An Application of the Intermittent Illumination Model for Measuring Individual's Corrective Reaction Time

Jui-Feng Lin†, Colin G. Drury‡

†Department of Industrial Engineering & Management,
Yuan Ze University,
Chung-Li, Taiwan 32003

‡Department of Industrial & Systems Engineering,
State University of New York at Buffalo,
Buffalo, New York 14260, USA

ABSTRACT

While modeling hand-control movements, a corrective reaction time indicates how fast our brain can generate a movement order based on received visual information. The corrective reaction time was found to range from 190 to 290 milliseconds in the literature, but with no data on individual difference. This pilot study applies Drury's (1994) the intermittent illumination model and modifies his experimental designs to measure individual corrective reaction time. Four participants performed computer-based circular tracking movements by using a tablet as an input device. While conducting movements, the screen cursor blinked to generate predetermined visual delays. Measured movement speeds with the corresponding delays were utilized to calculate the corrective reaction times. The result of corrective reaction time ranges from 193 to 919 milliseconds longer than the reasonable range. Suggestions are given to deal with the potential issues.

Keywords: Corrective Reaction Time, Psychological Refractory Period, Hand-Control Movements, Tracking Movements, Intermittent Illumination Model

INTRODUCTION

A corrective reaction time indicates a time during which our brain receives visual feedback, programs a movement order, and sends the order to the controlled limbs. While performing a hand-control movement, such as pointing a finger to click a light switch on a wall, human behaves like a correction servo (Craik, 1947, 1948). This servo continuously performs ballistic movements (Lin, Drury, Karwan, & Paquet, 2009) to correct movement misalignment between the controlled object and the anticipated movement path or aimed target. To make the corrections, movement orders are made mainly based on visual feedback that provides the dynamic misalignment information. Although our eyes continuously capture the visual stimuli, the visual feedback on making corrections is intermittent, instead of continuous. This intermittent feature is due for the psychological refractory period (Welford, 1952) during which our brain is so busy for generating a new movement order that it need to temporally ignore the visual stimuli. Hence, the length of the corrective reaction time affects how rapidly and accurately we can perform hand-control movements.

HISTORY OF MEASURING CORRECTIVE REACTION TIME

The relevant findings on corrective reaction time come mainly from the studies of movement accuracy. The pioneer work on the accuracy of movements by Woodworth (1899) showed that movements made at a rate of 140 times/minute or greater were equally accurate with or without visual feedback. This led him to conclude that the time required to process visual feedback for movement control is about 450 milliseconds. This finding was further supported by Vince (1948) who used similar reciprocal movements that was tested in Woodworth’s experiments. However, the experimental tasks conducted by Woodworth (1899) and Vince (1948) were reciprocal movements in which the measured movement time might include the time spent on reversing the movement direction after the targets were reached. Hence, Keele & Posner (1968) argue that the 450 milliseconds as the corrective reaction time was overestimated. To deal with the issue, instead of reciprocal movements, Keele & Posner (1968) asked their participants to perform discrete movements at different rates, comprising 190, 260, 350 and 450 milliseconds. Light-on and light-off conditions were manipulated to compare the effect of visual feedback on movement accuracy. Their results showed that visual feedback was helpful for all movement durations beyond190 milliseconds. This led Keele and Posner to conclude that the time required for the visual feedback loop to operate was somewhere between 190 and 260 milliseconds. Later, Beggs & Howarth (1970) were also interested in examining time delays in processing visual feedback while performing sagittal-direction aiming movements. In contrast to the measurement methods used by previous investigators, Beggs & Howarth (1970) used an experimental paradigm in which the initial part of the movement trajectory was illuminated and the room lights were extinguished as the hand approached the target. Their idea to achieve the corrective reaction time was that aiming accuracy would diminish if vision is removed when the hand is less than one corrective reaction time from the target. Close to Keele & Posner's (1968) findings, a mean corrective reaction time of 290 milliseconds was reported by Beggs & Howarth (1970). Their finding of 290 milliseconds as the corrective reaction time was further applied by Drury, Montazer, & Karwan (1987) to build optimization models for self-paced tracking movements with good results.

More recently, 238 milliseconds as the corrective reaction time was predicted by Drury's (1994) intermittent illumination model. Based on the concept that paced tracking performance is disrupted by intermittent illumination of the course and the controlled element (Katz & Spragg, 1955), Drury (1994) integrated the models by Howarth, Beggs, & Bowden (1971) and Drury (1971) and then theoretically developed a model (Equation 1) that is able to obtain the duration of corrective reaction time.

Equation 1

$$\frac{1}{c} = K \times \sigma_\theta \times \left(t_r + \frac{d^2}{2(l+d)}\right)$$

where, c is the controllability (Drury, 1971), K is a constant (Howarth et al., 1971), σ_θ is the angular accuracy (Howarth et al., 1971), l is the light period, d is the dark period, and t_r is the corrective reaction time. The model predicts the linear relationship between the inverse of the controllability and the visual feedback cycle time, $t_r + d^2/[2(l+d)]$, which represents the sum of the corrective reaction time and the expected delay manipulated by the intermittent illumination of l and d. This model was tested with the data of three-intermittent illumination experiments conducted by Tsao & Drury (1975) on self-paced circular tracking movements. The results showed that the model explained over 90% of the variance in the slopes of the speed/width regression for a variety of dark and light intervals. Moreover, the model gave an estimate for the corrective reaction time as 238 milliseconds.

Although the role of corrective reaction time is important, unfortunately we know little about it. The corrective reaction time is not only a psychological element of our motion mechanism, but also plays an essential role in modeling hand-control movements. The self-paced tracking movement models by (Drury et al., 1987; Lin et al., 2009; Montazer, Drury, & Karwan, 1988) and self-paced aiming movement models by (Crossman & Goodeve, 1963/1983; Keele, 1968; Lin et al., 2009) have demonstrated that the length of corrective reaction time directly affects the movement speed and movement time if a given movement accuracy needs to be maintained. However, so far, the corrective reaction time has been assumed to be a general property – with no data on individual differences. The literature only tells that the reasonable value of the mean corrective reaction time ranges from 190 to 290 milliseconds. To understand the corrective reaction time better and study individual differences, the objective of this research is to apply Drury's (1994) intermittent illumination model and modified his experimental designs to directly measure individuals' corrective reaction time.

MEHTOD

PARTICIPANT AND APPARATUS

Two male and two female graduate students, aged from 25-30 years, were recruited to participate in this pilot study. They were all right-handed with normal or corrected-to-normal vision.

A personal computer (PC) with a 17” (432 mm) LCD monitor of resolution 1280 × 1024 pixels resolution was used. The PC ran Visual Basic (VB) using a self-designed experimental program that displayed experimental task and measured task performance. An Intous 3 305 mm × 488 mm drawing tablet with a tablet stylus was utilized as the input device. The movement distance ratio between the tablet and the computer screen was set as 1:1, equalizing visual & physical movement distances on the screen and the tablet.

EXPERIMENTAL SETTING AND PROCEDURES

While conducting the experiment, the participants sat alongside a dual surface adjustable table on which the monitor and the tablet were placed on the rear and the front surfaces, respectively. Both the monitor and the tablet were adjusted to heights where the individual participants felt comfortable. While performing movements, the participants wore a nylon half-finger glove and kept resting their hands on the tablet surface to keep the friction between moving hand and the tablet surface small and constant. A cardboard screen was placed between their eyes and the tablet to hide the visual feedback from their moving hands so that they only visual feedback was from the monitor screen.

To apply the intermittent illumination model, the experiment in this study was designed similarly to Drury (1994). However, instead of drawing circles on white paper, our participants moved the screen cursor to draw circles within circular courses shown on the screen. To conduct the tasks, they physically draw circles with the stylus on the tablet. The courses were defined by two concentric circles with a mean circle radius, 200 pixels (see Figure 1). A movement started by pressing down on the stylus cursor on the start point placed at the top location of the courses. Instead of controlling the intermittent illumination using the slide projector utilized in Drury (1994), the visual information of the cursor was intermittently displayed. Once the cursor was moved away from the start point, the start point disappeared and the cursor started to blink according to predetermined appearing/disappearing periods (see Table 1). However, the circular courses did not blink, eliminating any issues of dizziness and eyes fatigue.

For each circular course, the participants needed to draw one and three quarter continuous circles in which the movement time was measured from half a circle to one and a half circles, ensuring measured movements with consistent speeds. They were asked to draw as quickly as possible, but without moving outside the circular courses. If the cursor was moved outside the courses, that movement was considered as a failure trial. The participant had to repeat that course until it was successfully completed. Each participant had half an hour to practice before the formal measurements.

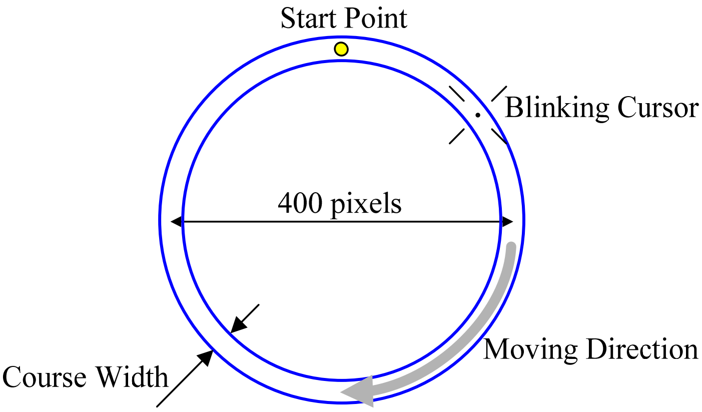

FIGURE 1 Demonstration of the experimental task.

EXPERIMENTAL VARIABLES

The independent variables were: course width and expected delay. The five values of course width were 24, 30, 36, 42, & 48 pixels (1 pixel ≅ 0.266 mm). The five values of expected delay with their combinations of light and dark durations determined by Equation 1 are listed in Table 1. The experimental combinations in this experiment were replicated two times, resulting in a total of 50 trials. All the trials were randomly conducted by each participant, taking about an hour to complete.

Table 1 Combinations of dark and light durations of the five values of expected delay

Expected Delay (millisecond)	**Dark Duration** (millisecond)	**Light Duration** (millisecond)
0.15	500	333
0.30	850	354
0.45	1150	319
0.60	1450	302
0.75	1750	292

The only dependent variable was speed measured for each trial. Due to the programming limitations, the time accuracy was about 16 milliseconds in task times averaging about six seconds.

RESULTS

ANALYSIS OF VARIANCE

Analysis of variance was performed on the speeds, using a mixed model with Width and Expected Delay Value as fixed effects and Participant as random, analyzing all the two-way and three-way interaction effects. There were significant main effects of Participant ($F_{3,100} = 5.85, p < 0.01$), Width ($F_{4,100} = 7.25, p < 0.01$), and Expected Delay Value ($F_{4,100} = 6.86, p < 0.01$). These main effects show that (1) the participants performed the movements at different speeds, (2) the increase of Width resulted in increased speed, and (3) speed decreased as Expected Delay Value increased. The two-way interaction effects were found with Participant × Width ($F_{12,100} = 11.03,\ p < 0.001$) and Participant × Expected Delay Value ($F_{12,100} = 5.07,\ p < 0.001$). The rates of increasing speed with increased width and decreased expected delay were different for the participants. Furthermore, the three-way interaction effect of Participant × Width × Expected Delay Value was also significant ($F_{48,100} = 1.54,\ p < 0.05$), indicating that the increase of Width had different sizes of effect on the two-way interaction effect of Participant × Expected Delay Value.

MODEL FITTING APPLYING DRURY'S (1994) METHOD

Since the main effects of Width and Expected Delay Value were found significant, the application of Drury's (1994) intermittent illumination model was able to be tested. Speed was first regressed on to Width for individual values of the expected delay to give the slopes, $1/c$ and intercepts shown in Table 2.

Table 2 Regression of speed on to width and calculated corrective reaction time

Expected Delay (s)	**Intercept** ($\boldsymbol{pixel} \times \boldsymbol{s^{-1}}$)	**Slope** ($\boldsymbol{s^{-1}}$)	**1/*c*** (s)	$\boldsymbol{r^2}$
0.15	-60.18	6.655	0.2474	0.985
0.30	-87.63	6.145	0.2742	0.917
0.45	-99.02	6.255	0.3317	0.984
0.60	-46.80	4.077	0.3396	0.868
0.75	-68.66	4.438	0.3877	0.937

The high linearity of data supported Drury's (1971) model, indicating a linear increase in speed with width. Then, as the method utilized in Drury (1994), the reciprocal of the slope (i.e., controllability) in Table 2 was regressed on to the intermittent illumination factor (i.e., the expected delay) to give

Equation 2

$$\frac{1}{c} = 0.2308 \times \left(0.919 + \frac{d^2}{2(l+d)}\right)$$

The model fitting of the data accounts for 95.4 % of the variance. The corrective reaction time obtained from Equation 2 was 919 milliseconds for all the participants on average. However, the obtained correction reaction time was much longer than the reasonable duration found in the literature (i.e., 190-290 milliseconds).

MODEL FITTING APPLYING A DIFFERENT METHOD

To calculate each individual participant's corrective reaction time, a modified method was utilized. Instead of calculating controllability ($1/c$) by regressing speed on width for individual values of the expected delay, the speed values of all experimental trials were divided by corresponding widths to obtain slopes and c values. This modified method provides more data sets, increasing available degrees of freedom. The obtained $1/c$ values specified to all participants and individual participants were regressed on to expected delay to give the intercept, slope, $1/c$ and corrective reactions time listed in Table 3. The regressions for individual participants are shown in Figure 2 below. As shown in Table 3, the model accounts for at least 81.1 % of the variance and the calculated corrective reaction time ranges from 193 to 792 milliseconds. Although, the model accounted for the data very well, only one of the calculated values of corrective reaction time is within the reasonable duration.

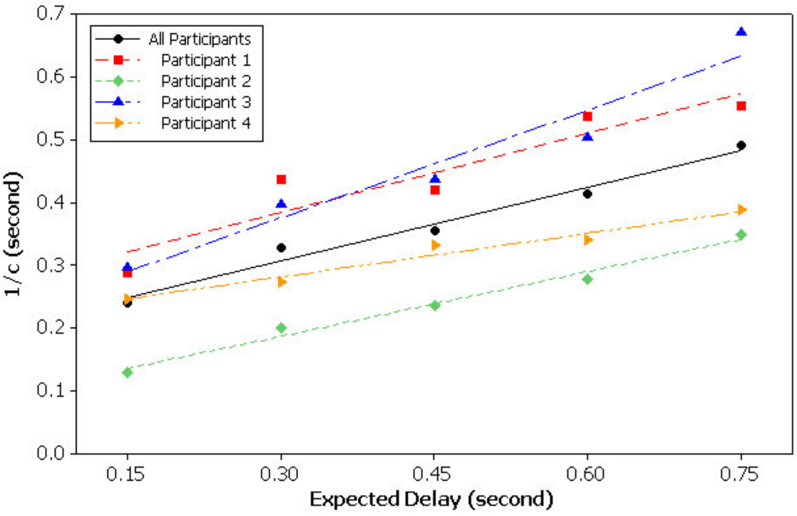

FIGURE 2 Relationships between controllability and expected delay.

Table 3 Regression of controllability on to expected delay and calculated corrective reaction time

Participant	**Intercept** (s)	**Slope** (unit)	**Corrective reaction time** (s)	r^2
All	0.1898	0.3914	0.485	0.973
1	0.2391	0.4847	0.493	0.860
2	0.0741	0.3830	0.193	0.924
3	0.1942	0.6213	0.313	0.811
4	0.2049	0.2587	0.792	0.911

DISCUSSION AND FUTURE RESEARCH

No matter whether Drury's (1994) original method or the modified method was used, the calculated values of corrective reaction time were larger than the reasonable duration from 190 to 290 milliseconds. Specifically, when Drury's (1994) model was applied, the mean corrective reaction time of the overall participants was found to be 919 milliseconds; when the modified method was applied, the values were found to be 493, 193, 313, 792 milliseconds for participants 1, 2, 3, and 4, respectively and a mean value of 485 milliseconds.

The potential explanations of the unreasonable corrective reaction time include (1) inadequate measurement duration, (2) inappropriate manipulations of the expected delay and (3) indirect movement control. In the experiment, movement speeds were only recorded from half a circle to one and half circles. The participants might be still adjusting their movement speeds after passing the cursor to half a circle, especially for long-expected-delay trials. Also, the strategy that the participants stopped movements and then waited for the cursor to reappear was found for long-expected-delay trials. The restart of movements might add to the reaction time after the reappearance of the cursor, resulting in lower movement speeds. Furthermore, according to our experimental design, visual feedback was obtained from the computer screen, but not from the controlled limb. The indirect visual feedback may increase movement variability once the movements were stopped for the long-expected-delay trials, compared to the short-expected-delay trails in which kinesthetic feedback was available while continuously moving.

Future research is suggested with new experimental designs. First of all, a longer duration of measurement and longer adjusted distance are recommended. The duration of measurement could be increased to two circles and the measurement could start once the cursor completed one circle. Secondly, the values of expected delay should decrease to avoid strategy of stopping movements while tracking the circular paths. Finally, instead of using the drawing tablet, a touch-screen monitor is suggested to eliminate the movement variability issue.

CONCLUSION

This pilot study tested the application of Drury's (1994) intermittent illumination model with a modified computer-based experiment to measure individual corrective reaction times. The calculated corrective reaction times from four participants' data were longer than the reasonable range reported in the literature (193–919 milliseconds compared to 190–290 milliseconds). Three potential reasons, (1) inadequate measurement duration, (2) inappropriate manipulations of the expected delay and (3) indirect movement control, were proposed to explain the longer corrective reaction times. Corresponding solutions were also suggested for future research.

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