How Do You Paper Fold?

Strategy Use With Varied Paper Folding Problems

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Motivation

Spatial thinking is critical to many everyday tasks. Spatial thinking, how people think of the orientation, shapes, location, and direction of objects plays a role in navigation, visualization, problem solving in science, mathematics, and more; spatial thinking is an important cognitive process. To analyze spatial thinking, and to evaluate spatial thinking in individuals, the Paper Folding task is often used.

Background. The Paper Folding task (PFT; Ekstrom, et al., 1976) is a widely-used measure of spatial thinking. In the PFT, a diagram shows a paper being folded, and then a hole is punched through it (Figure 1). Participants select the answer choice that accurately represents what the paper would look like unfolded (i.e., where the punched holes are located). However, it is unclear whether participants rely solely on spatial strategies – mentally folding and unfolding the paper – or other non-spatial strategies in solving these problems.

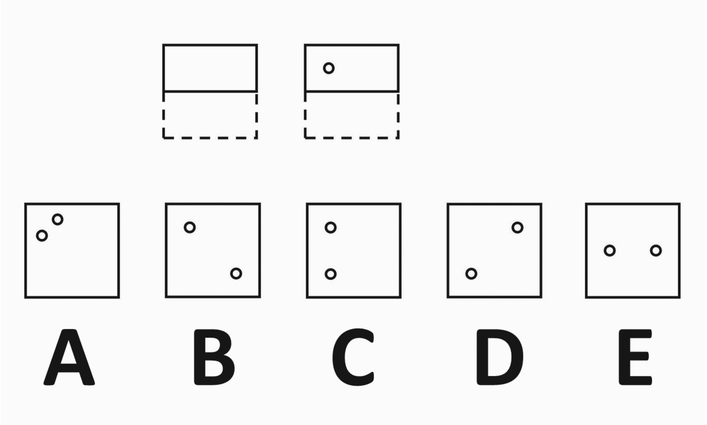


Figure 1. An example Paper Folding Problem on a PFT; a figure of a piece of paper is folded on top, and below are the response options of what the paper would look like unfolded.

Purpose. Since it's uncertain whether the traditional Paper Folding Task involves spatial thinking, a new version of the PFT was developed which allowed for a more in-depth analysis of strategies use. We investigated the new version of the PFT, and how specific characteristics of each paper folding problem might contribute to the use of spatial thinking, or to other problem solving strategies, to better understand how people go about completing a PFT. This way, we can learn whether people rely on their spatial skills or alternative approaches to solving a fundamentally spatial task, and move toward creating a more reliable measure of spatial ability.

Research Questions

- Do people rely solely on spatial thinking when solving PFT?
- What paper folding problem characteristics contribute to the use of spatial strategies?
- How do paper folding problem characteristics affect problem solving processes?

Methods

Participants. Twenty-four participants (age$_m$=21) completed a new version of the PFT, followed by a retrospective think-aloud task. These participants signed up for the experiment through the online portal SONA, and were paid $20 for their participation.

Materials. We used a 500 hertz eye tracker, the SMI Red 500, with iViewX software. A chinrest was used to minimize the participants' movements to ensure proper eye tracking. Each paper folding stimulus was presented one at a time on a 22 inch Dell monitor using the Experiment Center software (Figure 2).

The paper folding problems are each composed of a probe, which represents the folding and punching of the paper, and then five response items, with one correct response. (Figure 3) Each problem's probe varied on several characteristics, which allowed for an in-depth analysis of strategies. These were number of folds per probe(Figure 4) and occlusion type. Occlusions include fold occlusions (Figure 5) and punch Occlusions (Figure 6).

Figure 2. Participant completing the paper folding task with the eye tracker and chinrest setup.

Design. The participants were assigned randomly, with counterbalancing, to one of four between-subjects groups. The new PFT was originally 36 problem, which would have been too long of a task, so it was broken down into shorter 18 problem tasks. Each group completed a set of eighteen paper folding problem, with each set being of comparable difficulty and overall problem types. The dependent variable was the strategies participants used in completing each problem, determined from their think-aloud.

Problems and Probe Types

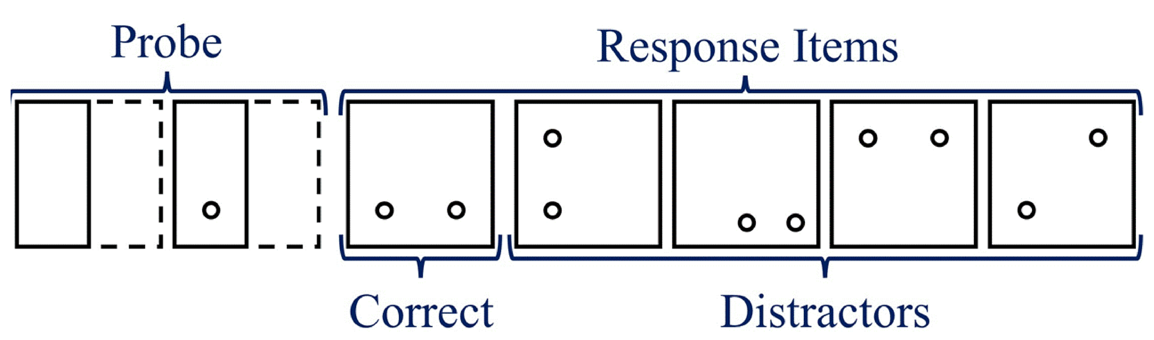


Figure 3. Each paper folding problem consists of a probe and response items, one of which is correct.

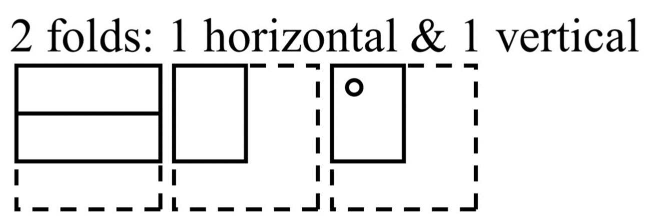


Figure 4. Probes can have varying numbers of folds; this one has two.

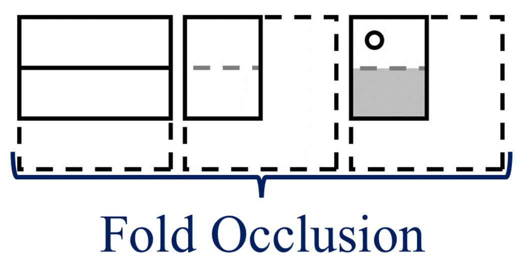


Figure 5. An example of a fold occlusion. A fold is covered up by another fold.

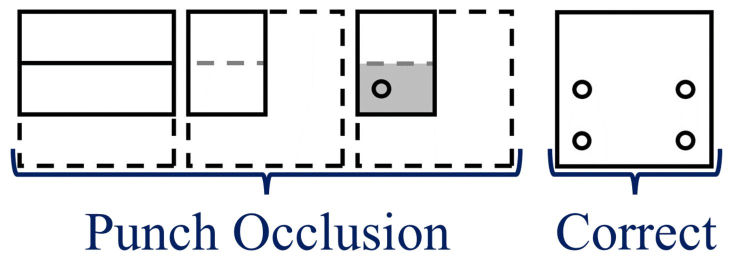


Figure 6. An example of a punch occlusion, a fold is covered up by another fold, and that covered fold is punched through

Results

To measure the spatial strategies used in each problem, we calculated the proportion of words in the think-aloud that were verbs which imply spatial thinking (e.g., "fold" or "imagine"), which gave us the "spatial frequency" variable. Similarly, we calculated the proportion of word that were other verbs, giving us the "nonspatial frequency" variable. Additionally, we recorded the total word count of each participant's think-aloud.

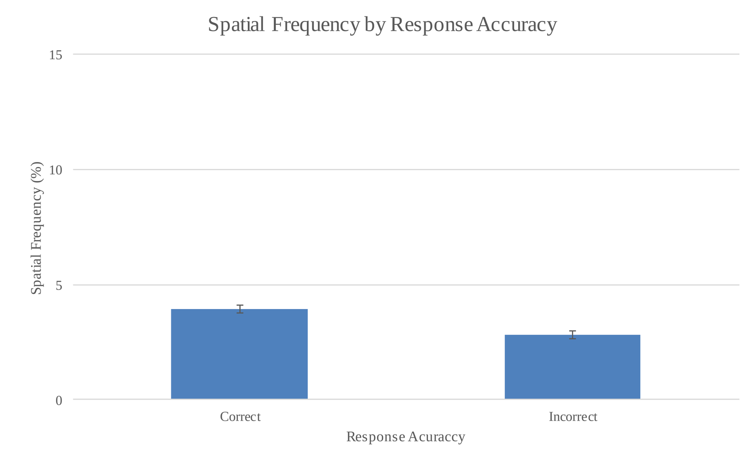


Figure 8. Spatial frequency by response accuracy. Error bars represent the standard error of the mean.

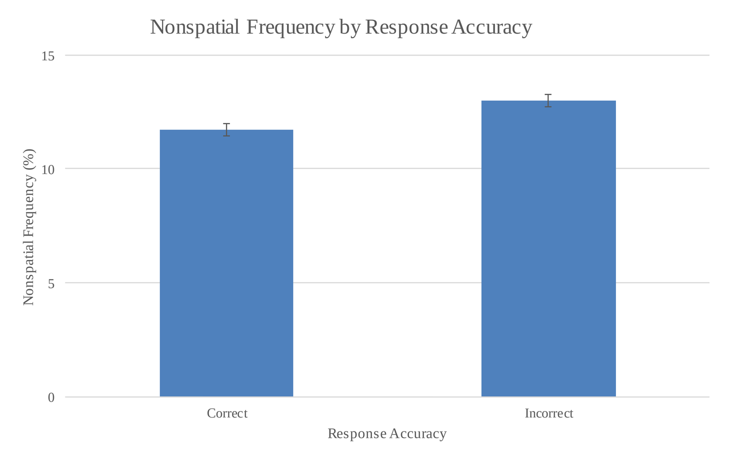


Figure 9. Nonspatial frequency by response accuracy. Error bars represent the standard error of the mean.

First, we explored the relationship between response accuracy, whether or not the problem was answered correctly, and spatial frequency. An independent samples T-test was conducted to compare spatial frequency in correct and incorrect responses (Figure 8). There was a significant difference in the spatial frequency for correct (M=3.94, SD=2.81) and incorrect responses(M= 2.81, SD=2.06); t(394)=3.87, p < .001. We also looked at the relationship between response accuracy and nonspatial frequency. An independent samples T-test was conducted to compare nonspatial frequency in correct and incorrect responses (Figure 9). There was a significant difference in the nonspatial frequency for correct (M=11.72, SD=4.43) and incorrect responses(M= 12.98, SD=5.56); t(394)=-2.37, p = .018.

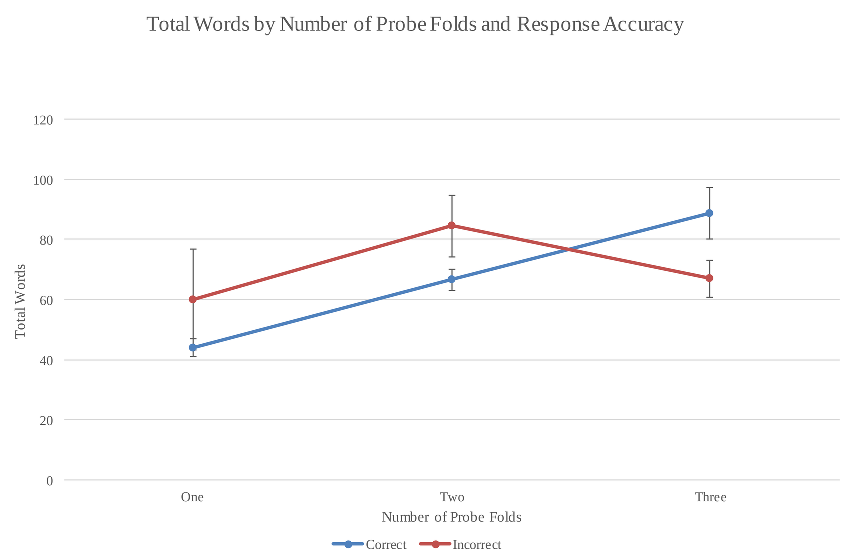


Figure 10. Mean total word count of think-alouds by number of probe folds and response accuracy. Error bars represent the standard error of the means

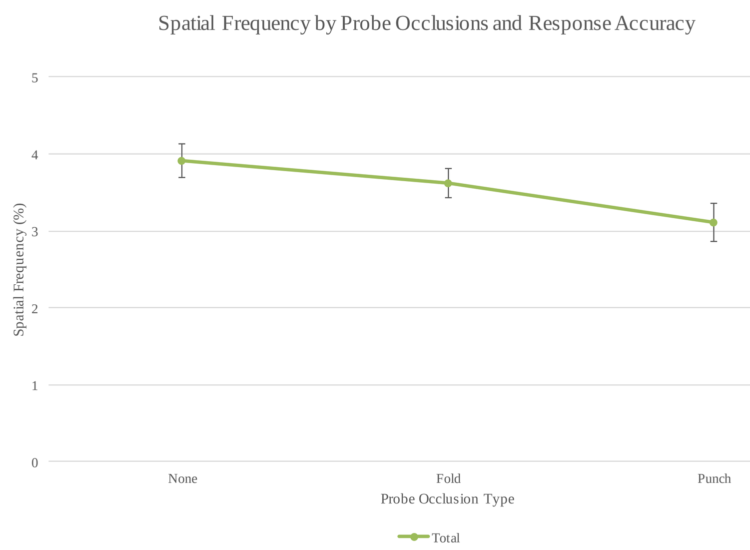


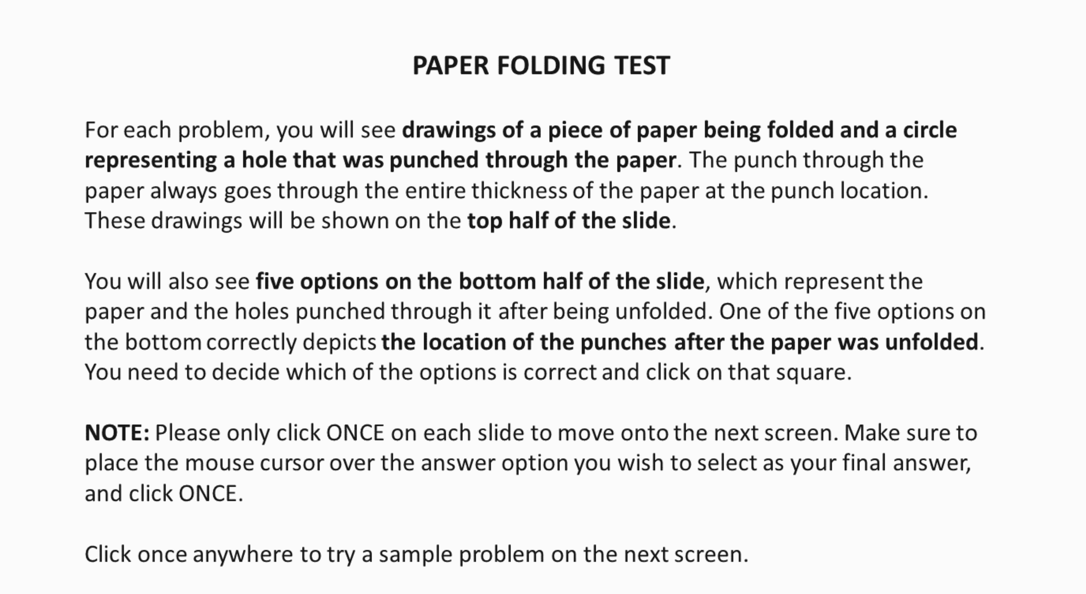
Figure 11. Mean spatial frequency by occlusion type. Error bars represent the standard error of the mean.

We then explored the relationship between number of probe folds in a problem and total word count of the think-aloud, both when responses were correct and incorrect. A one-way between subjects ANOVA was conducted to compare the effect of probe folds on total words in one, two and three fold problems, when answers were correct. There was a significant effect of probe folds on total words for the three conditions [F(2,281) = 11.12, p < .001] We also explored the same relationship, but when answers were incorrect. A one-way between subjects ANOVA was conducted to compare the effect of probe folds on total words in one, two and three fold problems, when answers were incorrect. There was no significant effect of probe folds on total words for the three conditions [F(2,109) = 1.21, p = .301]

Finally, we explored the relationship between spatial frequency and probe occlusion type. A one-way between subjects ANOVA was conducted to compare the effect of probe occlusion types on spatial frequency in probes with no occlusion, fold occlusions, and punch occlusions. There was a significant effect of probe folds on total words for the three conditions [F(2,393) = 3.381, p < .035]

Methods, cont.

Procedure. Participants were seated with their heads resting on the chinrest in front of the eye tracker and a computer monitor. The participants were presented with instructions (Figure 7), followed by 18 paper folding problems on the monitor, and clicked on the answers, while the eye tracker ran. Afterwards, the participants were shown a gaze replay of where they were looking throughout the task, and were asked to think aloud, narrating their thought processes and strategies when solving each problem, and their explanations were recorded.



PAPER FOLDING TEST

For each problem, you will see **drawings of a piece of paper being folded and a circle representing a hole that was punched through the paper**. The punch through the paper always goes through the entire thickness of the paper at the punch location. These drawings will be shown on the **top half of the slide**.

You will also see **five options on the bottom half of the slide**, which represent the paper and the holes punched through it after being unfolded. One of the five options on the bottom correctly depicts **the location of the punches after the paper was unfolded**. You need to decide which of the options is correct and click on that square.

NOTE: Please only click ONCE on each slide to move onto the next screen. Make sure to place the mouse cursor over the answer option you wish to select as your final answer, and click ONCE.

Click once anywhere to try a sample problem on the next screen.

Figure 7. The instructions for the PFT presented to participants prior to the task

Conclusions and Discussion

Response Accuracy and Spatial Thinking.

- There was higher spatial frequency and lower nonspatial frequency when answers were correct. The opposite is true when answers were incorrect.
- Use of spatial thinking is related to improved performance on these tasks, demonstrating that the Paper Folding test can be used to evaluate the presence of spatial thinking.

Total Words and Number of Folds.

- Problems with more probe folds let to more total words in the think-aloud explanations, but only when responses were correct
- When problems are complex, explanations and strategies thus become more complex, but if the problem is too difficult, explanations don't reflect anything.

Occlusions and Spatial Thinking.

- More spatially complex problems unexpected lead to lower spatial frequency
- If a problem is too spatially complex, participants will abandon attempting to use spatial thinking.

Overall. While performance on the Paper Folding Task can be indicative of the presence of spatial thinking, it is clear that many problems end up not involving spatial thinking, particularly complex or difficult ones. The Paper Folding Task is still widely used to evaluate spatial capacity in individuals, but since the difficult problems don't involve spatial thinking, the test does not effectively capture degree of spatial ability

Future Directions. With an understanding of the shortcomings of the paper folding task, we can work to develop a more accurate measure of spatial ability, in the form of an improved paper folding task, as well as improving other commonly used spatial/visual tests. Further research delving deeper into what strategies and thought processes individuals use when solving spatial problems would be valuable in developing improved tests, and to create effect ways to train spatial skill.

Acknowledgements

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