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Abstract

This study investigated the extent to which cognitive measures of individual differences predict strategy shifts in a series of procedural-motor curve-drawing tasks. College students participated in a task which required them to trace or draw various forms of a figure-8 before completing a battery of cognitive tests. Three distinct drawing strategies emerged, and the tendency to vary these strategies was quantified using Shannon's Entropy. The results indicated that participants employed multiple strategies early in a block of trials before eventually settling on a preferred strategy. Additionally, higher creativity scores were associated with higher entropy, whereas participants with higher verbal and working memory ability preferred to settle on their preferred strategy.

Keywords: strategy switching; strategy shifting; individual differences; entropy.

Introduction

When performing tasks, people often encounter circumstances in which they must change their current strategy when it becomes problematic. For example, when weather conditions turn unfavorable, pilots might switch to an alternate strategy in order to successfully land the plane. College students may need to switch strategies to succeed in different courses (e.g., problem solving for math, memorizing terms for biology, developing motor skills for music, etc.), and chess players need to switch between an arsenal of strategies both within and across matches to consistently win. Different strategies are required for multitasking in a complex, dynamically changing world. Old strategies are abandoned and new ones adopted at an adaptive pace. In order to switch strategies, individuals presumably must recognize when and why a particular strategy is failing.

Although, in general, people will retain and use strategies that proved effective in the past, there are also a number of motivations for strategy change. It may occur in response to feedback and performance failure on previous trials (Reder, 1987; Lovett & Anderson, 1996; Brand, 2008). However, Roberts, Taylor, and Newton (2007) have reported that individuals persist in utilizing a sub-optimal strategy even when performance is poor. According to the Dunning-Kruger effect (Kruger & Dunning, 1999), a lack of metacognitive awareness might inhibit people from realizing they have selected an inferior strategy. Roberts et al. (2007) also reported that there needs to be sufficient motivation before strategy change is likely to occur.

A soft constraints hypothesis (Gray et al., 2006) posits that people strategically plan more actions in advance when a task requires longer delay times or controls that are costly to manipulate. Walsh and Anderson's (2009) studies of arithmetic problem-solving suggest people change strategies when the task becomes excessively difficult or stressful. These experiences require substantial mental deliberation, and the harder the task becomes, the more likely a person will consider a strategy change. This suggests that strategy selection is more explorative and deliberative prior to settling on a set strategy (Walsh & Anderson, 2009).

Shifts in strategy are not only associated with the task and environment, but also by the characteristics of the individual. Researchers have attempted to identify the characteristics of people (i.e., individual differences) who exhibit a propensity for flexible strategy use. Schunn and Reder (2001) analyzed the Kanfer–Ackerman Air Traffic Control Task and found that a person's ability to select and execute a correct strategy is governed mostly by working memory capacity and reasoning ability. Reasoning ability was also correlated with the ability to determine when a particular strategy was not working. In another study, Roberts and Roberson (2001) reported that spatial reasoning ability predicts strategy shifting in spatial tasks.

Although early cognitive research presupposed that cognitive processes are universal and largely invariant across individuals and tasks, it is now widely accepted that aptitudes for specific skills can vary across individuals and different people recruit different strategies to perform the same task (e.g. Miller et al., 2002; Schaeken, De Vooght, Vandierendonck, & d'Ydewalle, 2000). It is conceivable that cognitive adaptability is a trait necessary to explain the inherently dynamic nature of cognitive processes as individuals adjust and adapt their available resources to ongoing circumstances. Given the variation in the structure and functioning of the brain, there exists inherent flexibility that may be quantified and used to predict differences in cognitive performance among individuals as well as within a given individual over time. This is the issue that motivated the present study.

The paradigm selected to elicit and assess strategy change in the present study was a curve-drawing task, specifically the drawing and tracing of figure-8s. We systematically varied the task constraints in order to identify the stable strategies people use to complete the task. The curve-drawing task was selected because the horizontal and vertical symmetry allow for consistency when modifying the stimulus or instructions and analyzing the data. Moreover, it is a moderately complex task, thereby negating a potential lack of understanding of the task, which could inhibit optimal strategy selection (Roberts et al., 2007). Such a task is also largely free of fluctuations in prior knowledge or expertise (as opposed to chess, for example), yet allows for multiple strategies.

Variation in strategy selection across trials was calculated using Shannon's Entropy (Shannon, 1948). Originating in information theory, entropy is a mathematical formulation of the uncertainty in a data channel. It is expressed as:

$$H(X) = -\sum_{i=1}^{n} p(x_i) \log_b p(x_i)$$

For the current study, X is the set of n distinct strategies, and $p(x_i)$ is the probability of a participant's use of each strategy. Higher entropy values indicate more variation in strategy use across trials; on the other hand, if the same strategy was used in all trials, then entropy would be 0. Additionally, the current study measured strategy shifting within a single task instead of across tasks, which is more common in the literature (Luwel, Schillemans, Onghena, & Verschaffel, 2009).

Method

Participants

Participants were 75 undergraduate students, 44 enrolled in the University of Memphis and 31 at the University of Notre Dame during the Spring 2009 semester. All participants participated in the study for course credit.

Apparatus

Participants engaged in a series of tasks that involve tracing or drawing figure-8s. The primary apparatus was a Wacom Techno Cintiq 21UX^{TM} system that consisted of an LCD monitor (43 cm x 33mm). The drawing task was performed in a subregion measuring approximately 22cm x 22cm. The system had a synchronization rate of 60 Hz, a response time of 20 ms, and a maximum report rate of 145 points/sec. The drawing task was performed with a stylus directly on the monitor.

Procedure

The experiment was divided into two phases that took approximately one hour each. The first phase was the curve-drawing task whereas the other was a battery of individual differences measures.

Curve Drawing. Participants completed a series of perceptual-motor tasks in which they traced or drew a series of figure-8s that were displayed on the screen. This was a within-subjects design in which participants completed each of 12 conditions designed to stimulate strategy change within and across each task. Participants first completed a practice session (*Unguided*, 5 trials) to familiarize themselves with the equipment. The next block (*Baseline*, 25 trials) added visual feedback upon completion of each trial, namely the speed and accuracy of their drawing, represented as a percentage, as well as the product of these two, called the composite score. Subsequent conditions altered either the target figure or the instructions and feedback in order to encourage participants to consider alternate strategies for completing the task. Figure 1 displays a screenshot of the interface, with the speed, accuracy, and composite score feedback bars for the current trial, scores for previous trials, and the drawing subregion in view.

There were several stimulus variation conditions. They included: random sizes of the figure-8 (*Random Size*, 50 trials); presenting the figure-8 horizontally and describing it as an infinity sign (*Infinity*, 25 trials); displaying various images (including a figure-8, a five-pointed star, and the logos for Sandia National Labs and the University of Notre Dame), then removing the image and asking the participant to draw the image from memory (*Memory*, 50 trials); a figure-8 rotated at various angles, where the participants were asked to trace the figure in one condition (*Angle Trace*, 50 trials) and draw the rotated figure-8 in a separate grid in the other (*Angle Draw*, 50 each). Examples of the stimuli are presented in Figures 2 and 3.

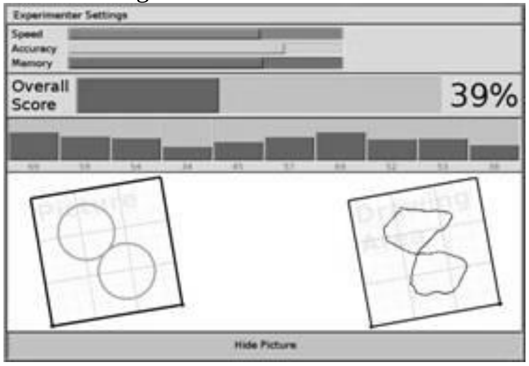

Figure 1: Screenshot of curve-drawing interface

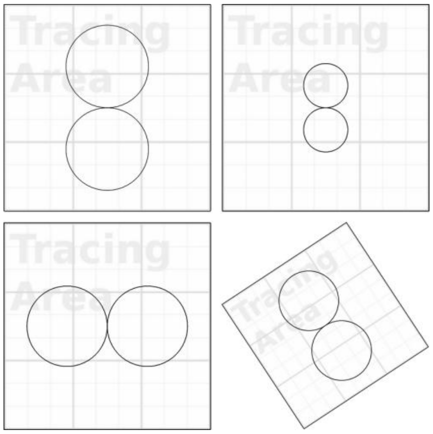

Figure 2: Examples of stimuli. Clockwise from top-left: Baseline, Random Size, Angle Trace, Infinity

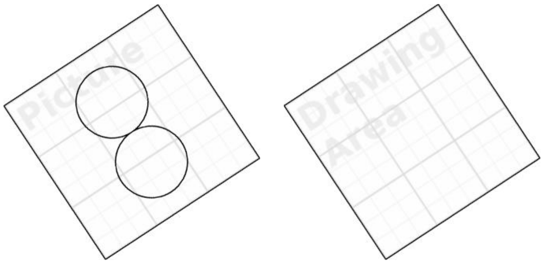

Figure 3: Angle Draw condition, with the target image on the left and the participants' drawing area on the right

Stimulus manipulations may encourage people to switch strategies, but altering the instructions and feedback may induce strategy change as well. These modifications included asking the participants to focus on speed or accuracy, with feedback scores adjusted accordingly (*Speed* and *Accuracy*, 25 trials each); presenting a standard figure-8 but without any marks from the pen (*No Ink*, 50 trials); presenting the next trial at random time intervals (Random interstimulus interval or *Random ISI*, 25 trials); and instituting a random, unspecified time limit before the trial would time out, which would result in a composite score of zero (*Trial Timeout,* 25 trials).

The Practice and Baseline conditions were always presented first and second, respectively, followed by either Speed or Accuracy (counterbalanced), with the remaining eight conditions following in random order.

Individual differences measures. Following the curve-drawing task, participants completed a battery of tests that measured various cognitive abilities. Participants self-reported their SAT Reasoning Test or American College Test (ACT) score (an ACT score was converted to an equivalent SAT score); all subsequent measures were administered via computer. These included measures of working memory (Automated Operation Span Task (Ospan); Unsworth, Heitz, Schrock, & Engle, 2005), creativity (Remote Association Task (RAT); Mednick, 1963), spatial reasoning (Mental Rotation Task; Shepard & Metzler, 1971), fluid intelligence (Raven's Progressive Matrices: Set 1; Raven, 1958), visual search and motor speed (Figure-Comparison Task; Salthouse & Mitchell, 1990), strategy shifting (Einstellung Water-Jug Strategy Task; Tresselt & Leeds, 1953), and general verbal ability (Shipley's Vocabulary Test; Shipley, 1946).

Results and Discussion

Identifying Dominant Strategies

Figure 4 displays the three strategies exhibited by the participants. In the figure, the dots refer to where the stylus first made contact with the screen; a second dot would indicate that the participant removed the stylus from the screen and placed it down again. As the stylus moves farther from the dot, the lines fade to indicate the drawing direction.

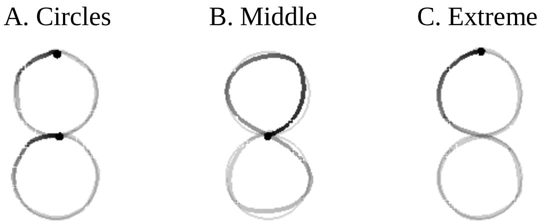
A. Circles B. Middle C. Extreme

Figure 4: Examples of the three predominant strategies

Strategy A (Circles) was defined as any trial in which a participant drew one full circle, picked up the stylus, placed it back on the screen, and drew the other circle. Strategy B (Middle) was defined as any trial in which the stylus was originally placed in any intersection point between the circles, and the figure was completed in one continuous motion (i.e., without removing and replacing the stylus from the screen). Finally, Strategy C (Extreme) was defined as any trial in which the stylus was not originally placed in the intersection between the circles, and the figure was completed in one continuous motion. Any trial not fitting these criteria was classified as 'Other.' Table 1 lists the proportion of observations in which each strategy was used in each condition.

Table 1: Proportion of strategy use in each condition

Condition	**Other**	**Circles**	**Middle**	**Extreme**
Practice	.34	.24	.18	.24
Baseline	.02	.26	.54	.17
Accuracy	.00	.30	.47	.23
Angle Draw	.05	.58	.20	.17
Angle Trace	.02	.22	.70	.07
Random Size	.01	.20	.70	.09
Infinity	.01	.15	.75	.09
Memory	.17	.33	.28	.21
No Ink	.02	.19	.71	.08
Random ISI	.02	.17	.61	.20
Trial Timeout	.01	.21	.57	.21
Speed	.02	.23	.50	.25
Total	**.06**	**.26**	**.52**	**.17**

Quantifying Uncertainty in Strategy Use

We computed the entropy, recurrence, and determinism to quantify the dynamics of strategy use in each condition. Recurrence and determinism are measures from dynamical systems theory and were computed using a categorical auto recurrence analysis (Richardson, Dale, & Kirkham, 2007). The recurrence rate (or simply recurrence) provides repetitiveness of strategy use across trials (higher recurrence = greater use of a similar set of strategies). Determinism, on the other hand, measures repetitive patterns in strategy use (high determinism = more repetitive patterns). Here, entropy strongly and significantly ($p < .05$) correlated with recurrence ($r = -.989$) and determinism ($r = -.862$). Therefore, the subsequent analyses exclusively use entropy.

Our analyses proceeded by assessing whether there were differences in entropy *across* conditions. We also expect variations in entropy *within* a condition, because when presented with a new stimulus, we expect participants to experiment with different strategies before settling on a new preferred strategy; thus, one prediction is that the entropy for the final set of trials should be lower than for the initial trials.

To test this hypothesis, we divided the trials in each condition into an initial and a final phase. Entropy was independently computed for each phase. For conditions with 25 trials, initial entropy was computed for trials 1-10 and final entropy for trials 15-25. For conditions with 50 trials, initial entropy was computed for trials 1-15 and final entropy was for trials 25-50.

A 2 × 10 (phase [initial|final] × condition) repeated measures analysis of variance revealed a significant main effect for condition, $F(9, 666) = 80.21$, $Mse = .092$, $p < .001$, partial $\eta^2 = .520$. Bonferroni posthoc tests indicated that there was significantly more entropy in the memory condition than the others ($p < .05$). This was expected, as both the stimuli and task were far more complex than any other condition. Also, the entropy associated with the Angle Draw condition was significantly greater than the Accuracy, Infinity, No Ink, Random ISI, Trial Timeout, and Speed conditions; there were no differences in the other conditions.

There was also a significant main effect for phase, $F(1, 74) = 68.67$, $Mse = .045$, $p < .001$, partial $\eta^2 = .837$. As expected, initial entropy was significantly higher than final entropy, $M_{\text{INITIAL}} = .579$, ($SE = .017$); $M_{\text{FINAL}} = .366$ ($SE = .020$).

The phase × condition interaction was significant, but yielded a smaller effect, $F(9, 666) = 5.746$, $Mse = .046$, $p < .001$, partial $\eta^2 = .072$. With the exception of the memory condition, final entropy was always lower than initial entropy. Table 2 displays the initial and final entropy scores for each condition.

Table 2: Initial versus Final Entropy

	Initial		**Final**		**Effect size**
Condition	*M*	*SD*	*M*	*SD*	*d*
Accuracy	.50	.25	.20	.29	1.1
Angle Draw	.67	.33	.42	.35	.74
Angle Trace	.53	.33	.32	.32	.64
Random Size	.50	.30	.33	.34	.54
Infinity	.51	.29	.20	.33	.99
Memory	1.1	.17	1.1	.18	-
No Ink	.50	.28	.30	.35	.62
Random ISI	.47	.29	.26	.32	.71
Trial Timeout	.52	.29	.27	.23	.99
Speed	.50	.26	.30	.33	.71

In summary, there is more uncertainty in strategy selection during the initial trials of each condition and less uncertainty during the final trials. Additionally, entropy during the final trials was not zero, indicating that at least some participants were still switching strategies at the end of the testing block. Finally, and more importantly, with the exception of the Memory and Angle Draw conditions, entropy was consistent across conditions. This indicates that it is not the task constraints, but individual differences, that might best explain the patterns in strategy use.

Individual Differences and Entropy

The individual differences measures were correlated with entropy (see Table 3). Cases that were more than two standard deviations from the mean were identified as outliers and removed from the analysis (Van Selst & Jolicoeur, 1994).

Table 3 shows that verbal ability (Shipley's Vocabulary test and SAT), working memory span (Ospan), and creativity (RAT) correlated with entropy. The negative correlations between Vocabulary, Ospan, and SAT indicate that participants with higher verbal ability and executive function demonstrated less variability in strategy selection. Some interesting patterns emerge when one considers initial versus final entropy. Participants with high verbal ability (Vocabulary and SAT) were more likely to settle on a preferred strategy (negative correlation with entropy). Participants with high working memory span (Ospan) consistently show lower entropy (negative correlation with both initial and final entropy).

There also seems to be a different pattern in creativity and intelligence. The RAT shows a positive correlation with both overall and initial entropy, suggesting a relationship between creativity and initial exploration. There should be a note of caution expressed about this measure, however, as over 40 percent were unable to produce a single correct answer on the RAT. Hence, it is important that this finding be replicated with a different sample.

Table 3: Correlations between individual differences and entropy

ID Measure	**Overall Entropy**	**Initial Entropy**	**Final Entropy**
Vocabulary	-.256**	-.143	-.433***
SAT	-.234*	-.120	-.283**
Ospan	-.419***	-.289*	-.415***
RAT	.205*	.274**	.189
Rotation	-.073	-.041	-.080
Speed	-.093	-.031	-.178
Water Jug	.069	.152	.074
Ravens	.008	.055	-.111

Notes. ******* $p < .01$, ** $p < .05$, * $p < .1$.

The next set of analyses sought to predict overall entropy, initial entropy, and final entropy from the individual difference measures. Only Vocabulary, RAT, and Ospan were considered because SAT was strongly correlated with Vocabulary ($r = .628$). A tolerance analysis indicated there were no multicollinearity problems ($VIF \approx 1$ for all three predictors). It should also be noted that the sample size was reduced due to missing data (particularly with Ospan), and the removal of some outliers. Hence, these regression models were constructed from the remaining sample of 40-45 participants.

A significant model emerged for overall entropy. Here, $F(3, 39) = 3.97$, $p = .015$, $R^2_{\text{adj}} = .175$. The significant predictors were creativity (RAT, $\beta = .266$, $p = .073$) and memory span (Ospan, $\beta = -.452$, $p = .003$). A better fit (with one fewer parameter) was obtained if Vocabulary is left out of the model, $F(2, 43) = 6.38$, $p = .004$, $R^2_{\text{adj}} = .193$. In summary, creativity (RAT, $\beta = .284$, $p = .045$) was a positive predictor of overall variability whereas memory span (Ospan, $\beta = -.456$, $p = .002$) was a negative predictor.

Similar patterns emerged for initial and final entropy. For initial entropy, $R^2_{\text{adj}} = .112$, RAT: $\beta = .331$, $p = .030$, Ospan: $\beta = -.290$, $p = .055$. For final entropy, $R^2_{\text{adj}} = .281$, RAT: $\beta = .362$, $p = .012$, Ospan: $\beta = -.374$, $p = .010$, and Vocabulary: $\beta = .-.332$, $p = .02$.

In summary, creativity, vocabulary, and memory span yielded a medium effect (Cohen, 1992) in predicting the variability in strategy use. Creative participants were more likely to shift strategies and explore different strategies, whereas participants with high verbal ability and memory span were more likely to persevere in their preferred strategies.

Predicting Performance

Correlations between the eight individual difference measures and speed and accuracy scores (the performance measures) did not yield any significant relationships. However, there was a significant correlation between entropy and accuracy ($r = -.414$, $p < .001$), but not between entropy and speed ($r = .084$). Initially, the negative correlation between variation in strategy use and accuracy might sound counterintuitive. However, it is important to note that strategy switching is usually associated with a switch cost which people encounter when they attempt to adjust to the newly adopted strategy (Luwel et al., 2009). Hence, individuals who switch strategies more (higher entropy) presumably experienced increased switch costs, and consequently, lower accuracy scores.

Conclusions

This study provides new information about what governs strategy selection, and we have discovered several interesting results concerning the nature of the task, number of repetitions of the task, and individual differences. The two most difficult tasks (Memory and Angle Draw) exhibited the largest amount of variation in strategy use. This finding is consistent with Walsh and Anderson’s (2009) recent findings on arithmetic problem-solving. The Angle Draw condition was particularly interesting; the figures were the same as in Angle Trace, but the added difficulty of drawing (versus tracing) caused a significant shift in strategy preference (Circles over Middles). These findings provide evidence that these manipulations were sufficiently difficult to promote cognitive restructuring on some level.

Within a task, people tend to explore different strategies early in the task before eventually settling on a preferred strategy. Also, there are some individual differences in cognitive ability that are associated with more strategy shifting; creative people are more likely to explore different strategies, whereas those with a high working memory span and reasoning/verbal ability tend to identify a preferred strategy and perseverate with it. Perhaps the latter individuals are quick problem-solvers and identify their preferred strategy immediately, while creative individuals are more willing to perseverate with multiple strategies until they are satisfied.

Although this study has provided some insight into strategy exploration both within the same task and across tasks, it remains to be seen whether these findings hold true when people are encouraged to change their strategy as a result of a change in the task (i.e., adaptive strategy shifting). This could be achieved by either drastically altering the task, where the necessity for a strategy change would be distinct and instantaneous, or by slowly modifying the task such that the exact moment one strategy becomes superior is much more nebulous. Additionally, measuring the time between stimulus presentation and task execution would provide a metric of planning strategy selection, which might be a predictor of strategy shifting.

Finally, Rakow, Newell, & Zougkou (2010) describe a recent model where certain people exploited the constraints of the task, whereas others were more exploratory in their strategy use. Although this model did not explicitly address creativity, one possibility is that the creative individuals might be more likely to exhibit exploratory behaviors, a possibility which is tentatively supported by the present data but requires more systematic experimental validation.

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