HITTS' LAW? A TEST OF THE RELATIONSHIP BETWEEN INFORMATION LOAD AND MOVEMENT PRECISION

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Abstract

An experiment was run to test the independence of information load (Hick's Law) and movement precision (Fitts' Law) using additive factors methodology.

There were two elements to the subjects' task. Firstly, subjects were required to classify stimuli according to a decision rule with a variable entropy. The stimuli were presented in the centre of the CRT screen. In response, subjects had to move a cursor from a starting point near the stimulus to the appropriate target. The targets were arranged in an annular pattern around the central point. The precision of the response movement was varied by manipulating the ratio of the radius of the annulus to the width of the target area.

The dependent measure was elapsed time between onset of the stimulus and completion of the response movement. Independence of the Hick's Law and Fitts' Law components of the reaction time was tested with an analysis of variance. Presence of an interaction would suggest that a decision stage and a response stage are dependent, and cannot be considered discrete steps in a serial process.

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With the increasing popularity of icon driven software systems there has been a trend towards "pointing" input devices such as the mouse, touch screen and joystick. These devices help reduce the cognitive and motor complexity required to recode an intention as an action. Operators are required to make a decision about a situation or an item of information and act upon the decision by moving a cursor to a designated area on CRT screen. What factors influence the efficiency and accuracy of such a task?

The operator's task can be divided into two parts, a decision part and a movement part, and there exist information theoretic measures predicting reaction time for each of these parts. Hick [1952] and Hyman [1953] proposed that reaction time increased with the number of bits per decision:

$$RT=a+bH \tag{1}$$

where

$$H=-\sum p_i \log_2(p_i)$$

Fitts [1954] proposed that movement time increased with the $\log_2$ of the ratio of movement amplitude to target width:

$$MT=c+d\ \log_2(2A/W) \tag{2}$$

Following Jagacinski, the combined RT and MT will be called capture time (CT). Reaction time (RT) will refer to the time between stimulus onset and the start of the joystick movement, while movement time will refer to the time between the start of the joystick movement and target capture. Operational definitions of the above events will be given below.

It is generally found that movement precision has very little effect on RT. This supports the notion that perceptual or cognitive processing is independent of the processing of motor movements. Fitts and Peterson [1964] found that as movement amplitude (A) was increased or target width (W) decreased, RT increased consistently, but only very slightly. However, manipulations of stimulus probablity did have an effect on RT. RT was longer the more uncertainty there was as to which of two targets would be signalled (Fitts and Peterson Practice Session, Experiments I and II). They also found that by making one of the two targets more probable, thus increasing redundancy, RT decreased to the more probable target (Experiment III). More recently, Jagacinski, Hartzel, Ward and Bishop [1978] tested the applicability of Fitts' Law as system dynamics and target uncertainty were varied. They found that movement precision and RT were independent. Finally, Gopher, Hartzell,Hart S. G., Lee E., and Dunbar S. [1983] have attempted a combination of Sternberg's memory scanning task with Fitts' Law and have on the whole found independence of the two subtasks.

Given these results, it could be hypothesized that overall capture time in an X-Y sorting task should be an additive combination of RT and MT. Combining Hick's and Fitts' Laws:

$$CT=\alpha + \beta H + \gamma \log_2(2A/W). \tag{3}$$

There appear to have been few explicit attempts to combine Hick's and Fitts' Laws in this fashion, even though it must follow from the findings outlined above. One attempt was made by Beggs, Graham, Monk, Shaw and Howarth [1972]. They proposed the combination in equation 3 and varied the accuracy of each movement and the number of possible movements in a continuous task. Subjects held a pencil and moved their hand between a home position and any of several targets, paced by a metronome. However, the combination of the two laws was not possible as a negative minimum movement time for the Fitts' law component made that Law invalid. Beggs et al. [1972] suggested that their rather unusual methodology may have been responsible for this.

The present experiment tests equation 3 in discrete trials and when movements are made with a joystick. The joystick is used to control the position of a cursor on a CRT screen. The dynamics are of order zero, with constant gain. Response uncertainty was manipulated by making the number of equiprobable responses either 2,4 or 8, resulting in 1,2 or 3 bit decisions. Subjects viewed the stimulus in the centre of the CRT screen, and made their response by moving the cursor to the target indicated by the stimulus. The mapping from stimulus to target was one to one, targets were labeled A,B, .. ,H and the stimuli were identical to the labels. Targets were arrayed in an annular fashion around the stimulus position, in a radially symmetrical arrangement. Movement precision was manipulated by varying the inner and outer radii of the targets. In this geometry the ratio of 2A/W used in (3) corresponds to the ratio of:

$$(radius_{outer}+radius_{inner})/(radius_{outer}-radius_{inner}) \tag{4}$$

In the present experiment, movement precision was either 3,4 or 5 bits. Jagacinski and Monk [in Press] and Card, English and Burr [1978] have found that with a joystick, diagonal movements, like those required to reach half the targets in this experiment, take slightly longer than vertical or horizontal movements. However, Jagacinski and Monk [in Press] show that Fitts' law still holds.

Response uncertainty and movement precision were crossed in a factorial design. If (3) is correct then there should be independent effects of response uncertainty and movement precision, but no interaction. Analysis of variance should show only response uncertainty to have a significant effect on Reaction Time (RT) and only movement precision to have a significant effect on Movement Time (MT). Capture Time (CT) should show significant effects of both response uncertainty and movement precision, but no interaction. Regression analysis ought to be able to fit a model akin to equation 3 to the data obtained.

METHOD

Design

There were three levels of response uncertainty (1,2,3 bits) and three levels of movement precision (3,4,5 bits). These were crossed in a factorial design and each subject served under all 9 conditions. The trials were chosen such that the subject made movements in each of the possible orientations an equal number of times at each level of response uncertainty.

The subjects' task was to view a letter which appeared in the centre of the CRT screen and move the cursor to the target which matched the letter. In the 1,2,3 bit decisions, subsets of the letters A,B, ..,H were used. Specifically, in the 1 bit decision, the subject had to choose between A and E, B and F, C and G, and D and H. In the two bit decisions the subject had to choose from A,C,E and G or from B,D,F and H. In the three bit decisions, the stimulus could be any one of the eight letters. In all cases, only targets corresponding to possible stimuli were displayed. Movement precision was manipulated within each response uncertainty block according to a latin square.

Apparatus

The experiment was run on an Apple IIe micro computer. Responses were made with a Measurement Systems joystick without spring return to centre. The maximum deflection of the joystick was about 30°. The gain was approximately 0.25° of visual angle for each 1° of joystick deflection. After presentation of the stimulus the position of the joystick was sampled every 10 mSec by installing an interrupt handler which trapped interrupts from a Mountain Equipment Inc. Clock card and read a Mountain Equipment Inc. analog to digital converter (ADC). Reaction and capture times were not calculated on line, and so were not fed back to the subject after each trial. ADC samples were spooled onto floppy disk, and analyzed off line by another program. All software, including the clock and ADC handler, was developed under the Apple version of the UCSD Pascal operating system.

Procedure

Subjects were run in eight 20 minute blocks, each of which comprised either the first or second half of the experimental design. They took between 3 and 7 days to run through the experimental design four times.

The instructions to the subjects asked them to be as time-efficient as possible while maintaining good accuracy. If their results showed any systematic inaccuracy, such as moving away from the cross hairs less than 200 mSec after stimulus onset, they were asked to avoid such errors when they next performed the task. Reaction time was operationally defined to be the time between the onset of the stimulus and when the joystick was deflected 0.3°. Capture time was the time between the onset of the stimulus and the beginning of a 350 mSec capture of the target.

Subjects

Seven undergraduate and graduate students at the University of Toronto served as subjects.

RESULTS

Three analyses of variance and three multivariate regressions will be discussed. The analysis of variance [1] took the within subjects experimental design into account. Much of the variation was found to stem from differences between subjects. The regression analysis employed six dummy variables in addition to response entropy and the index of difficulty in order to take between subject differences into account. In this way the regression analysis was made more consistent with the ANOVAs.

Reaction time was found to vary significantly with response entropy ($F(2,12)= 41$, $MSE=71$, $p<0.001$). There was a significant interaction between response entropy (H) and index of difficulty (ID) ($F(4,24)=3$, $MSE=3$, $p=0.037$) detected, but the amount of variance actually involved was neglible. The regression analysis showed an r^2 of 0.95.

Movement time varied significantly with both H and ID, but the ANOVA showed that by far the greatest part of the variation can be attributed to the ID ($F(2,12)= 87$, $MSE= 71$, $p<0.001$) as opposed to the H ($F(2,12)= 5.6$, $MSE= 17$, $p = 0.019$). There was no significant interaction found between H and ID. The regression showed an r^2 of 0.90, but with a negative intercept (about -100 mSec).

Capture time showed a significant effect of H ($F(2,12)= 89$, $MSE= 44$, $p<0.001$) and, ID ($F(2,12)= 91$, $MSE= 67$, $p<0.001$) but no interaction at all. In fact, the F score of the interaction term was almost precisely 1.

The best fit of equation 3 (Hitts' Law) for this data is thus:

$$CT=344 + 137H + 170\log_2(ID)$$

with an r^2 of 0.96.

DISCUSSION

It appears that the data supports a relation of the form of equation 3. Both the ANOVA and regression analysis

[1]The joystick was sampled every 10 mSec, and so all the ANOVAs are in terms of this unit of time.

indicate that most of the variance in subject performance can be accounted for by such an expression. As hypothesized, response entropy and movement precision have independent effects on capture time over a fairly broad range of uncertainties.

The analysis of variance showed a great amount of the variation was due to differences between subjects. Thus, adding dummy variables to the regression analysis increased the r^2 for CT from about .45 to about 0.96. This would indicate that the difference between subjects was in large part due to different intercepts, and can probably be attributed to the relative lack of practice of the subjects, as well as the lack of on line performance feedback.

Movement time was found to vary not only with ID, but also with H. Examination of Figure 3 will indicate that this effect seems to occur in those trials with H=3. One possible explanation starts with the observation that only in the H=3 trials does the subject have to deal with targets separated by 45°. This could be tested by adding such configurations into H=2 and H=1 cells.

A few subjects showed little difference in movement time between ID=4 and ID=5. This is possibly due to the fact that the difference between these two movement precisions was manipulated using width of the target rather than amplitude of the motion.

Within the conditions tested in this experiment Hitts' law appears to hold. The next step might be to generalize the manipulation of H, since response entropy was varied here by controlling the number of equiprobable targets, and not by presenting targets with different probabilities. This would have the aditional benefit that a wider range of H could be tested.

Finally, in the procedure described here the task of the subject was a highly discrete one. The subject had several seconds to contemplate the targets before the onset of the stimulus. It is possible that the subject was able to prepare himself for the upcoming movement in a way which contributed to the high degree of independence between H and ID. In contrast, in a setting in which each trial led into the next with no gaps inbetween, and in which there may be more incentive for the subject to overlap reaction and movement times, the independence of H and ID might disappear.

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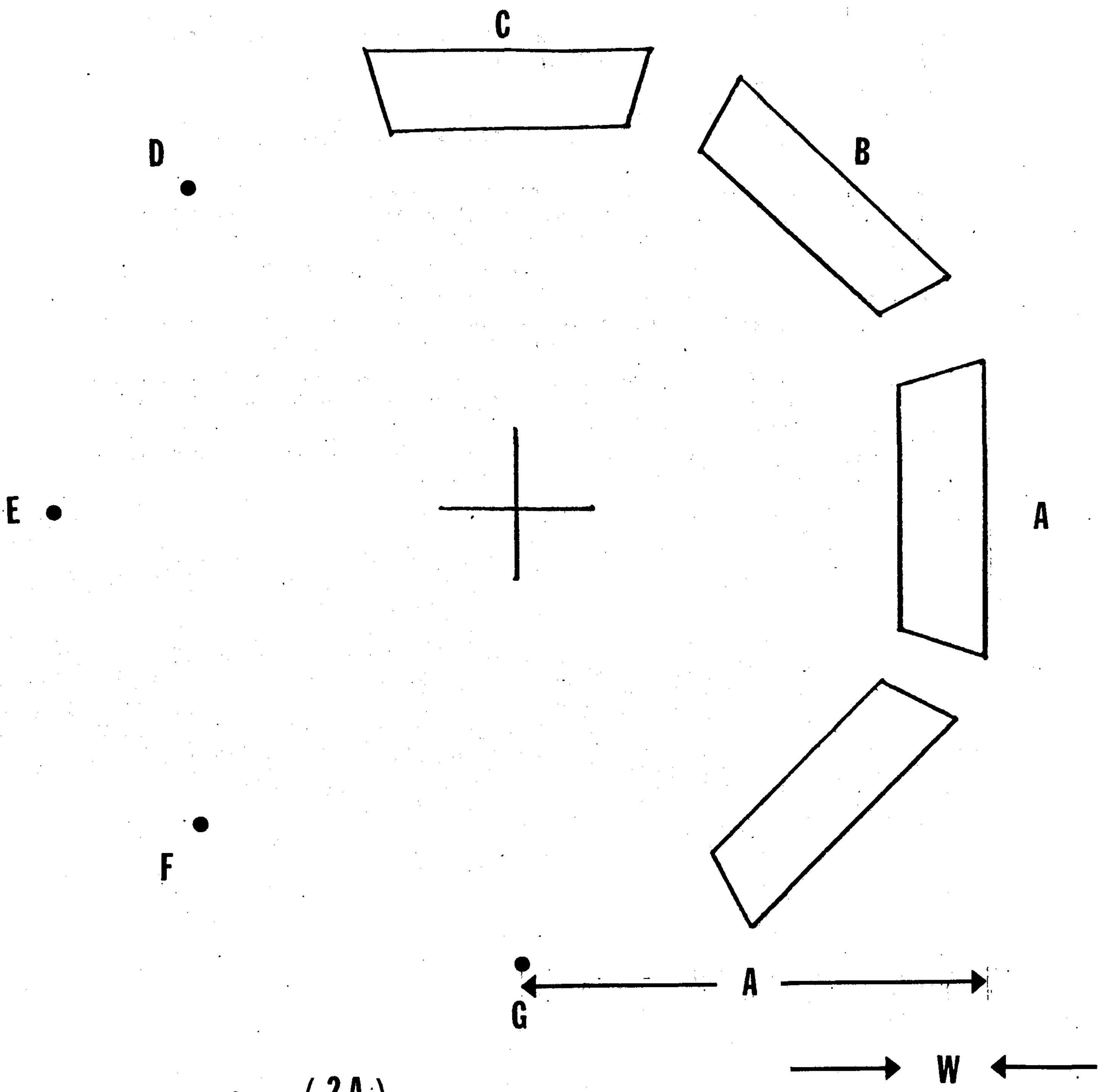
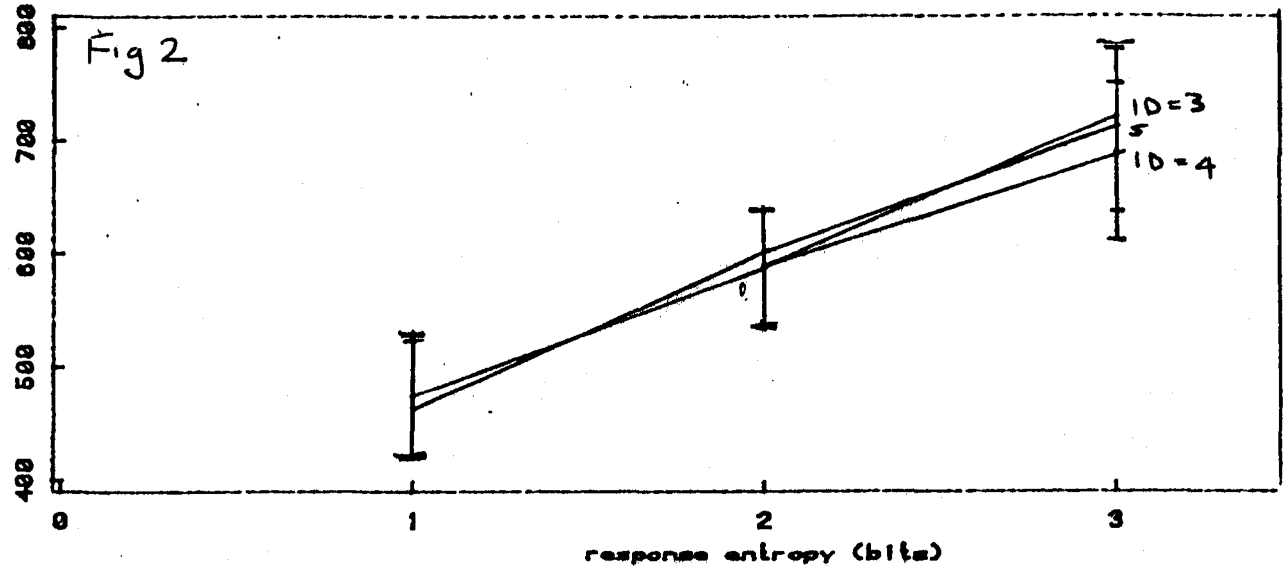


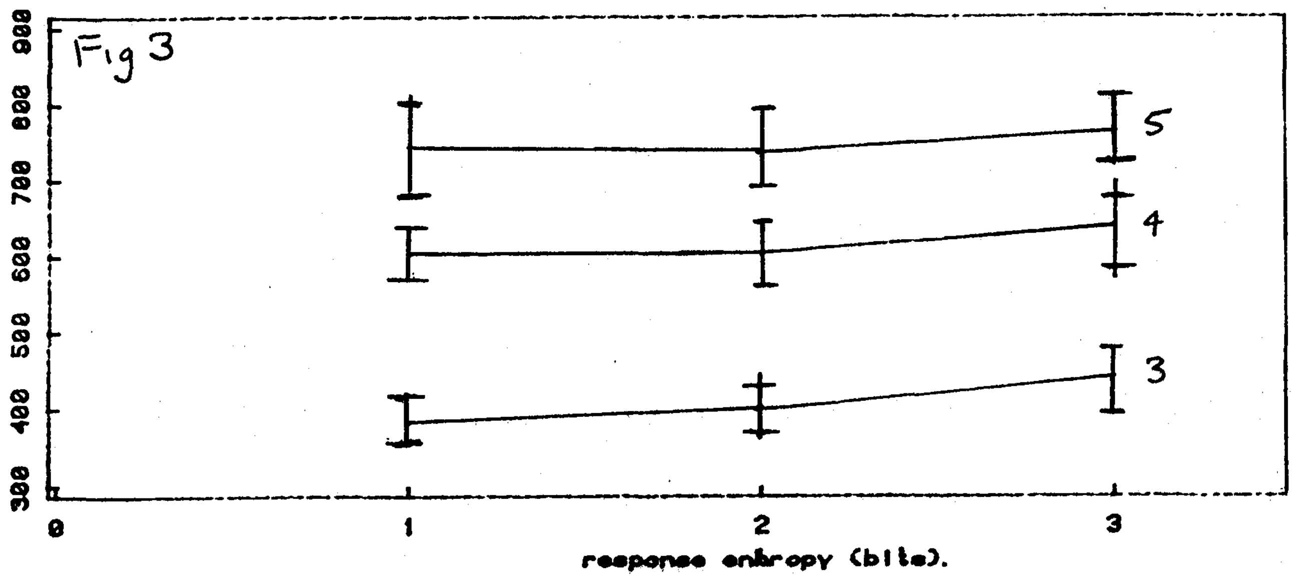
$$ID = \log_2\left(\frac{2A}{W}\right)$$

FIG. 1

reaction time (mSec) vs response entropy



movement time (mSec) vs response entropy



capture time vs response entropy