eccentricities and methodology used. However, response time to a visual stimulus was clearly influenced by the use of different body segments (the eyes, hands, and feet), concurrent use of multiple body segments, target speed, and demands on accuracy.

Because the abilities of athletes to pay attention to central and peripheral visual field information are very important for good performance in many sport situations, the response to visual stimuli will play a role in determining quality of performance. Although some studies have been successful in identifying response differences to different visual field stimuli, others have indicated no differences. Those researchers, who investigated the use of central and/or peripheral vision, have primarily done so to determine responses for tasks which involve moving toward target location. Few have studied these responses during defensive tasks requiring avoidance or during defensive tasks requiring avoidance and interceptions. Studies involving TOWARD and avoid responses to visual stimuli presented in different parts of the viewing field are more rare, yet would offer insight to performance of various activities, including driving and sparing as described previously.

## **VIII. FUTURE DIRECTIONS**

### **A. Need for Future Investigations**

The ability to avoid sudden appearance of moving stimuli and to protect the body from an attack is an essential function for humans (Cooke & Graziano, 2003; King, et al., 1992; Schiff, 1965), which can be used for defensive actions in various environments, including combative sports. Although numerous researchers study TOWARD responses toward a specific stimulus, like that used for offensive actions, little is known about the TOWARD and AWAY responses used in defensive actions. Responses determined in offensive actions do provide some insight to potential outcomes associated with defensive actions. Although the limited research on defensive actions reveals similarities to those for offensive actions in that RT and MT are highly dependent on the specified task, one must avoid the direct generalization of such information.

The limited research of avoidance behaviors on response time does not allow for good comparisons between MT and RT for TOWARD and AWAY responses. This raises the question about how RT and MT in TOWARD response are different from the RT and MT in AWAY response, two responses commonly used for defensive actions (i.e. the block and withdrawal). Another issue involve the use of task inconsistency for studying TOWARD and AWAY responses. One must wonder whether using two opposing movements without considering directions are adequate for use in real life situations.

To perform successful avoidance response, people must quickly and correctly perceive an object, which can be presented or approach from any part of the visual field. Presentation of stimuli in the central visual field is most common in research and the limited studies involving responses to eccentric visual cues reveal conflicting results. Few researches have investigated RT and MT in response to an object at various angles of eccentricity in avoid response even though avoidance behaviors are essential survival skills. Future research should study these avoid and TOWARD responses to different visual field stimuli to gain greater insight to defensive behaviors.

Another limitation of previous research is that there is little study of practice effects on AWAY responses. This limitation raises the question of how RT and MT for AWAY tasks change with practice. More specifically, there is need for additional research on how long the practice effects on RT or MT last.

Clearly, there is need for additional research on TOWARD and AWAY response in different visual field. Posing experimental questions and associated hypotheses for future research will help summarize these findings. Accordingly, the following aims and hypothesis are proposed.

## **B. Developed Aims and Hypotheses**

Several questions remain in regards to associations among response time components, visual field stimulation and defensive actions. Based on limitations of previous work, the following aims and hypotheses are posed.

Aim1: To investigate the effect of target eccentricity on response time during the performance of defensive actions. Specifically, does RT and/or MT during TOWARD or AWAY defensive actions increase with target eccentricity? We leave this as a question due to the conflicting results on this issue identified in the literature.

Aim2: To investigate how RT and MT differ for TOWARD and AWAY responses for defensive behaviors. Evidence suggests that RT for an AWAY responses are faster than those for a TOWARD responses (King, et al., 1992). It is hypothesized that AWAY tasks will have shorter RT than those for TOWARD responses.

Aim3: To investigate the effect of practice on RT and MT for TOWARD and AWAY responses for defensive behaviors. Previous findings suggest that experts produce faster RT and/or greater accuracy during avoidance behaviors. It is hypothesized that RT for TOWARD and AWAY responses will decrease with practice.

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## APPENDIX B---CONSENT FORM

### CONSENT FORM (Nonclinical)

1. Study Title: The influence of target eccentricities on hit and avoid responses
2. Performance Site: Louisiana State University and Agricultural and Mechanical College
3. Investigators: The following investigators are available for questions about this study, M-F, 8:30 a.m. - 5:00 p.m.  
Dr. Jan M. Hondzinski 578-9144  
Taegyong Kwon 578-7448
4. Purpose of the Study: to better understand the association between target eccentricities and different aspects of response time during movement toward and away from targets
5. Subject Inclusion: Individuals between the ages of 18 and 50 who do not report psychological or neurological conditions, have corrected or uncorrected visual acuity of 20/20, no history of motion sickness and be willing to participate.
6. Number of subjects: 40
7. Study Procedures: Subjects will perform right or left head rotations as rapidly as possible in response to a suddenly appearing stimulus presented in different portions of the left and right viewing fields. The experiment consisted of two response conditions: HIT and AVOID. In the HIT condition subjects rotated their head in the direction of target appearance, while in the AVOID condition participants rotated their head in the direction opposite target appearance. The torso will be strapped to the chair back to prevent unwanted movements. Eye and body movements along with neck muscle activity will be recorded. Electrodes, like those used to collect heart rate are attached to the forehead, right and left sides of the eyes and right and left sides of the neck for eye movement and neck muscle activity recordings, respectively. An eye tracker in which small video cameras record your eye movements may replace that of the electrodes on your face. Video-taped performances will be used for backup data collection during the task performance.  
Practice procedure: All participants experience the following sequence of test and training: (1) Pre-test, (2) Training (5 days over 2 wks), and (3) Post-test. Pre- and Post-tests are described above. During the Training period, ½ the participants will practice responding to visual stimuli the HIT condition, while the other half will practice the AVOID condition. Each practice includes warm up and mandatory rest periods to avoid fatigue. Participants may take longer rests when requested.
8. Benefits: Control subjects will be volunteers from the college community that may earn extra credit for research participation.  
Taekwondo athletes from the community will also be recruited

for participation. No other benefits for subjects exist. The information extracted from the subject's performance will be beneficial to future studies involving visuomotor/sensorimotor control.

9. Risks: The minimal risks associated with this study are as follows. Participation in the present study would involve no more risk than that associated with sitting and performing quick head movements. There is an inadvertent risk that information of subject performance is somehow made public. However, every effort will be made to maintain the confidentiality of the study records. Files will be kept in a secure room to which only university personnel have access. Skin sensitivity to tape and electrode gel is possible. We use tape that has shown to be less likely to cause such sensitivity and suggest to wash areas that come in contact with tape and/or gels immediately after the experiment.
10. Right to Refuse: Subjects may choose not to participate or to withdraw from the study at any time without penalty or loss of any benefit to which they might otherwise be entitled.
11. Privacy: Results of the study may be published, but no names or identifying information will be included in the publication. Subject identity will remain confidential unless disclosure is required by law.
12. Signatures:

The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about subjects' rights or other concerns, I can contact Robert C. Mathews, Institutional Review Board, (225) 578-8692. I agree to participate in the study described above and acknowledge the investigator's obligation to provide me with a signed copy of this consent form.

\_\_\_\_\_  
Signature of Subject

\_\_\_\_\_  
Date

**Study Approved By:**  
Dr. Robert C. Mathews, Chairman  
Institutional Review Board  
Louisiana State University  
203 B-1 David Boyd Hall  
225-578-8692 | [www.lsu.edu/irb](http://www.lsu.edu/irb)  
**Approval Expires:** 9-29-2012

## **VITA**

Taegyong Kwon was born in November 1974, in Daegu, Korea. He was athlete for tennis, badminton and fin swimming. He graduated from Keimyung University in Daegu, Korea, in 2000. In 2002, he graduated from Keimyung University with a Master degree in physical education. After that he moved to United States to continue his education. He started a doctoral program in motor control at Louisiana State University (LSU) in August 2004 and pursues his doctoral degree at LSU under the direction of Dr. Jan Hondzinski. During this time he served as the Instructor for tennis, golf and anatomy undergraduate course. Taegyong was a two time recipient of LSU's Lilian Olson scholarship given by College of Education.