# Laboratory Report: Replicating Zhang & Norman's Experiment 2

**John C. Giordano**
**Sonna M. Patel**
**SYS 623**

**University of Virginia**
**School of Engineering and Applied Science**
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## I. Problem Description

For this project, we were asked to read "Representations in Distributed Cognitive Tasks" by Zhang and Norman and select an experiment to replicate. After careful consideration, we chose to replicate Experiment 2, wherein the authors seek to establish that the cognitive tasks of the Towers of Hanoi game are re-distributed from internal to external representation. The easier the problem is, subject performance increases as tasks are re-distributed to external representations. We chose this experiment for several reasons, including; relative ease of replicating experiments based on materials required, straightforward hypothetical thesis and conclusion, and multiple variations of the Towers of Hanoi game in the experiment.

Our hypothesis for this experiment is that Zhang & Norman's conclusions are valid in that as cognitive tasks are re-distributed from internal to external representations, subject performance improves and the problem is easier to solve. A possible null hypothesis is that Zhang & Norman's conclusions are invalid based on data obtained from replicating their experiments, but we do not anticipate rejecting the experimental hypothesis in this case. The purpose of our work is to obtain experience in conducting tests with human subjects and designing experiments based on the work of others.

## II. Methods

**Subjects** The subjects for our experiments included 10 graduate students enrolled in Computer Science and Biomedical Engineering at the University of Virginia who volunteered to assist in conducting the experiment. No rewards were offered for their participation.

**Materials** Materials in the I123 condition, or "Waitress and Oranges", included three binder clips of increasing size ("small", "medium" and "large") which represented oranges. In the I12 –E3 condition, or "Waitress and Donuts", materials included three paper rings and three large marking pens used as pegs. The I1-E23 condition, or "Waitress and Coffee" included three plastic cups of increasing size wherein all three could be stacked on top of one another in only one possible configuration. When the experiments were conducted, the cups were empty.

**Design** As in Zhang-Norman, each subject played all three games, one for each of the conditions, in a randomized order. Also, the starting and ending configurations were not randomized, which replicates the conditions in the original experiment. While there were six possible permutations in which the games could be played, due to similar limitations in the number of subjects available, we only conducted experiments with 10 subjects. This provided sufficient data points and statistically significant results. Data was collected regarding the duration of each subject's game, the number of moves required to reach the desired final state, and the number of errors each subject made during the course of each game.

**Procedure** Each subject was seated at a table or workstation and read the purpose and rules aloud or silently. If the subject could recall and recite the rules twice without referring to them, they were instructed to start the game. The desired final state of the game was presented to the subject and kept in view for the entire game. The rules were obscured from their view.

**Observation #1** Since we did not have a video camera at our disposal in order to record subject movements, we devised a data recording sheet that the observes used to gather the pertinent information regarding subject performance. These data sheets included the state of the game with each of the subject's moves. It was extremely difficult to record the state of the game at each move as a number of subjects executed several moves in rapid succession, prohibiting the observer from recording the state at each move. At a minimum, the number of moves was recorded, along with the start time, finish time and number of errors. Video recording of such experiments is considered advisable.

**Observation #2** More than one subject commented on the "learning" aspect of the experiment – that is, despite which order the games are played in, once the subject decomposes the abstraction of the game, the subsequent iterations become easier to play. One subject, upon being introduced to the materials and rules of the first iteration ("Waitress and Oranges", the more most difficult and abstract of the games) commented that the game was "not quite Towers of Hanoi, but very similar". Many computer science students and faculty are very familiar with Towers of Hanoi recursion and non-recursion alogorithms.

**Observation #3** As the games were played, subjects noticeably talked to themselves why playing the games, particularly for the waitress and oranges game and the waitress and donuts game. When asked why, subjects reported that it helped them to remember the rules, particular because each game had three and two rules (respectively), that they had to remember.

**Observation #**4 Although the cups used in the experiment were able to be stacked in only one configuration and subjects were asked to pretend coffee was in the cups, some subjects found this difficult to remember.

## III. Results

The results from the Zhang Norman experiment are presented in Figure 1. The results from our experiments are presented in Figure 2. Average values for the three different conditions are shown on the graphs. Time to complete the game, the total number of steps, and the error that occurred with each game were measured. With a decreasing number of internal conditions, subjects accurately represented the results of the Zhang Norman experiment. The solution times, steps, and errors, on average, decreased with decreasing internal rules.

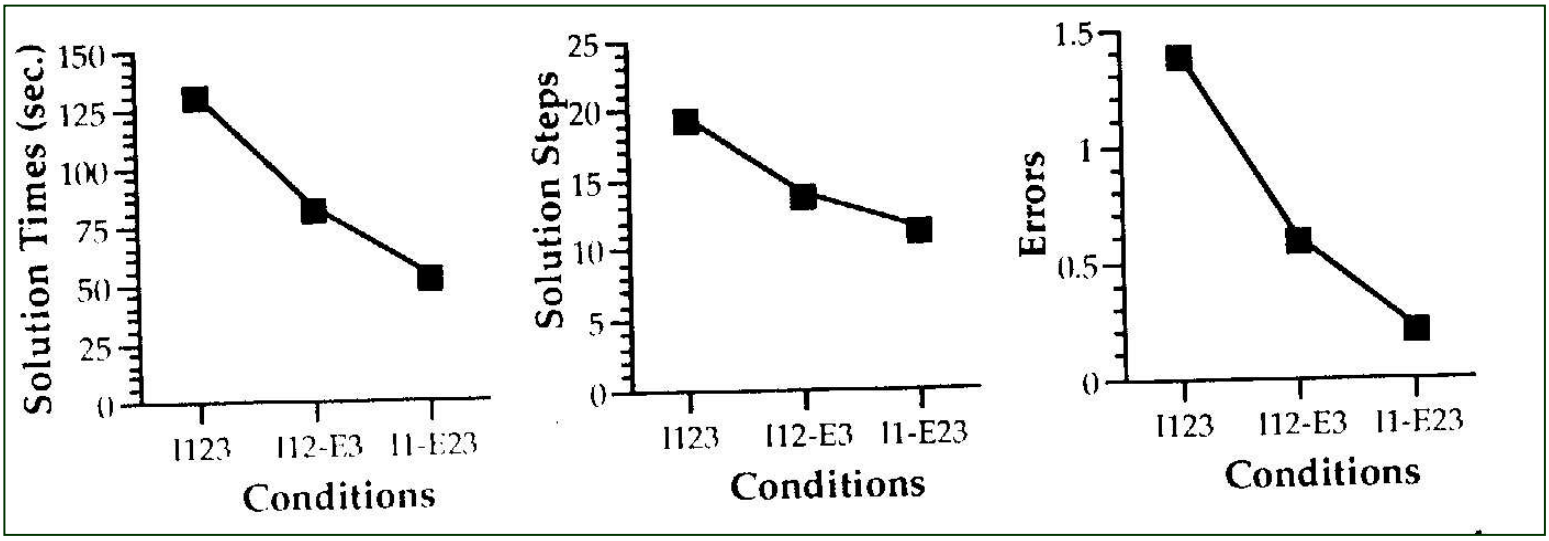



**Figure 1: Zhang and Norman's Results**

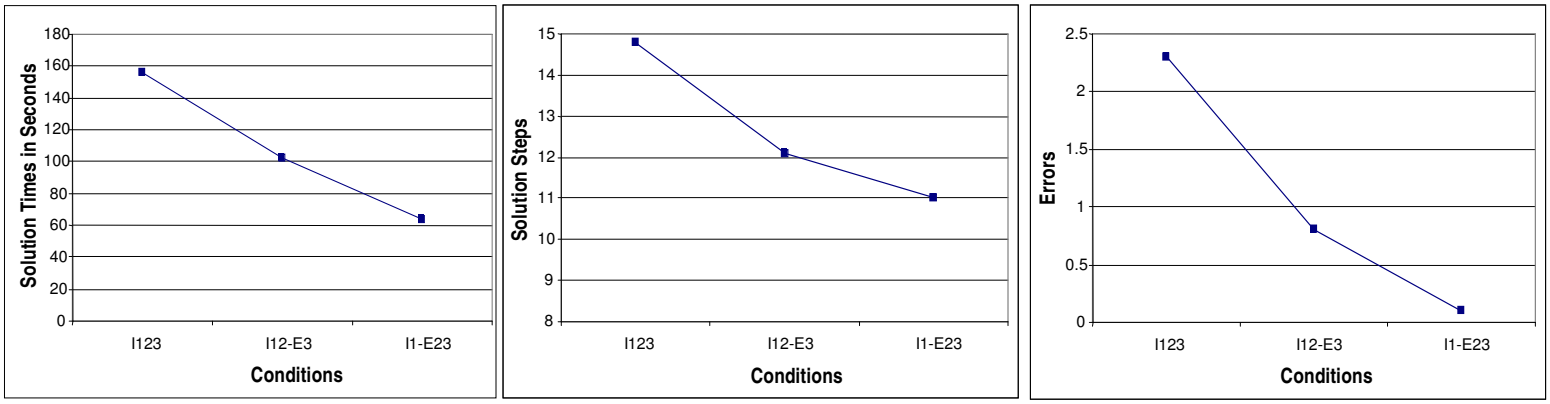



**Figure 2: The results of replicating Zhang and Norman's Experiment 2**

## IV. Discussion

This experiment replication accurately summarizes the results of the Zhang Norman experiment. Their hypothesis, "that the more rules are distributed in the external representation, the easier the problem" (Zhang, 1994) proved to be true as presented in the results. The three different games, Waitress and Oranges, Waitress and Donuts, and Waitress and Coffee were used to prove that the more the rules were externalized, the easier the problem. For the waitress and coffee game, subjects were able to complete the solution in the least amount of time, with the least number of errors, and taking the smallest number of steps (on average) when they had to memorize only one rule. The purpose of this particular game was to prove that an external rule, or one that does not have to be memorized, would make an easier problem.

Coffee was not actually placed in the cups in the experiment, and although subjects found this difficult to remember, there was only one error. In order to exactly simulate the experiment, it may have been beneficial to actually fill the cups with coffee or water. This may have reduced the load on the working memory.

The reason this problem was easier may be that subjects only had to consider one rule. Rules did not have to be checked prior to each move of the coffee cup. In fact, as reported in the observations, subjects did not have to repeat rules to themselves as they were playing the Waitress and Coffee game, because there was only one rule to remember. Working memory is required when having to process the three internal rules, which is mentally taxing, and requires more time, and steps, as seen in the data.

Another factor for the waitress and coffee being an easier problem may be a theory introduced by Zhang and Norman called recursive strategy. The problem was reduced to one simple strategy, move the smallest cup first. Without a video camera, as mentioned in the procedure, it is very difficult to review the significance of each step. With the video camera, Zhang and Norman are able to evaluate individual moves by each subject. They suggest that subjects may have discovered this recursive strategy when in certain games the small or medium sized objects were moved to the final state, first.

Overall, this experiment supports the findings of the Zhang and Norman paper. Although limited by resources such as a video camera and the number of subjects, our hypothesis that as cognitive tasks are re-distributed from internal to external representations, subject performance improves and the problem is easier to solve is correct.

## V. Reference

Zhang J. and Norman D. "Representations in Distributed Cognitive Tasks", In *Cognitive Science*, March 1994. Pages 87-122.

## Appendix

Example Data Sheet used to record subject performance during experiments

Data Sheet

Subject Designator: 1 2 3 4 5 A B C D E

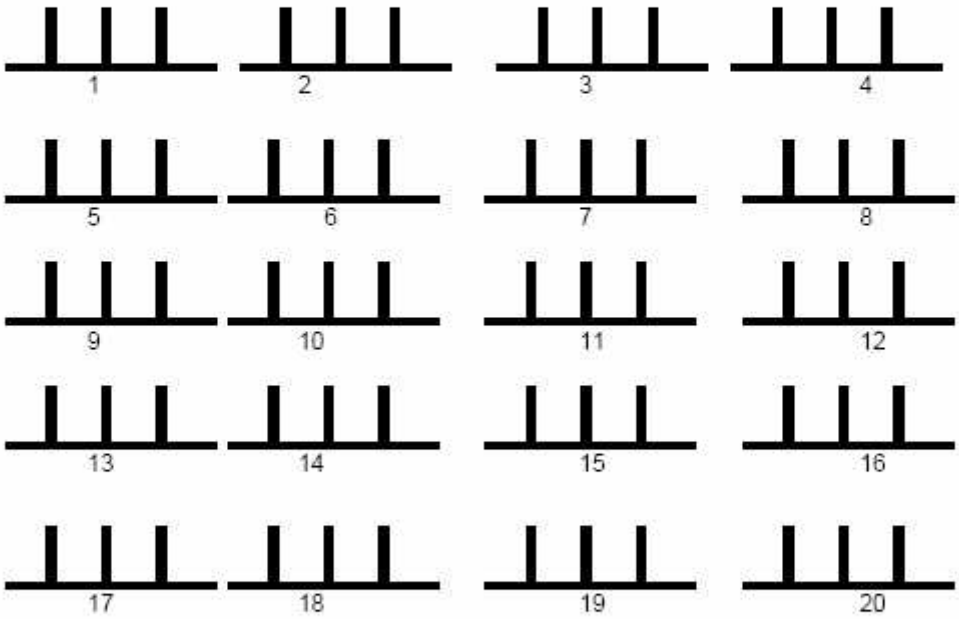
Game Played: O C D

Initial Configuration: S1 S2 S3

Did subject recite rules twice without error? Y N
Does subject have end configuration in front of them? Y N

Start time:_____

Record each move:




Stop Time:_____

Total number of steps:_____

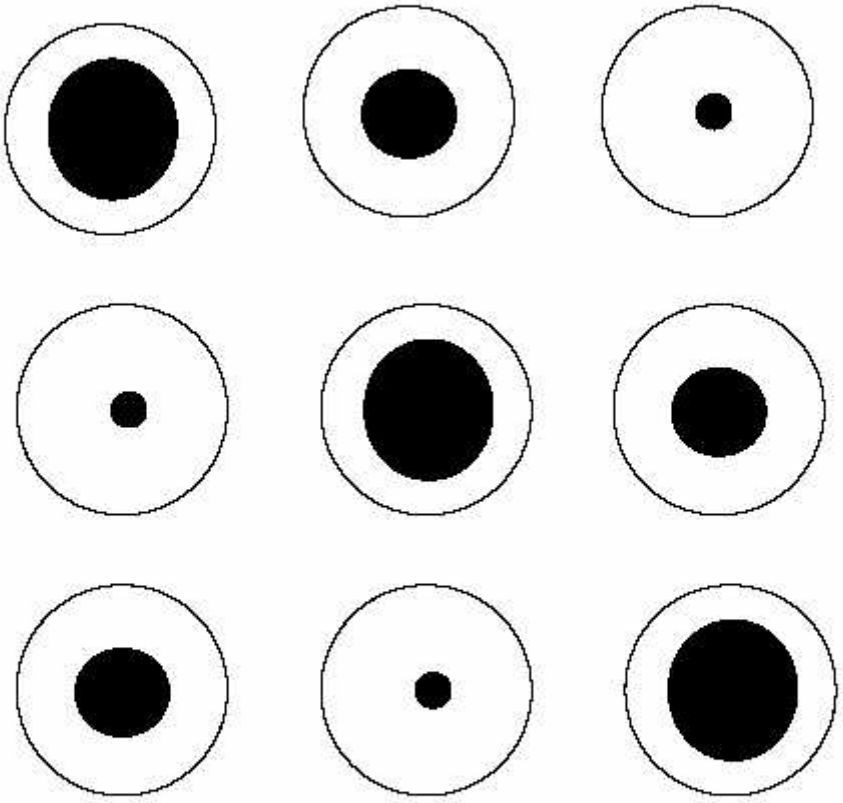
Number of Errors:_____

Total Time to complete experiment:_____

Example Instruction Sheet used by the subjects to memorize rules and view desired final state of their game.

## Waitress and Oranges

Purpose: Re-distribute the oranges to the customers into the circled configuration.



Rules of the Game

1. Only one orange can be transferred at a time.
2. An orange can only be transferred to a plate on which it will be the largest
3. Only the largest orange in a plate can be transferred to another plate.

Experimental Data

| SUBJECT | **Times** | | | **Steps** | | | **Errors** | | |
|---|---|---|---|---|---|---|---|---|---|
| | Oranges | Donuts | Coffee | Oranges | Donuts | Coffee | Oranges | Donuts | Coffee |
| | I123 | I12-E3 | I1-E23 | I123 | I12-E3 | I1-E23 | I123 | I12-E3 | I1-E23 |
| 1 | 40 | 25 | 18 | 7 | 7 | 7 | 1 | 0 | 0 |
| 2 | 65 | 170 | 40 | 13 | 25 | 11 | 1 | 1 | 0 |
| 3 | 180 | 120 | 50 | 17 | 9 | 11 | 2 | 1 | 0 |
| 4 | 190 | 60 | 40 | 16 | 9 | 9 | 0 | 0 | 0 |
| 5 | 157 | 115 | 140 | 11 | 11 | 17 | 2 | 1 | 0 |
| A | 315 | 230 | 110 | 20 | 19 | 9 | 4 | 3 | 0 |
| B | 55 | 45 | 110 | 7 | 7 | 13 | 0 | 0 | 0 |
| C | 115 | 25 | 44 | 13 | 11 | 16 | 1 | 0 | 0 |
| D | 180 | 140 | 55 | 21 | 15 | 8 | 6 | 1 | 0 |
| E | 265 | 90 | 30 | 23 | 8 | 9 | 6 | 1 | 1 |
| | **156.2** | **102** | **63.7** | **14.8** | **12.1** | **11** | **2.3** | **0.8** | **0.1** |