Spatial Information is Exploited to Adjust Hand Movement When Hitting Moving Target

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ABSTRACT

When hitting a moving target, hand movement has to be adjusted according to online information. But it is not clear whether other information would be the used if temporal information has been provided to direct the interception action of hand. This study investigated how the kinematics of interception movement were affected by moving target in different conditions. Three kinds of targets including stationary, uniform motion and accelerated motion were hit by participants. The result reveals that although three tasks are performed within the same time, the hand movements are significantly different. This suggests that in addition to temporal information, spatial information also plays an important role in the motor control during interception.

Key Words: Interception, Time to Contact, Spatial Information, Temporal Information

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Introduction

Intercepting a moving object is a complex task. When an interception occurs, it is necessary that the intercepting effector and the target object be at the same location (spatial coincidence) at the same time (temporal coincidence) (Tresilian, 2005). Thus, not only must the movement be initiated and directed to the right place at the right time, it must also be adjusted on-line to ensure spatial and temporal coincidence. However, it is likely that the way how the target object moves towards the interception point plays a significant role in determining how the interception movement unfolds (Brenner & Smeets, 2009). But very little is known about how people control their movement according to different input during interception. In the other words, will hand movements be different when the interception path and point are fixed?

Previous research indicates that time-to-contact (TTC) can be exploited during interception. Lee (1976) proposed that the optical variable tau could be used to estimate TTC basing on the visual perception of a braking car. He showed that tau was defined by the inverse of the relative dilation of the retinal image or the relative rate of change of visual angle. Strong evidences show that tau is used in the timing of interception movement (Kaiser & Mowafy, 1993; Yilmaz & Warren, 1995). Additionally, many researchers (Andersen & Kim, 2001; Tresilian, 1999; Kim & Grocki, 2006; Bastin & Montagne, 2005) claim that there are still other factors that influence the estimation of interceptive activity, for example, motor control relies on both an explicit representation of the interception zone (IZ) and the time-to-contact (TTC) (Merchant, Zarco, Prado & Perez, 2009).

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Obviously, there are many ways in which one could reach to point a target. In the other words, there is flexibility or plastic in our movement. However, Brenner & Smeets (2007) studied flexibility during interception tasks by forcing their participants to adopt different interceptive paths. They found that only one path was the most appropriate among many different interceptive paths. It may because there is the constraint in movement time and the hand movement has to exploit the temporal information of moving target. In the present study, it is anticipated that even if estimating Time-To-Contact provides enough information to hit the moving target, spatial information still influences the motor control of hand.

In current study, we aim to investigate whether hand movement will become similar when the temporal information is provided to participants to hit the moving target. It is possible that spatial information, for example, the distance between target and interceptive zone, is also exploited in motor control. To simplify the design, the targets were hit at the same place and participants were required to finish the tasks along a straight line within the same time. So, the hand velocity reflects the process of motor control during interception. Three kinds of targets (including stationary, uniform and accelerated motion) were tested. We predicted that there would be significant differences among them if updated spatial information of targets were used to adjust the hand movement. Otherwise, three conditions would be similar since they had the same movement time.

Methods

Participants

13 college students (7 male, 6 females, aged 21-27) from Zhejiang University were recruited. All participants were right-handed and had normal or corrected-to-normal vision. Handedness was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971). All participants provided informed consent before participating in the experiment. They were compensated for their time and were naive with respect to the purpose of the experiment.

Materials

Experiments were conducted indoors without illumination. Experimental stimuli were presented via a Viewsonic 19-inch LCD display with a resolution of 1280*780. Participants' position was fixed at a distance of approximately 40cm above the display screen. The real-time kinematic data were collected at 200Hz with an OPTOTRAK 3020 (Northern Digital, Waterloo, ON, Canada) optoelectronic recording system. To measure the movements of the finger, one IRED was attached to the cuticle of the index-finger. Care was taken to permit freedom of hand movement (see Figure 1). Data were analyzed offline with in-house software written in C++. The stimulus was programmed in C++ and the movement data from Optotrak System was calculated online to judge if the target was hit by finger.

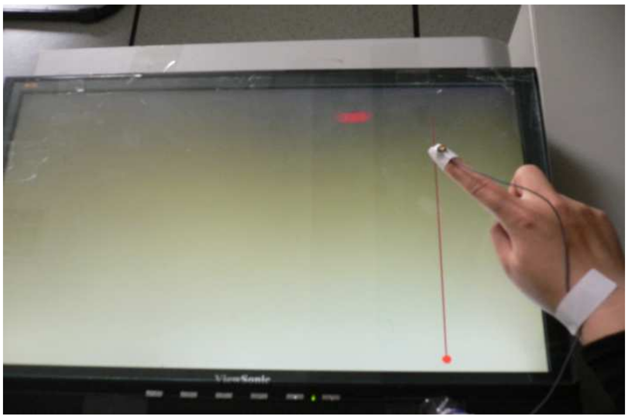

Figure 1. The experimental scene. Participants started to hit the moving target along the straight line. The object moved horizontally in uniform motion and accelerated motion condition and would be hit when it passed the line (Interception point).

The size of the ball remains constant throughout the experiment, approximately 1cm in diameter. The speed of uniform-motion condition is set at 15cm/s. The accelerated movement increases speed at a constant acceleration. In stationary condition, a number counting down from 10 will be displayed on the static ball, decreasing by 1 every 100ms until reaching 0. Participants must strike the ball exactly when the countdown ends to be considered a successful interception (See Figure 2 a,b). Under all circumstances, the ball will first move for 0.8-1s, then a "beep" will sound, reminding participants that the task has begun. In stationary tasks, the ball will disappear from the screen after the priming sound, and a stationary ball will immediately appear at the interception point. The movement time for three conditions are exactly 1s. There is a control condition that the target moves slowly at 10cm/s, which is designed to avoid the pattern because the movement time is always the same in three experimental conditions. In this condition, the movement time of hand changed from 0.5s to 1.2s and the data of IRED were not analyzed.

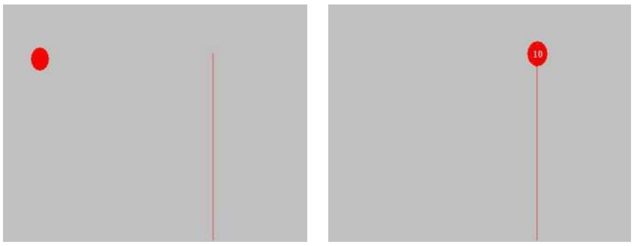

Figure. 2a Figure. 2b

Figure 2. The stimuli used in experiment. Fig 2a shows the stimuli in Uniform-motion condition and Accelerated-motion condition. Fig 2b shows the stimuli in Stationary-motion condition. Participants hit the target along the straight line when the center of target move to the line or the Number on the ball changes into Zero.

Procedure

This experiment adopted within-subject design including 3 types of movement: Uniform motion, stationary motion and accelerated motion. Each level was repeated 10 times, for a total of 40 trials, which are arranged in a randomized sequence. The control condition requires participants to hit a slowly moving target and the movement time of hand is from 0.5-1.5s. The control condition repeated 10 times is inserted between any two experiment conditions to rule of the effect of previous session.

The experiment began with the ball appearing in a random location on the screen, moving from left to right. The participant will place his/ her forefinger at the starting point. After 0.8-1s with a "Beep", the participant initiated hand movement along the designated line, attempting to hit the ball exactly when it crossed the line. The hit of each trial is judged by the program. After each trial, the words "hit" or "miss" will be displayed on the screen accordingly. The next trial will begin after an interval of 4s. Before beginning the formal experiment, participants were required to do practice rounds. Data was collected and its wave was filtered by using the matlab filtering function. Peak speed, peak acceleration and relative time to peak speed are calculated.

Data and statistical analysis

The data were analyzed offline. We conducted paired t-tests to investigate possible differences on Peak velocity, Ratio between time to Peak velocity and total time, and Peak acceleration.

Results

Velocity data are low-pass filtered using the matlab filtering function, whose cutoff frequency is 20Hz. Data would be excluded due to excessive reaction time, halfway halt, and/ or too long or short movement time. Figure 3 shows an example velocity curve during the interception task for Uniform-motion, accelerated-motion, and Stationary conditions.

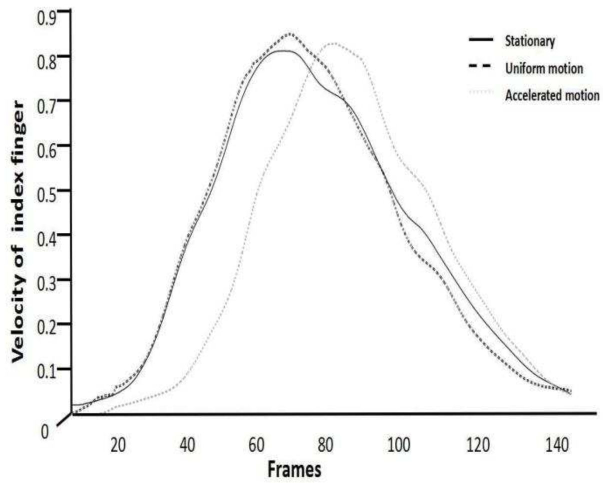

Figure 3. The velocity of index finger. The curves includes three conditions (Stationary, Uniform motion and Accelerated motion). Frames are the amounts of sampling point in Optotrak.

Peak velocity of index finger

Paired t-tests were conducted to compare the difference between Stationary condition and Uniform-motion condition, Accelerated-motion condition and Uniform-motion condition.

The Peak velocity of Uniform-motion condition is larger significantly than that of Stationary condition (t (12) = -2.228, p = 0.046), and there is no significant difference between Uniform-motion condition and Accelerated-motion condition (t (12) = 0.35, p = 0.732).

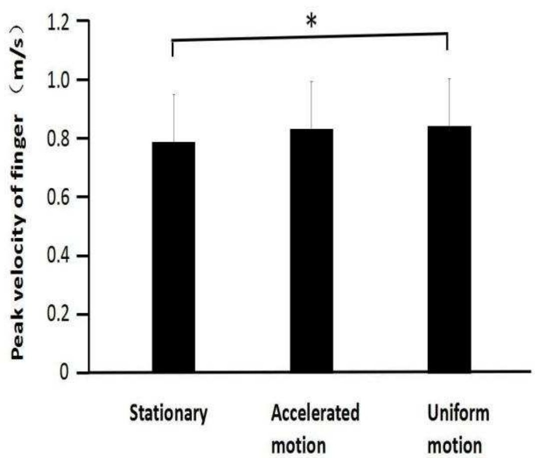

Figure 4. The mean Peak velocity of index finger. There is significant difference between Stationary condition and Uniform-motion condition.

Ratio between time to Peak velocity and total time

Figure 5 shows the mean values of Ratio between time to Peak velocity and total time. It is calculated with the time to Peak velocity/Total movement time of hand which reflects the phase of acceleration and deceleration during interception. Pairs t-tests revealed the Ratio of Accelerated-motion condition is larger than that of Uniform-motion condition (t (12)= 2.419, p = 0.032) and Stationary condition (t (12)= 2.691, p = 0.02).

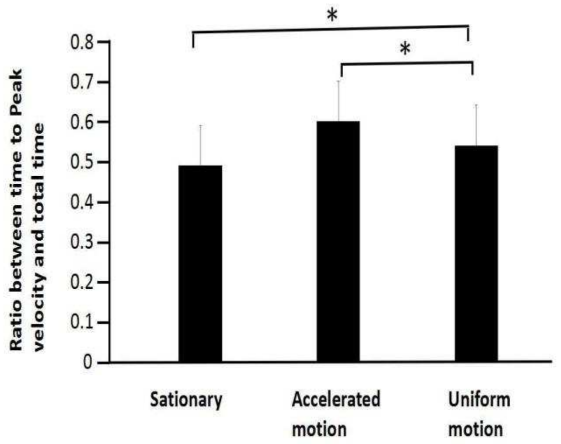

Figure 5. The mean Peak velocity of index finger. There is significant difference between Stationary condition and Uniform-motion condition.

Peak acceleration

Mean Peak acceleration of three conditions are shown in Figure 5. Pairs t-tests shows that there is no significant differences between Stationary condition and Uniform-motion condition (t (12)=1.431, p=0.178) , and between Accelerated-motion condition and Uniform-motion condition (t (12)= 1.706, p = 0.114).

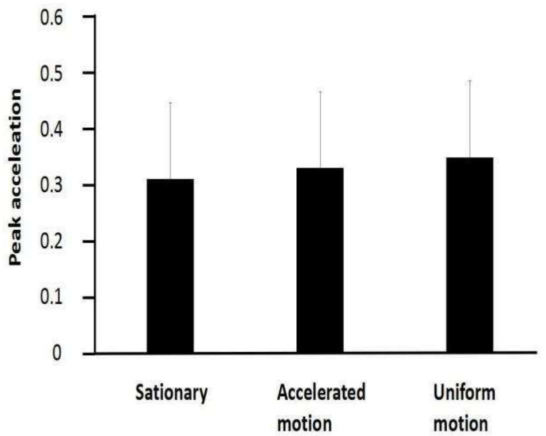

Figure 6. The mean Peak acceleration. There is no significant difference between Stationary condition and Uniform-motion condition, and between Accelerated-motion condition and Uniform-motion condition.

Discussion

When we reach to point a static object or hit a moving target, both of these two movements accelerate firstly and then decelerate. Of course, there is time constraint in interception which results in the differences with pointing task in motor control. In current study, we fixed the movement time of hand and interception path to investigate if there were differences in motor control when all the experimental conditions provided temporal information. Although the participants completed all the conditions perfectly, their hand movements were significantly different among different conditions. The peak velocity of Uniform-motion condition is larger significantly than that of Stationary condition, and the time to peak velocity in Accelerated-motion condition is larger than the other two conditions.

When hands were stretched out to intercept moving targets (whether covered or not), the faster the moving targets, the shorter the hitting movement time(Van Donkelaar *et al.*, 1992; Chieffi *et al.*, 1992). This is called speed coupling effect (Brenner & Smeets, 1995; Mason & Carnahan, 1999; Tresilian & Lonergan, 2002). However, Caljouw *et al.* (2004) demonstrated when participants were forced to hit the moving target slightly, this effect disappeared. These results also indicate that interception movement is plastic, but on the other side, there are some strategies or optimization movement when we perform interception. In current study, participants act differently although they hit the same target within the same time. Particularly, both countdown numbers (Stationary condition) and moving target (Uniform-motion condition) provided enough temporal information for them to control their hands, but they still exploited different mode in interception. It may because not only the time to contact is estimate to adjust the movement of hand, but also the spatial information, i.e. the position of target, the distance between target and inception point, is also used during interception. Some researchers have also proposed that the nervous system could use either spatial or temporal parameters to control interception movement depending on the visual properties of the moving target (Merchant & Georgopoulos, 2006). That is to say, for example, even if a target moves very slowly, it is possible to initial our reaction only because it is too close to us. Maybe short distance means we have no much time to act, we tend to react differently to protect ourselves as moving objects are often dangerous.

Previous research shows that acceleration is not used in time estimation (Senot *et al*., 2003; Benguigui *et al*., 2003). In our research, the Ratio between time to peak velocity to total time in Accelerated-motion condition is significantly larger than that in Stationary condition and Uniform-motion condition. There is no difference between the later two conditions. The results are reasonable because the motion of Accelerated-motion condition is uneven, but Stationary condition and Uniform-motion condition vary uniformly. Therefore, if only the updated information is used to estimate time, the hitting movement would always lag behind the object because it moves acceleratedly. The spatial information may also play an important role in Accelerated-motion condition. So it takes more time for hand to achieve the peak velocity because the target moves faster at the later stage.

In conclusion, although temporal information is enough for participants to estimate the time to contact and adjust the movement of hand since the interception path and point are fixed. However, the spatial information is also used to control the hand movement.

Acknowledgments

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