CHOICE REACTION TIME IN CARD SORTING TASKS:

VALIDATION OF THE HICK-HYMAN LAW

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Introduction

Choice reactions are common day occurrences. During normal everyday activities, one frequently encounters situations presenting one out of a number of signals or stimuli, each requiring a different response. Stop lights can present one of three colored lights, red, yellow or green, requiring different reactions or behavior. Equipment or machinery may alert the user of change in status by various signals, requiring a specific response from the user.

In many situations, immediate response time to these signals is important for health and safety reasons. The incorrect or delayed response to a red stop light can cause an accident, incorrect or delayed response to medical equipment signaling an emergency situation can cause the loss of life.

For these and other reasons, it is important to understand factors affecting response time to signals or stimuli, especially when confronted with choice reaction scenarios.

Analysis of stimulus and response requires the conversion of information being communicated, into a measurable format. In studying communication systems, Shannon (1948) developed what is referred as the information theory, which calculates the amount of information provided into bits of information, depending on the number of options offered.

Applying this information theory to choices of stimuli, Hick, was able to demonstrate a linear relation between the bits of information (calculated by number of stimuli), and the response time to the stimuli (Hyman, 1953). Hyman (1953) took this concept one step further, by varying the number of equally probable alternatives, the probabilities of alternatives, and the sequences of alternatives, and found the same results. These combined results can be summarize as: an increase in bits of information (stimuli) will result in a linear increase in response time to that stimuli, and is commonly referred to as the Hick-Hyman Law.

The Hick-Hyman Law has frequently been referred to and applied to a variety of experiments. Murray and Caldwell (1996) conducted an experiment where the participants' task was to monitor a number of video displays in an industrial security system. One set of findings provided support for the Hick-Hyman Law, where, as the number of human figures presented in the displays increased, the mean response times directly increased.

Wallace and Fisher (1998) conducted an experiment, using audio stimuli, as it would be used in an in-vehicle collision-avoidance system. This experiment tested and supported the Hick-Hyman Law, where response time to audio stimuli increased as information content of the stimuli increased, allowing generalization of the Hick-Hyman concept to audio stimuli.

Our goal in this experiment is to validate the Hick-Hyman Law, using various card sorting tasks. Three tasks will be used, presenting three different sets of stimuli or information to the participant, and recording response time and errors. Response times and error rates will each be compared to the amount of information presented in each task, looking for a linear relation between the two.

Method

Participants

One subject was used and was a 23 year old, male graduate student that had previous experience with playing cards, but never had performed sorting tasks on them. The range from which to choose the subjects from was very broad and basically was inclusive to any adult. We choose to stay away from those individuals that were younger then 18 years of age.

Apparatus

The apparatuses utilized in the experiment were a stopwatch to calculate the time of completion for each trial and a normal 52 card deck of playing cards, with Jokers removed. The playing cards used to do the various sorting tasks were Large Index Hoyle Cards. The other pieces of equipment that we used were a lab table that was big enough for the subject to sort the cards, and a chair to sit on.

Definition of Variables

Before we conducted the experiment, we defined our variables that we were going to use and measure. The independent variables were the bits of information as calculated from the different sorting tasks and the speed at which to conduct the trials. The dependent variables we measured were reaction time (speed) and the number of errors made. There were no subject variables during this experiment, we only used one subject.

Controls

In an effort to control the testing environment, we eliminated memory rehearsal by varying the three tasks and conducted them at different speeds. So rather than repeatedly each task four times, tasks were performed sequentially, alternating between fast and slow to reduce "practice" effect. The subject was allowed to determine the sort position. The experiment was conducted on two separate sessions, under similar circumstances. Subject variables we controlled by using only one subject, with no practice allowed between sessions.

Procedure

Three sorting tasks used for this experiment:

Task 1: Black vs. Red
Task 2: Suits
Task 3: Odds, Evens, and Picture Cards (Aces were considered "1")

Each trial was conducted two different subject determined speeds: the slow, a comfortable pace; fast being as fast as the subject could, with verbal encouragement by one of the experimenters. The sequence of trials and tasks is displayed in Appendix 1.

The participant sat down at the table and held the shuffled 52 card deck face down in their left hand and was asked to sort the cards in a specific manner four inches away from their left hand.

Two experimenters sat in front of the subject and the third experimenter sat next to the subject. One experimenter collected the times using the stopwatch and provided background noise in an effort to make the subject go faster during the fast trials. The second experimenter collected the data and observed any mistakes that were made during each trial. The third experimenter collected the data as well, counted the number of physical errors that were made (placing the wrong card in the wrong pile) and shuffled the cards after each trial.

Before the actual experiment took place, the subject was given three "warm-up" runs through the deck. This allowed the subject to get used to the deck and the acts of sorting them onto the table.

For each trial, the subject was told what type of sorting task to perform on the cards and whether or not to go at his own pace or as fast as he could. Once the cards were sorted, an experimenter went through each of the piles to see if any playing cards were miss-sorted.

Time was calculated from the instant the subject flipped over the card with this right hand and the time stopped when he placed the last playing card.

Errors were determined by two different methods. The first method was the actual incorrect sorting of the cards. The second method of error was called a "touch." This type of error was defined as a touch of the playing card to the wrong pile. So for example, if the subject attempted to place the playing card in the wrong pile and touched it and then realized the mistake and compensated for it, then that is still considered an error.

After each trial, the cards were shuffled four times, to eliminate any remnants from the previous trials. This same procedure was repeated for each trial.

Results

The data collected as part of this experiment is displayed in Appendix 1. Originally Time in minutes was collected; this was then converted to Time in seconds/card (sorting speed) for a more understandable metric of comparison. Errors were also collected as part of the experiment.

A method in which to view this data is in terms of bits. In trials 1 and 2, the quantity of bits present is 1 and 2 respectively. For trial 3, the quantity of bits is not as straightforward as probability is now a factor (unlike trials 1 and 2 which all have equal probability). The formula for converting probability functions to bits is:

$$\sum_{i}^{n} p_i * \log_2\left(\frac{1}{p_i}\right)$$

In trial 3, there are 20 odd cards, 20 even cards, and 12 face cards. This scenario results in a bit count of 1.55 for the trial. Assigning a bit value to the data set allows for new axial graphing of the data. It is now possible to chart the data against mean response time and mean errors per trial.

Figures 1 and 2 show the mean sorting time per card (in seconds) plotted against the bits of information present in each trial. A simple linear regression line is plotted against this data to aid judgment of the hypothesis. The higher an R^2 value of the best-fit line is, the more indicative of probability that the trend line fits the data. In both cases of Fast and Slow testing, the R^2 value exceeds 0.99.

Linear: Mean Sort Time (per card) vs. Bits; Fast

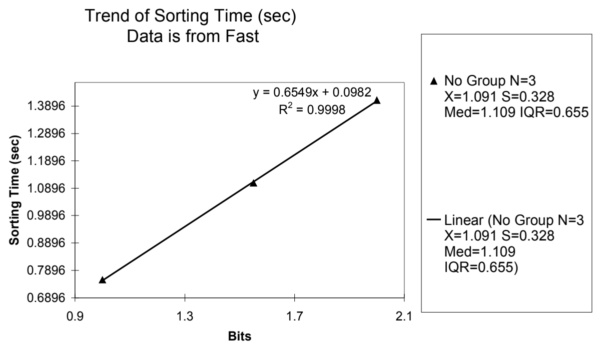

Figure 1

Linear: Mean Sort Time (per card) vs. Bits; Slow

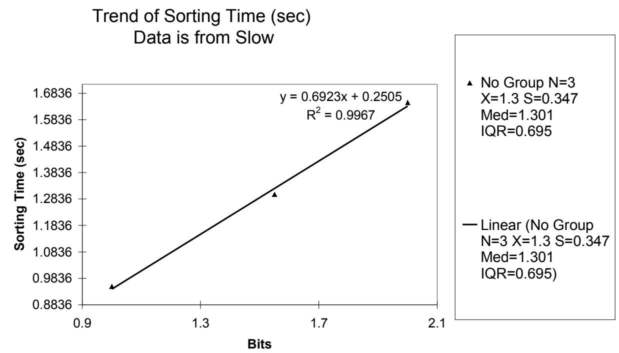

Figure 2

Figures 3 and 4 show the mean errors per trial plotted against the bits of information present in each trial. The same methodology is employed for these plots: linear regression. In these plots, for both cases of Fast and Slow testing, the R^2 value exceeds 0.99.

Linear: Mean Errors vs. Bits; Fast

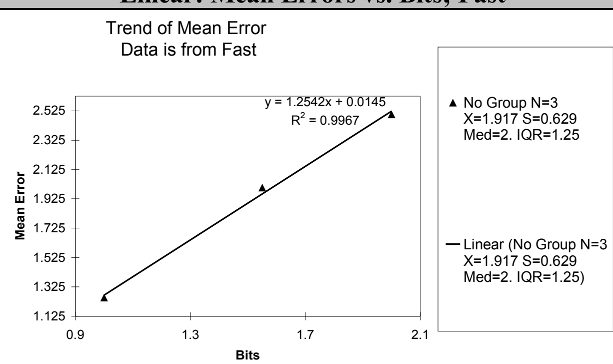

Figure 3

Linear: Mean Errors vs. Bits; Slow

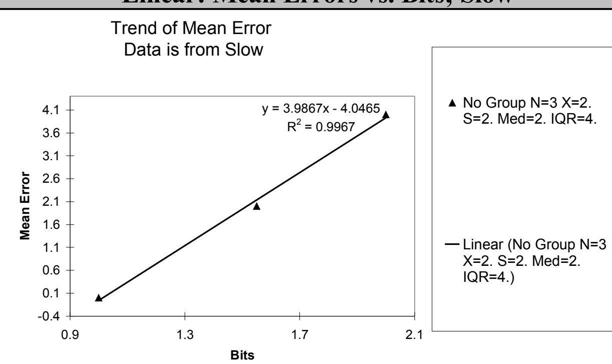

Figure 4

Discussion

Reaction time is often used as a measure of cognitive processes in response to various stimuli. Choice reactions occur when there is more than one potential stimuli, each requiring a unique response. This suggests that as choices or potential number of stimuli increases, additional cognitive processing is required, resulting in an increase in reaction times.

This concept has been confirmed and is known as the Hick-Hyman Law, where reaction time is a linear function of stimulus information (Hyman, 1952).

To test this law, we studied the relationship between choice reaction time and three different sets of stimuli, at two different rates of speed. Our results demonstrate a linear relation between choice reaction time and the amount of stimuli information, at both rates of speed, which validates the Hick-Hyman Law.

We also studied the relationship between error rates and the three different sets of stimuli, at two different rates of speed. These results also produced a linear relation between error rate and amount of stimuli information. The Hick-Hyman Law does not take into account error rate, as errors were not allowed in Hyman's study (Hyman, 1952), but does follow the same logic, that as stimuli information increases, so would cognitive requirements, potentially causing more errors. This concept warrants further study, as error rate may be a more critical factor than reaction time in certain real world situations.

An anomaly observed in our data is within the error rate vs. stimuli information trials at two different speeds (Figures 3 and 4). One would expect higher error rates at higher speeds, but we found the opposite. Trial 1 (1 bit of information) slow, had fewer (0) errors than trial 1 fast. Trial 3 (1.55 bits of information) slow had approximately the same mean error rate as trial 3 fast. Trial 2 (2 bits of information) slow had more mean errors than trial 2 fast.

Practice may have potentially influenced results as indicated by a faster reaction time in later trials (see Appendix 1). Because times were averaged across the trials of the same task, the practice effect may not be a factor in these results.

Limitations

Even though our results validate the Hick-Hyman law, some limitations to our experiment are pointed out, which future studies may want to consider.

Due to time constraints and out of convenience, we were limited to one subject, and only 8 trials of each task (4 slow and 4 fast), resulting in a total of 24 trials analyzed.

This experiment was not conducted in a tightly controlled environment. Even though all trials took place in the same environment, there were other activities taking place in that environment, that could have potentially interfered with the subjects tasks.

In tasks two and three, there were other factors involved, specifically discrimination of stimuli and response to stimuli, potentially affecting cognitive processing, that were not considered in our experimental design or analysis.

Efficient discrimination of the stimuli (cards) may be affected by the color distribution among the suits in task 2, and the color distribution within the odd and even groups in task 3. Varying response, or placement of the sorted cards in each task, could affect results also.

In this study, no consistent method of discrimination or card placement was observed or identified by the subject, so these points may not affect our results.

In future studies, especially involving additional subjects, method of discrimination of stimuli and response (placement of cards) could possibly be identified and address in design and analysis.

Generalization / Conclusion

We validated the Hick-Hyman Law, and have shown that reaction time is a linear function of the amount of stimulus information, where stimulus varies from 1 to 2 bits of information. This conclusion can be applied to many real world scenarios, a couple pointed out already are traffic stoplights, and signals indicating state or condition of equipment. In general, multiple signals ought to be avoided where critical or fast response is required. This specific experiment's results could possibly apply directly to bank tellers' task of counting or sorting money of varying denominations and color.

Appendix 1: Experimental Data

TRIAL	TASK	SPEED	TIME (MIN)	TIME (s/ card)	ERRORS
1	1	Slow	0.915	1.056	0
2	2	Fast	1.016	1.172	1
3	3	Slow	1.881	2.170	9
4	1	Fast	0.754	0.870	1
5	2	Slow	1.237	1.427	4
6	3	Fast	1.244	1.435	3
7	1	Slow	0.796	0.918	0
8	2	Fast	1.047	1.208	7
9	3	Slow	1.300	1.500	4
10	1	Fast	0.633	0.730	2
11	2	Slow	1.165	1.344	1
12	3	Fast	1.148	1.325	1
13	1	Slow	0.861	0.993	0
14	2	Fast	0.959	1.107	0
15	3	Slow	1.181	1.363	2
16	1	Fast	0.681	0.786	2
17	2	Slow	1.052	1.214	0
18	3	Fast	1.395	1.610	3
19	1	Slow	0.732	0.845	0
20	2	Fast	0.821	0.947	0
21	3	Slow	1.360	1.569	1
22	1	Fast	0.550	0.635	0
23	2	Slow	1.055	1.217	3
24	3	Fast	1.103	1.273	3

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