# The Effect of Concurrent Hand Movement on Estimated Time to Contact in a Prediction Motion Task

by

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**A thesis submitted in partial fulfillment of the requirements for the degree of**

**Master of Science**

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***Abstract***

In many activities, we need to predict the arrival of an occluded object. This action is called prediction motion or motion extrapolation. Previous researchers have found that both eye tracking and the internal clocking models are involved in the prediction motion task. Also, it is reported that concurrent hand movement facilitates the eye tracking of an externally-generated target in a tracking task, even if the target is occluded. The present study examined the effect of concurrent hand movement on the estimated time to contact (TTC) in a prediction motion task. We found that different (accurate/inaccurate) concurrent hand movements had the opposite effect on the eye tracking accuracy and estimated TTC in the prediction motion task. That is, the accurate concurrent hand tracking enhanced eye tracking accuracy and had the trend to increase the precision of estimated TTC, but the inaccurate concurrent hand tracking decreased eye tracking accuracy and disrupted estimated TTC. However, eye tracking accuracy did not determine the precision of estimated TTC.

***Preface***

This thesis is an original work by Ran Zheng. The research project, of which this thesis is a part, received ethics approval from the University of Alberta Research Ethics Board, Project Name "Development of Perceptual Motor Capacity", Pro00056877, July 6, 2015.

Parts of this thesis have been published: Zheng, R., & Maraj, B. K. (2018). The effect of concurrent hand movement on estimated time to contact in a prediction motion task. *Experimental Brain Research*, *236*(7):1953-1962.

***Acknowledgements***

I would like to thank everyone who helped me to complete this degree.

First, I would like to like to express my sincere gratitude to my advisor Dr. Brian Maraj. You are always so supportive, patient and willing to help. The door to your office is always open whenever I have a question. I can not finish the study without your help. Your help is far more than knowledge and research.

Besides, I would like to thank the rest of my thesis committee: Dr. Jones and Dr. Boliek, for your insightful comments and suggestions.

I would also like to thank Dr. Chiu, Dr. Chapman, Dr. Misiaszek and Dr. Jones. Your reading materials enrich my knowledge and broaden my horizon.

Finally, I must express my very profound gratitude to Flix Lin and Nanxi Yan. Thanks for your help in piloting experiment, collecting and analysing data. A team makes a complex work easy.

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***Chapter 1: Introduction***

In our daily life, many activities require us to reach to moving objects. Sometimes moving objects may be occluded by other objects during movements. For example, when we play soccer or basketball, our teammates or rivals may also block our vision of the ball. Similarly, when we cross the street, we see a coming car and it may be blocked by other cars. Therefore, we make an estimation of when the car will arrive at the crossing or when the ball will arrive at our designated spot, from the brief viewing information. We call such a task prediction motion (PM) task (Rosenbaum, 1975; Tresilian, 1995, 1999) or a motion extrapolation task (Makin & Poliakoff, 2011; Makin & Chauhan, 2014). More specifically, there are two typical laboratory settings to study PM tasks. The first is a production task in which participants view a moving target for a certain amount of time after which it becomes invisible or occluded, after which they predict when the occlude target arrives at a designated spot (Rosenbaum, 1975; Tresilian, 1995). The second is called a discrimination task where participants judge whether the occluded target, which may change its velocity after occlusion, reappears on time, too early or too late (Makin & Poliakoff, 2011).

## 1.1 Prediction Motion

A prediction motion task is a special type of coincidence anticipation (CA) task. Moving objects, which are always visible in the CA task, will disappear at a prescribed point in prediction motion tasks. While time-to-contact (TTC) is the actual amount of time remaining before the moving object arrives at the prescribed spot (Tresilian, 2012); estimated TTC is the participants' estimation of TTC. The discrepancy between the estimated TTC and the actual TTC of the moving object is an important criterion to determine accuracy in the PM tasks.

Many factors may influence the estimated TTC in prediction motion tasks, such as target size, visible time and target velocity (Lyon & Waag, 1995; Sokolov & Pavlova, 2003). Sokolov and Pavlova (2003) studied the effect of target size, target speed and visible time on the accuracy of estimated TTC in the prediction motion task. A target with the size of either 0.2 or 0.8 deg moved at one of 3 possible speeds (2.5, 5 or 10 deg/s). The visual path was either 2.5 or 10 deg. Participants judged when the target had reached one of 7 possible positions between 0 and 12 deg. Sokolov and Pavlova reported that target size affected the accuracy of estimated TTC in opposite ways with low and high speeds in visible motion. That is, participants' estimated TTC was more accurate with large target (0.8 deg) compared to small target (0.2 deg) when the speed is low (2.5 deg/s), but the estimated TTC was more accurate with small target compared to large target at high speed (10 deg/s). The authors also found that the estimated TTC was more accurate with short visible extent (2.5 deg) compared to long visible extent (10 deg) at low speed, but the accuracy for the visible extent also reverted when the target speed was high.

However, occlusion time appears to be the most important factor (Yakimoff, Mateeff, Ehrenstein, & Hohnsbein, 1993). When Yakimoff and associates (1993) examined the timing accuracy of prediction motion tasks, they varied the occlusion distance and target velocities to get different occlusion times. These authors suggested that the timing error was similar if the occlusion time was the same, regardless of the velocity and occlusion distance. Tresilian (2012) stated that the timing errors of prediction motion tasks are small if the occlusion period is short.

There are two theories that have been put forward in an attempt to explain how we can accurately predict the time to contact of an occluded target. The first is called the internal clocking strategy (DeLucia & Liddell, 1998). According to this strategy, it is possible to estimate the time to contact before the disappearance of moving targets. Participants count down the time and initiate their response when they think the time elapsed has reached the estimated time. Based on the "tau" hypothesis (Lee, 1976), an optic variable can be used to estimate the TTC. More specifically, the change of the ratio of the visual angle between moving object and the contact point is perceived. The ratio is then used to estimate the time to contact and predict the arrival of the moving object. Thus it is not necessary to continue tracking the target once it disappears (Tresilian, 1995).

The second strategy is called the tracking strategy. This approach emphasizes that tracking with the eye or covert attention is involved in the prediction motion task. Individuals will continue to track the moving target as accurately as possible even when it becomes invisible (DeLucia & Liddell, 1998, Makin & Chauhan, 2014).

### 1.1.1 Eye movement and prediction motion

The shift of gaze from one object to another is called saccade, whose velocity is up to 900 deg/s (Goldberg & Walker, 2012), depending on the visual angle between the two objects. Saccades are generated at two clusters of nuclei in brain stem: pontine reticular formation (horizontal saccades) and mesencephalic reticular formation (vertical saccades) which receive the command from superior colliculus. In addition, the frontal eye field projects directly to the superior colliculus (Goldberg & Walker, 2012).

Different from saccades, smooth pursuit eye movements keep an object of interest in the fovea. Slower than the saccade, the eye can only track an object from 1 deg/s to 100 deg/s. However, if the object velocity exceeds 30 deg/s, smooth pursuit eye movements will be compensated by catch-up saccades to follow the targets closely (de Brouwer et al., 2002). In addition to the frontal eye filed, middle temporal (MT) and medial superior temporal (MST) areas of the cerebral cortex also are involved in the smooth pursuit eye movements (Goldberg & Walker, 2012).

At the initiation of a smooth pursuit eye movement, when the eye is stationary, retinal slip (discrepancy between the eye position and the target position) drives the eye movement. A catch-up saccade is generated to bring the eye to the target position. Once the eye catches up with the moving target, the goal of the smooth pursuit movement is to keep the target in the fovea. However, there exists significant delay in visual feedback, which comes from the motor command efference time, visual information reafferent time and the central processing time. The efference copy (copy of the motor command) of the eye movement can be used to predict the future position/velocity of eye to compensate the sensory feedback delay (for a review, see Bennett, 2015).

There exists debate about whether eye movement is involved in temporal estimation (Tresilian, 1995; Huber & Krist, 2004; Bennett et al., 2010; Makin & Poliakoff, 2011). Huber and Krist (2004) asked participants to observe a ball rolling off a horizontal surface and landing onto a ground. The course of the fall was occluded and similar to that in the natural environment (i.e. gravitational acceleration). The authors did not consider resistance as they thought it was offset by the air drag. Participants clicked a button when they predicted the ball contacted the ground. To examine the role of eye movements in the temporal estimation, eye fixation and free eye movement conditions were both involved in that study. The authors found the accuracy of the temporal estimation was similar in the two conditions. Thus Huber and Krist concluded that eye movements were just the by-product of mental imagery and eye fixation would not affect the accuracy of temporal estimation.

Although early researchers (e.g., Tresilian, 1995; Huber & Krist, 2004) stated that tracking was not involved in the PM tasks, some recent studies have demonstrated strong evidence to indicate that the clocking strategy is not enough to explain the results from PM tasks. DeLucia and Liddell (1998) examined whether the tracking or the cognitive clocking only is used in a prediction motion task. The researchers used an interruption paradigm (Cooper, 1989), that is, an object moved at a constant speed and was occluded for a varying duration. Then the target reappeared at either the correct position or the wrong position (more advanced or less advanced). They then asked the participants to answer whether the target reappeared at the correct position or not. Participants did not know where or when the target would reappear. Therefore they could not count down the time to predict time to contact. The authors found that participants had similar errors in the interruption paradigm and the production task where they were required to judge when the target arrived at a prescribed spot. Based on these results, the authors concluded that participants also used tracking (cognitive motion extrapolation) in addition to the clocking strategy in the prediction motion task.

In addition to the results above, converging evidence has demonstrated that tracking is involved in PM tasks, which is typically studied using ocular tracking (Bennett et al., 2010; Makin & Poliakoff, 2011). It has been demonstrated that both smooth pursuit and catch up saccades are used to track visible moving objects (de Brouwer, Missal, & Lefèvre, 2001).. Tracking the occluded target, which disappears after moving for a short time, means that the eye could track the target for a small amount of time (100-200 ms) perfectly. Then participants track the occluded target with a combination of reduced velocity pursuit and catch-up saccades, but less accurate than the first 100-200 ms (Orban de Xivry et al., 2006; Makin & Poliakoff, 2011; Bennett & Barnes, 2003, 2005).

Bennett and colleagues (2010) investigated the influence of eye movement on the accuracy of prediction motion tasks. The authors required participants to perform prediction motion tasks with free eye movement or with a fixation point. The results showed that the velocity effect was only on the fixation group, that is, participants made greater underestimation errors for the slow-moving object compared with fast-moving object when the TTC was between 1 and 1.5 s. On the contrary, the free eye movements group was not influenced by different target velocities if the TTC was the same. In agreement with Bennett et al. (2010), Makin and Poliakoff (2011) had the similar conclusion that eye movements enhanced the accuracy of prediction motion tasks. If eye tracking was not adopted in PM tasks, eye fixation would not have an effect on the estimated TTC.

### 1.1.2 Common rate controller hypothesis

A recent hypothesis for prediction motion is the common rate controller hypothesis (for a review, see Makin, 2017), which states there is an existing controller responsible for pacing all the mental simulations. Makin and associates (Makin & Bertamini, 2014; Makin & Chauhan, 2014) have extended the extrapolation of position (prediction motion) to other dimensions, e.g. number space or colour space. Makin and Chauhan (2014) asked participants to perform both position and number extrapolation tasks. The extrapolation task was similar to a prediction motion task where participants first observed a target moving horizontally. Then the target would be occluded by an occluder. Participants were required to estimate when the occluded target arrived at the end of the occluder by clicking a button. In the number extrapolation tasks, as depicted in Fig. 1, participants watched a number decreasing from 10 to 0 with decrement of 0.2. Analogous to occlusion, the counter disappeared before the number reached to 0. Participants had to predict when the counter became 0 by pressing a button. In both number and position extrapolation tasks, the occlusion times were 1, 2 or 4 seconds. The authors found both the estimated TTC and the constant error were comparable in the two tasks. Thus, Makin and Chauhan (2014) proposed that there is one common rate controller which guides extrapolation in different dimensions (e.g. position and number).

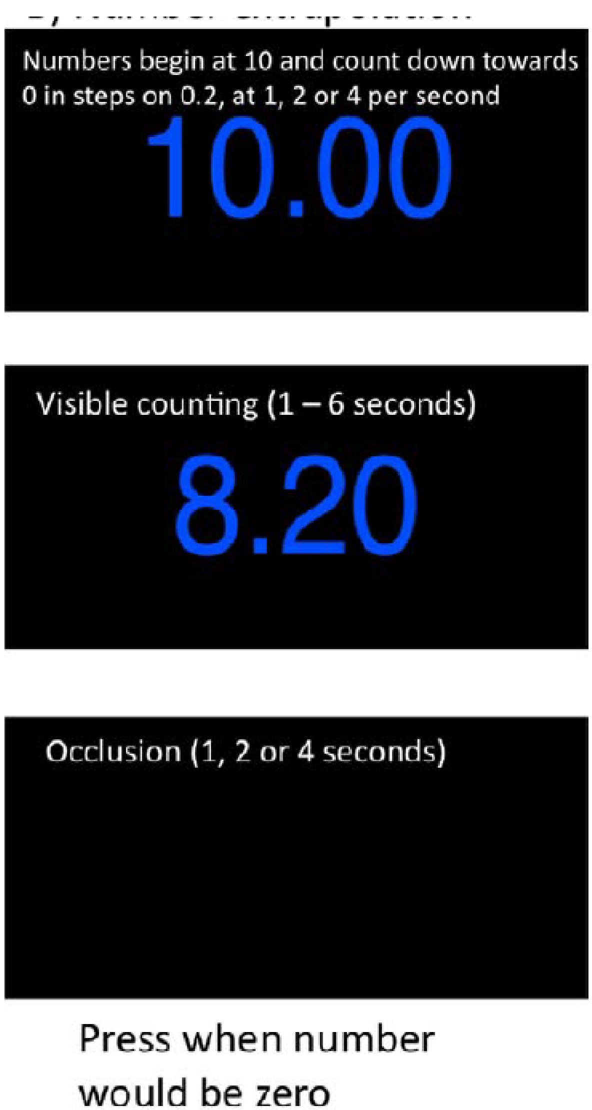



Figure 1 Example of number extrapolation task adapted from Makin and Chauhan (2014)

### 1.1.3 Development of temporal estimation ability

It has been reported adults have a better temporal estimation ability than children (Benguigui et al., 2008). Practice in a laboratory setting can also improve the accuracy of temporal estimation quickly (Fialho & Tresilian, 2017). People with sport expertise are more accurate than those without (Nakamoto et al., 2012). In addition, the estimated TTC is more accurate when the object moves at the gravitational acceleration compared to other accelerations and constant velocity (Zago et al., 2005). Zago and colleagues (2005) reported participants correctly intercepted 85% of targets with the gradational acceleration, but the successful rate for 0 g target was only 14%. It is probably that people deal with gravitational acceleration in daily life, for example the free fall of an apple. However, people barely see an object falling at constant velocity in daily life. In addition, Benguigui and associates (2008) reported people use different strategies to estimate TTC at different ages. Younger children (6, 7.5 and 9 years old) preferred using occlusion distance to estimate the TTC. Differently, older children (10.5 years old) and adults use the occlusion time to estimate the TTC. The temporal estimation in the older children and adults are more accurate than that in the young children.

## 1.2 Eye hand coordination

Eye hand coordination refers to the relationship between eye movements and hand movements, and the use of visual information for goal-directed manual movements (Rizzo et al., 2017). More than one century ago, Woodworth (1899) found the initial portion of the goal-directed movement was fast and stereotyped, whereas the hand movement became slower and discontinuous when the hand approached the vicinity of the target. Thus, he concluded the goal-directed movement comprised two phases: the pre-planned phase and the controlled phase. In the same study, Woodworth (1899) also examined the role of vision in the goal-directed movement by comparing the performance of aiming movements in vision and no vision condition. He found that the accuracy the hand's endpoint was higher in the vision condition, but the discrepancy of the accuracy between the two conditions disappeared when the movement time was limited to be within 450 ms. Thus Woodworth (1899) concluded 450 ms was the minimum time to use visual feedback.

Since then, numerous lines of research (for a review, see Rizzo et al., 2017; Carey et al., 2002) have been done to study the relationship between eye movements and hand movements, as well as the role of vision in goal-directed movements (for a review, see Elliott et al 2001, 2008). Many researchers conclude the eye and hand are driven by common motor commands (van Donkelaar et al. 1994; Kreyenmeier et al., 2017). In the aiming movements, the primary eye and hand movements usually undershoot the target, together with subsequent corrections to go to the target area (Helsen et al., 2000). In addition, Fisk and Goodale (1985) found that the hand had a longer reaction time (the time delay between the appearance of the stimulus to the initiation of the movement) when moving to a target on the contralateral side (a target on the different side of the limb) compared to that on the ipsilateral side (a target on the same side of the limb). Unexpected, the authors also found the eye had a longer reaction time when the hand moved to the contralateral side compared to the ipsilateral side. Different from the hand, both left and right eyes were involved in the movement, thus it is impossible to define contralateral or ipsilateral for the eye movement. The reaction times of eyes to both sides were similar when there were no hand movements. Thus the hand reaction time has affected the reaction time of the eye. There must exist a coupling between eye and hand reaction times.

Moreover, the eye plays a role in guiding the hand movements (Land, 2006). The eye completes the movement earlier than the hand. The hand reaches its peak acceleration at the time the eye finishes its primary movement (Binsted et al., 2001). Helsen et al. (2000) examined the coupling of the eye, finger, elbow, and shoulder during a manual aiming movement. Participants were requested to complete a 40cm aiming movement with their dominant hand. They were allowed to move their eyes, hands, elbows, and shoulders freely. The authors reported there was co-occurrence of the completion of the primary saccade and peak velocity of the finger, elbow and shoulder, which can be interpreted as visual information was essential for online control because when the eye reached the target, the deceleration phase of the limb started with the assistance of the visual information.

Moreover, there also is some existing literature that demonstrates evidence for eye hand coupling in tracking both self-generated and externally-generated targets (Vercher, Quaccia, & Gauthier, 1995; Bennett, Donnell, Hansen, & Barnes, 2012). Specifically, when tracking a self-generated moving target using the eye and  hand together, the eye more closely follows the moving target when compared to eye tracking only (Gauthier & Hofferer, 1976; Gauthier, Vercher, Mussa Ivaldi, & Marchetti, 1988). Concurrent hand tracking also reduces the catch-up saccade (Mather & Lackner, 1980). In addition to enhancing tracking of unpredictable targets (Niehorster, Siu, &Li, 2015), concurrent hand tracking can also facilitate smooth pursuit in tracking predictable moving objects. Bennett et al. (2012) investigated the influence of hand tracking on eye tracking during transient occlusion. Participants were asked to track constant velocity or accelerating targets using eyes only or with eyes and hands together. The target was viewed for 600 ms before being occluded. Then it reappeared and continued moving for another 400 ms, before finally disappearing again. The results showed that eye velocity in the ocular manual condition was closer to the target velocity compared to the ocular only condition when tracking a high constant velocity target. Moreover, concurrent hand movements assisted the eye by reducing saccadic distance in tracking constant velocity targets. Based on these results, Bennett and associates suggested that concurrent hand movements facilitated eye tracking.

### 1.3 Effect of concurrent hand movements on estimated TTC

Few studies have examined the effect of concurrent hand movement on temporal estimation in an anticipation timing task. Bootsma (1989) found the concurrent hand movement improved the accuracy of the temporal estimation compared to a single button press task. On the contrary, Williams, Jasiewicz and Simmons (2001) reported the concurrent hand movement had a negative contribution to the temporal estimation. However, these authors asked participants to move their hands in the opposite direction with respect to the moving target. More recently, Rodríguez-Herreros and López-Moliner (2011) examined the contribution of proprioception (hand movement) to the temporal estimation in the anticipation timing task. In the perceptual condition, participants made a single button press, while in the perception-action condition, the participant moved their hands either in the same direction as the moving object or perpendicular to the moving object before pressing the button. The authors found participants benefited from proprioception only when the hand moved in the same direction as the moving object.

Similarly, Kerzel (2001) reported inaccurate hand movements interfered the short-term memory of the target velocity. The researcher asked participants to judge which of the two subsequently presented visual stimuli moved faster. The interval of the presentation of the two stimuli was 4 seconds, during which participants performed hand movements which could be faster or slower than the first visual stimuli. The author found the hand movements affected the judgement systematically. That is, slower hand movements decreasing the remembered velocity of the first visual stimuli and vice versa. Kerzel (2001) concluded visual velocity information and hand velocity information were stored together.

So far, we have uncovered only one study which examined the effect of hand movement in a discrimination task for prediction motion. Wexler and Kalm (2001) compared the performance between passive and active prediction motion. The rotation motion of the target was actively produced by the hand in the active condition while participants could only observe the rotation in the passive condition. Participants were required to judge if the target position was backward or forward when the target reappeared after occlusion. To make the two conditions similar, the authors used replays of the active condition in the passive condition. The authors found that participants estimated positions further advanced in the active condition compared to the passive condition. However, participants did not pursue the target with eyes all the time in both conditions as they were not required to do so. Thus, it is still unclear as to whether concurrent hand movements facilitate performance in prediction motion tasks, or more specially the production task. To this end, the current study aimed to examine if concurrent hand movements would facilitate performance in a prediction motion task. To examine this, we compared the performance in an ocular only condition and ocular manual condition in a prediction motion paradigm

It was hypothesized that concurrent hand movements would make the eye stay closer to the moving target, especially when the target is occluded. The eye movements/hand movements updated the internal representation of the moving target continuously before and after target occlusion. Thus, accurate eye/hand tracking movements would improve the accuracy of estimated TTC.

## *Chapter 2: Method*

### 2.1 Participants

Ten right-handed participants (M= 25.3 years old, SD=2.8, 4 females) were recruited for the experiment, all had normal or corrected to normal vision. None of them had professional sport training experience before. Participants signed a consent form prior to the experiment and were allowed to take breaks anytime during the experiment. All procedures were approved by the Research Ethics Board at the University of Alberta.

**2.2 Apparatus**

Participants sat 45cm away from a touch screen (Acer, T232hl) with a refresh rate of 60 Hz and a resolution of 1920 x 1080. A blue circle (1.5 cm diameter) located 10 cm left to the center of the screen served as the start position. Another blue circle of the same size located 10 cm right to center was the end position; subtended a visual angle of 25 degrees[1]. The stimuli were generated using E-prime (v 2.0 Psychology Software Tools Inc., Sharpsburg, PA). As illustrated in Fig 2, hand movements were recorded by a 3D motion analysis system (Optotrak, Northern Digital, Inc., Waterloo, ON, Canada) using one infrared light-emitting diode (IRED) placed on the index finger and using a sampling rate of 240 Hz. A head mounted eye tracker (Applied Sciences Laboratory (ASL) 6000), with a rigid body (including three IREDs) to allow free head movements, was used to record the position of the left eye at a sampling rate of 240 Hz. A nine-point calibration grid on the screen was used to calibrate eye position for each participant before the experiment.

[1] The total movement distance was 20 cm. We chose such movement distance because a) it was a moderate movement distance for hand movements, b) and it was long enough to make three different occlusion times.

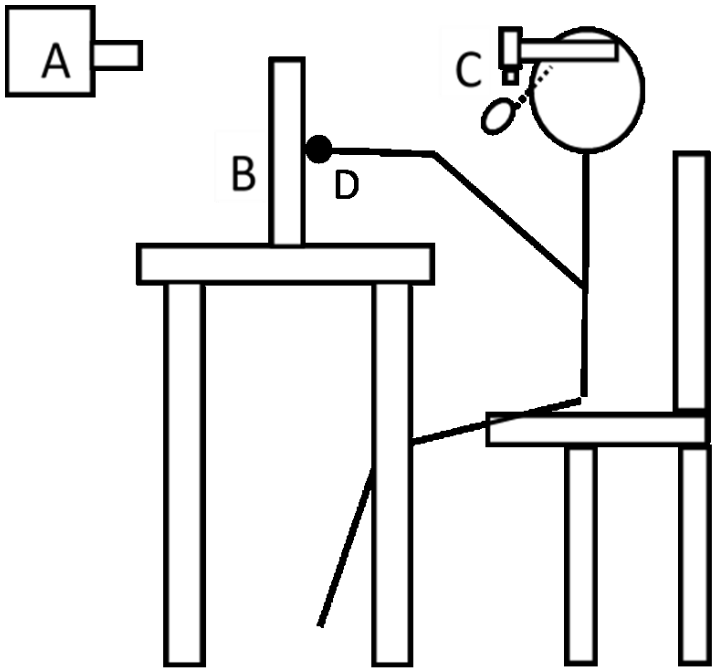



Figure 2 Experimental setup. A: Optotrak, B: Touch Screen, C: eye tracker, D: infrared light-emitting diode (IRED)

**2.3 Procedure**

At the beginning of each trial, participants looked at the start position (Ocular only condition) or placed their finger on the start position (Ocular manual condition). A red circle (target) with a diameter of 1.5 cm appeared at the start position for 2 seconds after the participants indicated that they were ready. After a random period between 1000 and 1500 ms, the target (red circle) started moving at a constant velocity of either 10, 13.3, or 20 cm/s (i.e 12.5, 16.6, and 25 deg/s), creating three different movement times from start position to end position (i.e., 1, 1.5, and 2 seconds). At the initiation of the target's movement, the motion analysis cameras and the eye tracker started recording simultaneously. For each trial, Optotrak recorded for a duration of 3 seconds and the Eye tracker stopped recording 0.5 s after the participant clicked the mouse or pressed on the screen. The moving target was no longer visible after travelling for 10 cm (midpoint). Participants were informed that the target would continue moving at its previous velocity after its disappearance and that they were required to track it even though they could not see it. Based on the position of the point of target occlusion (PTO), participants had the same viewing and occlusion times: 0.5 s for the fast-moving target, 0.75 s for the medium-moving target or 1s for the slow-moving target. Participants were asked to perform two different tasks, using a prediction motion paradigm in the horizontal plane. First, they were required to predict the arrival time of a moving target by clicking a mouse (Ocular only condition). Second, the participants were asked to move their index finger to track the moving target from initiation to the end position and to touch the screen upon their estimated time to contact (Ocular manual condition). Feedback of the actual target position relative to the estimated time to contact was provided at the end of each trial. A red circle representing the actual target location would appear after participants clicked the mouse (Ocular only condition) or pressed on the screen (Ocular manual condition). Prior to the test, the two tasks were clearly explained to each participant. Participants were also given 6 practice trials in order to familiarize themselves with the two tasks prior to the test trials. In the experimental portion, participants were required to perform 20 trials at each velocity for each task, giving a total of 120 trials. Order of the two tasks was presented in a counterbalanced fashion across each participant and target velocity presentation was totally randomized.

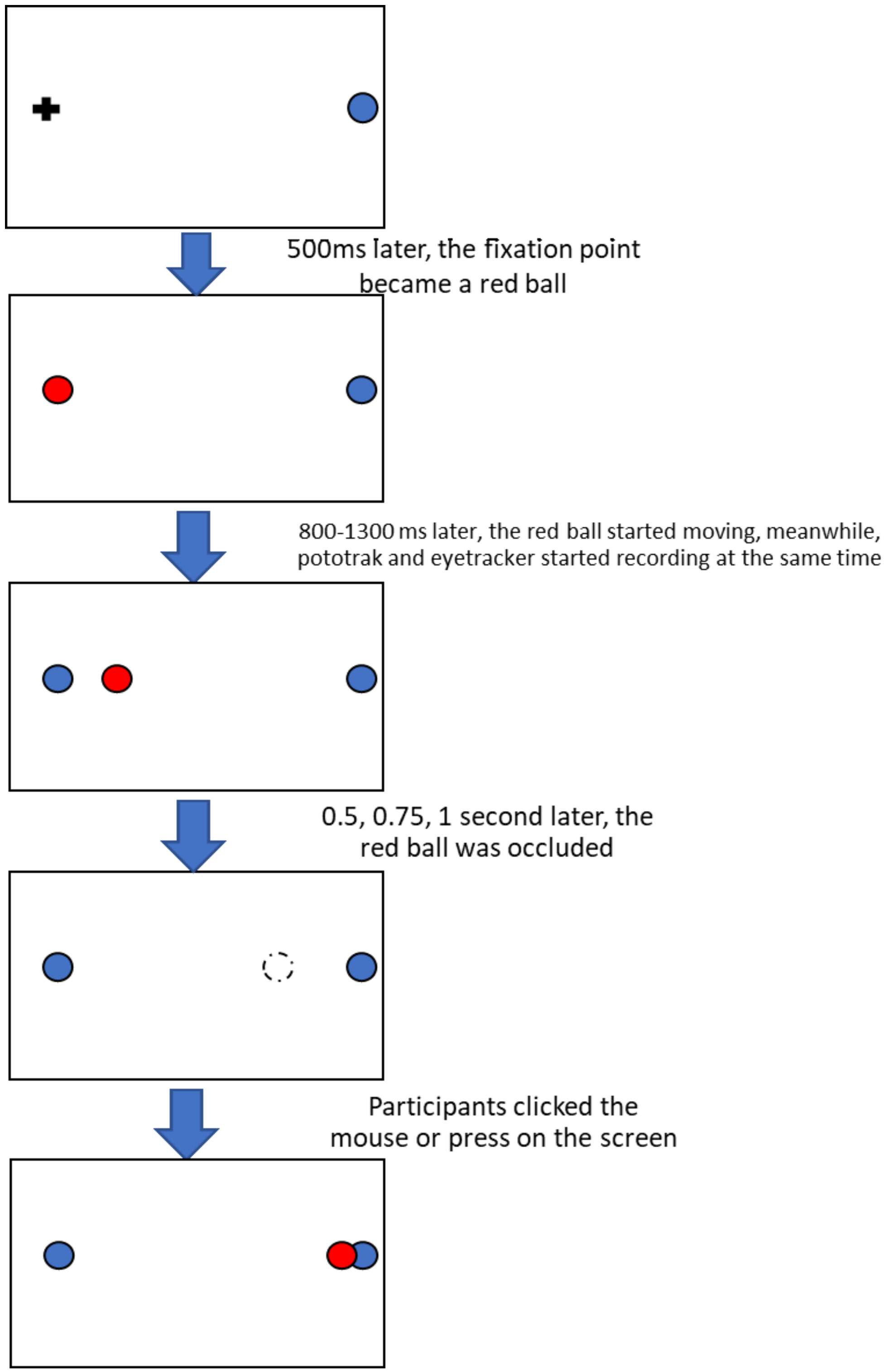



Figure 3 experimental procedure.

## 2.4 Data Analysis

### 2.4.1 Accuracy and Consistency

Constant error (CE) of the arrival time was defined as the time difference between the target's actual arrival time from the start position to the end position and the estimated arrival time by participants. A negative CE meant participants responded prior to the arrival of the target, whereas a positive CE indicated a late response by the participant. Variable error (VE) was the standard deviation of participant estimated arrival times. It indicated the consistency of estimated time to contact. In addition, hand accuracy was measured by the spatial difference between the endpoint position of hand and the center of the end position (Blue circle). VE of endpoint position of the hand was also calculated. CE, VE and hand accuracy data were derived from E-prime software.

### 2.4.2 Kinematics

Hand and eye position data were filtered using Butterworth filter with a low pass frequency of 20 Hz. A central difference algorithm was used to obtain eye and hand velocity. Onset of the movement was defined as the first frame when velocity exceeded 30 mm/s for 20 ms. Offset of movement was defined as the first frame when velocity was lower than 10 mm/s and maintained for more than 20 ms[2]. Root mean square error was the difference between the eye position and the center of the moving target determined at each kinematic sample (240 Hz). As illustrated in Figure 4, root mean square error of the first half (RMSE1) was the determined

[2] The onset and offset criterions were similar to those used in Glazebrook et al. (2015). However, the maintenance time was longer in the current study. It was because the eye velocity may be reduced to 0 when tracking occluded target. However, the eye immediately increased its velocity after it decreased to 0. To find the correct offset frame instead of the one at which the eye velocity was 0 but increasing soon after, 20 ms was a long enough offset time.

by every kinematic sample from movement onset to the point of target occlusion (PTO). Root mean square error of the second half (RMSE2) was determined by every kinematic sample from PTO to the movement end. In addition, we also calculated the onset time of the anticipatory saccade after target occlusion. The onset of the anticipatory saccade was defined as the first frame after target occlusion when acceleration exceed 6000 $mm/s^2$ (750 $deg/s^2$) and maintained for more than 10 ms (Bennett et al., 2012). All the kinematic variables were calculated by a custom written MATLAB (Mathworks Inc.) program for each trial. RMSE was used to measure the tracking performance. Smaller RMSE values indicated that the trajectory of eye/hand was closer to that of the moving target (Mazich, Studenka, & Newell, 2014) and that eye tracking accuracy was greater (Fooken, Yeo, Pai & Spering, 2016)

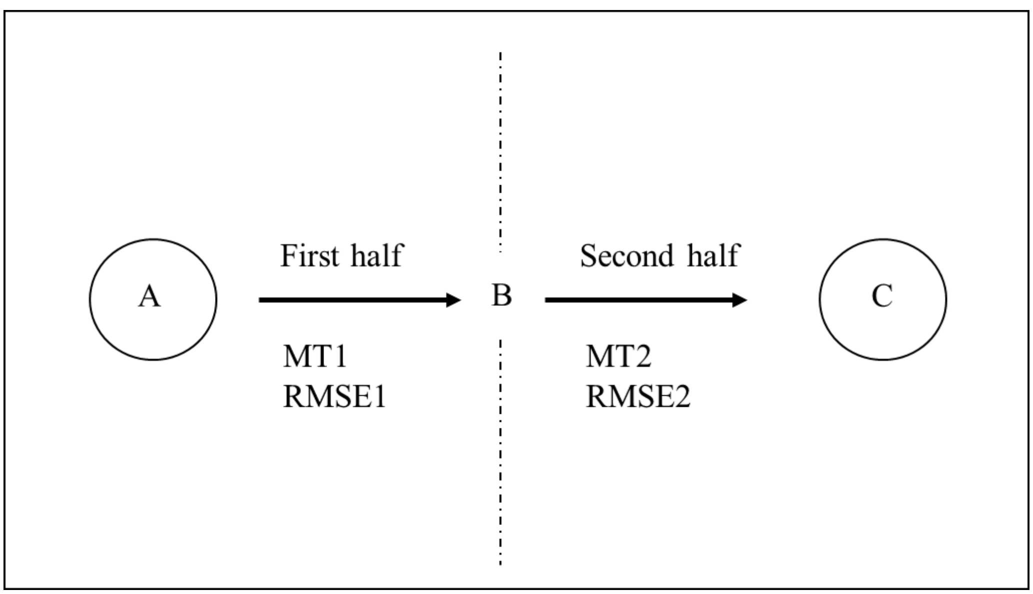



Figure 4 Schematic representation of the task and dependent variables. A: Start position, B: Point of target occlusion (PTO), C: End position (Blue circle). First half is from A to B, where the target is visible. Movement time/RMSE for this distance is MT1/RMSE1.Second half is from B to C, where the target is occluded. Movement time /RMSE for this distance is MT2/RMSE2.

Dependent variables were submitted to a 2 Condition (Ocular only and Ocular manual) by 3 Velocity (Fast, Medium, Slow) repeated measures ANOVA. Alpha level was set at 0.05 for all analyses and Tukey's HSD post-hoc procedure was used for main effects or interactions where appropriate.

***Chapter 3: Results***

Details of the eye movement kinematics were listed in Table 1**.**

Table 1. Mean (SD) of MT1, MT2, RMSE1, RMSE2 and Velocity as a function of Condition and Velocity

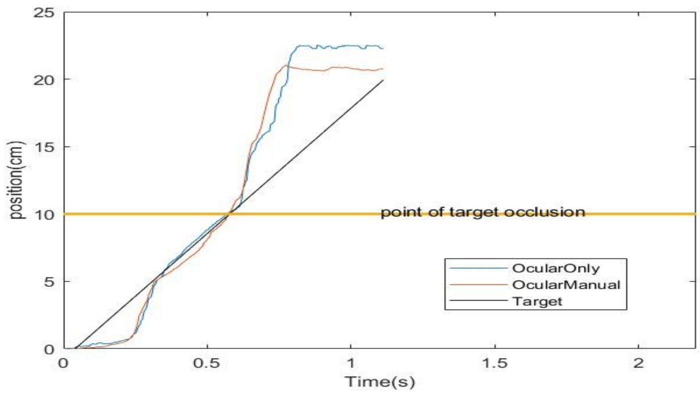
| | Ocular only | | | Ocular manual | | |
|---|---|---|---|---|---|---|
| | Slow | Medium | Fast | Slow | Medium | Fast |
| MT1 (s) | 0.970 (0.039) | 0.706 (0.026) | 0.438 (0.024) | 0.987 (0.038) | 0.706 (0.034) | 0.435 (0.029) |
| MT2 (s) | 0.555 (0.089) | 0.414 (0.061) | 0.243 (0.045) | 0.576 (0.151) | 0.444 (0.111) | 0.188 (0.067) |
| RMSE1 (cm) | 1.68 (0.468) | 2.0 (0.396) | 2.97 (0.467) | 1.52 (0.355) | 1.97 (0.338) | 3.30 (0.769) |
| RMSE2 (cm) | 3.22 (0.607) | 3.11 (0.523) | 4.24 (1.032) | 2.70 (0.171) | 2.98 (0.370) | 4.72 (1.07) |
| Velocity (cm/s) | 11.3 (4.06) | 14.4 (4.63) | 23.4 (7.96) | 9.82 (1.49) | 14.1 (3.90) | 28.3 (8.57) |

### 3.1 Eye and hand movement

Kinematic analyses of the eye movements indicated that a catch-up saccade followed the initial reaction to the moving target after which the eye stayed close to the moving object until target occlusion. Moreover, the eye scaled its velocities to the target velocities (Fast: 23.85 cm/s, Medium:15.25 cm/s, Slow: 10.56 cm/s) at the time of target disappearance. However, the eye could track the moving target for a short time (100-200 ms) after target occlusion. The eye then lagged behind the moving object and finally, an anticipatory saccade brought the eye to the end position before the arrival of the moving target in both tasks (Figure 5). All the participants had the anticipatory saccade after target occlusions for the slow and medium moving target in both conditions, as well as the fast-moving target in the ocular only condition. However, two out of the ten participants had the anticipatory saccade just before the target occlusion in the ocular manual condition for the fast-moving target.

Similar to the data for the eye, the hand initiated its movement after stimulus onset. As illustrated in Figure. 6, the hand had a steady velocity phase for the medium and slow-moving targets. When the moving target was occluded (10 cm from the start position), the hand positions for the slow and medium moving targets were 10.16 cm and 10.26 cm respectively. At the same time, the hand also scaled velocities to the slow and medium moving target. The hand velocity for the slow and medium moving targets were 11.1 cm/s and 16.9 cm/s respectively. However, for the fast-moving target, the hand position fell behind the moving target at the time of target disappearance (7.98 cm). By comparison, the hand also traveled at a much greater velocity (39.3 cm/sec) than the other two conditions. Further, as depicted in Figure 6, the velocity profile for the fast-moving target resembled a reaching movement in that it had both an acceleration and deceleration phase. When the hand finally landed on the end point, the constant error for the spatial hand end position of the slow, medium and fast-moving targets were 0.183, 0.198 and 0.176 cm respectively.

*a*


25
20
15
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5
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position(cm)
point of target occlusion
OcularOnly
OcularManual
Target
0
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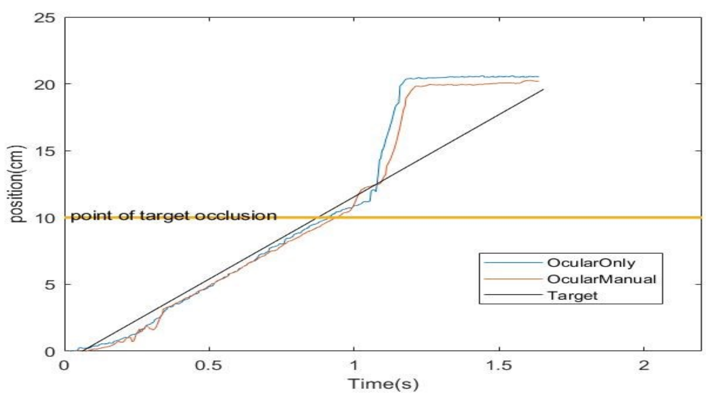
1.5
2
Time(s)

*b*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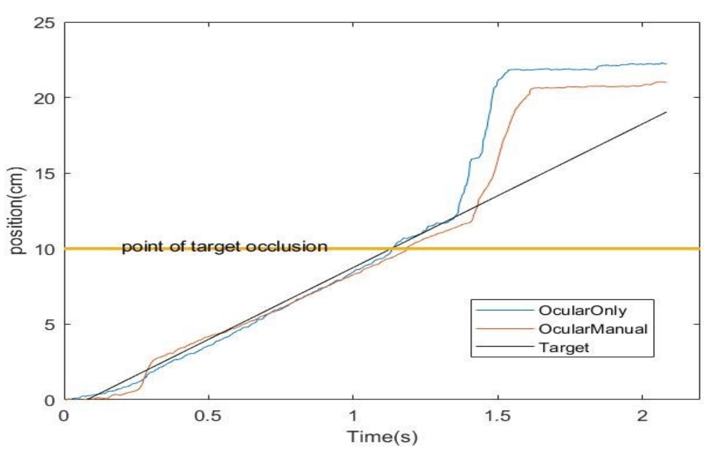
Time(s)

*c*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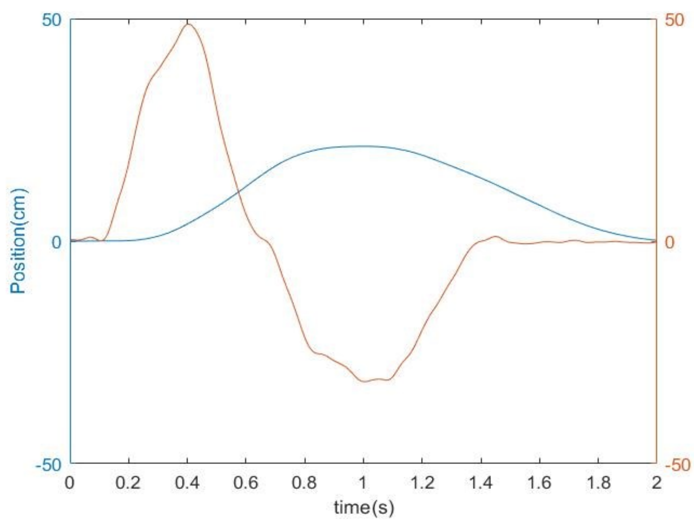
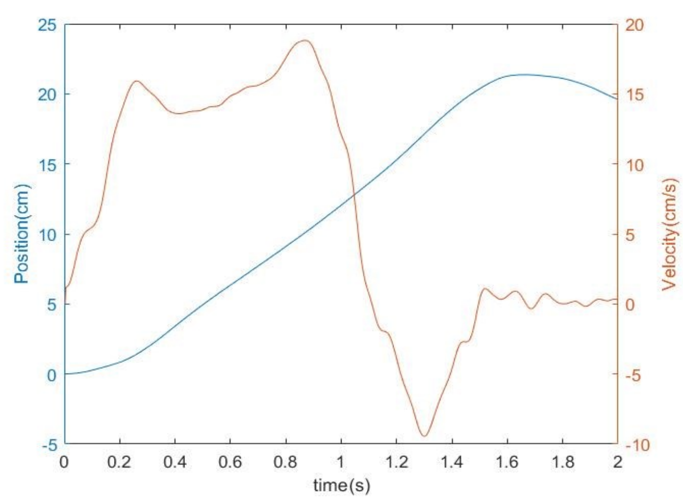
Time(s)

Figure 5 Representative raw eye position trajectories for (a) fast, (b) medium and (c) slow moving target from single trials from one typical participant. Horizontal line shows the point of target occlusion.

*a*




*b*



*c*

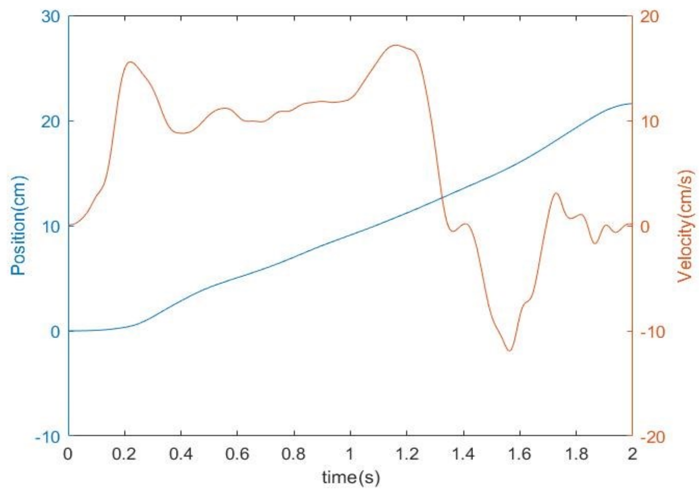



Figure 6 Examples of hand position and velocity profile for the fast (a) medium (b) and slow (c) moving target from one typical participant.

### 3.2 Constant Error of estimated time to contact (TTC)

There was a main effect for Velocity, $F(2, 18) = 15.83$, $\eta^2 = 0.638$ ($p<0.01$) and significant Condition by Velocity interaction, $F(2, 18) = 6.06$, $\eta^2 = 0.402$, ($p<0.01$). Overall, estimated time to contact was more accurate for the fast-moving target (0.006 ±0.06 s) compared to the slow-moving target (-0.09 ±0.058 s). The interaction revealed that participants overestimated the TTC for fast moving target in the Ocular manual condition, but underestimated in the Ocular only condition (see Fig. 7). In addition, there was a trend that participants were more accurate in the Ocular manual (-0.02 s) condition than the ocular only (-0.06 s) condition ($p$=0.055).

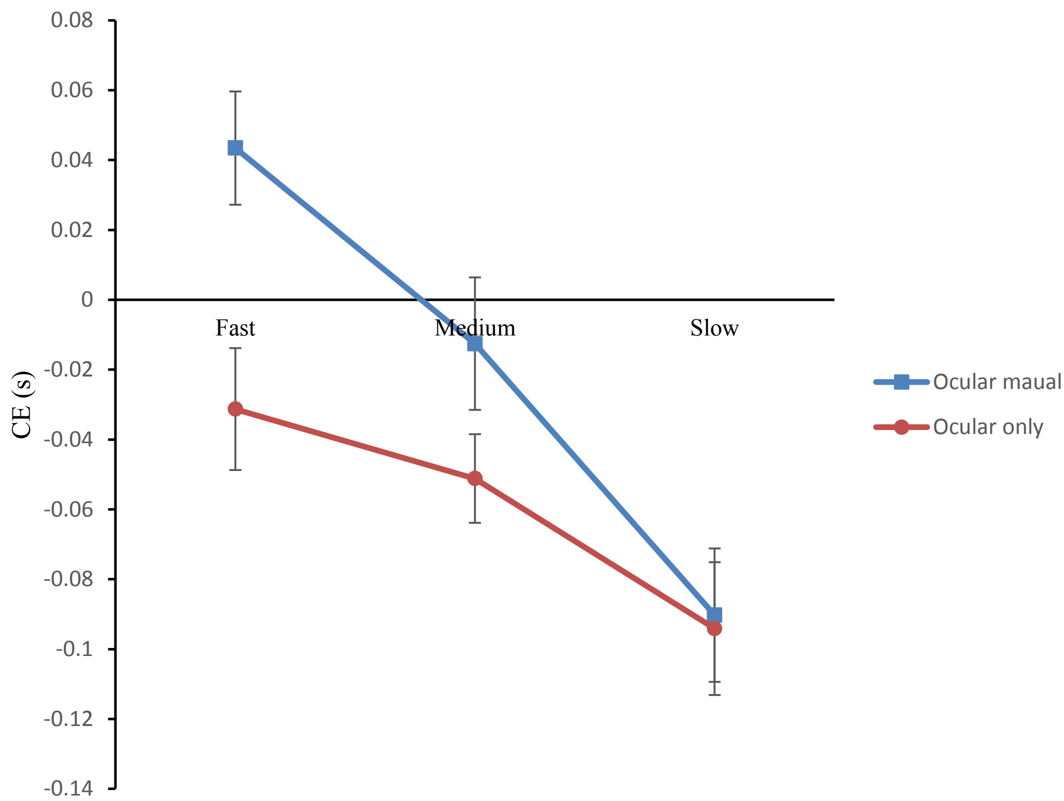



Figure 7 Mean constant error (s) as a function of Condition and Velocity. Error bars represent standard error of mean. Negative CE indicates underestimation of TTC

### 3.3 Variable Error of estimated TTC

There were main effects for Condition, F (2, 18) = 19.67, $\eta^2$=0.686 (p<0.002), and Velocity F(2, 18)=24.806 , $\eta^2$=0.734 (*p*<0.001). The Condition by Velocity interaction F(2, 18)= 4.18, $\eta^2$=0.317 (*p*<0.032) was also significant. Overall, the main effect for Condition showed that participants were more consistent in the Ocular manual condition compared to the Ocular only condition. The main effect for Velocity revealed that VE decreased as a function of target velocity (Fast: 0.072 s, Medium: 0.104 s, Slow: 0.126 s). The three were significantly different from each other. In addition, the Condition by Velocity interaction F (2, 18) = 4.18, $\eta^2$=0.317 ($p$<0.032) was significant. Tukey's HSD analysis of the interaction indicated that VE was smaller in the Ocular manual condition than the Ocular only condition, except for the fast-moving target condition (see Fig. 8).

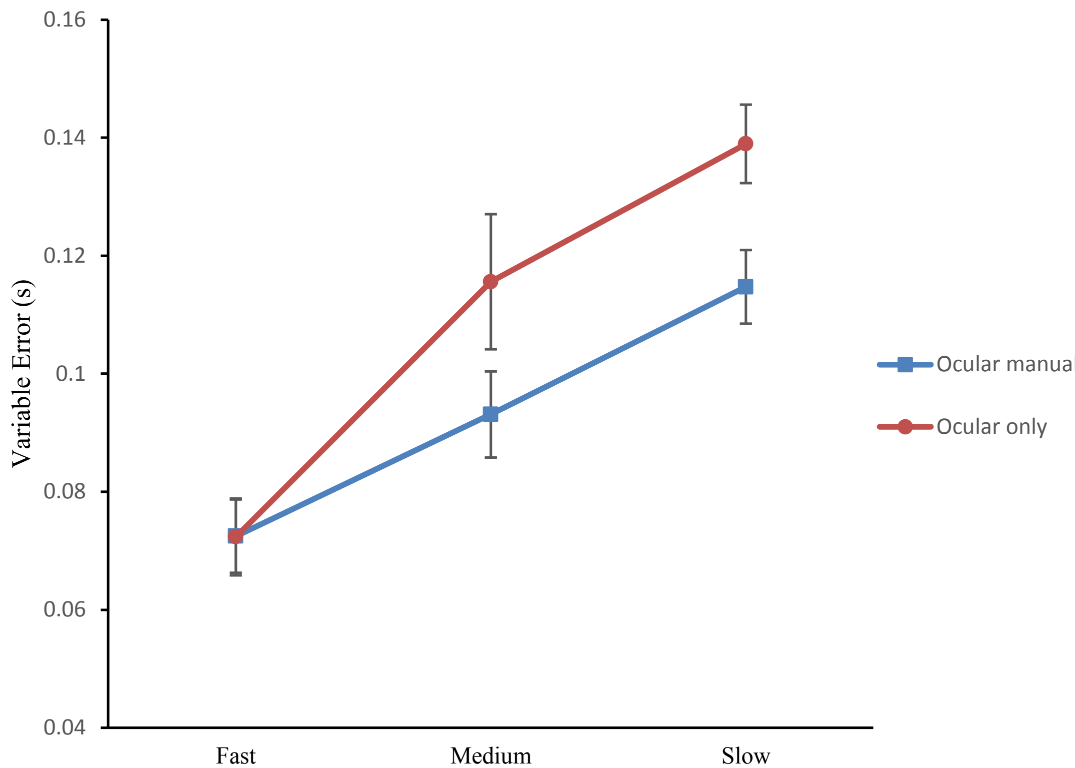



Figure 8. Mean variable error (s) as a function of Condition and Velocity. Error bars represent standard error of mean.

### 3.4 Root-Mean-Square error of the eye

There was a main effect for Velocity on RMSE1 of the eye, F (2, 18) = 99.056, $\eta^2$=0.916 ($p$<0.001). Post hoc analysis of the main effect for Velocity revealed that RMSE1 for the slow (1.6 cm) and medium moving targets (1.88 cm) were smaller compared to the fast-moving target (3.13 cm).

As for RMSE2, there was a main effect for the Velocity as well, $F(2, 18) = 17.56$, $\eta^2 = 0.661$ ($p < 0.001$). Similar to RMSE1, RMSE2 for the slow (2.96 cm) and medium moving targets (3.04 cm) were smaller compared to the fast-moving target (4.48 cm). In addition, a significant interaction of Condition by Velocity was also found on RMSE2, $F(2, 18) = 11.12$, $\eta^2 = 0.553$ ($p < 0.001$). As illustrated in Fig. 5, RMSE2 for the slow-moving target was smaller in the Ocular manual condition (2.70 cm) than the Ocular only (3.22 cm) whereas RMSE2 for the fast-moving target was smaller in the Ocular only condition (4.24 cm) than the Ocular manual condition (4.72 cm).

**3.5 Onset time of anticipatory saccade (OTAS) after target occlusion**

The analysis of OTAS revealed a main effect for Velocity, $F(2, 18) = 77.7$, $\eta^2 = 0.889$ ($p < 0.001$), as well as a Condition by Velocity interaction, $F(2, 18) = 6.58$, $\eta^2 = 0.553$ ($p < 0.01$). Tukey's HSD analysis of the interaction showed the OTAS increased with target velocity. Similar to the RMSE results, concurrent hand movements with different target velocities had different effects on the OTAS. That is, the OTAS for the slow-moving target was longer in the Ocular manual condition than the Ocular only condition, but the OTAS for the fast-moving target was shorter in the Ocular manual condition (Fig. 9). In addition, the OTAS increased with the decreasing of target velocity in both conditions, which meant the OTAS increased with the occlusion time in both conditions.

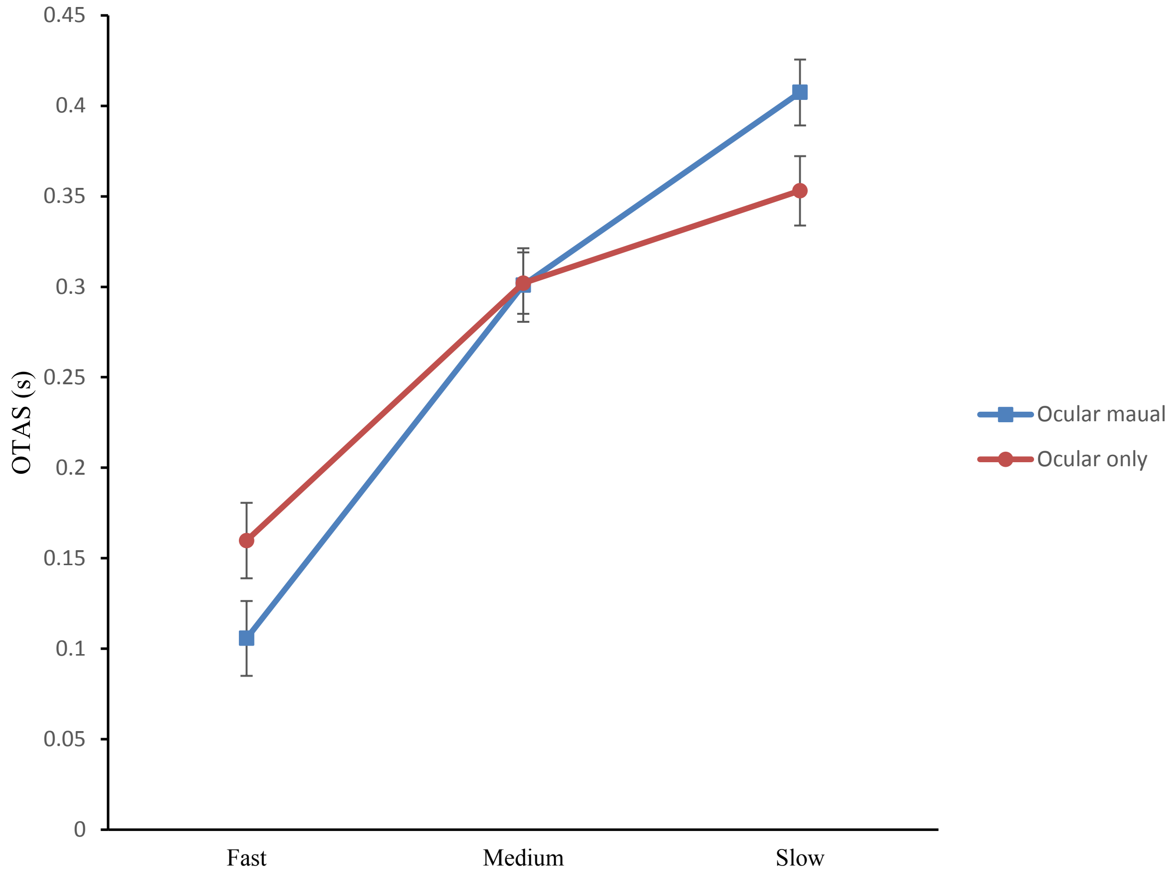



Figure 9 Mean OTAS (s) as a function of Condition and Velocity. Error bars represent standard error of mean

## *Chapter 4: Discussion*

The aim of the present study was to examine the effect of concurrent hand movement on performance in prediction motion tasks. To this end, we utilized a prediction motion paradigm to compare a traditional button press task to a new task which involved concurrent hand movement. We hypothesized that concurrent hand movement could facilitate the estimated time to contact (TTC) in prediction motion tasks. We based this on previous findings that tracking was involved in the PM task (Makin & Poliakoff, 2011) and that concurrent hand movement could facilitate eye tracking to an occluded target (Bennett et al., 2012). Results of the present experiment indicated that concurrent hand movements with different target velocities had different effects on the estimated TTC. Specifically, concurrent hand movements with the medium and slow-moving targets were relatively more accurate when tracking and had the trend to increase the precision of estimated TTC in the ocular manual condition compared to the ocular only condition. On the contrary, concurrent hand movements with the fast-moving target were relatively inaccurate when tracking and disrupted the estimated TTC in the ocular manual condition.

### 4.1 Estimated time to contact

Participants increased the accuracy and consistency of estimated TTC as a function of velocity. It was possible that target occlusion time accounted for this change. The occlusion times were 1, 0.75 and 0.5 second for target velocities of 10, 13.3 and 20 cm/s respectively. It has been reported that the accuracy and consistency decrease with the occlusion time (Yakimoff et al., 1993; Tresilian, 1995; Bennett et al., 2010; Makin & Poliakoff, 2011). In the present study, participants had the shortest occlusion time when the target velocity was high, thus their estimated TTC was the most accurate and consistent for the fast-moving target. In addition, estimated TTC was more consistent in ocular manual condition compared to ocular only condition. This finding is supported by results from an anticipation-timing task (Rodríguez-Herreros & López-Moliner, 2011), where the moving target is always visible. It appears that the online feedback is more specific in ocular manual condition compared to the ocular only condition as the refinement of the timing precision is better with concurrent hand movement (Tresilian, 1995). Thus participants had more consistent estimations in the ocular manual condition.

When the target velocity was high (shortest TTC), there was an underestimation of the estimated TTC in the ocular only condition, but an overestimation in the ocular manual condition. We suggest that the estimated TTC may have been disrupted by the inaccurate hand movement. Similarly, it has been reported the accuracy of estimated TTC in an anticipation-timing task was worse when the hand movement was incongruent with the moving target, compared to a single button press task (Williams et al., 2001) or compared to a task with congruent hand movement (Rodríguez-Herreros & López-Moliner, 2011). Wexler and Kalm (2001) stated that the concurrent hand movement was involved in a high-level mechanism that predicted the outcome. In addition, the store (representation of current moving target configuration) is continuously updating on the basis of the efference copy or the proprioceptive information, both before and after target occlusion. When the efference copy or the proprioception about the concurrent hand movement could not represent the moving object, the store was consequently disrupted by the inaccurate input, especially after target occlusion.

It has been reported more skilled baseball players have a later interception time than less skilled players (Fooken et al., 2016). The authors explained that players could track the target longer time if they intercepted late. In the present current study, overestimation was similar to later interception while underestimation was analogous to early interception. However, we did not find a longer tracking time (MT2) when participants overestimated TTC. Conflicting results may be caused by different experimental design. Fooken et al. (2016) did not have explicit occlusion distance and found eye tracking accuracy determine the temporal estimation accuracy. In the present study, we had a relative explicit occlusion distance. Our results indicated superior eye tracking did not increase temporal estimation accuracy. Though 1 s was the longest occlusion time in the present study, it was still a relative short occlusion time compared to the long occlusion time in the other studies (Bennett et al., 2010). Therefore it was normal to find a underestimation in the ocular manual condition when the target velocity was high. As stated above, the overestimation was in the ocular manual condition was due to the inaccurate hand tracking movements instead of longer eye tracking time (Fooken et al., 2016)

Unexpectedly, we did not find significantly more accurate estimated TTC with the accurate hand tracking movement. However, there was a trend ($p$=0.055) that CE was smaller in the ocular manual condition than the ocular only condition. It is possible that this trend was biased by the positive CE for the fast-moving target in the ocular manual condition. But we cannot conclude the positive CE for the ocular manual condition was more accurate than the negative CE in the ocular only condition as the absolute error was similar in the two conditions.

Nevertheless, we found the CE for the medium-moving target (medium TTC) had the trend to be more accurate in the ocular manual condition than the ocular only condition. The difference (42 ms) between these two conditions was very close to the critical value of Tukey’s HSD test (44 ms). Therefore, it was possible to improve the accuracy of estimated TTC with the concurrent hand movement. However, it might be difficult to improve the estimated TTC (e.g. only when the hand movement was accurate, and the occlusion time was moderate) in the production task. In contrast, it is relative easier to disrupt the estimated TTC, e.g. eye fixation or free eye movement (Bennett et al., 2010), size of the moving target size (Sokolov & Pavlova, 2003) and moving background during occlusion part (Battaglini et al., 2016).

### 4.2 Eye movement and eye hand coordination

Similar to results by Benguigui and Bennett (2010), we found that the eye did not maintain smooth pursuit after target occlusion, even with the accurate concurrent hand movements. An anticipatory recovery (anticipatory saccade in the current study)[3] brought the eye to the end position before the arrival of the target. It has been reported that the anticipatory recovery of the eye in tracking transient occluded target was modulated by an internal variable gain controller (Bennett & Barnes, 2003). In an eye tracking task with a transient occluded target, the anticipatory recovery is timed to the moment of the target disappearance (Bennett & Barnes, 2005). Moreover, occlusion duration does not affect its onset time (Bennett & Barnes, 2003). These authors (Bennett & Barnes, 2005) listed two advantages of this timing strategy. First, velocity and position errors started accumulating when the target disappeared. It was better to eliminate these errors as soon as possible. Second, participants did not have to count the duration of occlusion time if they timed the anticipatory recovery at the moment of target disappearance. However, in the present study, the onset times anticipatory saccade increased with occlusion times in both conditions (Fig. 9). It was possible that different internal variable gain controllers or mechanisms accounted for the timing of the anticipatory recovery in the production task and eye tracking task. Different from an eye tracking task, the moving target does not reappear after occlusion in the production task. The main purpose in the production task is to estimate the TTC accurately. If participants timed the anticipatory recovery to the moment of the target disappearance and did not time the occlusion duration, they could not

[3] In the current study, the time of minimum eye velocity after target occlusion was just before the onset time of the anticipatory saccade. Thus, we can regard the time of anticipatory recovery as the onset time of the anticipatory saccade.

estimate the TTC accuracy in the production task. We suggest that the anticipatory recovery was determined by the occlusion duration in the production task. In addition, instead of tracking the occluded target as accurately as possible, the eye finished its movement much earlier than the arrival of the moving target (Benguigui & Bennett, 2010; Makin & Poliakoff, 2011) in the production task.

It has been suggested that there may be reciprocal motor signals exchanged between the eye and the hand during tracking which involves an eye/hand synergy (Huang & Hwang, 2013). We recognize that the eye uses retinal input to track the moving target when it was visible (Barnes, 2008). However, it could only use extra retinal input (e.g., short-term velocity memory system) to track the moving target after its disappearance (Barnes & Collins, 2008). With the assistance of concurrent hand movement to track an occluded target, it is possible for the eye to have a greater source of extra-retinal input (e.g. proprioception) (Bennett & Barnes, 2006) and stay closer to the moving target (Gauthier et al., 1988). In addition, proprioception could also be used to confirm the efference copy when the moving target is occluded (Bennett et al., 2012; Wexler & Kalm, 2001). Consequently, concurrent hand movements would facilitate the eye to track the moving target after its disappearance.

In the current study, though the timing of anticipatory recovery was different from that of the eye tracking task and tracking the occluded target might not be the priority, we still found the hand movement affected the eye movements after target occlusion. First, the hand movement had different effects on the eye tracking accuracy based on the similarity between the hand movement and the moving target. That is, the eye tracking accuracy benefitted from the motor signals of hand for the slow-moving target and was deteriorated by the motor signals of the hand for the fast-moving target. As illustrated in Figure 6, the hand had the longest time of steady-state velocity for the slow-moving target, which was scaled to velocity of the moving target. We suggest that the motor signals of the hand for the slow-moving target were closely related to the characteristics of the moving target. It has been reported that better eye tracking accuracy enhanced the precision of intercepting occluded targets (Fooken et al., 2016). However, more accurate eye tracking in the ocular manual condition did not enhance the precision of estimated

TTC in the production task. It is possible that the size of interception region (a zone or a single point) or the movement trajectory (linear or parabolic) may account for the different results. For the fast-moving target, motor signals of the hand were not consistent with the characteristics of the moving target. Thus the hand had little or no steady-state hand velocity for the fast-moving target (Fig. 6).

Second, we found that the concurrent hand movement influenced the onset time of the anticipatory saccade (OTAS) in a manner similar to the eye tracking accuracy. This indicated that the internal variable gain controller that accounted for the velocity recovery was not invariant. Therefore the hand movement had an influence on this controller. The discrepancy between OTAS and occlusion duration was smaller with the accurate hand movements and larger with the inaccurate movements. As stated before, the anticipatory recovery was related to the occlusion duration. We suggest that participants had a more accurate estimation of the occlusion duration with the accurate hand movement, but the estimation was less accurate with the inaccurate hand tracking.

**4.3 Does eye movement really matter?**

Though the current experiment did not test the role of eye movements in temporal estimation directly (e.g. comparing eye fixation and free eye movement), the results seemed to support the notion that more accurate eye movements did not increase the accuracy of temporal estimation in the prediction motion tasks (Benguigui & Bennett, 2010, Peterken et al., 1991; Huber & Krist, 2004; c.f. Bennett et al., 2010; Makin & Poliakoff, 2011). The current finding seems to aggravate the debate about the role of eye movements in prediction motion. However, if we divide prediction motion tasks into production task and discrimination tasks, the debate may not exist anymore. Benguigui and Bennett (2010), Huber and Krist (2004) used the production task in the experiment while Makin and Poliakoff (2001) designed discrimination tasks. Though Bennett et al. (2010) reported the advantage of free eye movement in the production task, the difference between free eye movement and eye fixation condition was minor (see introduction). That is, no overestimation or underestimation was found in eye fixation condition. Thus it might be safe to conclude that the free eye movements only improve the accuracy of estimated TTC in the discrimination task.

Then the question arises: why do participants only benefit from eye movements in the discrimination task? Though both discrimination task and production task belong to prediction motion, there are a few significant differences between the two. First, a moving target will never reappear again after occlusion in the production task, while it will reappear in the discrimination task. Second and most importantly, there is no explicit occluder in the discrimination task (Makin, 2017). Thus it is impossible to estimate the time to contact before occlusion based on the target velocity and the length of the occluder, which can be a default strategy in the production task (Benguigui and Bennett, 2010; Tresilian, 1995). In the studies of intercepting occluded targets, Fooken and associates (2016) designed a parabolic trajectory for the moving targets instead of linear movement (Bennett et al., 2010). In addition, the research did not have a clear sign of end position (e.g. end of an occluder or an end point). Participants could intercept the occluded target anywhere within an interception zoon. Thus, participants did not have the exclusive knowledge of the length of the movement trajectory and could not estimate the TTC before occlusion. Fooken and associates (2016) found the final interception accuracy was determined by the eye tracking accuracy.

Here one more question arises: do eye movements really matter in the production task? To me, the answer is not really. The role of eye movements in the production task is much smaller than that of a discrimination task. However, eye movements have several advantages in tracking a visible target. First, the foveal vision has the highest visual acuity, which decreases with the increasing of the retinal eccentricity (Jonathan et al., 1978). In a tracking task, Van Donkelaar and colleagues (1994) reported the hand tracking moved at a faster velocity than the moving target when the eye was fixated. Second, greater source from the eye (e.g. proprioception and efference copy) is available when the eye follows the moving target compared to eye fixation condition (Bennett & Barnes, 2006). The additional source may increase the accuracy of the estimation of target velocity. Given the assertions above, participants should have more accurate estimated TTC in the free eye movement condition than eye fixation condition, which is NOT observed in almost all the studies (Peterken et al., 1991; Huber & Krist, 2004). Even though differences were found between eye fixation condition and free eye movement condition, these differences were minor (Bennett et al., 2010; Makin & Poliakoff, 2011). If free eye movements have the advantage in velocity perception during visible phase and the final temporal estimation is similar between fixation condition and free eye movements condition, I deduce that the occlusion phase eliminates the advantage of velocity perception in the free eye movements condition.

Lastly, I propose a hypothesis which may explain how people perform production tasks and discrimination tasks. During the visible phase, people can construct an internal representation of the moving target based on the perception of the target velocity. The accuracy of the internal representation decreases with the time after target occlusion. Moreover, there is a reciprocal link between the effector (eye/hand) and the internal representation. The internal representation is able to drive the effector after target occlusion. The information (efference copy, proprioception) from the effector is able to update the internal representation.

In the production task where the occlusion distance is explicit, people can estimate the TTC based on the target velocity and occlusion distance. However, the estimated TTC is not fixed. As the internal representation of the target can be updated by concurrent hand movement (Wexler & Kalm, 2001), moving background (Battaglini et al., 2016) before and after target occlusion, the estimated TTC will change with the variation of the internal representation. As is stated before, the priority in the production task is to estimate the TTC accurately. The default strategy is calculating the estimated TTC before target occlusion (Baurès et al., 2010; Bennett et al., 2010). The internal representation of the target drives to eye to the end position much earlier before the target arrival in the production task (Benguigui & Bennett, 2010).

In the discrimination task where the occlusion distance is not explicit, participants can not calculate the estimated TTC before occlusion. It has been reported the discrepancy between the estimated TTC and actual TTC increases with the occlusion time (Yakimoff et al., 1993). It is possible the accuracy of the internal representation of the target decreases with the increasing of occlusion time. In the eye fixation condition, no source can be used to update the internal representation. However, in the free eye movement condition, extra-retinal information from the eye (proprioception/efference copy) may help decrease the decay of the accuracy of the internal representation. The internal representation of the target makes the eye to track the occluded target as close as possible in the discrimination task. In summary, eye movements are more important in the discrimination task than the production task. Eye fixation condition affects discrimination task more than production task.

## ***Chapter 5: Conclusion***

In summary, the present study showed the timing of the anticipatory recovery in the production task was different from that seen in tracking transient occluded targets and was influenced by the concurrent hand movements. Moreover, tracking the occluded target accurately might not be the priority in the production task. Different (accurate/inaccurate) concurrent hand movements had the opposite effect on the eye tracking accuracy and estimated TTC in the production task. However, the superior eye tracking did not increase the precision of estimated TTC.

## 5.1 Limitations

1. In the current study, there was only one occlusion distance. The occlusion time was only confounded with target velocity.
2. To remove the effect of learning, it is better to add some filler trials. That is, some trials in which the target moved at different velocities. Filler trials will not be used in the final analysis.

## 5.2 Future directions

1. As is stated in the limitation section, it is better to have a condition where the occlusion time was fixated, and the occlusion distance was confounded with velocity.
2. The current study found the inaccurate hand movement affected the estimated TTC. However, the effect was making the TTC estimation from underestimation to overestimation. A future study may be designed to test when the target moved at moderate velocity and the hand moved in a opposite direction to the eye.
3. The current study found an anticipatory saccade brought the eye to the target location and eye tracking was not important after target occlusion. Some other researchers have found that eye tracking accuracy determines the accuracy of temporal estimation. These lines of research did not have an explicit end position. Instead, they had an interception zone. Thus, future research can be designed to examine the effect of end position type (a zone or a point) on the estimated TTC.

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***Appendix A***

Faculty of Physical Education and Recreation

E488 Van Vliet Centre

Edmonton, Alberta, Canada T6G 2H9

Development of perceptual motor capacity

Dear Participant,

Thank you for your interest in this study. This letter describes the research purpose and the rights and responsibilities of being a participant. It also outlines what is involved if you decide to participate. We encourage you to direct any questions about this study toward us at any time. Our names and contact information are listed below.

Brian Maraj brian.maraj@ualberta.ca

Ran Zheng rzheng1@ualberta.ca

The purpose of this study is to investigate the perceptual motor system capacity as it pertains to the prediction motion tasks. During activities such as playing soccer, or basketball, individuals use visual information of the environment to make judgments of where objects are in space at a given time following a period of occlusion.

To measure the characteristics of this perceptual motor capacity, we would like you to participate in an experimental protocol (taking about 45 minutes to an hour to complete). You will complete two different protocols. The order of these protocols will be randomized and you will have a ten-minute break between the two protocols. In both protocols you will watch an animation and you will respond in one of two ways. You will either press a spacebar on a keyboard or you will slide your finger across a computer screen. Testing will take place in the Perceptual Motor Behaviour Lab at the University of Alberta (E-436 Van Vliet Centre).

In one protocol, you will be seated at a desk and will watch an animation on a computer screen. You will see a red ball rolling across the screen toward a target. The red ball will disappear mid way through its path. You will be asked to press the spacebar on a keyboard when you estimate that the ball will reach the target.

In the other protocol, you will again be seated at a desk in front of a computer screen and presented with a similar animation of a ball moving towards a target that will disappear half way through its path. When the ball disappears, you will be asked to slide your finger from a blue circle to the target of the moving red ball. Your goal will be for your finger to arrive at the target at the same time that the red ball would.

During the second protocol, we will outfit you with a plastic ring to place on your dominant index finger. This ring has a small marker that will light up during the animation. Special cameras will record the position of this marker. In addition, you will wear a head mounted eye tracker that will monitor the movement of your eyes during the trials.

This research is valuable because we will learn more about how motor skills can be transferred to different environments. Apart from gaining knowledge about how perceptual motor capacity can be studied, there will be no immediate benefits to you.

Should an injury occur, we will assist you in obtaining appropriate medical attention. This includes contacting EMS or escorting you to the nearby Glen Sather Sports Medicine Clinic.

To ensure confidentiality, personal information will be coded and stored in a locked lab to which only the investigators have access. Information is normally kept for a period of 5 years post-publication, after which it will be destroyed. You will never be identified in any publication or presentation.

You are free to withdraw from this study at any time without any questions asked. If you decline to continue or you wish to withdraw from the study, please indicate to the researcher either verbally or in writing your intention to do so. Your information will be removed from the study upon your request.

After you read this letter, you will have the opportunity to ask us questions and talk about the study. If you decide to participate, we will ask you to read and sign an informed consent form.

If you have concerns about this study, you may contact the University of Alberta Research Ethics Office at (780) 492-2615.

Thank you,

Brian Maraj Ran Zheng

*Appendix B*

Faculty of Physical Education and Recreation

E488 Van Vliet Centre

Edmonton, Alberta, Canada  T6G 2H9

*INFORMED CONSENT FORM*

**Part 1 (to be completed by the Principal Investigator)**

**Title of Project:** "Development of perceptual motor capacity"

**Principal Investigator(s):**
Brian Maraj

**Co-Investigator(s):**
Ran Zheng

Include affiliation(s) and work phone number(s)

Faculty of Physical Education and Recreation tel: (780) 492-8649

**Part 2 (to be completed by the research participant)**

| | | |
|---|---|---|
| Do you understand that you have been asked to be in a research study? | Yes | No |
| Have you read and received a copy of the attached Information Sheet | Yes | No |
| Do you understand the benefits and risks involved in taking part in this research study? | Yes | No |
| Have you had an opportunity to ask questions and discuss this study? | Yes | No |
| Do you understand that you are free to refuse to participate, or to withdraw from the study at any time, without consequence, and that your information will be withdrawn at your request? | Yes | No |
| Has the issue of confidentiality been explained to you? Do you understand who will | Yes | No |

have access to your information?

This study was explained to me by:

I agree to take part in this study: ______________________________

______________________________ ______________________________
Signature of Research Participant Date

______________________________

Printed Name

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.

______________________________ ______________________________

Signature of Investigator or Designee Date

**The information sheet must be attached to this consent form and a copy of both forms given to the participant.**