What Can Gaze Switching Reveal About Spatial Thinking Strategies In A Paper Folding Task?

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Background

The **Paper Folding Test** (PFT; Ekstrom et al., 1976) is widely cited as an objective measure of spatial ability. In each PFT problem, a diagram shows a piece of paper that is folded and then punctured with a pencil (Figure 1). Participants then choose the answer choice that accurately represents what the paper looks like once unfolded. In our study, we developed a new PFT that was designed to allow us to identify the strategies that people use when solving spatial tasks.

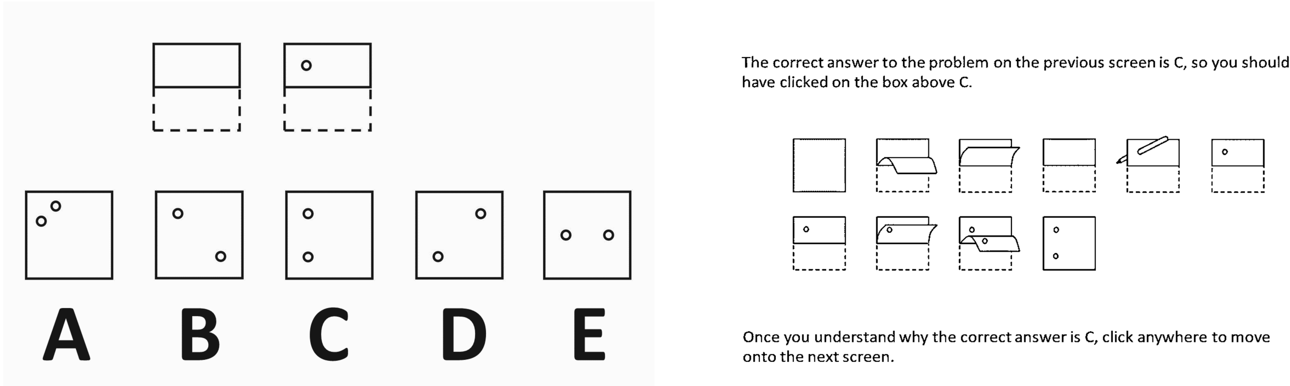

Figure 1. Example PFT item with an explanation of how to solve it

Motivation

Spatial and visual thinking are essential to many aspects of everyday life, including navigation, mathematics, and problem solving, and as a result spatial ability has been cited as a predictor of success in many of those areas. The PFT has been used as a way of categorizing "high spatial ability" people, but what if people are using non-spatial strategies to solve the PFT? **Can we create a new PFT that will help us to analyze the particular strategies that people use to solve each problem?**

Research Goal

Previous research suggests that people may employ both spatial and non-spatial strategies when completing the PFT. Our new version of the PFT was designed with a wider variety of probe characteristics and response types in order to allow us to identify the strategies people used to complete it. We investigated the extent to which people focus on question prompts (indicative of spatial strategies) and answer choices (indicative of non-spatial strategies, such as eliminating distractor answers).

Method

Participants
We had 23 participants between the ages of 18 and 35 years (age_m=21), who were paid $20 per hour. Participants volunteered through an online portal that is open to any member of the local community.

Materials
Eye tracker
Using an SMI Red 500Hz eye tracker, we calculated how frequently participants' gaze switched between the prompt (i.e., diagram of paper being folded) and the answer choices.

Stimuli were presented on a 22in. Dell screen.

We used a chin rest to minimize participants' head movements while eye tracking.

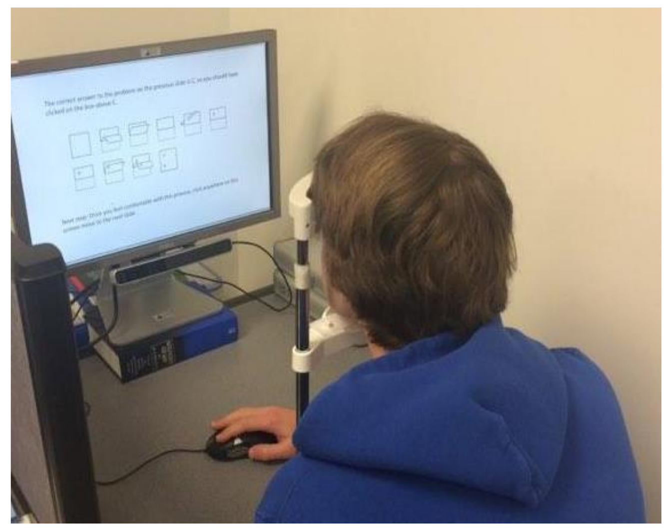

Figure 2. The eye tracking set up with chin rest and stimulus presentation

Paper folding stimuli
There are two 36-question tests in the new PFT, which were divided into four tests of comparable difficulty with 18 questions each.

Other measures of spatial strategies
Participants completed a Qualtrics survey that measured both their spatial abilities and their perceptions of their spatial abilities.
Participants then completed a retrospective ThinkAloud task, in which they watched a video of their eye movements during the first task and explained, out loud, the strategies that they used to complete each item.

Types of Occlusions

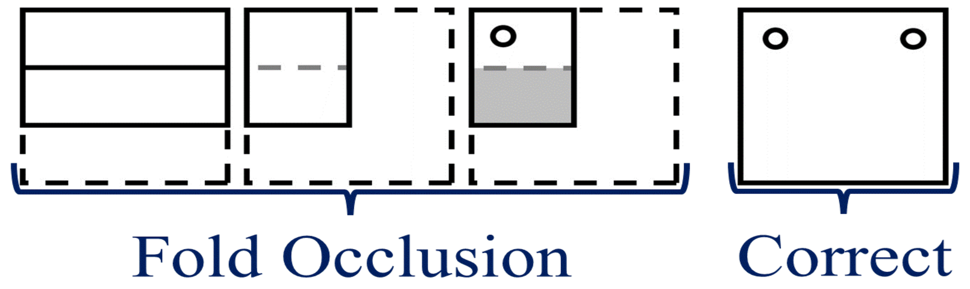

Figure 3. This diagram shows an example of a "fold occlusion" in which the part of the paper that is hidden is affected by a fold, but not the hole punch

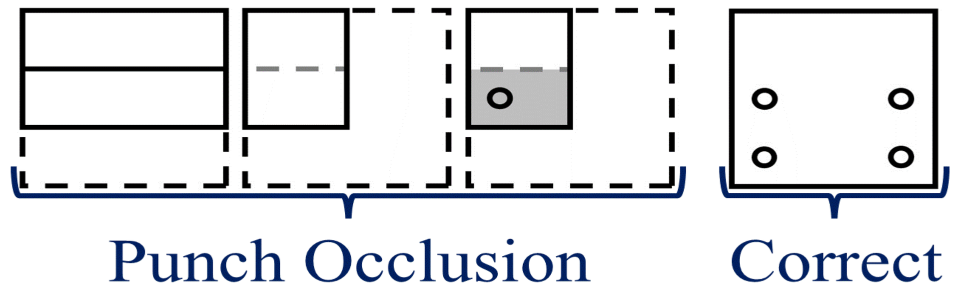

Figure 4. This diagram shows an example of a "punch occlusion" in which the part of the paper that is hidden is affected by the hole punch. This is considered to be more difficult to understand than a fold occlusion.

Results

We found that, as problem complexity increased (i.e. number and type of paper folds), participants' gaze switched significantly more within prompts, indicating that participants spent more time using spatial strategies to attempt problems that were more difficult (Figure 7, Figure 10). However, with regard to transitions that represented non-spatial strategies (i.e. transitions that involved analyzing and comparing the answer choices), the number of transitions tended to peak around moderately difficult problems, and decrease again for more difficult problems (Figure 5, Figure 6, Figure 8, Figure 9).

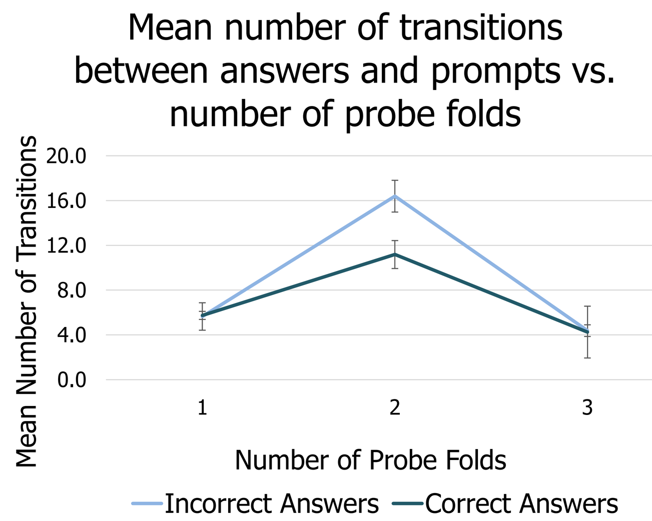

Figure 5. The mean number of transition states between answer choices and prompts for correct and incorrect answers as affected by the number of folds made in the paper. Error bars represent the standard error of the mean.

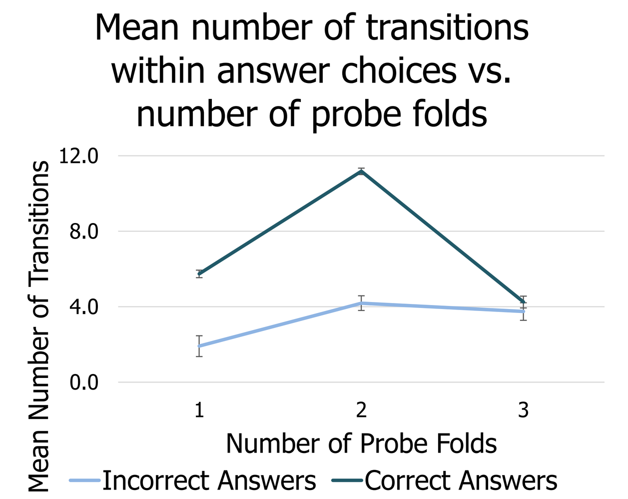

Figure 6. The mean number of transition states within answer choices for correct and incorrect answers as affected by the number of folds made in the paper. Error bars represent the standard error of the mean.

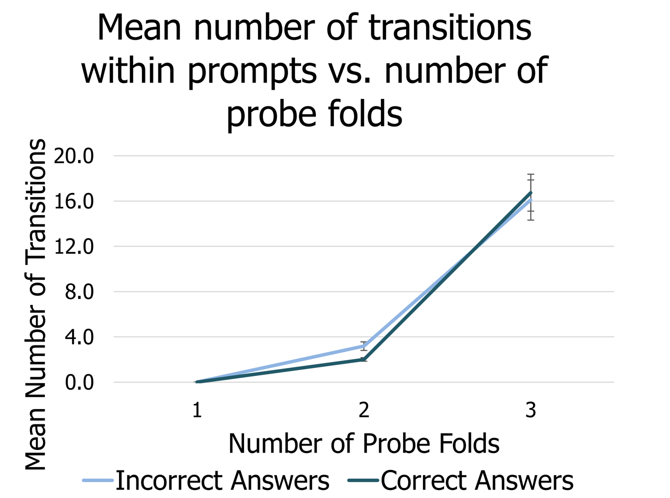

Figure 7. The mean number of transition states within prompts for correct and incorrect answers as affected by the number of folds in the paper. Error bars represent the standard error of the mean.

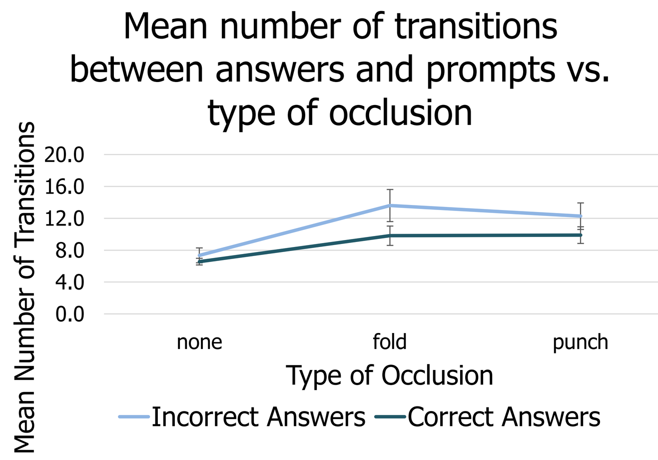

Figure 8. The mean number of transition states between answer choices and prompts for correct and incorrect answers as affected by the type of occlusion in the stimulus. Error bars represent the standard error of the mean.

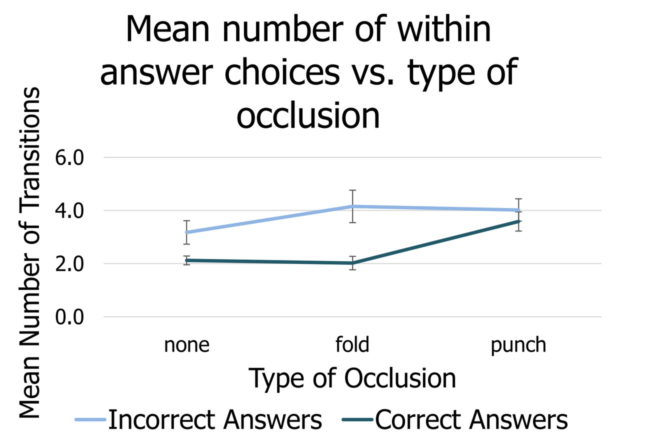

Figure 9. The mean number of transition states within answer choices for correct and incorrect answers as affected by the type of occlusion in the stimulus. Error bars represent the standard error of the mean.

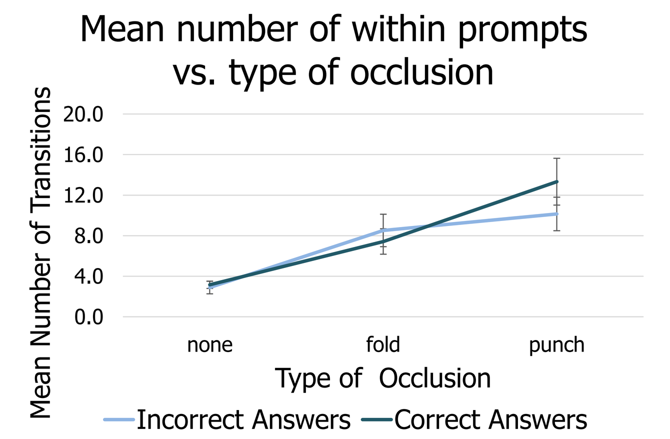

Figure 10. The mean number of transition states within prompts for correct and incorrect answers as affected by the type of occlusion in the stimulus. Error bars represent the standard error of the mean.

ANOVA with IV: Number of Probe Folds				
Correct or Incorrect?	Type of Transition	df	F	Sig.
Incorrect	transitions within answers	2	2.736	.069
	transitions within prompts	2	45.615	.000
	transitions between prompt and answers	2	25.096	.000
Correct	transitions within answers	2	12.813	.000
	transitions within prompts	2	92.687	.000
	transitions between prompt and answers	2	36.740	.000

ANOVA with IV: Type of Occlusion				
Correct or Incorrect?	Type of Transition	df	F	Sig.
Incorrect	transitions within answers	2	1.070	.346
	transitions within prompts	2	6.302	.003
	transitions between prompt and answers	2	3.477	.034
Correct	transitions within answers	2	10.905	.000
	transitions within prompts	2	22.370	.000
	transitions between prompt and answers	2	7.901	.000

Figure 11. ANOVA values for the independent variables we studied, with significant values highlighted in green

Method, cont.

Design
The participants were split into four groups (i.e., a between-subjects design), and each group completed 18 paper folding items. The dependent variable we measured was the number of transitions, measured by the eye tracker, participants made between areas of interest on the stimuli.

Procedure
Participants first completed the 18 PFT items, while an eye tracker tracked their eye movements. Finally, participants completed the Qualtrics survey and retrospective ThinkAloud task.

Measures
Dependent variable: mean number of fixation transitions between different areas of interest (i.e. between prompts, between answer choices, or between answer choices and prompts)
Independent variables: number of folds (1, 2, or 3), type of occlusion (none, fold, or punch)

Discussion

When participants were observed to be using spatial strategies, the number of transitions increased as problem complexity increased. This trend was evident for both the number of folds and the type of occlusion. Interestingly, when participants were tasked with actually choosing an answer after analyzing the prompts (represented by transitions within answer choices and transitions between prompts and answer choices), we found that participants demonstrated significantly more transitions when the prompts were moderately difficult.

We interpreted these results to mean that, **for more difficult problems, participants spent longer analyzing the problems and *attempting* to use spatial strategies, but eventually turned to non-spatial strategies when the spatial strategies failed**. We can conclude that the PFT is not strictly a measure of an individual's spatial ability, because, especially on more difficult problems, we found that participants are not using spatial strategies to arrive at an answer.

In the future, we hope to integrate this research with other research on the strategies people use to solve spatial problems in order to create a new paper folding test that better captures individual differences in spatial ability.

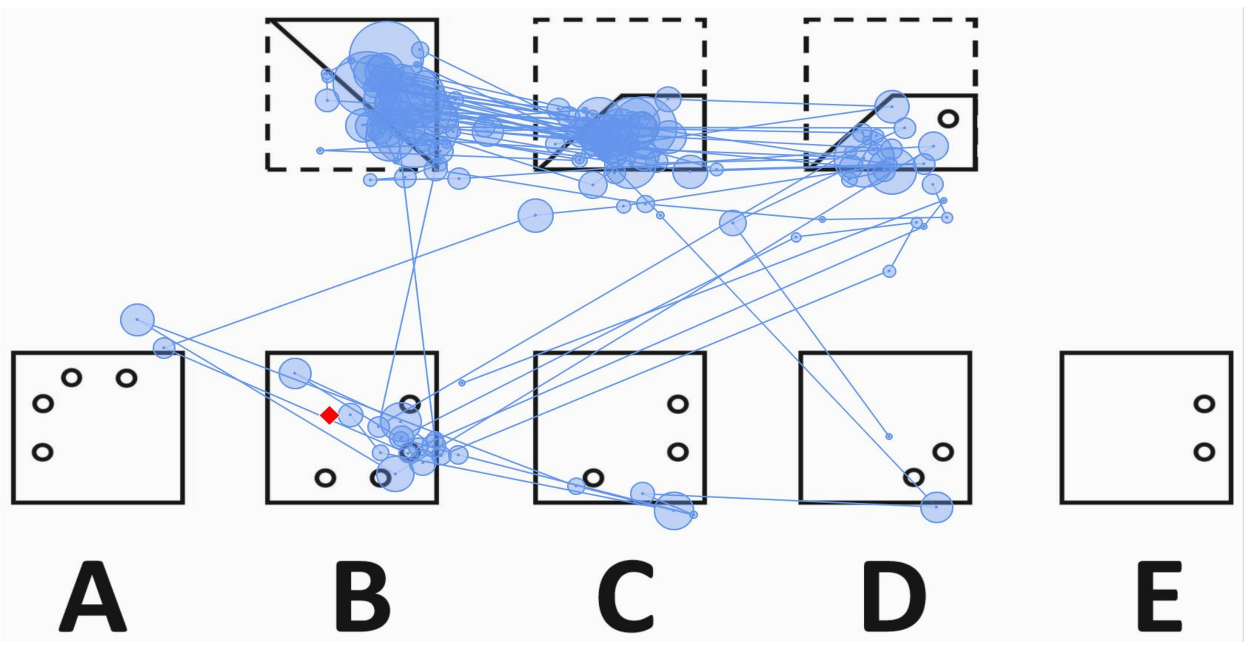

Figure 12. This is a simplified picture of an eye tracking scan path. Larger circles indicate a longer fixation at that point. The red square represents the answer that the participant chose.

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